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| RESEARCH ARTICLE

Little Zab River water suitability assessment applying three water quality index mathematical models (Horton, National Sanitation Foundation (NSF) and Malaysia)

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| ABSTRACT
Surface water is considered one of the most common sources of water supply, due to the various environmental challenges. Therefore, it has become necessary to conduct monitoring of surface water quality to ensure it is safe for use. This led to increasing interest in models-based research for water quality determination. This research investigated the evaluation of water quality index (WQI) for the *Little Zab River* in the Northern region of Iraq for 14 years. Several parameters were selected including (pH, DO, BOD_5, PO_4^{-3}, NO_3^- , alkalinity, TDS, Cl^- and temperature). The results showed that the (temperature, pH, alkalinity, NO_3^-, Cl^- and TDS parameters were all within the permissible limits, while (DO, BOD_5, and PO_4^{-3}) were sometime higher in some years. Three mathematical models were selected in WQI evaluation including (Horton, National Sanitation Foundation (NSF) and Malaysia). The resulting WQI values for the three proposed models are 45.45, 77 and (28-30) % respectively. Also, the river suitability for irrigation is assessed through several indices including (Kelley's Index (KI), Sodium Adsorption Ratio (SAR), Magnesium Hazard (MH), Soluble Sodium Percentage (SSP), Permeability Index (PI), and Total Hardness (TH)). The results fall within the permissible limits, except for PI in some years. Future studies should prioritize tasks the development of water quality assessment models, using machine learning and artificial intelligence for predictive modelling and risk evaluation, in a sustainable and environmentally friendly approach.

| KEYWORDS

WQI, Little Zab River, Irrigation Suitability, Mathematical Modeling.

| ARTICLE INFORMATION

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1. Introduction
Water is an essential vital resource for sustainability life on this earth. However, purposes such as population growth and industrial activities, have resulted in an increasing water pollution issue, and hence a water quality degradation (Uddin, et.al., 2021) Domestic wastes dumping in water bodies is essentially responsible for over than 80% of surface water pollution, especially in developed countries (Plessis, 2022). Water pollution arises from the improper management of water resources by human activities, including industrial development, agricultural practices, including unrestrained use of mineral fertilizers and excessive addition of pesticides, and processes like the dissolution of rock particles through water-rock interactions (Dehkordi et.al., 2024). these influences contribute to changes in water characteristics, making the water invalid for purposes like human consumption, irrigation of crops, and industrial processes. Identifying and mitigating these sources of pollution is crucial in achieving effective water resource management and ensuring environmental sustainability. Surface water contributes effectively in support, including drinking and home use, irrigation of crops, and industrial processes. In particular, domestic use accounts for 5% of it, industrial use accounts 20%, while the agricultural purposes account for the majority (75%) (FAO, 2017). In the field of water quality assessment, researchers have attempted to develop classifications and guidelines for irrigation water quality. However, these existing guidelines

have proven unsatisfactory due to the variability of field conditions and their inability to contribute an inclusive understanding of water characteristics in reservoirs or rivers. To overcome this challenge, researchers proposed the use of an indicator that integrates all relevant water quality parameters, presuming it gives a comprehensive and easy description of water quality (Ewaid et.al., 2019). The Water Quality Index (WQI) known is a valuable tool used to determine the water quality of various water sources, as such surface water and well water several parameters and comparing the values of parameters with established standard values and subsequently converting multiple water quality parameters into a single numerical value (Uddin et.al., 2021). The parameters of water quality incorporate: biological, chemical and physical characteristics, used to determine the suitability of water for uses such as drinking, home use, industry and irrigation (Poojashree et.al., 2022). Water properties can be influenced by changes in constituents or parameters, so, continuous monitoring and periodic data collection are crucial in gathering water quality information (Jaywant and Arif, 2024)
This research aims to determine the suitability of Little Zab River water for Irrigation using the WQI evaluation.

2. Materials and Methods

2.1 Geographical location

Water semples were collected from the Little Zab River located in the northern region of Iraq fig. (1). It originates from the northwestern Iranian mountains and is united with the Tigris River to the south of the Great Zab River in the northern region of Iraq (Kurdistan). The Little Zab River is about 400 Km in length with two dams built on it, and it is fed by seasonal rainfall and snowmelt.

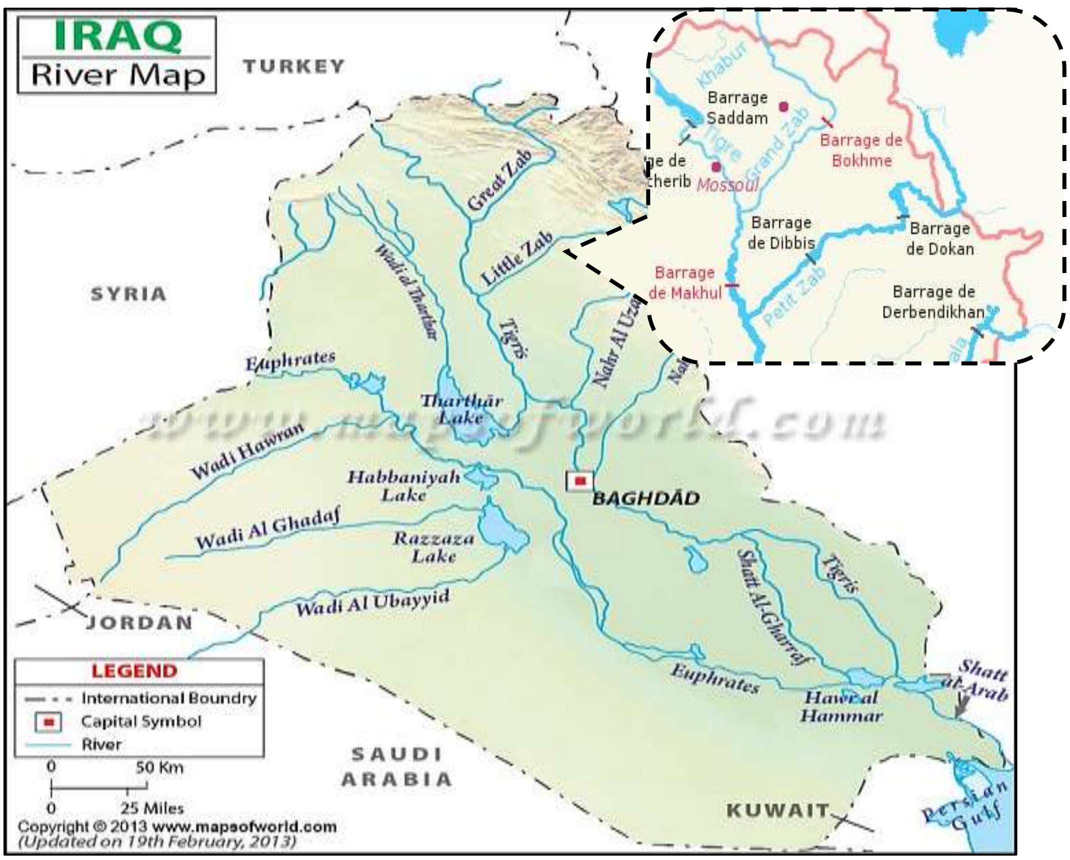


Fig. 1 The Little Zab River map (Solecki, 2005).

2.2 Sample analysis

The water samples were collected by using 1 liter polyethylene bottles that were rinsed thoroughly prior to collection. pH and Electrical Conductivity (EC) measurements were conducted in situ by using a portable multimeter (TWT). The water samples were then transported to the laboratory for analysis, where various parameters such as Sodium Na^+ and potassium K^+ were determined by flamephotometer. While, calcium Ca^{2+}, magnesium Mg^{2+}, chloride Cl^-, carbonate CO_3^- and bicarbonate HCO_3^- have been determined through titration process. On the other hand, sulphates SO_4^- was determined by ultraviolet spectrophotometer. Additionally, nitrate NO^- was determined by optical spectrophotometer. All the conducted measurement were reformed according to the procedures proposed by (APHA, 2017). The Iraqi water reservation limits are illustrated in table 1 below.

Table (1): Iraqi river regulatory limits (Ashour, 2024).

Parameter	Regulatory Limits
pH	6.5-8.5
TDS	< 1000 mg/L
DO	> 5 mg/L
PO4-3	< 0.4 mg/L
NO3-	< 50 mg/L
BOD5	< 5 mg/L
Cl-	< 30 mg/L
Alkalinity	20-200 as CaCo3 /L

2.3 IWQG software

Irrigation Water Quality Guidelines (IWQG) is a design program assessing water use for irrigation according to some physical and chemical parameters and indexes according to FAO standards 1994 developed by the National Center for Water Resources and certified by the Ministry of Water Resources as illustrated in table (2) (FAO, 2017).

Table (2): Normal range of chemical parameters in irrigation water (FAO, 2017).

Parameters	Symbol	Unit	Normal Ranges
Potential Hydrogen	(pH)	—	6.5-8
Electric Conductivity	(ECw)	dSm^{-1}	0-3
Total Dissolved Solids	(TDS)	$mg\ l^{-1}$	0-2000
Calcium	(Ca2+)	$mg\ l^{-1}$	0-20
Magnesium	(Mg2+)	$mg\ l^{-1}$	0-5
Potassium	(K+)	$mg\ l^{-1}$	0-2
Sodium	(Na+)	$mg\ l^{-1}$	0-40
Nitrate	(NO3-)	$mg\ l^{-1}$	0-10
Phosphate	(PO4-)	$mg\ l^{-1}$	0-20
Carbonate	(CO3-)	$mg\ l^{-1}$	0-0.1
Bicarbonate	(HCO3-)	$mg\ l^{-1}$	0-10
Chloride	(Cl-)	$mg\ l^{-1}$	0-30
Sulphate	(SO42-)	$mg\ l^{-1}$	0-20
Boron	(B-)	$mg\ l^{-1}$	0-2
. Sodium Adsorption Ratio	SAR	$(mg\ l)^{1/2}$	0-15

This program determines the water class for irrigation and then locates the weight (Wi) for each parameter (ith) and the subindex quality (Qi). The (Wi) weight specified depending on the parameter's values in the intended region and the norm based on (Ayers and Westcot, 1994), as illustrated in tables (3) and (4).

Table (3): The values of subindex quality (Qi) and weights (Wi) are calculated (IWQ), ECw ($\mu s\ cm^{-1}$), while parameters SAR, Na+, Cl- and HCO3- ($meq\ l^{-1}$) (Ayers and Westcot, 1994).

Qi	ECw (μs cm-1)	SAR	Na (Meq l-1)	Cl (Meq l-1)	HCO3 (Meq l-1)
(0-35)	$EC < 200$ $EC \geq 3000$	$SAR < 2.0$ $SAR \geq 12.0$	Na < 2.0 Na ≥ 9.0	Cl < 1.0 Cl ≥ 10.0	HCO3< 1.0 HCO3− ≥ 8.5
(35-60)	$1500 \leq EC < 3000$	$6.0 \leq SAR \leq 12.0$	6.0 ≤ Na < 9.0	7.0 ≤ Cl < 10.0	4.5 ≤ HCO3 < 8.5
(60-85)	$750 \leq EC < 1500$	$3.0 \leq$ SAR <6.0	3.0 ≤ Na < 6.0	4.0 ≤ Cl < 7.0	1.5 ≤ HCO3 < 4.5

(85-100)	$200 \leq EC < 750$	$2.0 \leq SAR < 3.0$	$2.0 \leq Na < 3.0$	$1.0 \leq Cl < 4.0$	$1.0 \leq HCO3 < 1.5$

Table (4): The characteristics of water quality for irrigation (Ayers and Westcot, 1994).

The potential issue of irrigation		(Restriction Degree)		
		None	Slight - Moderate	Sever
Salinity	EC (dS m-1) at 25 ◦C	< 0.7	$0.7 - 3$	> 3
	TDS (mg l-1)	< 450	$450 - 2000$	> 2000
Sodicity	SAR= $0 - 3$ and ECw	> 0.7	$0.2 - 7$	< 0.2
	SAR= $3 - 6$ and ECw	> 1.2	$0.3 - 1.2$	< 0.3
	SAR= $6 - 9$ and ECw	> 1.9	$0.5 - 1.9$	< 0.5
	SAR= $12 - 20$ and EC	> 2.9	$1.3 - 2.9$	< 1.3
	SAR $20 - 40$ and ECw	> 5	$2.9 - 5$	< 2.9
SAR		< 3	$3 - 9$	> 9
Cl- (meq l-1)		< 4	$4 - 10$	> 10
HCO3 (meq l-1)		< 1.5	$1.5 - 8.5$	> 8.5
pH		$6.5 - 8.5$		

WQI involves two essential procedures: the first procedure includes the statistical analysis of main parameters such as ECw (electrical conductivity), Na+ (sodium ion), HCO3- (bicarbonate ion), Cl- (chloride ion), and SAR (sodium adsorption ratio). These parameters are considered crucial indicators in evaluating water quality for irrigation.

The second procedure involves assessing the Qi, Wi and IWQI to each parameter based on the values observed in the specific area of study. The determination of (Wi) values follows the criteria established by (Ayers and Westcot, 1994), as presented in tables (3) and (4). The aggregate Combination of the weights (Wi) assigned to each parameter must equal one.

Qi = qimax – {(X ij – Xinf) * qiamp / Xamp} ------(1)

Where:

qi max = the maximum value of a subindex quality (qi) within a class..

Xij = the studied value of a specific parameter..

Xinf = denotes the minimum value within the same parameter class.

qiamp = represents the regular ambit of the class..

Xamp = signifies the regular ambit of each parameter within a class.

These values are used in calculations to locate the appropriateness of water for irrigation.

The final procedure in IWQI application involves calculating the IWQI value using equation (2), and, its unitless value ranges from (0 to 100).

$IWQI = \sum_{i=1}^{n} [W * Qi]$ ---------------(2)

The IWQI values are used to assess the appropriateness of water for irrigation.

These values are separated into five categories, as illustrated Table (5).

Table (5): Characteristics and Categories of IWQG (Sarhat and Al-Obaidi, 2022).

IWQI value	Restriction type	Symbol	Recommendations	
			Types of plants	Soil
(85 – 100)	No Restriction	(NR)	This water is suitable for plants without any risk of toxicity.	It is ideal for most soil types with a low likelihood of causing salinity and sodicity problems. It is also recommended to add leaching requirements during irrigation, unless for soils with soft permeability.
(70 – 85)	Low Restriction	(LR)	This water is generally appropriate for irrigation purposes, except for plants that are sensitive to high salt levels.	It is suitable for soils with moderate permeability or light texture soils and can be used for salt leaching. However, caution should be exercised as it can lead to sodicity issues, especially the soil's high clay content.

(55 – 70)	Moderate Restriction	(MR)	These plants can withstand a certain level of salt content in the soil or irrigation water without significant negative effects.	it can be utilized in soils with moderate only permeability. It is advised to employ this water for the leaching of salt-affected soils
(40 – 55)	High Restriction	(HR)	It is appropriate for plants that can tolerate moderate to high salt. However, it is important to implement salinity control measures, except when applying water with low concentrations of (Na+), (Cl-), and (HCO3-) ions	Only in high permeability soils, it is permissible to usage water with an Electrical Conductivity (EC) exceeding 2 dS m-1 and a Sodium Adsorption Ratio (SAR) greater than 7. However, it is recommended to implement a schedule of frequent irrigation to manage the potential adverse effects of high EC and SAR levels on plant growth and soil quality.
(0 – 40)	Severe Restriction	(SR)	This water is appropriate for plants with high salt tolerance, except when the water contains very low concentrations of (Na+), (Cl-), and (HCO3-) ions	on usual conditions, it is not recommended to use the water described, which has low concentrations of salt and high values of SAR, for irrigation purposes. However, in certain special cases, it can be used occasionally. To prevent salt accumulation, it is necessary to apply excess amounts of water and use this class of water usage to soils with higher permeability. Additionally, gypsum application is required to mitigate the effects of low salt concentrations

Irrigation water suitability is determined by using a number of indices including (Soluble sodium percentage (%Na), Permeability index (PI), sodium absorption ratio (SAR), Magnesium hazard (MH) and Kelly Index (KI). The mentioned indices are calculated through the below equations: (Madu et.al., 2022).
Soluable sodium percentage (SSP%) can be calculated by using equate (3), (Gharaibeh et.al., 2021).
SSP % (meq l-1) = $(Na+K)/(Ca+Mg+Na+K)$ * 100 ------------------- (3)
The regulatory limits for this index are: (Madu et.al., 2022).

Categories	**Excellent)**	**Good**	**Permissible**	**Doubtful**	**Unsuitable**
SSP %	<20 %	20 - 40	40-60	60-80	>80

For the Permeability Index PI can be calculated by using equate: (Rasheed et.al., 2022)
PI (meq l-1) = Cl- + 0.5$*SO$4-2 ...... (4)
This index is classified into three classes depending on the regulatory limitations as follows in the table: (Ma et.al., 2020)

Categories	**Class I**	**Class II**	**Class III**
PI %	>75% (suitable)	25-75% (good)	<25% (unsuitable)

- The Sodium Adsorption Ratio (SAR) of irrigation water is a constant related to the sodium percentage (ESP) present in the soil that is ready to be exchanged to the water body in contact, it is also used to quantify the measurable sodium hazard of irrigation waters (Minhas and Qadir, 2024).
- It is Evaluated by using the following formula (Mahmood and Aziz, 2024).

SAR (meq l-1) = $〚Na〛$ ^+/√(($〚Ca〛$ ^(2+) + $〚Mg〛$ ^(2+))/2) ....(5)
When SAR < 3 then the water is suitable for irrigating, and an SAR value > 9 characterize water as unsuitable for irrigation.

- Magnesium hazard (MH) is evaluated using eq. (6)

MH = $〚Mg〛$ ^(2+)/(($〚Ca〛$ ^(2+) + $〚Mg〛$ ^(2+))) * 100 ....(6)
If MH< 50%, then water body is acceptable for irrigation uses. However, an MH >50% may affect crops growth and yield if used for irrigation (Misaghi et.al., 2017).

- Kelly's Index (KI) determined degree by using the following formula:

KI (meq l-1) = $Na/(Ca + Mg)$ -------- (7)

When KI ≤1, that indicate suitability for irrigation. However, if KI > 1, then it reflects unsuitability of water for irrigation uses (Uddin et.al., 2017).

- Total Hardness (T.H) is determined by regulatory limitations using equation (26)

T.H = [Ca2+] *2.497 + [Mg2+] *4.117……… (8)

A TH range of (50-150) is desirable as an irrigation source. While a TH> 300 ppm characterized as very hard water, such water is not recommended to be used for irrigation (Seifi et.al., 2020).

3. Mathematical Modeling

The water quality index (WQI) is a remoteness number describing the water quality by combining several measurements (Aldoury et.al., 2024). Any WQI model usually includes a number of succeeding steps to calculate the WQI value which summarized below (Sutadian et.al., 2018).

1. Parameters selection: All WQI comprises one or more parameters of water quality to be utilized in the evaluation.
2. Sub-index generation: the sub-index is calculated by converting the parameter concentrations into a unit less number referred to as the sub-index value.
3. Assigning the weight value: each parameter is assigned a weighting depending on its importance to the process.
4. Aggregation Function: this step is conducted to quantify the WQI score by combining the sub-index of each single parameter with its weighting value and the overall combination of all the used parameters give a single index number (Sutadian et.al., 2016).

There are two mathematical functions that are frequently used to calculate the aggregation score:

- The additive form

WQI = ΣSI * WI ………………….(9)

Where:

SI = the sub-index value.

WI = the weight value.

- The multiplicative form

WQI = Π SI WI ………………..(10)

5. WQI computation: the number resulting from the aggregation step is ranged according to a rating scale to classify the water body, wither it is in good or bad quality (Uddin et.al., 2021).

Three mathematical models are used in this research to quantify the WQI value. these three models are:

6. The Horton index: it is used for surface waters assessment. It is also used as an assessment tool for sewage water treatment (Ewaid and Abed, 2017).

- National sanitation foundation (NSF-WQI): It usually used in surface water quality evaluation in various environments (Lumb et.al, 2011).
- Malaysia WQI (MWQI): this model evaluates and classify the surface water quality (Gazzaz et.al, 2012).

3.1 Parameter Selection

3.1.1 The Horton index: selecting the model's parameters depends on their importance regarding the environmental considerations. This model involves the use of eight water quality parameters, including: (DO, pH, Total dissolved solids, coliforms, alkalinity, chlorides and carbon chloroforms extract) (Abbasi and Abbasi, 2012).

3.1.2 NSF-WQI: The water quality parameters for this model are selected according to the Delphi technique. It involves the use of eleven parameters, which classify water quality into five Categories: (Tomas et.al., 2017; Ewaid, 2016)

- Chemical (pH and DO)
- Physical (turbidity, temperature and TS)
- Microbiological (BOD and fecal coliforms)
- Toxic compounds and pesticides.
- Nutrients and total phosphate.

3.1.3 MWQI: it encompasses six parameters used for the determination of water quality including: DO, COD, BOD, SS, pH and Ammoniacal Nitrogen (NH3-N) (Khuan et.al, 2002).

3.2 Sub - index Generation

3.2.1 The Horton index: the sub – index evaluation is based upon the use of a linear scaling function depending on parameter concentration or the pollution level. Its values are in the range of (0-100), where for surface water bodies 0 reflects the worst pollution conditions and 100 represents excellent quality. On the other hand, the sub-index value for sewage treatment 100 is allocated when the treatment plants serve the largest population range (95 - 100%). However, if less than half of the population is served, then 0 value is recorded (Shah and Joshi, 2015).

3.2.2 NSF-WQI: A panel of experts specified the sub – index value for this model to be in the range of (0-1). 1 is considered when the measured values fall within the recommended guideline, otherwise a value of 0 is given to the parameter's sub-index value (Sutadian et.al., 2016).
3.2.3 MWQI: a unique curve with a specific threshold is developed for each included parameter to quantify the sub-index value. the curves functions and their thresholds are displayed in table 6 (Cristina et.al., 2014).

Table 6: MWQI Parameter thresholds and sub-index (Uddin et.al., 2021)

Parameters	Limitd	Sub Index value
DO	DO ≤ 8	= 0
	DO ≤ 92	= 100
	8 < DO < 92	= - 0.395 + 0.030DO2 - 0.00020DO3
pH	pH < 5.5	= 17.02–17.2 pH + 5.02 pH 2
	5.5 ≤ pH < 7	= -242 + 95.5 pH - 6.67 pH 2
	7 ≤ pH < 8.75	= -1 81 + 82.4 pH - 6.05 pH 2
	pH ≥ 8.75	= 536 –77.0 pH + 2.76 pH 2
COD	COD ≤ 20	= -1.33 COD + 99.1
	COD > 20	= 103*exp (- 0.01 57 COD) - 0.04 COD
BOD	BOD ≤ 5	= 100.4 – 4.23 BOD
	BOD > 5	= 108* exp (-0.055 BOD) - 0.1 BOD
SS	SS ≤ 100	= 97.5* exp (- 0.00676 SS) + 0.05 SS
	100 < SS < 1000	= 71 * exp (- 0.0061 SS) + 0.01 5 SS
	SS ≥ 100	= 0
NH3	NH3≤ 0.3	= 100.5 - 105 NH3
	0.3 < NH3 < 4	= 94*exp (-0.573 NH3) - 5*I × - 2 I
	NH3 ≥ 4	= 0

3.3 Parameters weightings
3.3.1 The Horton index: Delphi technique is used to set the weighting value in this model which were in the range of (1-4). A value of 1 is given to the following: chlorides, special conductivity, carbon chloroform extract and alkalinity. 2 is assigned to fecal coliforms. And 4 is set to the following parameters: (pH, DO, and sewerage treatment (Rocha and Andrade, 2015).
3.3.2 NSF-WQI: The weight values in table 7 are assigned to this model by using unequal weighting method that must sum up to a value of 1 (Lowe et.al., 2017).
3.3.3 MWQI: An expert panel used unequal weighting technique that sum to 1 in assessing the models parameters weighting values as described it table 8 (Amneera et.al., 2013).

Table 7: NSF-WQI Parameters weighting values (Lowe et.al., 2017).

Parameter	Weighting Value
pH	0.11
DO	0.17
Turbidity	0.08
Temperature	0.10
TS (Total solids)	0.07
BOD	0.11
Fecal Coliform (FC)	0.16
Nitrates	0.10
TP (Total phosphate)	0.10

Table 8: MWQI Parameters weighting values (Amneera et.al., 2013).

Parameter	Weighting Value
DO	0.22
pH	0.12
COD	0.16

BOD	0.19
SS (Suspended solids)	0.16
NH3-H (Ammoniacal Nitrogen)	0.15

3.4 Aggregation

3.4.1 The Horton index: the WQI score is aggregated using the additive function formula: (Smajl et.al., 2022).

WQI = $[(\Sigma\ W\_i\ *\ S\_i\ \ )/(\Sigma\ W\_i\ )]$ * m1m2 ....(11)

Where:

m1 = temperature coefficients, (Temp < 34 ◦C → m1 = 0.5, Temp > 34 ◦C → m1 = 1).

m2 = obvious pollution coefficients, (if obvious pollution is present → m2 = 0.5, if obvious pollution is not present → m2 = 1).

3.4.2 NSF-WQI: The NSF model utilizes the multiplicative function mentioned in Eq. (12) as the aggregation function.

3.4.3 MWQI: A simple additive aggregation formula is used as shown in eq (14):

WQI = 0.22*SIDo + 0.12*SIpH + 0.16*SICOD + 0.19*SIBOD +0.16*SIss + 0.15*SIAN ....(12)

3.5 WQI evaluation

3.5.1 The Horton index: this model recommends five water quality classes as described in table 9 (Ismail, and Robescu, 2017).

3.5.2 NSF-WQI: The WQI outputs are in the range of (0-100) as mentioned in table 10, where 100 reflects excellent water quality and 0 is the worst water quality (Sandra et al., 2023).

3.5.3 MWQI: this model suggested three classes to describe the WQI value for surface water bodies as seen in table 11 (Hossain and Patra, 2020).

Table 9: The Horton WQI classes (Ismail and Robescu, 2017).

WQI score	Class
100-91	Very good
90-71	Good
70-51	Poor
50-31	Bad
30-0	Very bad

Table 10: NSF-WQI classes (Sandra et al., 2023).

WQI score	Class
100-90	Excellent
89-70	Good
69-50	Medium
49-25	Bad
24-0	Very bad quality

Table 11: NSF-WQI classes (Hossain and Patra, 2020).

WQI score	Class
100-81	Clean
80-60	Slightly polluted
59-0	Polluted

4. Results and Discussion

This research investigated the evaluation of WQI for the Little Zab River in Northen region of Iraq, by selecting a number of parameters (pH, DO, BOD5, PO4-3, NO3- alkalinity, EC, Cl- and temperature). The Samling procedure started from Jan. 2010 to the end of Dec. 2024. The maximum, average and minimum values for the selected parameters are illustrated in figure (2-10).

Looking into Fig. (2), it is clear that the pH levels for all the time interval falls within the regulatory limits in the range of (6.5-8.5) represented by the two yellow lines represent. It is clear that the DO and BOD5 concentrations represented in figs. (3) and (4) fall within the regulatory limits of water bodies represented by the yellow lines., except for the minimum value of DO concentration in 2024 falls below limits and the maximum value of BOD5 concentration in 2013 exceeded the regulatory level (Ashour, 2024). This indicates that the Little Zab River represents a fresh water environment. In fig. (5 and 6), the PO4 and NO3 concentrations throughout the entire time interval of 14 years where within limitations marked by the yellow lines except for PO4 levels in 2011 and 2013. The Alkalinity measurements showed in fig. (7) are below limitations, but the maximum readings are close to the upper limit due to the geological composition of the rivers bottom which composes mostly of rocks and gravels that add extra minerals and salty content to the rivers water. This can be clearly seen when looking into the TDS concentrations in fig. (8), where the maximum concentrations reaching almost 300 m/L and even exceeding 400 mg/L in 2024. However, all the TDS values are under limitation by a large margin. The Cl- concentrations in fig. (9) are all under limits due to the fact that Little Zab River located in the Northen region of Iraq is close to its original sources in Iran. In addition, there is little to no industrial activities alongside the region, resulting in small addition of chlorine to the rivers water. Temperature variations through the entire time interval of 14 years displayed in fig. (10) reflects a natural fluctuation with ongoing seasons and years in the range of (22.8-11.4).

For WQI evaluation, three mathematical models were used including (Horton-WQI, NSF-WQI and Malaysia WQI). The resulting WQI values for the three models are displayed in fig. (11).

Fig (11) shows that the Horton model (represented as the red line) calculated a WQI value of 45.45% which is denoted as Bad Water Quality according to the proposed model. This is due to the fact that the sub-index according to the proposed models is a constant value depending on whether the measured parameter falls within the regulatory limits or not (Uddin, et.al., 2021. And since that all the selected parameters are within regulatory limits except for EC values for all years, then the Horton WQI model generated a fixed number.

Looking into the green line in fig. (11), the NSF model also produced a constant WQI value of 77%, therefore the Little Zab River is described according to the model under consideration as Good Water Quality excluding year 2011 that has a WQI value of 59% which is characterized as Medium Water Quality (Sutadian et.al., 2016). This is a result to the fact that the PO4 value in 2011 surpassed the regulatory limiting concentration. Hence the NSF model fabricated a steady WQI value.

Unlike the previous models, the Malaysia model demonstrated by the blue line in fig. (11), generated a varying WQI value with a range of (28-30) % for the whole-time interval. This is a result to the different method this model is proposing in determining the sub-index value. It recommended the use the equations mentioned in table (6) to quantify the sub-index taking into account the parameter threshold assigned to each equation. The calculated WQI for this model depicted the Little Zab River water as polluted Water Quality. This characterization is in fact the result of the selected parameters used in this model. As mentioned in section 1.3, this model involves the use of six water parameters (Khuan et.al, 2002). However, there was only three true measurements available for calculation, and as a result the model generated a low WQI number.

When comparing the three used models, it might seem that the Horton and the NSF models are better in characterizing the water body quality. However, the Malaysia model is in fact more accurate. The mentioned precession is in fact due to the employment of mathematical equations advocated by this model in computing the sub-index.

The suitability of the Little Zab River as an irrigation source is assessed through the determination of a number of indices including (KI, SAR, MH, SSP, PI, Na and TH), and all the suggested indices are introduced in fig. (12). Fig. (12 A) displays KI index with a range of (0.1-0.15), which is way below the regulatory of KI ≤ 1. Therefore, according to KI range the Little Zab River is considered as a suitable source of irrigation. Also, the SAR values depicted in fig (12 B) indicates a ranging value of (1-1.6). This range less than the regulatory limit of 3, characterizing the river as irrigation appropriate.

The MH index range is (23-31) %, which is < 50% regulatory index, denoting water body as acceptable for irrigation (Misaghi et.al., 2017). PI% in fig. (12 B) has a range of (23-42) %. This range falls between two classes, Class II (25-75%, good), and Class III (<25%, unsuitable), denoting the river water as good in some years and unsuitable in others (Ma et. al., 2020). The SSP % index was in the range of (12-16) % which is <20%, reflecting an Excellent irrigation source as stated by the regulatory (Madu et.al., 2022). Finaly, when examining fig (12C), it is obvious that the real TH and the TH calculated form eq. (8) have the same range of (162-184) meq/L and (162-182) mg/L, respectively. Both TH ranges are above the regulatory limit of (50-150), but below a value of 300 ppm. Therefore, the Little Zab River may not be characterized as desirable for irrigation, but also is not described as very hard water (Seifi et.al., 2020). The relatively elevated TH ranges is linked to the geological formation of the northern region of Iraq where the Little Zab River is flowing. This region comprises of rocky foundation and mountains, which may add extra mineral and salty content to the river's water (Rasheed et.al., 2022).

Overall, it may be agreeable to characterize the Little Zab River as a convenient water body to be used for irrigation purposes.

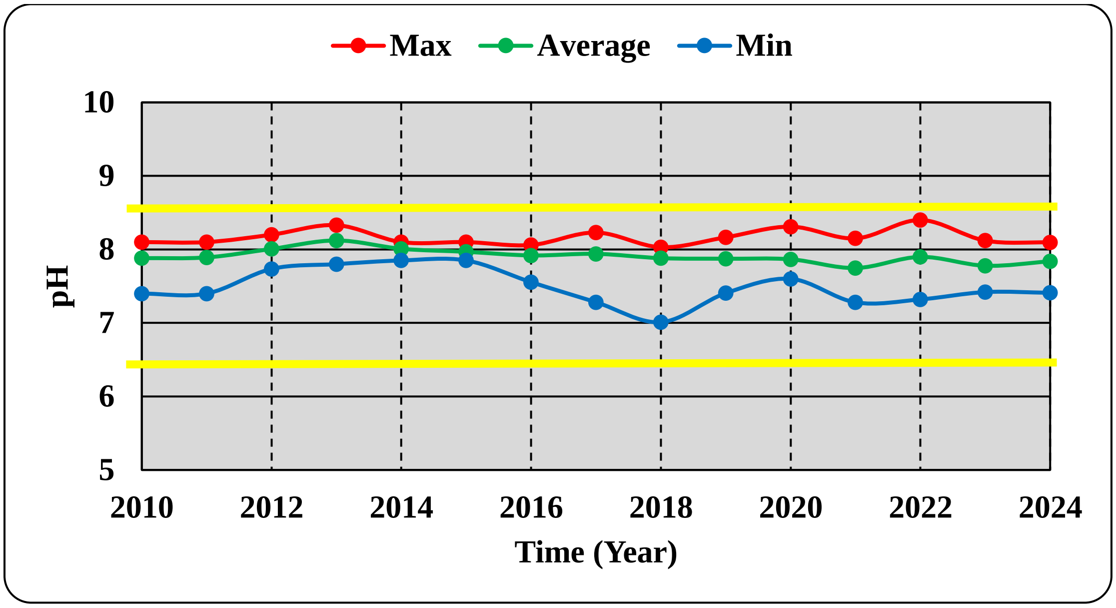


Fig. 2 Max, Ave. and Min. values for pH.

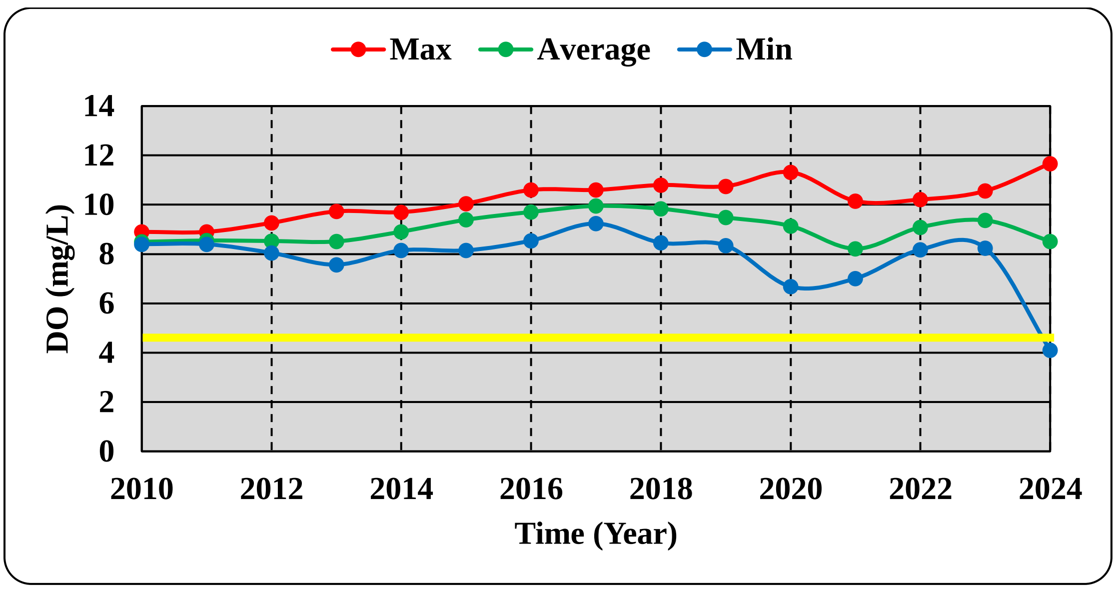


Fig. 3 Max, Ave. and Min. values for DO.

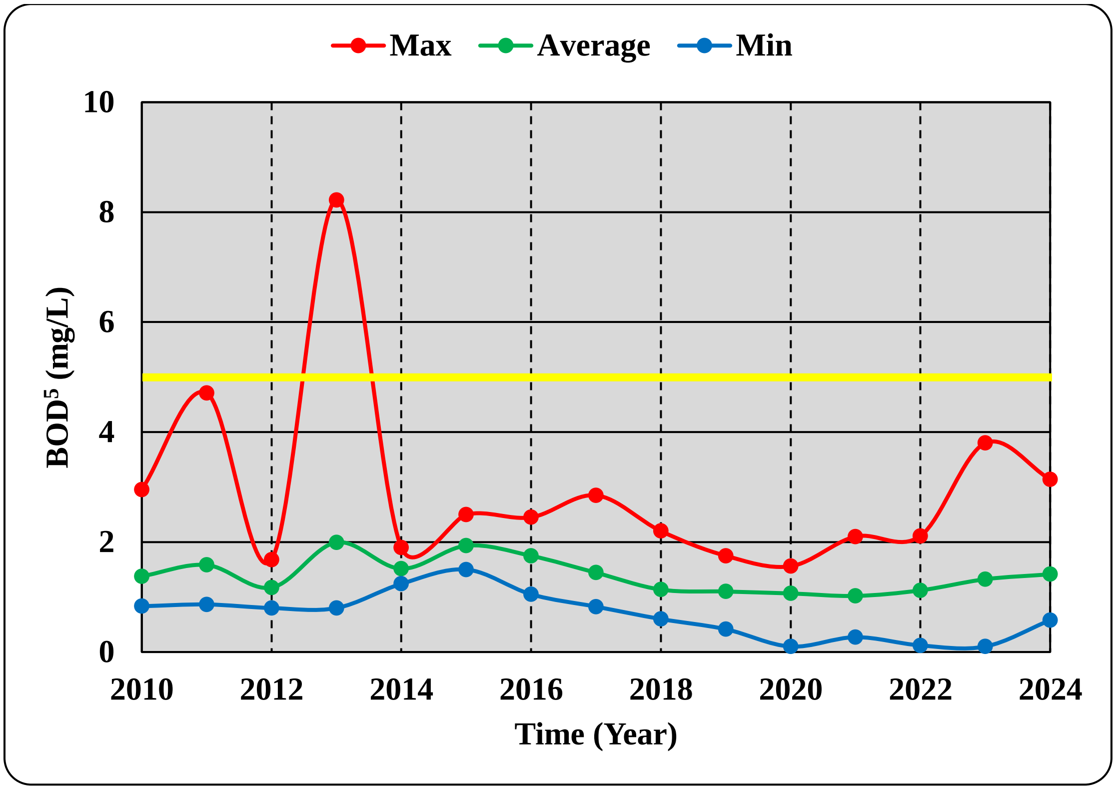


Fig. 4 Max, Ave. and Min. values for BOD5.

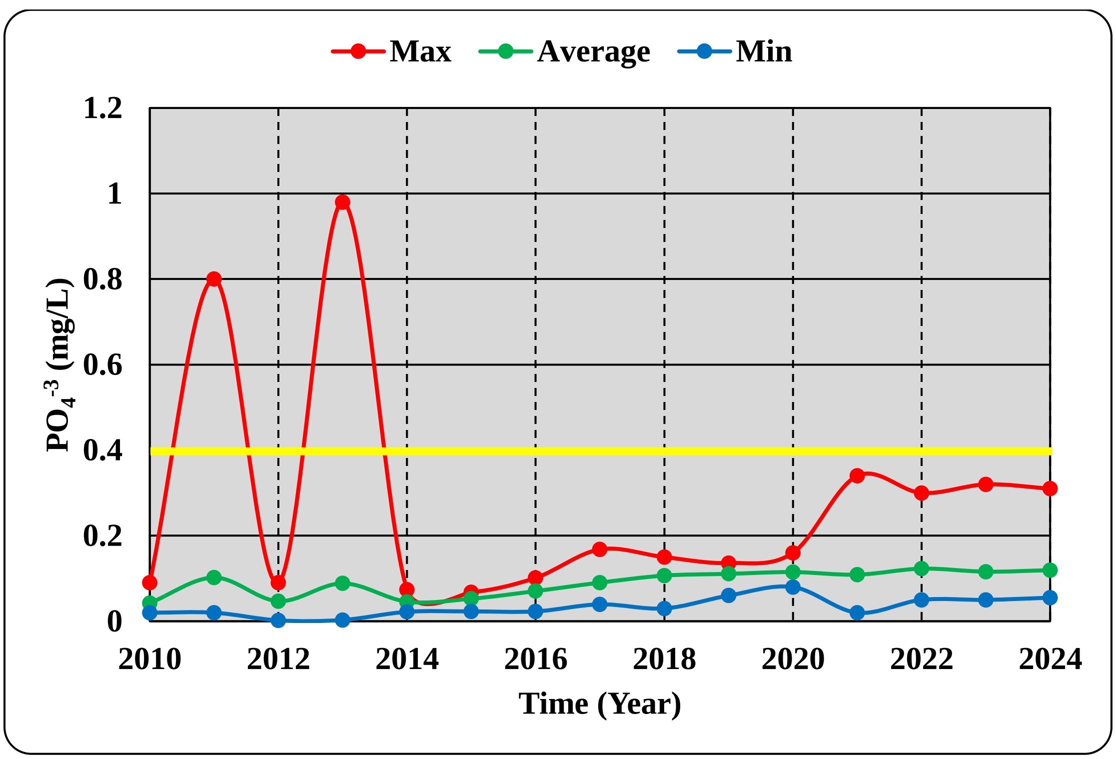


Fig. 5 Max, Ave. and Min. values for PO4-3.

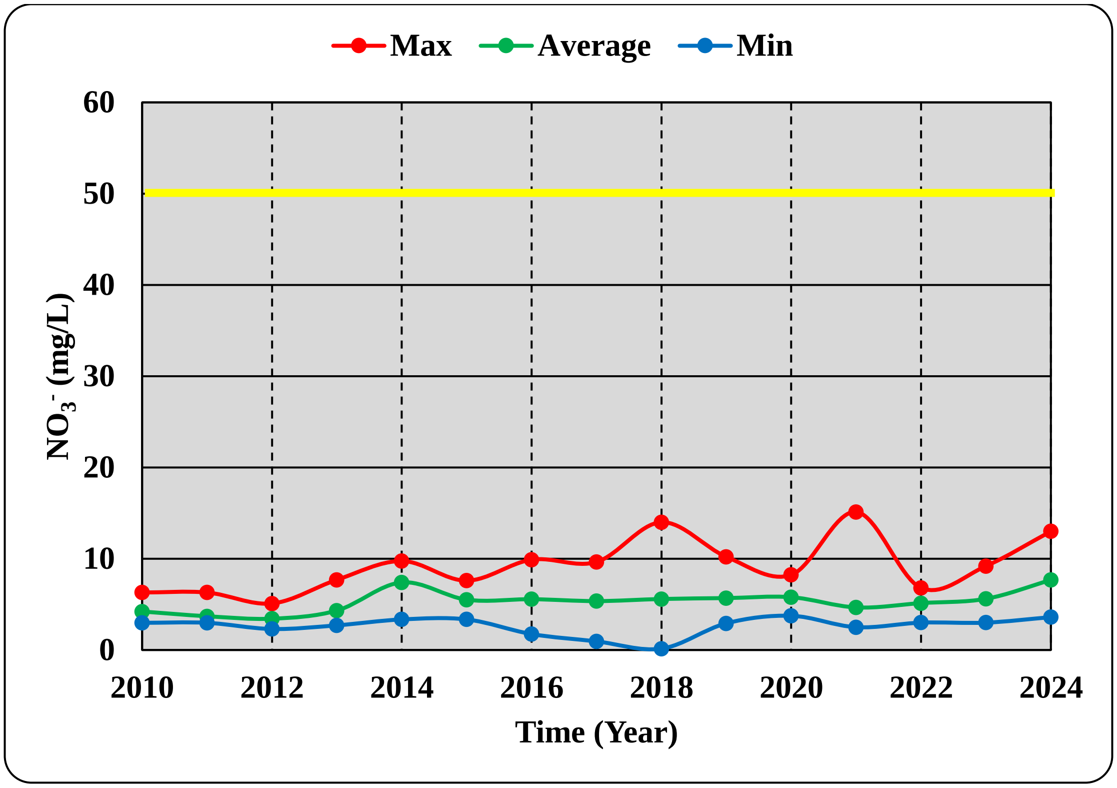


Fig. 6 Max, Ave. and Min. values for NO3-.

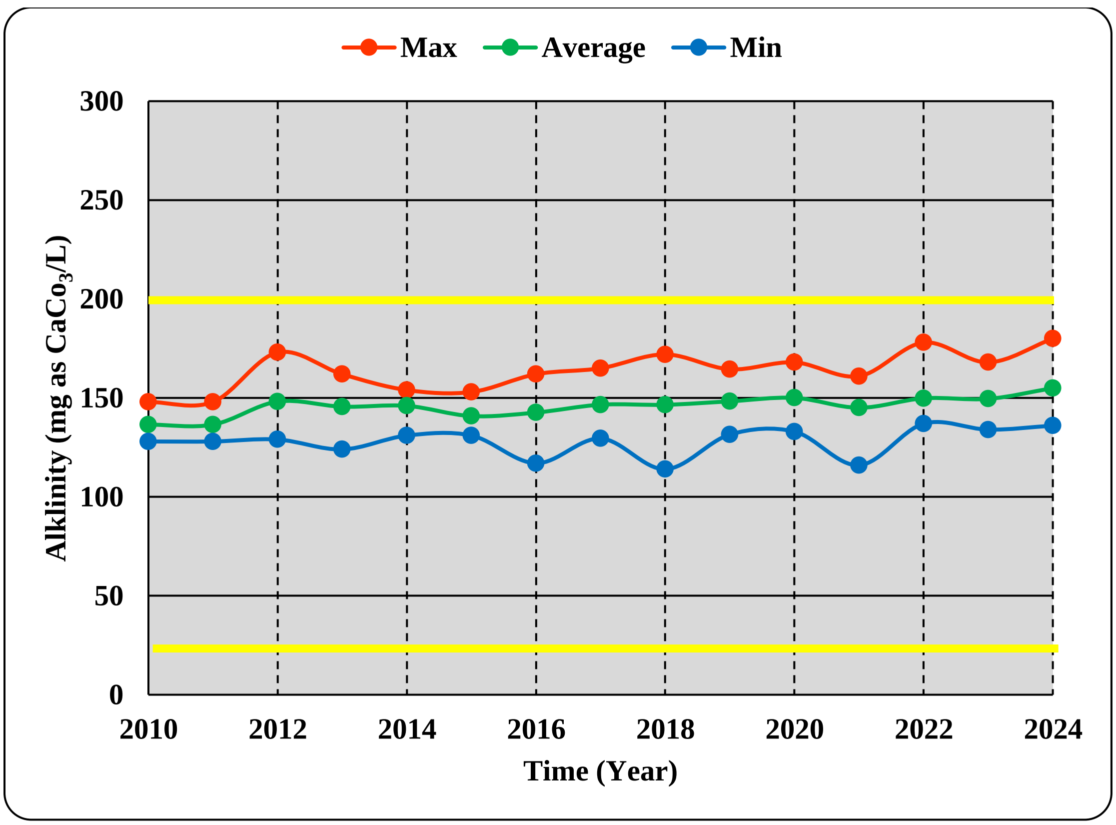


Fig. 7 Max, Ave. and Min. values for Alkalinity.

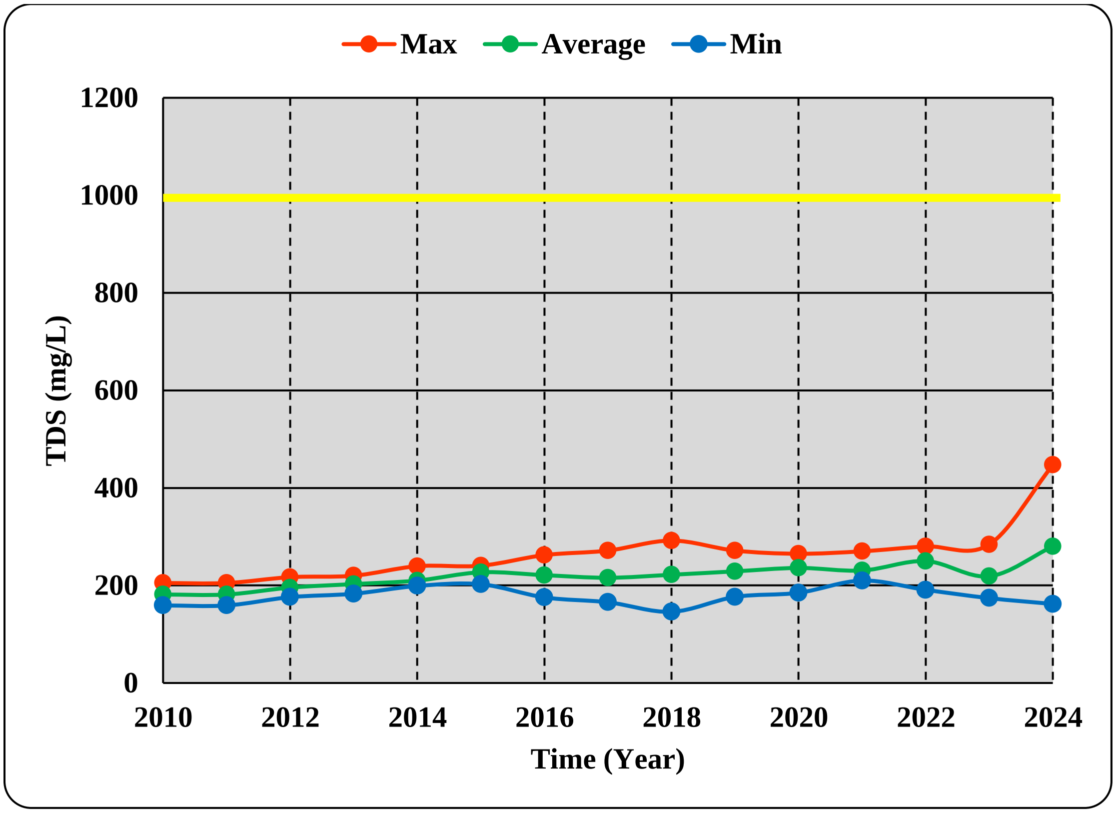


Fig. 8 Max, Ave. and Min. values for TDS.

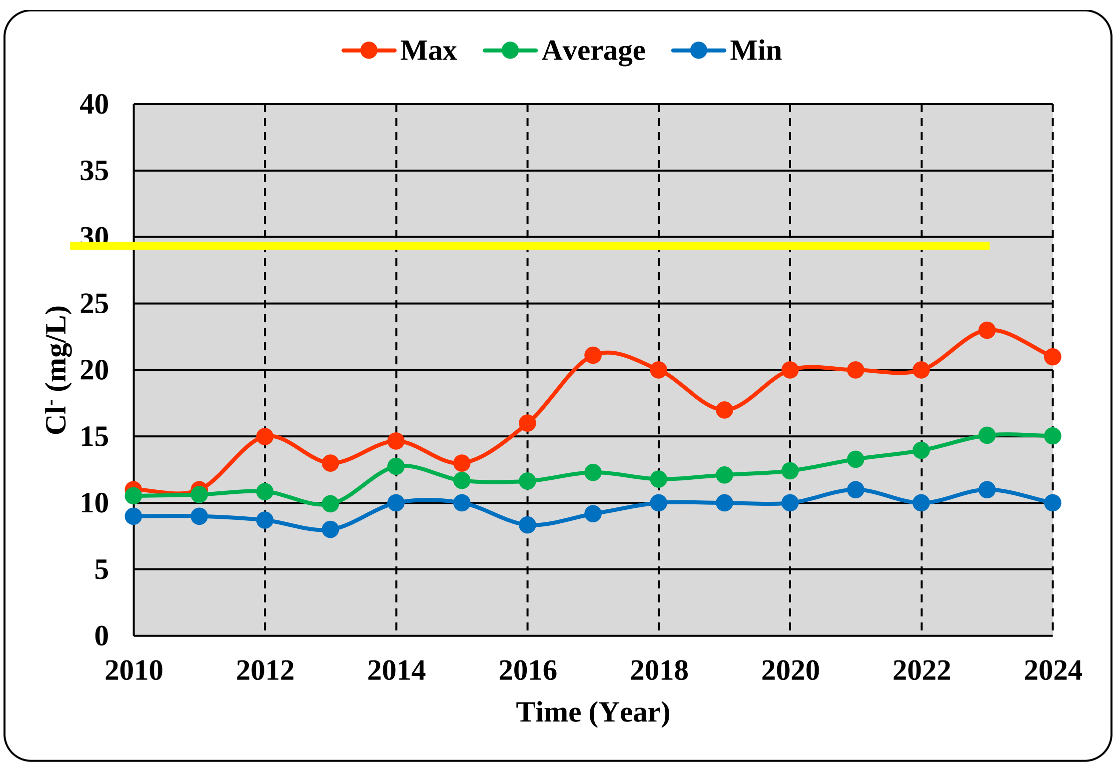


Fig. 9 Max, Ave. and Min. values for Cl-.

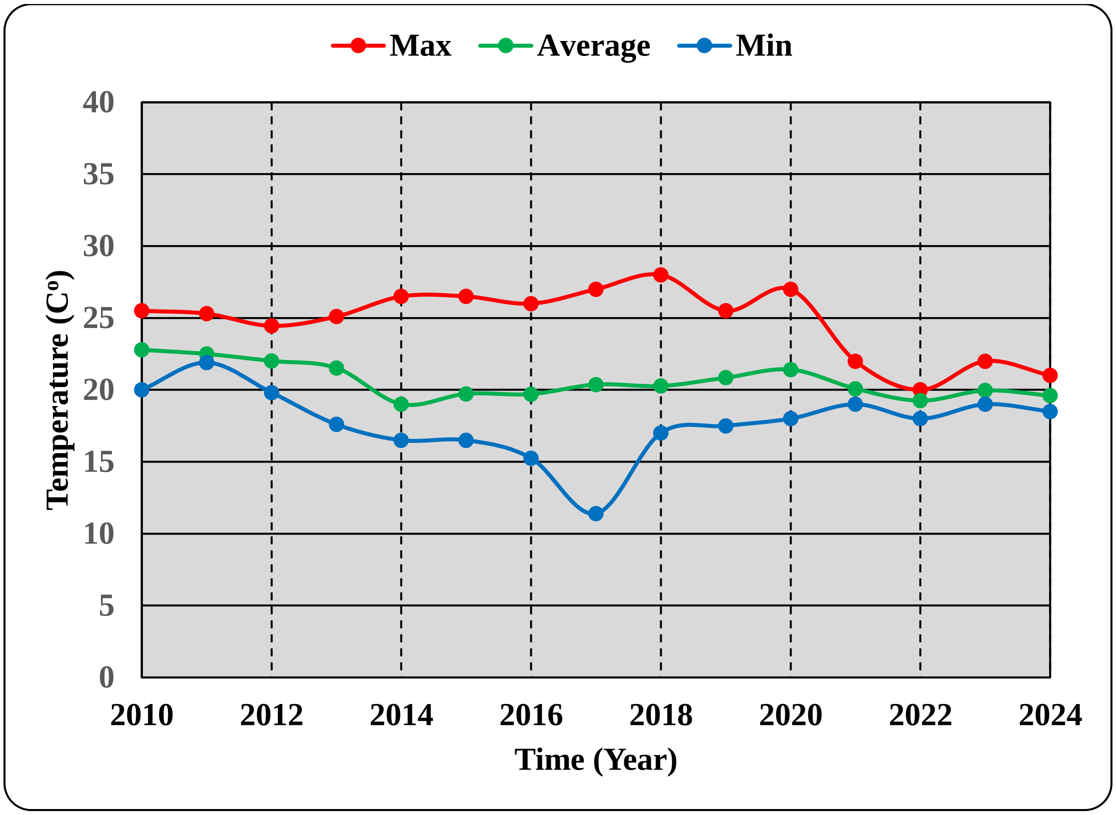


Fig. 10 Max, Ave. and Min. values for Temperature.

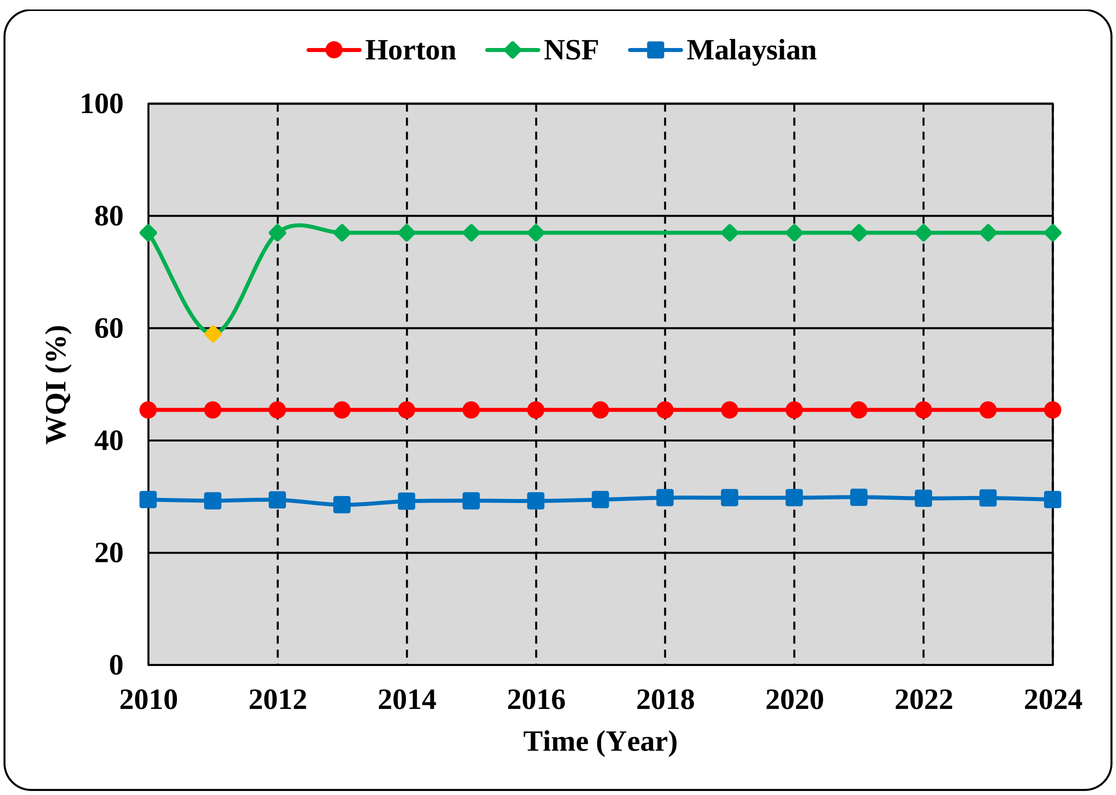
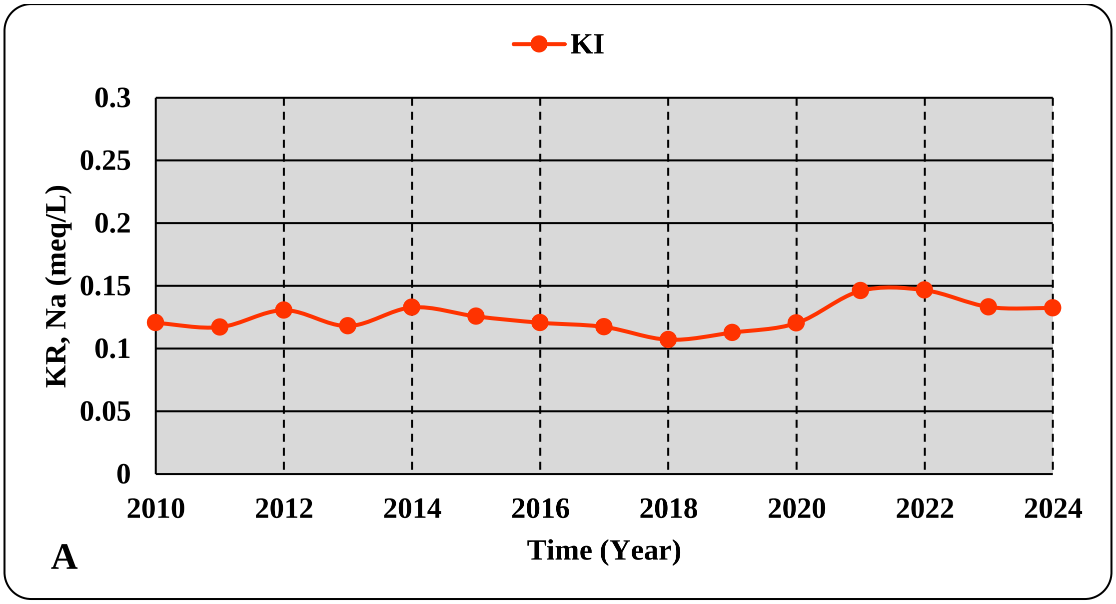
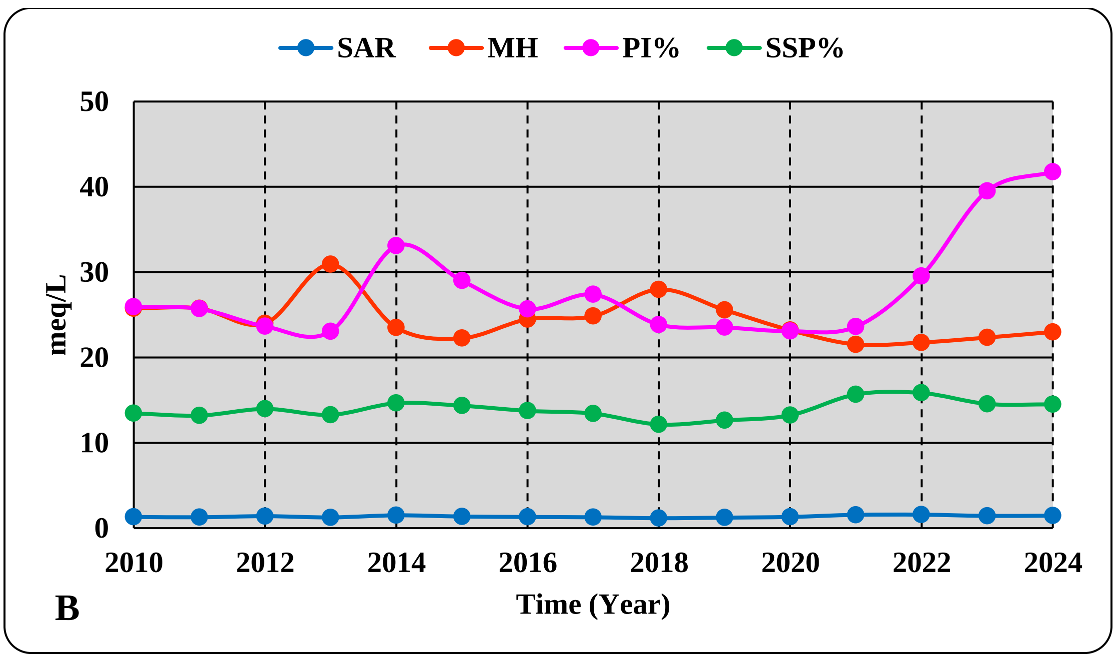


Fig. 11 WQI evaluation through mathematical models.


KI
KR, Na (meq/L)
0.3
0.25
0.2
0.15
0.1
0.05
0
2010
2012
2014
2016
2018
2020
2022
2024
Time (Year)
A


SAR
MH
PI%
SSP%
meq/L
50
40
30
20
10
0
2010
2012
2014
2016
2018
2020
2022
2024
Time (Year)
B

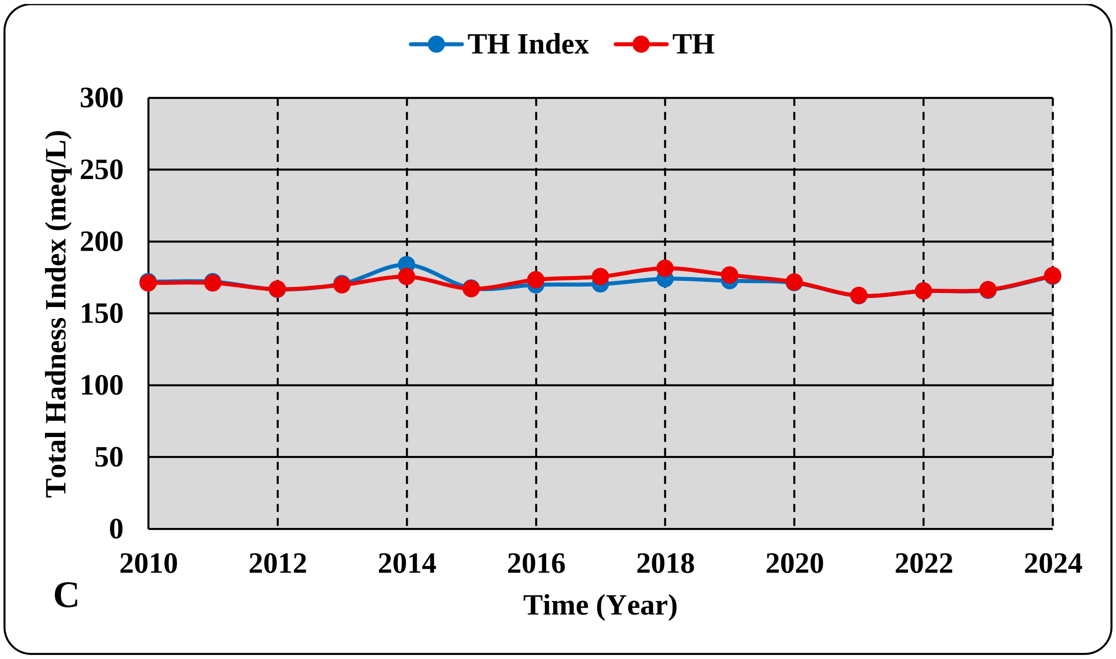


Fig. 12 Irrigation water quality standards. A: KI, B: SAR, MH, PI%, SSP%, C: TH index, TH.

5. Conclusion

The Water Quality Index (WQI) is a valuable tool used to determine the water quality of various water sources, including surface water and well water by considering multiple parameters. The water body under investigation is the Little Zab River located in the northern region of Iraq with a time interval of 14 years (2010-2024). Three mathematical models were used in evaluation the WQI including (Horton, NSF and Malaysia) and the WQI values were (45.45, 77) % and (28-30) %, respectively. Also, the irrigation water indices including (KI, SAR, MH, SSP, PI, Na and TH) were evaluated to investigate the suitability of the proposed water body for irrigation. Most of the calculated indices were less than the regulatory limits, indication the suitable use of the water body for irrigation.

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