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A Proposed Index of Water Quality Assessment for Irrigation

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Abstract

A water quality index in a simplified concept is a way for combining the complex water quality data into a single value or single statement. This study comprised the development of a new index called the'irrigation water quality index (IWQI)'. This index has advantages by reflecting the suitability of water for specific use,(e.g. irrigation water supply) and using a combination of many parameters that limits water suitability to soil characteristics or crop yield.. The New proposed index method utilizes five limitation groups that have been mentioned by Ayers and westcot (1985) with few modification in their classification categories for irrigation water quality assessment . These limitation groups are: (a) salinity limitation, (b) infiltration and permeability limitation, (c) specific ion toxicity, (d) trace element toxicity; and, (e) miscellaneous impacts on sensitive crops . A linear combination of these groups is formulated to form the so-called IWQI, which is a technique that could be used to classify irrigation waters with respect to four suitability categories. The mathematical equations to transform the actual concentration values into rating values (quality sub indices) have been formulated. Weighted minimum operator method was proposed to obtain overall index scores based on individual index (sub-index) values. It is hoped that this proposed method has provided an index (IWQI) used as a simple tool for analysis that serve decision-makers , non-technicians and/or farmers. This method has not been applied previously weighted and their current results look much better than the results of the un weighted minimum operator method , especially when there are sub indices of low values with low weights, along with indices of low values with high weights .The proposed technique was applied to assess the irrigation water quality of Tigris , Euphrates and Shatt Al Arab rivers in Iraq based on observed water quality data. Data representing the monthly sampling of the three rivers were collected during 2008 and considered in this study. Results revealed that the overall quality of the surface water in Tigris river falls under the'suitable' class and remain so until Kut city, and then ranged from moderately suitable to unsuitable until Qurna. In Euphrates river the suitability of water falls under suitable class from Saqlawiya until Kifil and then the quality ranges from moderately suitable to unsuitable until Qurna area. Water of Shatt Al Arab was not suitable through the year except in Jan, Feb, and Oct where the water was slightly suitable. On the other hand, water quality for Tigris and Euphrates was strongly affected by water returns resulted mostly by agricultural use and to a limited extent by domestic uses inside and outside of Iraqi territories. This technique is hoped to help decision- makers in reporting the state of the water quality, as well as verification of the spatial and temporal variations.

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Keywords: irrigation water quality; water quality index; weighted minimum operator

دليل مقترح لتقييم نوعية المياه للري

الخلاصة

ان دليل نوعية المياه بمفهوم مبسط هو طريقة لربط البيانات المعقدة لنوعية المياه في قيمة واحدة أو عبارة واحدة . تشتمل هذه الدراسة على وضع دليل جديد يسمى 'دليل نوعية مياه الري '.(IWQI) هذا الدليل له مزايا بأنه يعكس مدى صلاحية المياه لاستخدام محدد هو ري المحاصيل ، وباستخدام ترابط من عدة معايير والتي تحدد ملائمة المياه لخصائص التربة أو المحصول. ان تقنية الدليل الجديد المقترح تستخدم خمس مجموعات من المتغيرات المحددة لأستخدام المياه والتي تم ذكرها من قبل Ayers and Westcot (1985) مع بعض التعديل جرى في هذه الدراسة ضمن فئات االتحديد الرئيسة لكل من هذه المتغيرات لتقييم نوعية مياه الري. ان مجاميع المتغيرات هذه هي : (أ) محدد الملوحة ، (ب) محدد الرشح والنفاذية ، (ج) محددات سمية ايونات معينة ، (د)محددات سمية العناصر النزرة ؛ و (هـ)محددات التأثيرات المتنوعة على المحاصيل الحساسة. والترابط الخطي بين هذه المجاميع تمت صياغته ليكون ما يسمى بـ IWQI ،. تمت صياغة المعادلات الرياضية لتحويل تركيز القيم الفعلية إلى قيم تقدير (المؤشرات النوعية) . تم اقتراح طريقة التجميع الموزونة على اساس الدليل الثانوي الأدنى للحصول على قيم الدليل العام . ومن المؤمل ان تكون هذه الطريقة المقترحة قد وفرت دليل (IWQI) يستخدم كأداة تحليل بسيطة تخدم الى حد كبير صانعي القرار وغير التقنيين و/ أو المزارعين. ان هذه الطريقة الموزونة لم تطبق سابقا ونتائجها الحالية تبدو أفضل بكثير من نتائج الطريقة السابقة(غير الموزونة) في التطبيق ،وخاصة عندما تكون هناك ادلة واطئة القيمة قليلة الوزن ومعها أدلة واطئة القيمة ذات وزن عالي . جرى تطبيق هذه الطريقة المقترحة والمستخدمة في هذه الدراسة على بيانات نوعية المياه المتوفرة لانهار دجلة والفرات وشط العرب في العراق لتقييم نوعية مياه الري فيها ، حيث تمثل هذه البيانات نتائج مختبرية لعينات مائية شهرية جمعت خلال عام 2008 من الانهار الثلاثة . أظهرت النتائج أن إجمالي نوعية المياه السطحية في نهر دجلة يندرج تحت فئة 'ملائم' ويستمر هكذا حتى مدينة الكوت، ثم تراوحت نوعية المياه بعد ذلك الى القرنة بين معتدل الملائمة الى غير ملائم . أما في نهر الفرات فقد كانت المياه تقع تحت صنف ملائم من منطقة الصقلاوية الى منطقة الكفل، بعد ذلك تتراوح نوعيتها بين معتدلة الملائمة الى غير ملائمة حتى منطقة القرنة . وفي شط العرب فقد كانت المياه غير ملائمة في كل أشهر السنة ماعدا في الأشهر الأول والثاني والعاشر حيث كانت قليلة الملائمة . من ناحية أخرى فان نوعية المياه تتأثر بشدة في معظمها عن بالمياه الراجعة من الأستخدام الزراعي وإلى مدى محدود عن طريق مياه الصرف الصحي الراجعة من الاستخدامات المدنية. هذه التقنية من المؤمل أنها تساعد صانعي القرار في معرفة حالة نوعية المياه لأغراض الري ، وكذلك التحقق من تغيراتها المكانية والزمانية .

Introduction

Water resources form one of the most important physical land resources in arid and semi arid areas where irrigated agriculture taking place . The quality and quantity of the water supply are equally as important as soil and other factors to the success of an irrigation project. Water quality and quantity were considered as important criteria to be evaluated for all land utilization types, therefore it was considered as a crop factor that determines land suitability classin FAO guidelines of land evaluati on(FAO,1985) .

{MoWR) –IRAQ

Irrigated agriculture is dependent on an adequate water supply of usable quality. Water quality concerns have often been neglected because good quality water supplies have been plentiful and readily available. This situation is now changing in many areas (Ayers and Westcot,1985). Conceptually, water quality refers to the characteristics of a water supply that will influence its suitability for a specific use. Quality is defined by certain physical, chemical and biological characteristics, and in irrigation water evaluation, emphasis is placed on the chemical and physical characteristics of the water and only rarely are any other factors considered i mportant (Sargaonkar and Deshpande , 2003, Ayers and Westcot, 1985) . A major objective of water quality assessment for irrigation is to determine whether or not the water quality meets the objective of irrigation for use in agriculture , to describe water quality at regional or national scales, and also to investigate change of quality in time. The overall suitability of water for irrigation depends upon (1) The nature of the soil, (2) Crop tolerance to salinity of various types of irrigation water, and (3) Water quality and the management of irrigation practices. Water quality criteria must be interpreted in the context of overall salt balances and toxicities and the effects on soil . It is commonly accepted that the problems originating from irrigation water quality vary in type and severity as a function of numerous factors including the type of the soil and the crop, the climate of the area as well as the farmer who utilizes the water. Nevertheless, there is now a common trend that these problems can be categorized into the following major groups: (a) salinity hazard, (b) infiltration and permeability problems, (c) toxicity hazards; and, (d) miscellaneous problems (Ayers & Westcot, 1985). The toxicity hazards can further be grouped into problems associated with specific ions as well as hazards related to the presence of trace elements and heavy metals. Traditional approaches to assessing water quality are based on a comparison of experimentally determined parameter values with existing guidelines. In many cases, the use of this methodology allows proper identification of limitations sources . However, it does not readily give an overall view of the spatial and temporal trends in the overall water quality in the main rivers or watershed (Debels et al., 2005). One of the difficult tasks facing managers (workers) in irrigation field is how to transfer their interpretation of complex water quality data into information that is understandable and useful to technical ,planners and decision makers. The possible solution to this problem is to reduce the multivariate nature of water quality data by employing an index that will mathematically combine all water quality measures and provide a general and readily understood description of water.

Since 1965, when Horton (1965) proposed the first water quality index (WQI), a great deal of consideration has been given to the development of 'water quality index' methods with the intent of providing a tool for simplifying the reporting of water quality data (Liou et al., 2004). However, there is no reliable water quality index has been developed in Iraq to assess water suitability of irrigation .

The main objective of this study is to develop an index method for assessing water quality based on the criteria given by FAO paper No.29 (Ayers and Westcot,1985) ,and to use this method to assess the general water suitability of irrigation , taking into consideration different crops and different water resources , especially rivers water. This index can be used further to serve land evaluation purposes. The only water criteria useful for assessment water quality for surface irrigation will be into consideration in this study.

Materials and Methods : A major objective of water quality assessment for irrigation is to determine whether or not the water quality meets the objective of irrigation for use in agriculture , to describe water quality at regional or national scales, and also to investigate change of quality in time. Internationally, there have been a number of attempts to produce a method that meaningfully integrates the data sets and converts them into information (Nagels et al., 2001).

Water quality indices provide a simple and understandable tool for managers on the quality and possible uses for irrigation water.

Irrigation Quality Index (IWQI):

Water quality indices aim at giving a single value to the water quality of a source on the basis of one or the other system which translates the list of constituents and their concentrations present in a sample into a single value. One can then compare different samples for quality on the basis of the index value of each sample. In this study a new index called the Irrigation Water Quality Index (IWQI) is developed to provide a simpler method for describing the quality of water from different water resources in Iraq for crop irrigation The IWQI was developed on the basis of the water quality standards (tables 1, 2) given by Ayers &Westcot (1985). The development process of a water quality index can be generalized in four steps:

1-parameters selection:
Selecting the set of water quality variables (indicators) of concern.

2-developing sub-indices:
Transformation of the different units and dimensions of water quality variables to a common scale developing curves or formulas for c omparing indicators on a common scale)

3-assignment of weights :
weighting of water quality variables(in dicators) based on their relative imp ortance t o overall water quality.

4-aggregation of sub-indices to produce an overall index
Formulation and computing the overall water quality index (Harrison et al., 2000) .

of these, steps 1, 2, and 4 are essential for all indices. Step 3 is also commonly taken through some indices , while some other indices may be formed without this step.

Selection of water quality parameters:

In irrigation water quality monitoring , priority should be given to those parameters which are known to be of importance to plant growth and which are known to be present in significant concentrations in the water source. However, In general and as mentioned by Ayers and Westcot(1985) , the quality of irrigation water resource is associated with five main groups of limitations which are (a) salinity limitation, (b) infiltration or permeability limitation, (c) specific ion toxicity, (d) trace element toxicity; and, (e) various miscellaneous effects to susceptible crops. These limitations have negative impact on soil quality and crop yield . However, it is important to note that these five limitations could sometimes occur simultaneously, thus making their relative significance more difficult to assess. Furthermore, spatial distributions of other factors such as soil type and crop pattern cause additional complexity to the problem . Therefore, it is clear that all of these parameters must be involved in some way to better assess irrigation water quality.

The proposed IWQ index is based on the linear combination of these five groups of irrigation water quality parameters(limitations). In this technique , all five groups are simultaneously included in the analysis and are combined to form a single index value , which is then assessed to determine the suitability of irrigation water. The water quality parameters forming these groups are selected according to guidelines presented by Ayers and Westcot (1985), given in tables 1 and 2 . These parameters are best characterized the associated limitations and also are combined with each other to form a general pattern of water quality for particular resource. Furthermore, these parameters are arranged such that the results obtained from this tool(index) would make sense to non- technical decision maker and that he/ she could use the method without difficulties . As shown in tables(3, 4),the proposed index incorporates EC parameter to represent salinity limitation (*Group 1*), SAR and EC to represent permeability limitation (*Group 2*); specific ion toxicity by including the parameters of sodium, chloride and boron (*Group 3*) , and the influence of miscellaneous effects to sensitive crops by including NO_3-N ,HCO_3 and pH (*Group 5*). A weighted a verage of the trace elements(*Group 4*) is used since same of these parameters might not be measured at all locations. The index is designed to allow the user to incorporate only the measured elements without causing any error in the analysis due to the non-measured ones. It should be noted that the influence of HCO_3 was not taken into account in the assessment of water quality in this study because its influence is only reflected to the use of water for sprinkler irrigation. The assumptions indicated by Ayers and Westcot(1985) were taken into consideration in this study especially the assumption that concerning soil texture.

Sub-indices development (Transformation of variables):

Transformation of the different units and dimensions of water quality variables (indicators) to a common scale (developing rating curves or formulas for comparing indicators on a common scale) . Water quality may therefore be rated for example between 0 and 100, 0 being poor and 100 being excellent or very suitable (Richardson 1997).The proposed classification for IWQI along with ranges of concentrations of selected parameters based on standards given by Ayers and Westcot(1985) (Tables 1,2)with slight modification shown in Tables (3 and4) as new categories, according to the degree of limitations .These new categories are:

- Category I: No restrictions
- Category II: Slight restrictions
- Category III: Moderate restrictions

◙CategoryIV:Severe toVery Severe restrictions.

However ,salinity indicator was based on five categories resulting from splitting the above forth category into severe and very severe elements the categories of restriction remain three because of the unavailability of enough data about their degrees of restriction except of the data available in the present literatures . The same is for the 5th Group of parameters. The technique also assigns rating values (sub-indices) for each parameter as shown in Tables (3 and 4). Sub-indices are value functions (rating values) to transform the different units and dimensions of water quality parameters to a common scale. Fixed sub-index values were assigned for reference concentration values to formulate equations.. However, in the 'slight to severe and very severe categories' the mathematical equations which transformed the actual concentration values into individual quality indices (rating values) for each parameter were formulated .Mathematical expressions were designed for each variable to obtain these rating values, where a constant values were assigned to each class of the values of ratings which are: "< 40, 40-60, 60 - 85, 85 - <100, 100 " (Sys et al,1985) against the ranges of restriction degrees which were specifically expressed by the reference concentrations of the variables (Tables 2,3,4). Regression analysis was performed for this purpose using the '*Statistical Package for the Social Science Software-SPSS-16.0 for Windows*'. Mathematical equations are given in tables 3,4. Mathematical expressions were designed for each variable to obtain these rating values, where a constant values were assigned to each class of the values of ratings which are:"<40, 40-60, 60- 85, 85 <100 ,100 (Sys et al,1985) against the ranges of restriction degrees which were specifically expressed by the reference concentrations of the variables (Tables 2,3,4). The normal sub- index (rating value) for each of the 5- different groups was formulated as follows:

●-The first group is the salinity hazard that is represented by the EC value of the water and is formulated as:

Subindex of the 1st group(I_1)= r1…(1)

where r_1 is the rating value of the unique parameter of group 1 (i.e the EC) as given in Table 3

●-The second group is the infiltration and permeability hazard that is represented by EC- SAR combination and is formulated as:

Subindex of the 2th group(I_2)=r_2…(2)

where r_2 is the rating value of the parameter of group 2 (EC- SAR combination) as given in Table 3.

●-The third group is the specific ion toxicity that is represented by SAR, chloride and boron ions in the water and is formulated as an average of the rating values of the three ions:

$$\textit{Subindex of the 3}^{rd}\textit{group}(I_3)=\sum_{j=1}^{3} r_j \quad ......(3)$$

where r_j is the rating value of parameter *j* (*j*= SAR, Chloride ion , Boron ion) , as given in table 3 .

●-The fourth group is the trace element toxicity that is represented by the elements given in Table 2 and is formulated as an average of all the rating values of the ions available for analysis:

Sub-index for the 4th group(I_4)=

$$\frac{1}{N}\sum_{k=1}^{N} r_k \qquad \text{……….(4)}$$

where r_k is the rating value (sub-index)of trace element k(k= 1,2,3…… N), N is the total number of trace elements available for the analysis, as given in table 3.

●-The fifth final group is the miscellaneous effects to sensitive crops that is represented by nitrate–nitrogen, bicarbonate ions and water pH , and is formulated as an average:

Sub-index of the 5th group(I_5)$=\frac{1}{3}\sum_{m=1}^{3} r_m$ …(5)

where r_m is the rating value (sub-index) of parameter m(m= $NO3$-N, HCO_3 ions, pH) as given in table 3.

Assignment of weights

The weighting of variables aims to assign a relative importance to each variable (or Group of variables)and elucidate interrelations between the different variables. In the proposed technique ,weighting was applied to each of assessment groups((variables), and thus, each one of these groups is given a weight before performing the aggregation of sub-indices . (Table 3 , 4) . The influence of each parameter Group in the total value of the index, can be represented by it's individual weight (W_k).

The temporary weight value (a) ranged on a basic scale of importance from 1 (very important Group of parameter(s)) to 5(less significant group of parameter(s)) . As the salinity hazard is considered to be the most important factor in irrigation water quality assessment , it is given the highest priority. On the other hand, the miscellaneous effects to sensitive crops are generally considered as the least important factor influencing the irrigation water. Between these two extremes, the infiltration and permeability hazards , specific ion toxicity and trace elements toxicity are rated in decreasing order of significance for irrigation water quality. The final weighting factor for each Group W_k was then given as follows:

$$W_k = \frac{1/a_k}{\sum 1/a_k} \qquad \text{……..(6)}$$

W_k : weighting factor for group k (k=1……p), p=5 ; a_k is the temporary weight of group k ($\sum W_k$=1)

Table (3) shows the weighting factors of different parameter groups. Therefore the weighting factors for the five groups listed in table(3) are 0.438, 0.219 , 0.1458, 0.1095 , 0.087 respectively.

When the tests results from fewer than all five measurements are available , we preserve the relative weights for each parameter and scale the total so that the range remains 0 to 1 or(0-100).

Overall index calculation - (aggregation of sub-indices): The minimum operator method is as an aggregation function to obtain the overall index. The minimum operator aggregation sub index represents the lowest sub-index score out of the five indices of the Groups, and indicates the restriction degree of the

variable(s) that plays most significant ro le in depleting the water quality.
Consequently, after identifying the parameter that contributes maximum to the pollution, appropriate counter measures may be taken to manage the pollution. By this method the lowest sub index represent the overall water quality index. In another word the calculation of the overall index is ob tained as follows:

Overall IWQI $= \min(I_1, I_2, \ldots I_p)$…(7)

Where $I_1, I_2, \ldots I_p$ are the sub indices of the variable Groups 1,2,…..p (p=5).This method has been used by smith(1989 , 1990), Wepener et al (1992).-

Weighted Aggregation method

To develop the present above index , the weighted Minimum operator method, developed by Fagin and Wimmers (2000) and also explained by Detyniecki(2001) was employed , according to the followi ng formula :

$$\underset{W1\ldots Wp}{\overset{\theta}{\mathrm{Min}}}(I_1, I_2, \ldots\ldots I_p) = \sum_{k=1}^{p} [\, k.(W_{\sigma(k)} - W_{\sigma(k+1)}).\ \min(I_{\sigma(1)} \ldots\ldots I_{\sigma(k)})\,] \ldots\ldots(8)$$

Where the weights are non negative, $\sum Wk = 1$, σ is a permutation that orders the weighting factors as follows:

$W_{\sigma(1)} \geq W_{\sigma(2)} \geq \ldots\ldots W_{\sigma(p)}$ and $W_{\sigma(p+1)} = 0;\ p=5$

Operators are stable for any positive lin ear transformation where , k = the order of the weighting factor of kth Group sub index (k=1 for group 1; k=2 for group $_2$………… k=5 for group 5) ,; W is the weighting factor ordered by σ ; Ik is the sub index of kth group (k=1…..p). It is believed that the present proposed method has not been used before this time for water quality assessment.

Suitability classes definition

Considering the general suitability of water for surface irrigation ,and after the total values of the weighted index(IWQI) were computed, a proposed water suitability classification for irrigation was built up in this study .The index value scales were used to set the upper and lower limits used in each class specified in Table 5 . Finally, after symbolizing suitability classes, secondary symbol(s) representing subclasses (limitations) and related to most limited group(s) of parameters that reduce water suitability index value were added as lower case letter(s)to the main symbol of suitability class . and listed as follows:

s = water salinity limitation(EC)
a =permeability or infiltration rate limitation
t = specific ion toxicity
t_1=Na –toxicity
t_2= Cl- toxicity
t_3=Boron- toxicity
r =trace elements toxicity
m= miscellaneous effects
m_1= NO_3-N limitation
m_2=HCO_3 limitation(only for sprinkler i rrigation)
m_3=pH limitation .

The degree of limitation of a group can be determined by subtraction of the sub-index value for the group from the maximum assumed contribution of this group in the total range (0-100) of the main IWQI [i.e the maximum assumed contribution of the ranked groups is for group1 (43.8%)

; group2 (21.9%) ; group3 (14.58%) ; group 4 (10.95%) ; group5 (8.7%)].

Data collection

The developed technique was then applied to assess water quality of Tigris and Euphrates and Shatt Al- Arab rivers as primary sources of irrigation water in Iraq. Accordingly, a database was created for the three rivers by collecting data from a total of 26 sampling sites shown in Figure 1 . These sites were selected in such a way to represent different sectors within Tigris and Euphrates courses. Water samples were gathered at midmonth interval periods during the year of 2008, and analyzed mainly for different chemical analyses for variables developed by Ayers and Westcot(1985).

Results and discussion: One of the challenges facing people working in the field of irrigation is how to interpret the technical results in a way that it becomes useful and clear for decision makers and planners. The ideal solution for this is to use an index that would reduce the amount of data with multivariate nature, and can establish – mathematically- a link among all necessary parameters so it can provide a clear description of the water quality.The use of indices to condense and summarize large volumes of water quality data has increasingly gained acceptance in the last decade. This has come about largely because of a practical need to concisely compare the overall water quality at many different locations. The present index is defined as the degree of limitation for irrigation in the water expressed as a percentage of pure water. Thus, for completely unsuitable water the quality index will be close to or similar to 0 whereas for excellent or very suitable quality water the index will be 100. The results of the technique are evaluated based on the degree of the restriction (i.e., none, slight , moderate , severe and very severe) on the use of water for irrigation. This new index is believed to assist decision makers in reporting the state of the water quality, and investigation of spatial and temporal changes. In general, the problems associated with the soils salt content increase as the total salt content of the irrigation water increases. Therefore, the irrigation water quality should be considered as an important tool in the sustainable management of the soil resources and the agricultural production (Wilcox, 1955). The proposed index uses the electrical conductivity parameter to represent the salinity hazard. This parameter could easily be measured in field conditions and does not require lengthy laboratory procedures. Furthermore, it is one of the required parameters for determining the infiltration and permeability limitations together with SAR. Even if TDS had been selected for quantifying the salinity limitation, the EC values would have been needed for assessing the infiltration hazard. Accordingly, it is more appropriate to use EC in determining both the salinity and the infiltration limitations . When EC is assessed alone to represent the salinity hazard, high values correspond to high salinity waters that must be restricted or used with caution. On the other hand, it is advantageous to have high EC values in high SAR irrigation waters when EC and SAR are assessed together to represent the infiltration limi tation. As seen from Table 1, high EC values act as counter balance for infiltration limitation of SAR in such situations. The development of IWQI incorporates the specific ion toxicity by including boron, chloride and sodium ions. A linear combination of these parameters is included in the index value. In this group, boron and chloride ions are assessed based on their concentration values whereas sodium toxicity is evaluated as SAR, which also necessitates the measurement of the concentrations of magnesium and calcium. The index also incorporates the trace element toxicity by including the parameters depicted in Table 2. A weighted average of the trace elements is used since some of these parameters might not be measured at all locations. However, the user should be aware of the fact that such limitations in data might create results that would fail to represent the actual field conditions for several parameters and might eventually result in errors in the overall suitability assessment. Despite the fact that the index computation is designed to allow the user to incorporate only the measured elements without causing any error in the analysis due to the non-measured ones, measuring all the trace metals given in Table 2 should be the primary objective of any suitability study to be conducted by the proposed technique. Finally, the index integrates the influence of miscellaneous effects to sensitive crops by including a linear combination of NO_3-nitrogen, bicarbonate and pH. Although one can argue that these factors might show considerable differences in different geographical settings with distinct soil conditions and different crop patterns, it is believed that the importance classification given in Table 3 could be used with safety for a typical agricultural pattern as a general quality assessment tool. As with any simplification process the potential for distortion of the information provided by the original data is great. The most common types of data distortion are referred to as ambiguity , eclipsing and rigidity (Ball et al. 1980; Swamee, P. K., and Tyagi, A. ,2007). Ambiguity problems exist when all the subindices indicate acceptable water quality for a given use, but the aggregated index does not. Eclipsing problems exist when the aggregated index fails toreflect poor water quality of one or more water quality variables. Rigidity problems exist when additional variables are included inthe index to address specific water quality concerns, but the faulty aggregation function might artificially reduce the value of the water quality index such that it does not accurately reflect the true water quality. As the number of water quality variables increases, the magnitude of the aggregated index decreases raising the issue of ambiguity again (Swamee, P. K., and Tyagi, A. ,2007, Couillard and Lefebvre, 1985) .Smith (1987,1989,1990) criticized all the above drawbacks(i.e. eclipsing, ambiguity and rigidity) associated with additive or multiplicative aggregation methods and advocated the use of the minimum operator since it "avoids eclipsing" and did not exhibit ambiguity or rigidity. The minimum operator aggregation function was employed in this study so as to identify the parameter with the lowest sub-index score that plays most significant role in depleting the water quality. Consequently, after identifying the parameter that contributes maximum to the pollution , appropriate counter measures may be taken to manage the p ollution. The minimum operated method has been used in different previous studies achieved by Smith (1989 ,1990) , Wepener et al (1992) , House and Ellis (1980) , Couillard and Lefebvre (1985) , Sarkar and Abbasi(2006). But ,despite of it´s advantages of easy and rapid application , Swamee and Tyagi (2000) and Sarker and Abbasi (2006) stated that even the minimum operator does not have an eclipsing problem, but it is not suitable as an aggregation, because it fails to give a composite picture of water quality. However, use the weighted minimum operated method proposed in this study gives important advantages over the previously used unweighted minimum operated method by weighting the limitations and adding symbols of the most effective limitations (parameters that reduce water quality) according to their orders in severity to the main suitability class symbol, and hence this takes into account and explain the infl uence of other limitations (Other groups or variables), which are in the same degree of intensity or less than the limitation (parameter) which was adopted in the building of the minimum sub index and thereby build the overall index . Therefore, this method gives a composite picture of water quality. In addition, it can be applied in the case of individual variables with more objective results than is the case in the previous un weighted method , as well as its application for the groups of variables used in this study. This weighted method has not been applied previously and it's current results look much better than the results of the previous method (non-weighted) in the application, especially when there are sub indices of low values and low weight , along with sub indices of low values and high weights. When the sub index value of salinity Group is less than the rest of the sub indices values of the four Groups of variables , the value of the overall index will has the same value of The salinity sub index. In the same time the result of the overall index will be equal to its counterpart in the non– weighted method . It should be pointed out that the results of the present method is not affected by increasing the number of selected variables to characterize water quality ,if that becomes necessary in the future. The method is also flexible to introduce some changes in restriction ranges of the values of the reference variables concentrations ,which can be obtained from the specialized researches on the impact of concentrations of these variables . But, despite (elements) on different crops.

Application of IWQI to water quality data of Tigris , Euphrates and Shatt Al- Arab Rivers

The sub-indices values were calculated for the collected raw data using the mathematical expressions that were given in Table 3,4 to assign each parameter a value of between 0 and 100. Then the ratings were calculated and thus the sub indices according to the equations 1-5 . In the next step , factor weighting for each Group of variables was calculated according to equation (6), as showed in Table (3). The last step included use the Weighted minimum operator method as a way of agglomeration to obtain the overall index values ,using equation (8) and weighting factors liste d in Table 3. variable ratings were conducted using SPSS 16.0 for Windows. Finally,according to water quality index obtained and the proposed classification scheme, a composite irrigation water suitability tables represent results in site and month and are obtained for the the three rivers based on the proposed index technique (Tables 6,7,8,9). The results obtained by applying the present methodology in this study was encouraging to determine suitability of water irrigation in the different areas along the three rivers. The following summary and tables(6,7,8,9) explain the results obtained from the application of this methodology. According to the results obtained by the application of proposed irrigation water quality index (IWQI), the water of Tigris river was suitable for surface irrigation from the sampling site of Feesh Khbour up to the Kut city, then water suitability started to be moderately suitable at Ali Al Gharbi site up to Amarah city . At Qurna region the water suitability was ranged in general from moderately suitable to slightly suitable during different months through the year. In Shatt Al Arab , water was ranged from almost unsuitable to unsuitable for irrigation, except in three months of Jan, Feb , and Oct ,where water was slightly suitable. Tables (6,7) representing the suitability of river water of Tigris and Shatt Al Arab for irrigation in both spatial and temporal term. The water in Euphrates river has more severe limitations for irrigation than in Tigris river. The water was suitable for irrigation starting from Saqlawiyah up to Kifil city (Table,8,9) , and then becomes slightly suitable with almost unsuitable up to Nassiriyah region with some records of almost unsuitable during different months. The water suitability was mostly unsuitable to sometimes almost unsuitable within the sector of Mdianah – Qurna . For the classes S2 – N2 in the three rivers , the important subclasses (limitations) present are salinity(EC) and Chloride toxicity. According to the overall index results (Tables 8,9) , there are several factors that deteriorate Euphrates water quality (i.e increase water salinity) including the uncontrolled agricultural water returns, mostly from the territories of Syria in addition to completely uncontrolled agricultural water returns inside Iraq . while for Tigris river, the most pollution results from the uncontrolled agricultural water returns from the territories of Iraq. The final results are believed to be a suitable tool in future agricultural management plans and in determining the most suitable site for assessing surface water and the overall groundwater quality for surface irrigation purposes. However, there are many factors that increase the degradation of water (ie, increasing water salinity, increasing chloride toxicity) in the three rivers, including return non controlled agricultural drainage water and that come partly from Euphrates basin in Syria and partly from Euphrates River basin in Iraq, in addition to return untreated agricultural waters of Tigris river basin in Iraq.

Conclusions

In this study, a new proposed method is introduced to assess the quality of irrigation waters with regards to the potential soil and crop problems. The proposed procedure is mainly an index method that considers the most significant problems (i.e., salinity, infiltration, toxicity) associated with poor quality irrigation waters. The technique linearly combines the associated quality parameters and forms the proposed IWQI index.

Once the water suitability table is o btained , the proposed methodology is believed to provide a fairly simple analysis tool even for a non technical decision maker and/or a farmer. The developed technique is Once the water s uitability table implemented to assess the irrigation water quality of Tigris and Euphrates , and Shatt al Arab rivers in Iraq. Based on the results of this application , it has been found that the water quality in Tigris river is mostly suitable for irrigation purposes in most parts of river course except in the river part Ali Al Gharbi - Qurna which is almost moderately suitable. In Shatt al Arab , Water was not suitable through the year exept in Jan, Feb, and Oct where the water was slightly suitable On the other hand , the results show that the water quality in Euphrates is suitable in the part of Saqlawiyah-Kifil, and moderately suitable in the part of Shanafiyah- Qurna. In addition, the study also provided vital information on the probable pollution that influence both rivers. Tables (6,7,8,9) representing the suitability of river water for irrigation in both spatial and temporal term is obtained. The proposed methodology is believed to provide a fairly simple analysis tool even for a non technical decision maker and/or a farmer .In addition , it is useful to determine the level of acceptability for the individual parameter by referring to the concentration ranges defined in the prop osed classification scheme . The use of weighted minimum method proposed in this study have the characteristics of weighting parameters, and the addition of the most effective limitations (variables which reduce the quality or water quality) symbols according to their precedence in the intensity of restriction to the main symbol of water suitability class , and thus it takes into account and shows the importance of other limitations (other Groups - variables), which are in the same degree of intensity or less than the limitation (variable) which was adopted in the building of the minimum sub index,and thereby building of the overall index. Therefore , it gives a comprehensive overview of water quality. In addition to it's applicability to the groups of variables used in this study , it can be applied for individual variables with more objective results than in the case of unweighted operator method . This weighted method has not been applied previously , and it's current results look much better than the results of the previous method (non-weighted) , especially when there are sub indices of low values and low weights, along with sub indices of low values and high weights. When the value of the salinity Group sub index is less than the rest of the sub indices values of the four groups of variables, the value of the overall index will be the same value of the sub index of salinity, and the result of the overall index will be also equal to its counterpart in the non-weighted method. It should be pointed out that the results of the present proposed method is not affected by increasing the number of selected variables to characterize water quality if that becomes necessary in the future. More over the method is flexible to introduce some changes in the restriction ranges of the values of the reference variables concentrations, which can be obtained from the specialized researches on the impact of concentrations of these variables (limitations) on different crops.

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Table (1) Irrigation water quality criteria classification (Ayers & Westcot, 1985).

Criteria	Unit	Degree of restriction on use		
		no	Slight-moderate	severe
EC	DSm^{-1}	<0.7	0.7- 3	>3
Infiltration rate				
SAR		$EC(DSm^{-1})$		
<3		>0.7	0.7--0.2	<0.2
3-6		>1.2	1.2-0.2	<0.2
6-12		>1.9	1.9-0.5	<0.5
12-20		>2.9	2.9- 0.5	<0.5
20-40		>5	5 - 2.9	<2.9
Specific ion toxicity				
-Sodium(Na)	(mgl^{-1})	<3	3- 9	>9
-Chloride(Cl)	(mgl^{-1})	<140	140- 350	>350
-Boron(B)	(mgl^{-1})	<0.7	0.7 - 3	>3
Trace elements toxicity	(mgl^{-1})	**See Table -2**		
Miscellaneous effects				
-Nitrate(NO_3)	(mgl^{-1})	<5	5- 30	>30
-Bicarbonates (HCO_3)	(mgl^{-1})	<90	90- 500	>500
-pH		8-7	>8-8.5	> 8.5
		7 -8	<7- 6.5	< 6.5

Table (2) Recommended limits for trace elements in irrigation waters (Ayers &Westcot, 1985; Crook, 1996).

Constituent (mgl^{-1})	Long term use (mgl^{-1})	short-term use (mgl^{-1})
Aluminium(Al	**<5**	**>20**
Arsenic(As)	**<0.1**	**>2**
Berylium(Be)	**<0.1**	**>0.5**
Cadimium(Cd)	**<0.01**	**>0.05**
Chronium(Cr)	**<0.1**	**>1**
Cobalt(Co)	**<0.05**	**>5**
Copper(Cu)	**<0.2**	**>5**
Floride(F)	**<1**	**>15**
Iron(Fe)	**<5**	**>20**
Lead(Pb)	**<5**	**>10**
Lithium(Li)	**<2.5**	**>5**
Manganese(Mn)	**<0.2**	**>10**
Molybdenum(Mo)	**<0.01**	**>0.05**
Nickel(Ni)	**<0.2**	**>2**
Selenium(Se)	**<0.01**	**>0.02**
Vanadium(V)	**<0.1**	**>1**
Zinc(Zn)	**<2**	**>10**

Table (3) Classification and mathematical equations formulated for IWQI index parameters

Hazard group	Weighting factor	parameter	Range	Rating function (Sub-index function)
1-Salinity	0.438	EC (dSm⁻¹)	x<0.7 0.7 ≤ x ≤ 1.5 1.5 ≤ x ≤ 3 3 ≤ x ≤ 4.5 4.5 ≤ x ≤ 6.7	y=100 y = 113.13 -18.75x y = 110 -16.667x y = 100 - 13.333x y = 182.7 -27.27x
2-Infiltration rate	0.219	SAR	EC(dSm⁻¹)	
		<3	x≥ 0.7 0.7 ≥ x ≥0.45 0.45 ≥ x ≥ 0.2 x≤ 0.2	y =100 y = 60x + 58 y = 100x + 40 y = 300x
		3-6	x≥1.2 1.2 ≥ x ≥ 0.7 0.7 ≥ x ≥ 0.2 x≤ 0.2	y =100 y = 30x + 64 y = 50x + 50 y = 300x
		6-12	x≥ 1.9 1.9 ≥ x ≥1.2 1.2 ≥ x ≥ 0.5 x≤ 0.5	y = 100 y = 21.43x + 59.286 y = 35.714x + 42.143 y = 120x
		12-20	x ≥2.9 2.9 ≥ x ≥1.7 1.7 ≥ x ≥ 0 .5 x≤ 0.5	y = 100 y = 12.5x + 63.75 y = 20.83x + 49.58 y = 120x
		20-40	x≥5 5 ≥ x≥ 3.95 3.95≥ x≥ 2.9 x≤2.9	y = 100 y = 7.143x + 64.286 y = 23.81x - 9.0476 y = 20.69x
3-Specific ion toxicity	0.1458	-Sodium(Na)	x<3 3 ≤ x ≤6 6≤ x ≤9 9≤ x ≤18 18≤ x ≤26	y = 100 y = -5x + 115 y = -8.3333x + 135 y = -2.2222x + 80 y = -5x + 130
		-Chloride(Cl) (mgl⁻¹)	x<140 140 ≤ x ≤ 175 175 ≤ x ≤ 350 350 ≤ x ≤ 700	y = 100 y = -0.4286x + 160 y = -0.1429x + 110 y = -0.1714x + 120
		-Boron(B) (mgl⁻¹)		y = 100 y= -11.54x + 108.08 y = -12.5x + 110

			x<0.7 0.7≤ x ≤ 2 2≤ x ≤ 4 4≤ x ≤ 6	y = -30x + 180
4- Trace elements toxicity	0.1095	See table 4		
5-Miscellaneous effects	0.087	-Nitrate(NO_3)-N (mgl^{-1}) - Bicarbonates (HCO_3) (mgl^{-1}) -PH	x<5 5≤ x ≤ 17.5 17.5 ≤ x ≤ 30 x>30 x<90 90 ≤ x ≤ 295 295 ≤ x ≤ 500 x>500 x= (8-7) 8 < x ≤ 8.5 x> 8.5 x=(7 -8) 7 > x ≥ 6.5 x< 6.5	y = 100 y = -1,2x + 106 y = -2x + 120 y = < 60 y = 100 y = -0,073x + 106,6 y = -0,12x + 121 y = < 60 y = 100 y = -80x + 740 y = < 60 y = 100 y = 80x – 460 y =< 60

Table (4) Classification and mathematical equations formulated for parameters of trace elements toxicity

parameter (mgl^{-1})	range	Rating function (Sub-index function)
Aluminium(Al)	x<5 5 ≤ x ≤ 20 x>20	y=100 y = -6.622x + 132.9 y=0
Arsenic (As)	x<0.1 0.1 ≤ x ≤ 2 x>2	y=100 y = -52.32x + 105.1 y=0
Berylium(Be)	x<0.1 0.1 ≤ x ≤ 0.5 x>0.5	y=100 y = -248.7x + 124.6 y=0
Cadimium (Cd)	x<0.01 0.01 ≤x ≤ 0.05 x>0.05	y=100 y = -2487.x + 124.6 y=0
Chronium(Cr)	x<0.1 0.1 ≤ x ≤ 1.0 x>1	y=100 y = -109.8x + 110.8 y=0
Cobalt (Co)	x<0.05 0.05 ≤ x ≤ 5 x>5	y=100 y = -20.16x + 100.9 y=0
Copper (Cu)	x<0.2 0.2 ≤ x ≤ 5 >5x	y=100 y = -20.74x + 103.9 y=0
Floride (F)	x<1 1≤ x ≤ 15 x>15	y=100 y = -7.132x + 107.0 y=0
Iron (Fe)	x<5 5 ≤ x ≤ 20 x>20	y=100 y = -6.657x + 133.2 y=0
Lead (Pb)	x<5 5 ≤ x ≤ 10 x>10	y=100 y = -19.92x + 199.4 y=0
Lithium (Li)	x<2.5 2.5 ≤ x ≤ 5 x>5	y=100 y = -39.82x + 199.5 y=0
Manganese(Mn)	x<0.2 0.2 ≤ x ≤ 10 x>10	y=100 y = -10.18x + 101.9 y=0
Molybdenum(Mo)	x<0.01 0.01≤ x>0.05 x>0.05	y=100 y = -2487.x + 124.6 y=0
Nickel (Ni)	x<0.2 0.2 ≤ x ≤ 2 x>2	y=100 y = -54.94x + 110.4 y=0
Selenium (Se)	x<0.01 0.01≤ x ≤ 0.02 x>0.02	y=100 y = -9803.x + 197.0 y=0

Vanadium (V)	**x<0.1** **$0.1\leq x \leq 1$** **x>1**	**y=100** **y = -108.8x + 109.7** **y=0**
Zinc (Zn)	**x<2** **$2\leq x \leq 10$** **x>10**	**y=100** **y = -12.46x + 124.8** **y=0**

Table (5) Proposed Water suitability scheme for irrigation Water quality index (IWQI).

Suitability index	Class	Definition	Symbol
>80	I	Suitable	S_1
60-80	II	Moderately Suitable	S_2
45-60	III	Slightly suitable (Marginally suitable)	S_3
30-45	IV	Almost Unsuitable	N_1
<30	V	Unsuitable	N_2

Table(6) :Values of irrigation Suitability index for Tigris river water along different locations during 2008 ,using weighted method.
Aggregation method=(weighted minimum operator method)

month	Feesh khaboor	Mousel Dam	Mousel	Shirkat	Tikrit	Samarah	Tarmiya	Tigris Arm	Muthana bridge	Suhada bridge	Aziziya	Kut	Ali Al Gharbi	Ammara	Qurna	Shatt Al Arab
Jan	_	_	_	_	91.03	91.98	91.03	80	92.6	90.6	88.7	89.7	84.1	85	80.8	60
Feb	89.7	91.03	91.03	91.03	91.5	_	91.5	86.9	93.4	90.6	88.7	90.6	78.3	79.2	80.8	58
Mar	83.7	89.6	90.67	89.6	86.9	90.2	91.6	85	95.5	97.2	88.7	88.7	74.7	70	70.8	40
Apr	81.3	86.8	90.2	91.6	88.45	88.45	88.45	85.5	90.1	90.1	92.6	92.6	81.7	81.7	78.3	41.3
May	83.7	82.9	91.1	90.2	89.7	90.67	91.1	85	89.7	86.9	86.9	87.5	77.5	78.3	77.3	42.3
Jun	90	83.7	93.5	91.5	91.03	91.1	90.2	83.3	90.6	90.6	85	85	73.3	68.3	46.7	10.9
Jul	90.67	82.1	92.5	91.5	91.03	91.5	94.5	81.7	95	88.7	85	85.8	75	70	63.3	2.7
Aug	94.9	88.45	91.1	91.6	91.5	91.5	95.4	81.7	92.6	86.9	85	85	76.7	67.5	67.5	21.8
Sep	96.8	86.8	91.5	94	94.5	94.5	95.4	81.7	81.7	85.8	83.3	83.3	71.7	68.3	40	19
Oct	93	86.8	85.5	89.7	91.6	91.5	94.9	81.7	94.4	86.9	86.9	85	71.7	68.3	48	51
Nov	96.4	91.6	91.6	96.4	96.4	96.4	100	83.3	92.6	88.7	86.9	85	68.3	63.3	48	42.7
Dec	94.5	_	91.5	94	96.4	94	94.5	81.7	96.2	92.5	88.7	88.7	68.3	68.3	63.3	40

Table(7): Classes of irrigation Suitability for Tigris river water along different locations during 2008 ,using weighted method.

month	Feesh khaboor	Mousel Dam	Mousel	Shirkat	Tikrit	Samarah	Tarmiya	Tigris Arm	Muthana bridge	Shuhada bridge	Aziziya	Kut	Ali Al Gharbi	Ammara	Qurna	Shatt Al Arab
Jan	S1a	S1a	S1a	S1a	S1a	S1a	S1a	S1s	S1s	S1s	S1s	S1s	S1s	S1s		S3 st2
Feb	S1a	S1a	S1a	S1a	S1a	S1a	S1a	S1s	S1s	S1s	S1s	S1s	S2st2	S2st2	S1s	S3 st2
Mar	S1a	S1a	S1a	S1a	S1a	S1a	S1a	S1s	S1s	S1s	S1s	S1s	S2st2	S2st2	S2st2	N1 st2
Apr	S1a	S1a	S1a	S1a	S1a	S1a	S1a	S1s	S1s	S1s	S1s	S1s	S1s	S1s	S2st2	N1 st2
May	S1a	S1a	S1a	S1a	S1a	S1a	S1a	S1s	S1s	S1s	S1s	S1s	S2st2	S2st2	S2st2	N1 st2
Jun	S1a	S1a	S1a	S1a	S1a	S1a	S1a	S1s	S1s	S1s	S1s	S1s	S2st2	S2st2	S3 st2	N2 st2
Jul	S1a	S1a	S1a	S1a	S1a	S1a	S1a	S1s	S1s	S1s	S1s	S1s	S2st2	S2st2	S2st2	N2 st2
Aug	S1a	S1a	S1a	S1a	S1a	S1a	S1a	S1s	S1s	S1s	S1s	S1s	S2st2	S2st2	S2st2	N2 st2
Sep	S1a	S1a	S1a	S1a	S1a	S1a	S1a	S1s	S1s	S1s	S1s	S1s	S2st2	S2st2	N1 st2	N2 st2
Oct	S1a	S1a	S1a	S1a	S1a	S1a	S1a	S1s	S1s	S1s	S1s	S1s	S2st2	S2st2	S3 st2	S3 st2
Nov	S1a	S1a	S1a	S1a	S1a	S1a	S1a	S1s	S1s	S1s	S1s	S1s	S2st2	S2st2	S3 st2	N1 st2
Dec	S1a	S1a	S1a	S1a	S1a	S1a	S1a	S1s	S1s	S1s	S1s	S1s	S2st2	S2st2	S2st2	N1 st2

Classes symbols: S1 =suitable ; S2=mod. Suitable ; S3= slightly suitable ; N1= almost unsuitable ; N2 = unsuitable
Subclasses symbols (limitations) :s =water salinity limitation(EC) ;a=infiltration limitation; t_2= Cl- toxicity ;

Table(8) : Values of irrigation Suitability index for Euphrates river water along different locations during 2008 ,using weighted method. Aggregation method=(weighted minimum operator method)

Month	Saglawiya	yusofiyah	Hindiya barrage	Kifil	Shanafiya	Samawa	Nassiriya	Mdianah	Al Izz Rivere	Qurnah
Jan	8.7	92.6	92.6		65.7	76.7	65	45.3	81.7	55.3
Feb	0.6	92.1	92.1	87.5	44.7	51.3	56.7	36.4	81.7	42
Mar	4.4	92.6	87.5	85	58.7	58	52.7	31.8	70	25.5
Apr	6.6	92.6	92.6	90.6	53.4	60	61.7	27.3	87.3	36.4
May	0.6	92.6	90.6	89.7	40.9	35.4	56	0.01	75	16.4
Jun	6.9	88.7	90.6	88.7	57.3	54.7	53.3	0	64.2	0
Jul	1.6	89.7	88.7	86.9	52	52.7	53.3	10.9	45.3	5.5
Aug	6.9	86.9	88.7	76.7	34.6	48.7	38.2	0	56	0
Sep	8.7	88.7	88.7	86.9	49.3	48	42.7	10.9	54.7	0.01
Oct	1.8	90.6	90.6	88.7	45.3	45.3	56	44	60	45.3
Nov	6.9	86.9	86.9	83.3	48	44	34.6	18.2	48	21.8
Dec	0.6	88.8	88.9	85	61.7	55.1	53.3	40	63.3	37

able(9): Classes of irrigation Suitability for Euphrates river water along different locations during 2008 ,using weighted method

Month	Saglawiya	yusofiyah	Hindiya barrage	Kifil	Shanafiya	Samawa	Nassiriya	Mdianah	AL Izz Rivere	Qurnah
Jan	S1s	S1s	S1s		S2t2s	S2st2	S2st2	S3st2	S1s	S3st2
Feb	S1s	S1s	S1s	S1s	N1st2	S3st2	S3st2	N1st2	S1s	N1st2
Mar	S1s	S1s	S1s	S1s	S3st2	S3st2	S3st2	N1st2	S2s	N2st2
Apr	S1s	S1s	S1s	S1s	S3st2	S3st2	S2st2	N2st2	S1s	N1st2
May	S1s	S1s	S1s	S1s	N1st2	N1st2	S3st2	N2st2	S2st2	N2st2
Jun	S1s	S1s	S1s	S1s	S3st2	S3st2	S3st2	N2st2	S2st2	N2st2
Jul	S1s	S1s	S1s	S1s	S3st2	S3st2	S3st2	N2st2	S3st2	N2st2
Aug	S1s	S1s	S1s	S2s	N1st2	S3st2	N1st2	N2st2	S3st2	N2st2
Sep	S1s	S1s	S1s	S1s	S3st2	S3st2	N1st2	N2st2	S3st2	N2st2
Oct	S1s	S1s	S1s	S1s	S3st2	S3st2	S3st2	N1st2	S3st2	S3st2
Nov	S1s	S1s	S1s	S1s	S3st2	N1st2	N1st2	N2st2	S3st2	N2st2
Dec	S1s	S1s	S1s	S1s	S2st2	S3t2s	S3st2	N1st2	S2st2	N1st2

Classes symbols: S1 =suitable ; S2=mod. Suitable ; S3= slightly suitable ; N1= almost unsuitable ; N2 = unsuitable
Subclasses symbols (limitations) :s=water salinity limitation(EC) ; t_2= Cl- toxicity ;

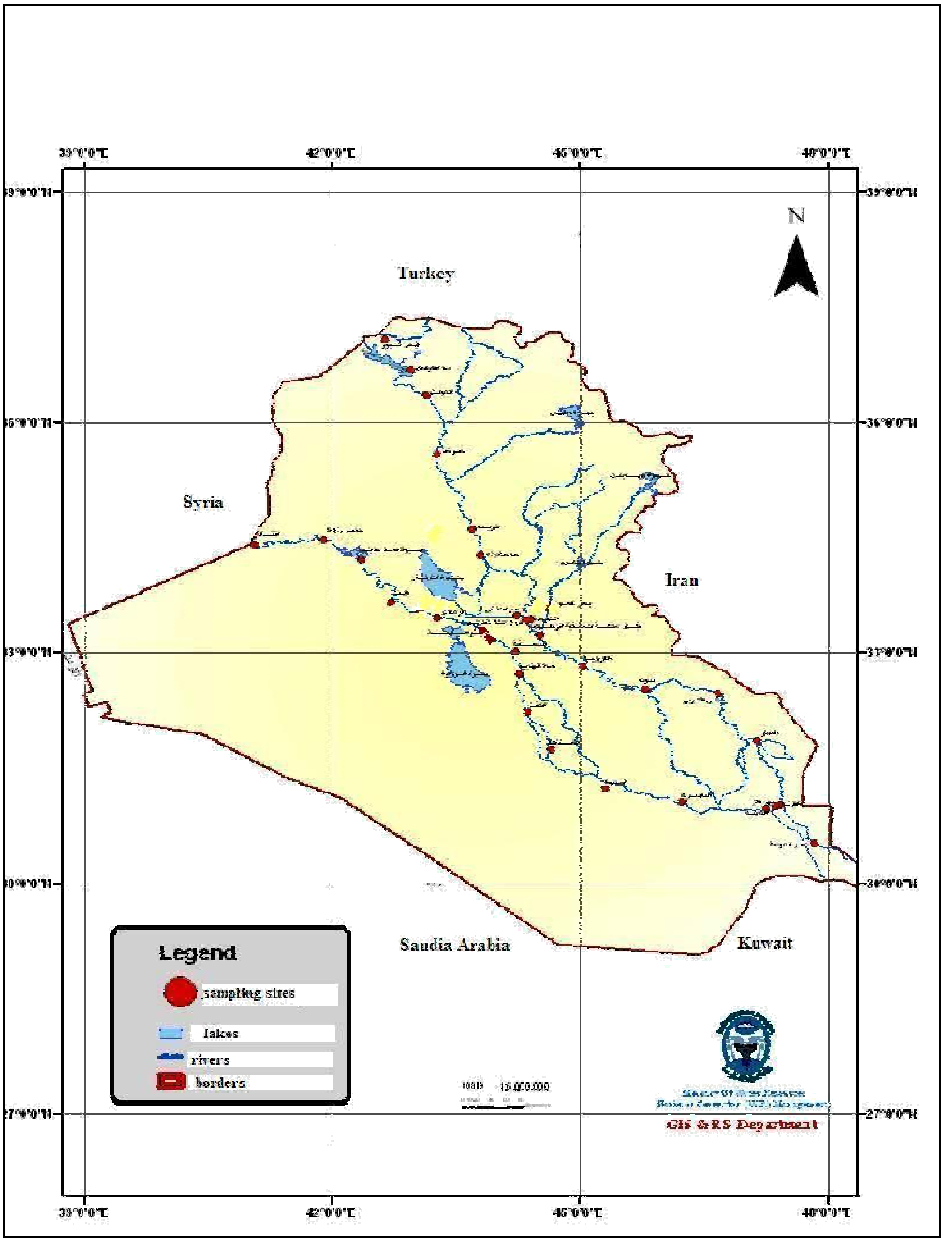

Figure (1) Location of water sampling sites on the three main rivers.