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Develop and Apply Water Quality Index to Evaluate Water Quality of Tigris and Euphrates Rivers in Iraq

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Abstract: *This study is an attempt to develop Iraqi river water quality index (IRWQI) which can be applied to evaluate the general water quality of the main Iraqi' rivers (Tigris and Euphrates) in its entire stretch for public uses. The index proposed in this work is composed of seven measurable parameters: total dissolved solids (TDS), total hardness (TH), pH, dissolved oxygen (DO), biological oxygen demand (BOD), nitrate (NO_3) and phosphate (PO_4). IRWQI is a mean to summarize large amount of water quality data into simple terms (e.g., good or poor) for reporting to authorities management and the public in a consistent manner. IRWQI can be effectively used to evaluate the spatial and temporal variations of surface water quality in the two main rivers. Calculation of water quality rating (sub-indexes) were based on giving a rating scores of 100, 95, 90, 80, 70, 60, 50, 40, 30, 20, 10 and 5 corresponding to the 5^{th}, 10^{th}, 20^{th}, 30^{th}, 40^{th}, 50^{th}, 60^{th}, 70^{th}, 80^{th}, 90^{th}, 95^{th} and 99^{th} percentiles, respectively to long term parameter observations. The associated best-fit formulas to each parameter rating curve were used to calculate aggregated index. The unweighted harmonic square mean formula, as a method to aggregate sub index results, has been suggested. This formula allows the most impaired variable to impart the greatest influence on the water quality index and will pose differing significance to overall water quality at different times and locations. The IRWQI developed was applied to seven selected sampling stations (T1 to T7) along Tigris river, six selected sampling stations (E1 to E6) along Euphrates river and one common selected sampling station (ET) after meeting of Tigris with Euphrates at Al Qurna. The results showed that water quality varied from very good to very poor range. In general the water quality was degrades downstream. Tigris water quality better than Euphrates water quality. There was no large different in water quality between dry season and wet season where engineering controls on the rivers have greatly reduced their seasonality.*

Key words: *Euphrates Rivers, IRWQI, Rating curve, Tigris River, TDS, Water quality.*

I. INTRODUCTION

Most of the urban centers in Iraq and a large portion of its population are located along and near the Tigris and Euphrates rivers. Euphrates and the Tigris rivers are of vital importance to people in domestic water use. They are essential resources for economic activities.

The evaluation of water quality in developing countries has become a critical issue in recent years, especially due to the concern that fresh water will be scarce resource in the future. Whereas water monitoring for different purposes is well defined (e.g., aquatic life preservation, contact recreation, drinking water use), the overall water quality is sometimes difficult to evaluate from a large number of samples, each containing concentrations for many parameters [1].

Water quality index (WQI) is a mechanism for presenting a cumulatively derived numerical expression defining a certain level of water quality [2]. In other words, WQI summarizes large amounts of water quality data into simple terms (e.g., excellent, good, bad, etc.) for reporting to management and the public in a consistent manner. The index reflects the status of water quality in lakes, streams, rivers, and reservoirs.

A number of indices have been developed to summarize water quality data in an easily expressible and easily understood format [3]. These indices have been the product of efforts and research development from governmental agencies in different strata, as well as from masters' and doctorate research. There are various water quality indices (WQI) to compare various physico–chemical and biological parameters [4,5].

Despite the various water quality indices have been developed and published in the literature, but so far ministries of environment and water resource in Iraq has made insufficient progress in developing and utilizing specific water quality index. In this study an index has been developed which can be used with data on physical, chemical and biological variables routinely collected by **water resource monitoring program.** Although some information is lost when integrating multiple water quality variables, this loss is outweighed by the gained understand of water quality issues by the lay public and policy makers. Improving understanding is very import to water resource managers in terms of increasing support for water resource improvement efforts.

II. WATER QUALITY INDEX

Water quality index was first formulated by Horton (1965) and later on used by several workers for the quality assessment of different water resources. It is one of the aggregate indices that have been accepted as a rating that reflects the composite influence on the overall quality of numbers of precise water quality characteristics [6]. Water quality index provide information on a rating scale from zero to hundred. Higher value of WQI indicates better quality of water and lower value shows poor water quality. Therefore, a numerical index is used as a management tool in water quality assessment [7]. WQI basically acts as a mathematical tool to convert the bulk of water quality data into a single digit, cumulatively derived, numerical expression indicating the level of water quality. This, consecutively, is essential for evaluating the water quality of different sources and in observing the changes in the water quality of a given source as a function of time and other influencing factors [8].

From literature review, it is clear that a great variety of water quality indices have been published. These indices differ from each other in term of fundamental structures and in term of the number and types of variables that have been selected for inclusion. The general procedure to calculate Water Quality Indexes depend on 3 common factors to develop it: 1) parameter selection, 2) determination of quality function for each parameter (sub-index) and 3) aggregation of sub-indices with mathematical expression.

2.1- Parameters included in WQI

Water quality assessment can be defined as the evaluation of the physical, chemical and biological nature of water in relation to natural quality, human effects and intended uses. In this study the WQI developed aids in the assessment of water quality for public uses (potable water supply, recreation, …) and to evaluate water quality management effectiveness. It can be used to improves comprehension of general water quality issues, communicate water quality status and illustrate the effectiveness of protective practice. In order to develop a water quality or river index for above purpose, there are seven parameters have been chosen. This parameters include: Total dissolved solids (TDS), total hardness (TH), dissolved oxygen (DO), pH, biological oxygen demand (BOD), nitrate (NO_3) and phosphate (PO_4) which monitored monthly among others by water resource monitoring program.

2.2- Quality rating formulas (sub-index)

The mean observed and predicted values of each water quality parameter were converted into sub-index scores for the parameter using the rating curves. These rating curves were developed in this study basically from statistical data analysis of raw data was acquired by long-term water resource monitoring program with assistance of water quality experts' opinions. Calculation of water quality rating (sub-indexes) were based on giving a rating scores of 100, 95, 90, 80, 70, 60, 50, 40, 30, 20, 10 and 5 corresponding to the 5^{th}, 10^{th}, 20^{th}, 30^{th}, 40^{th}, 50^{th}, 60^{th}, 70^{th}, 80^{th}, 90^{th}, 95^{th} and 99^{th} percentiles, respectively to each parameter observations. The associated best-fit formulas to each parameter rating curve were used to calculate aggregated index. Each of seven parameter sub-index (SI_i) used to calculate the overall water quality index have been listed below:

<u>For TDS:</u>
If $TDS \leq 450$ $SI_{TDS} = 100$
If $TDS > 5500$ $SI_{TDS} = 10$
If $450 < TDS > 5500$ $SI_{TDS} = -34.1 \ln (TDS) + 304.8$

<u>For TH:</u>
If $TH \leq 100$ $SI_{TH} = 100$
If $TH > 1200$ $SI_{TH} = 10$
If $100 < TH \leq 1200$ $SI_{TH} = 6.57 E\text{-}5*(TH)^2 - 0.1626 (TH) + 111.1$

<u>For PH:</u>
If $4.5 \leq PH < 7.0$ $SI_{PH} = 1.9 EXP((PH-1)*0.66)$
If $7.0 \leq PH \leq 7.6$ $SI_{PH} = 100$
If $7.6 < PH \leq 10.5$ $SI_{PH} = 100 EXP((PH-7.65)*-0.528)$
If $10.5 < PH < 4.5$ $SI_{PH} = 10$

<u>For DO:</u>
If $DO < 3.3$ $SI_{DO} = 10$
If $DO > 12.5$ $SI_{DO} = 100$
If $3.3 \leq DO \leq 12.5$ $SI_{DO} = -59.6 + 24.9*DO - 0.98*DO^2$

<u>For BOD:</u>
$SI_{BOD} = 100 * 0.86 ^ BOD$

<u>For NO_3:</u>
If $NO_3 \leq 1$ $SI_{NO3} = 100$
If $NO_3 > 1$ $SI_{NO3} = 102*0.8887^{(NO_3)}$

<u>For PO_4:</u>
If $PO_4 < 0.03$ $SI_{PO4} = 100$
If $PO_4 > 1.2$ $SI_{PO4} = 10$
If $0.03 \leq PO_4 \leq 1.2$ $SI_{PO4} = 99.5*0.17^{(PO_4)}$

2.3- Aggregation and calculation of water quality index

Aggregation is the process of combining and simplifying a group of sub- indices. The unweighted harmonic square mean formula, as a method to aggregate sub index results, has been suggested as an improvement over both the weighted arithmetic mean formula and the weighted geometric mean formula. The formula is given by Cude [9]:

$$WQI = \sqrt{\frac{n}{\sum_{i=1}^{n}\frac{1}{SI_i^2}}}$$

Where WQI is water quality index result, n is the number of sub-indices, and SI_i is sub-index. This formula allows the most impaired variable to impart the greatest influence on the water quality index and will pose differing significance to overall water quality at different times and locations.

2.4- Classification of WQI Scores

The index equation generates a number between 10 and 100, with 10 being the poorest and 100 indicating the excellent water quality. Within this range designations, present study have been set to classify water quality as illustrated in (Table 1) into six classes of water quality as very poor, poor, fair, good, very good and excellent.

Table .1 Classification scheme for water quality index scores.

WQI Range	Class	Statement
< 45	VI	Very poor
45 – 60	V	Poor
61 – 69	IV	Fair
70 – 79	III	Good
80 - 90	II	Very good
91 – 100	I	Excellent

III. MATERIAL AND METHODS

3.1- study sites

The Euphrates and Tigris Rivers flows within three of the Middle East countries: Turkey, Syria, and Iraq. The Tigris stretch section in Iraq about 1400 km while the length of the Euphrates in Iraq about 1060 km. Euphrates crosses Syria before flowing into Iraq and meeting Tigris, which also crosses Syria for short distance (about 40 km), and together they form Shat Al Arab in the south of Iraq. The Tigris–Euphrates Basin was shown in fig.1. Seven selected sampling stations located along the Tigris stretch and six selected sampling station along the Euphrates Rivers as well as one station after joint meeting between two rivers were chosen inside Iraq state to assess the water quality of two rivers. The selected sampling stations of Tigris river are T1 (Fishkhabor), T2 (Al Shirgat), T3 (Tarmiah), T4 (Baghdad), T5 (Aziziah), T6 (Kut) and T7 (Amarah). The selected sampling Stations of Euphrates river are E1 (Al Qaim), E2 (Fallujah), E3 (Al Kefil), E4 (Shnafia), E5 (Samawa) and E6 (Nasiria). The common sampling station ET (Al Qurnah), where Tigris river meet Euphrates river. It is worth mentioning that the first selected station for each river is located in the entry point of a river at Iraqi borders which often represents the baseline water quality to other downstream stations.

3.2- Methodology

This study did not involve any field data collection or laboratory water quality analysis. The available long-term water quality monitoring data of 39 sampling stations for Tigris river and 22 sampling stations for Euphrates river were analyzed to develop water quality index. The developed water quality index proposed in this study was applied to selected sampling stations along the Tigris and Euphrates rivers at 2012 to evaluate water quality of two rivers for public use. Seven related parameters (TDS, TH, pH, DO, BOD, NO_3 and PO_4) plays a significant role to assess general water quality based on common and important physical, chemical and biological parameters of surface water were chosen to calculate WQI at selected locations.

IV. RESULTS AND DISCUSSION

The water quality index was designed to permit comparison of water quality among different stretches along the same river or between different Iraqi rivers.

4.1- Parameters selection importance

Depending on the data availability and to ensure main Iraqi rivers water quality, seven water quality parameters were selected in WQI. With too many variables, small individual changes are not detectable in the aggregated water quality index value [9]. Understanding water quality parameters and their characteristics is important to identify the quality of the water, to know the reasons which led to changes in the quality, and to help in interpreting these changes**.** These parameters include: TDS, TH, pH, DO, BOD, NO_3 and PO_4.

An effort has been made by Bharti N and Katyal D. [10] to carry out a review of important indices formulated all over the world used in water quality assessment. From the analyses of 36 indices, it appears that they have 35 common parameters of which, the most common and frequent of the cases is the dissolved oxygen 15 indices, pH in 11 indices, BOD in 11 indices, total phosphorous and phosphates in 11 indices, nitrates in 10 indices, total dissolved solid in 8 indices and total hardness in 5 indices [11].

Total dissolved solids (TDS) are represents salts and minerals dissolved in the water (mg/L) that cannot be removed by conventional filtration [7]. Water salinity (expressed as TDS) is an increasing problem in Iraq. Salinity increases as the river water flows southward and evaporation, sewage effluent, dissolution of limestone and evaporate bedrock, and agricultural drainage all increase the salinity. River water can be classified by the amount of TDS as: fresh water < 1500 mg/L TDS, brackish water 1500 to 5000 mg/L TDS or saline water > 5000 mg/L TDS [12]. In this study TDS is considered to be a good indicator for water salinity, and it gives general information about the sum of ions in the water. TDS can be employed to establish potential water usage or to evaluate the quality of supplied water; it affects everything that consume, lives in, or uses water. If the TDS passes 1000 mg/l, water becomes less usable and it is no longer potable for human consumption [13]. Above 3000 mg/l, it is not suitable for most municipal or agricultural usages.

As shown in fig. (2), it is clearly demonstrated that the TDS increases steadily along the stretch of the Tigris river for both wet season (average of January, February and March months) and dry season (average of Jun, July and August months), while fig. (3) shows an exception for Euphrates river where TDS concentrations at upper stretch increased steadily especially at dry season then began decrease at downstream station E6 and later compared with previous stations. The main reason to decreasing TDS at lower stretch belong to partially dilution with better water quality discharged from Al Garraf branch river from Tigris. Primary sources for TDS in receiving waters are agricultural and residential runoff, leaching of soil contamination and point source water pollution discharge from industrial or sewage treatment plants [14].

Total hardness is mainly a reflection of major ions, e.g., Ca^{+2}, Mg^{+2}, CO_3^{-1} and HCO_3^{-1}, being present in the water. These ions enter the river water by leaching from minerals like Calcite, gypsum and Dolomite, which exist throughout the course of the river. Kannan [15] has classified water on the basis of hardness values in the following manner; 0- 60 mg/L, soft, 61-120 mg/L, moderately hard, 121-160 mg/L, hard and greater than as 180 mg/L very hard. Hardness below 300 mg/L is considered potable but beyond this limit produces gastrointestinal irritation [16]. Normally water hardness does not pose any direct health problem but may affect the consumer acceptability of water in terms of taste and cause economic problems [17]. The results was showed increase trend in hardness concentration along with downstream direction for Tigris and Euphrates rivers. There are strong correlation between TDS and hardness, however high TDS concentrations in water usually indicate high level of hardness in water [18]. Therefore, using both parameters in calculating WQI maximize the effect of TDS on water quality index which reflect the purpose of using index for public used.

pH is a measure of acidity or alkalinity. pH is an important parameter to monitor as it can significantly impact the physiological processes of aquatic biota when changes to the natural pH range occur [19]. Furthermore, it can influence the solubility of nutrients and pollutants. The measure of pH is very important as an indication of water quality due to the sensitivity of organisms to the pH of their environment. pH is also important in assessing the suitability of water for drinking [17]. The results as listed in table 1 and 2 showed variability along the course of rivers.

Dissolved oxygen (DO) is essential for water quality, ecological status, and health of a river. This is due to its importance as a respiratory gas, and its use in biological and chemical reactions [20]. DO is also important when assessing the suitability of water for drinking. Low DO in source water can increase the conversion of nitrate to nitrite and sulphate to sulphide as well as increase the concentration of ferrous iron in solution, leading to discoloration in drinking water [17]. The presence of pollutants can reduce the oxygen carrying capacity and the concentration value of dissolved oxygen in river water.

Biological oxygen demand (BOD) is the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in given water sample at certain temperature over a specific time period and considered as an important water quality indicator. BOD could be preferred over COD because BOD represents better the biodegradable pollutants in the water body and most of the water quality models can simulate this parameter [21].

Nutrients (nitrate and phosphate) are an important indicator of water quality and originate from a range of point and diffuse sources, particularly the discharge of sewage effluent and agricultural runoff (fertilisers, waste from livestock). Excessive nutrients can result in eutrophication and algal blooms, can significantly impact aquatic ecosystem health, and reduce ecological and recreational values of freshwater resources [22]. However, agricultural discharges may contribute with high nitrate levels resulting from excessive fertilizer use in agriculture, when microorganisms break down fertilizers, decaying plants, manures, animal feedlots or other organic residues.

4.2- Observed change in WQI

To calculate the WQI, the raw analytical results for each parameter, having different unit of measurement, are first transformed into non-dimensional sub-index values rating from 10 (worse case) to 100 (ideal) depending on the parameter's contribution to water quality impairment. These sub-indices are then combined to give a single water quality index rating value ranging from 10 to 100. The unweighted harmonic square mean formula used to combine sub-indices allows the most impacted parameter to impart the greatest influence on the water quality index [9]. Thus the result from all sampling stations in two seasons is showing that Water Quality Index is in very good range to very poor range because in method that assign fixed weights to variables will pose differing significance to overall water quality at different times and locations.

The quality of water in the Tigris river as shown in fig. 4 near the Turkey border (sampling station T1) is assumed to be ranged from good to very good quality, water quality degrades downstream, with major pollution inflows from urban areas due to poor infrastructure of wastewater treatment. The diversion of excess water to prevent flooding problems from Tigris to the Al-Tharthar Depression caused considerable increase in the salinity (expressed as TDS) in return water to the river system, due to the very large evaporation rate, dissolution of salt and gypsum from soil of the depressions, and salt ground water effects. These three significant reasons have seriously diminished water quality [23]. The effect of Al-Tharthar Depression clear on the water quality at station T4 where the WQI status become fair at station T4 (Baghdad). Urbanization and an increasing population imply an increase in water consumption for domestic, industrial, and agricultural purposes. This increase in water demand consequently means an increase in the discharged waste water from all these sectors into river water [24,25]. After Tigris river joining Euphrates river (worse quality) at station ET (Al Qurna) the water quality more decreased, it become poor quality. At T6 the water quality slightly increased that may be belong to increasing the ability of river to self purification, where the concentration of nitrate decreased as well as the BOD. At lower stretch of Tigris river, the water quality can be severely affected by the irrigation return waters causing degrading in water quality, where at T7 and later quality of water was recording backing down.

The river water quality of the Euphrates as shown in fig. (5), is varying greatly from place to place along the river. This variation is due to a combination of natural factors and human activities. Euphrates starts with good or very good water quality index at sampling station E1 (the point of iterance Iraqi border from Syria), usually the TDS there is about 600 mg/l . Most other physiochemical parameter in good quality range. Gradually water quality decreases downstream, and the worse quality happen at stations (E4, E5 and E6) then the river water quality improved slightly from very poor quality to poor quality. At the mouth of the river into Shat al Arab where joining Tigris river (better quality), the quality of water convert to fair status.

The water quality of Euphrates River within Iraq especially south of Bagdad (at sampling stations E4 and later) is not satisfactory mostly [26]. Poor irrigation practices have led to major degradation of land and water. Inefficient irrigation techniques that are practiced have contributed to an increase in the salinity of the soil. Irrigation practices such as flood and furrow requires a lot of water to flood the farm land. As a result for this practice, a large quantity of excess water will be generated, which either seep into the groundwater or reaches to the river. There are more than 16 drains working and conveying drainage wastewater along Euphrates River especially at middle and lower stretch. These drains play a significant role in altering the quality of Euphrates river water. These drains discharging return irrigation water into the river which contains high concentration TDS, NO_3 and PO_4 [27]. This will led to an increase in the salinity and cause a massive increase in the growth of algae or plankton in Euphrates River. The final quality depends on how much water flows through the river and in which quality, as well as how much return water enters the river and the concentration of the water in the drains [18].

The Euphrates flows rapidly in the upper course due to large differences in elevations. In the middle and lower stretch in Iraq, the river velocity becomes very low and the river is consider to be a slow running stream [28]. The very gentle gradient of the Euphrates river [25] reduce the ability to self- purification and remove certain amount of pollutants by degrading or dispersing it.

The population growth in large suburban residential areas have developed along Tigris and Euphrates rivers stretch without adequate infrastructure, and sewage treatment plants are not enough for this expansion. Most of the solutions in this case are by constructing new bypasses to discharge the untreated wastewater into the river directly, which causes river water quality degradation [18].

In general, WQI in wet season as shown from fig. (4) and (5) for Tigris and Euphrates rivers respectively, is slightly less than in dry season. Although the amount of rain falling during wet season that may be reflected on the amount of river discharge and thus improve the quality of the water, but engineering controls on the rivers have greatly reduced their seasonality. In addition to the runoff and increasing the quantity of return flow from irrigation all that affect the water quality.

Water quality of the Euphrates entering Iraq is less than the Tigris, currently affected by return flow from irrigation projects in Turkey and Syria as well as sewage water system which are directed to the river (27). The quality of the water in both the Euphrates and the Tigris is further degraded by return flows from land irrigated in Iraq as well as urban pollution [29].

V. CONCLUSION

Developed Iraqi river water quality index (IRWQI) was applied to evaluate the water quality of Tigris and Euphrates rivers for public uses. The results showed that water quality varied from very good to very poor range. Tigris water quality was largely degraded after sampling station T3, where the effect of Al Tharthar depression was very clear on water quality. High impact of agriculture return flow on water quality was noticed at middle and lower stretch of Tigris and Euphrates rivers. Euphrates water quality was severely degraded at lower stretch (at sampling stations E4 and later). In general water quality of Tigris river better than in Euphrates. There was no large different in water quality between dry season and wet season where engineering controls on the rivers have greatly reduced their seasonality.

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Figure (1). Tigris and Euphrates rivers [30]

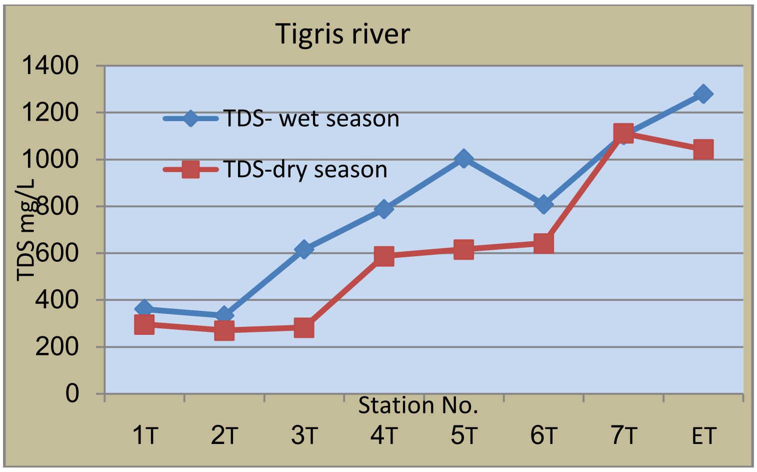

Figure (2). Changes in total dissolved solids along Tigris river.

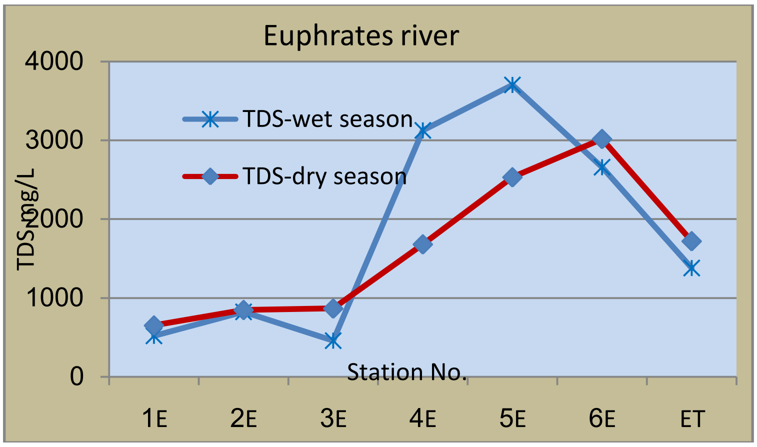

Figure (3). Changes in total dissolved solids along Euphrates river.

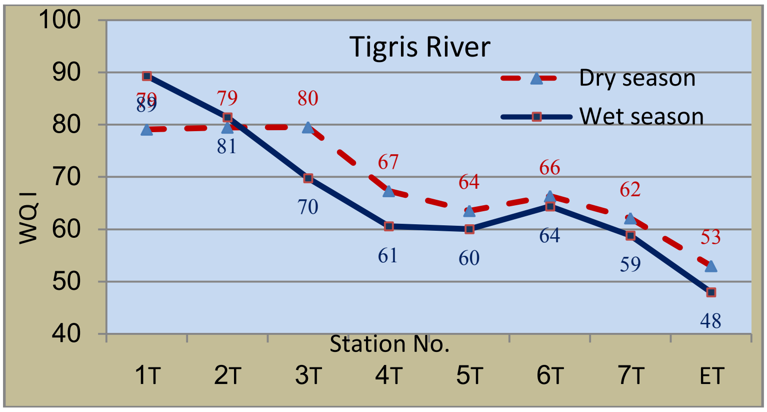

Figure (4). Changes in water quality index along Tigris river

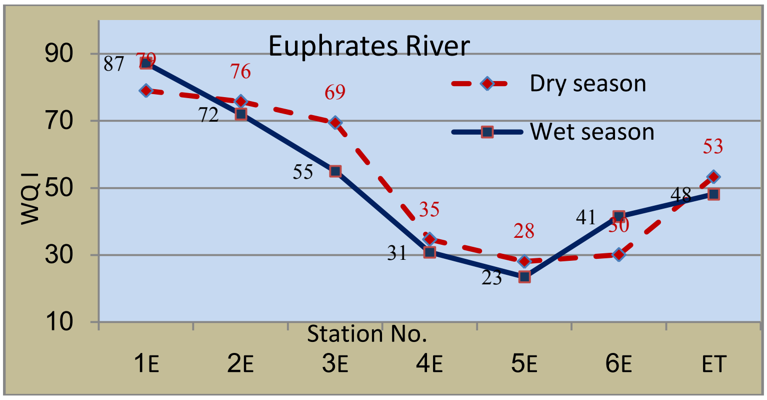

Figure (5). Changes in water quality index along Euphrates river.