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ASSESSMENT OF GROUNDWATER QUALITY FOR IRRIGATION USING WATER QUALITY INDEX (IWQ INDEX) IN AL-KASIK SUBDISTRICT NORTHWESTERN, IRAQ

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ABSTRACT
This research work analysed groundwater quality in Al-Kasik district northeastern of Mosul city, Iraq. The area is agricultural land which uses well water for livestock watering and irrigation. Groundwater samples were collected from five wells during dry season to determine the following parameters: pH, electrical conductivity (EC_{25}), anions, cations, soluble sodium percentage (SSP), sodium absorption ratio (SAR), residual sodium carbonate (RSC) and potential salinity, permeability index and Kelly Ratio, IWQ index model was applied for the evaluation. The well water samples were evaluated for agricultural uses according to universal standard classification. Results indicated that most of the measured parameters were high especially electrical conductivity (5369µS/cm), with P. Salinity, Sodium, Calcium and Sulfate ions having 30.7, 15.3, 34.0, 29.3 meq. l^{-1} respectively. These have an effect on water quality hence considered being of very high salinity (C_4) according to United State Salinity Laboratory (USSL). According to the water quality index (IWQ index), the analyzed water was specified as low restriction (LR) to Severe restriction (SR) for irrigation.

Keywords: *Water Quality; Groundwater; Quality Index; Water Quality Models.*

1. INTRODUCTION

The problem of over-exploitation of water resources arising from increasing demand will lead to several future problems in many countries in the world, especially in arid and semi-arid areas. In recent decades, as a result of economic development and rapid growth of the population, there have been clear changes in the use of land, resulting in increased demand for water for various civil, industrial and agricultural activities [1, 2]. As a result of this demand, there is equally an increased pressure on agricultural production coupled with the limited area of land suitable for agriculture, as well as the reduction in the quantity and quality of water for irrigation [3]. For example, in Iraq, salinity has been identified as a problem with saline-affected land and the salinity has reported to have reached as high as 70% of the total arable land [4]. Poor or lack of proper agricultural management has aggravated rapidly the agricultural problems and has reached an alarming rate. Therefore, the study of these problems is important to provide the necessary information required to preserve suitable land for agriculture and future generations [5]. The use of modern technologies in the management of agricultural land for irrigation such as water quality models (WQI) is one of the most important means of determining the pollutions and water quality and its suitability for different uses [6,7,8]. Generally, the quality of irrigation water depends on the following factors:

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1.1 Salinity Hazard

Water quality is highly dependent on the quality and quantity of dissolved salts found in it. The high salt levels in irrigation water will lead to the accumulation of salts in the root zone and the emergence of salinity problems [9] as it reduces the amount of available water for absorption by the roots. It can also lead to a decrease in plant growth and wilting if the soil is not washed with low-salt water [10].

1.2 Permeability and Infiltration Hazard

The rate of water infiltration as a function of many water qualities and soil factors (soil structure, soil texture, and soil organic content), and problems of permeability when using water with high levels of sodium (expressed in SAR) is of essence, as the sodium works to break the soil pools and dispersing soft minutes to the clogging of soil pores. The most important factors affecting the permeability is soil salinity and sodium adsorption ratio [11].

1.3 Specific ion toxicity

Some ions (sodium, chloride, and boron) cause toxicity problems to the plant at high concentrations in irrigation water and increasing concentrations in plant tissues lead to deterioration of growth and production. However, the degree of toxicity depends on plant type and absorption rate. Perennial plants are more sensitive to these ions than annual plants. In general, toxicity problems are associated with salinity and permeability problems [11].

1.4 Miscellaneous effects

Some water standards which have an impact on the quality of irrigation water include the pH, this affects the balance of carbonate and water content of the mineral elements. When water is acidic, it hinders the absorption of calcium ions and magnesium and aluminum by the roots, while alkaline water provides a suitable condition for the absorption of many of the elements and nutrients by the plant root environment but is responsible for the accumulation of calcium carbonate [12,8]. The normal range of irrigation water is from pH 6.5 to 8.4. The pH of water changes with the production of hydrogen or hydroxyl ion in different chemical reactions with the redox potential, temperature, and pressure [13]. Also, the bicarbonate and carbonate ions responsible for raising the value of pH more than 8.3 and encourages the deposition of calcium and magnesium ions leaving sodium ions prevalent in the soil solution, which affects the soil and plants.

As for nitrate ions, they are a source of nitrogen for plants, but their increased application to soil has a detrimental effect on the plant production and delaying the maturity of crops and fruits as well. But their accumulation causes health risks to consumers such as children's disease, diabetes, dysfunction of the thyroid gland, immunity and many cancers [14,15]. This study used the IWQ index to assess the groundwater quality of the Al-Kasik area for irrigation purposes.

2. MATERIALS AND METHOD

Some physical and chemical properties of some groundwater sources were examined in Al-Kasik area of Tall Afar district, Nineveh governorate, north-west of Mosul city, latitude and longitude (42 ° 40 '16'' W, and 36 ° 28 '09'' N') as shown in Table 1 and Fig.1.

The studied wells were considered to be deep as a result of their depth exceeding 20 m [12], most of them have an unpalatable taste and used for domestic, irrigation and livestock watering purposes. The study area is characterized by a lower formation that contains evaporites and gypsum salts, anhydrite and dolomite. This leads to deterioration in the quality of the water passing through it [8]. Water samples were collected during the summer season with three replicates per well. Each sample was analyzed for chemical and physical properties such as pH, electrical conductivity, positive and negative ion using universal standard methods for sampling and analysis [16;17]. The specific properties of irrigation water, such as soluble sodium percentage (SSP), sodium absorption ratio (SAR), residual sodium carbonate (RCS), potential salinity (P. S), Kelley ratio (KR) and permeability index (PI) were calculated from the following equations as previously applied by [13, 18, 19,20,21:

$SSP = \{[Na +K] / [Ca+ Mg+Na+K]\} \times 100$

$SAR = [Na] / \{[Ca +Mg]/2\}^{1/2}$

$PI = Na [(HCO^3)^{1/2} / (Ca+Mg+Na)]$

$RSC= (CO_3+HCO_3) – (Ca + Mg)$

$1/2\ SO_4 + Cl =PS$

$PS=1/2\ SO_4 +Cl$

$KR = Na / [Ca + Mg]$

Where units are used with the m.eq l^{-1}.

The quality of water used for irrigation was also assessed using the global classification of the American salinity laboratory USDA [22]. We also applied other from Donnen as quoted by [23], for the combined effect of the concentration of ionic chloride and sulfate. Additionally, classification according to [1] was also applied for each of the SSP, RSC, PS, and KR. The use of a water quality index model (IWQI) to evaluate irrigation water, which was developed by Meireles et al, [24] which includes the following steps: Diagnosis of the most important criteria and characteristics in determining water quality for irrigation purposes. It is determined by measuring the quality values of (qi) for each standard following the quality standards proposed by the University of California Committee [10], shown in Table 2

To calculate q_i values using the following equation:

$\mathbf{q_i} = q_{i\,max.} - [\,(X_{ij} - X_{inf.}) \times q_{i\,amp.} / X_{amp.}]$

q_{imax}: represents the highest values of q_i in the class,

X_{ij} represents the observed values for the parameter, X_{inf} represents the corresponding value for the minimum limit of the class to which the parameter belongs to q_{iamp} is the class capacity. To assess X_{amp}, of the last class of any parameter, the upper limit was considered to be the highest value determined in the physio-chemical analysis of the irrigation water samples.

Give weight (w_i) for each recipe used in the model to be adjusted with the total sum of the weights equal to the correct one, and shown in Table 3, and finally, calculate the value of the water quality from the following equation:

WQI=$WQI = \sum_{i=1}^{n} q_i + W_i$.......2

After finding the value of WQI water quality is assessed by reference to the water quality in Table 4.

Table 1: Coordinates of the study wells on Al-Kasik area, Mosul city.

Well No	latitude (E)	Longitude (N)	Uses
1	42°66'58"	36°47'93"	
2	42°66'90"	36°47'59"	For domestic purposes,
3	42°66'71"	36°47'40"	irrigation, livestock and poultry
4	42°66'95"	36°47'21"	watering
5	42°66'84"	36°46'96"	

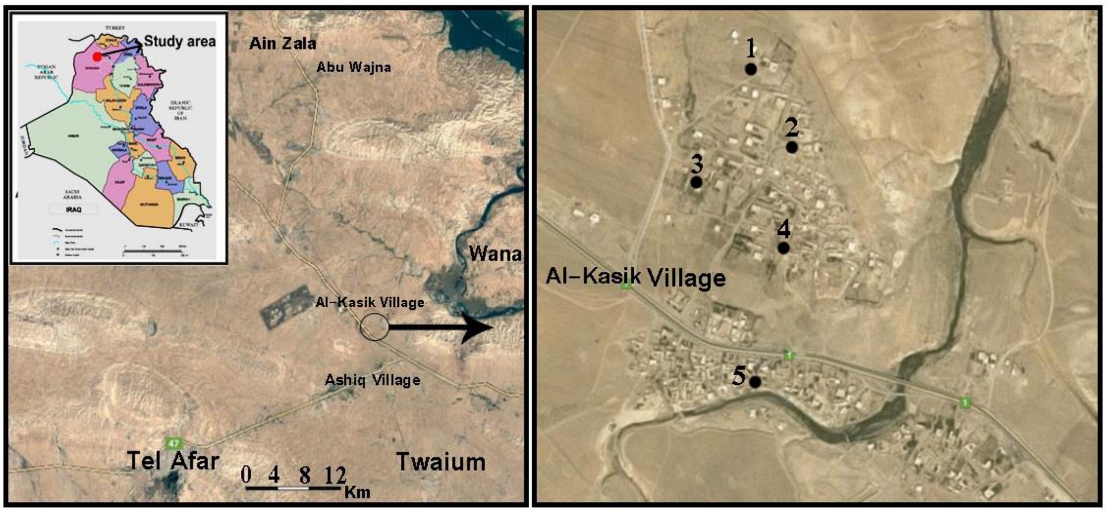

Fig.1: Map of Nineveh Governorate showing study area.

Table 2: Parameter limiting values for quality measurement qi calculation

HCO_3 meq/l	Cl meq/l	Na meq/l	SAR	EC_{25} µS/cm	qi
<1.5≤ $HCO_3$1	<4 Cl 1 ≤	<3Na2 ≤	<3 SAR2 ≤	≥200Ec 750 >	100 -85
<4.5$HCO_3$1.5≤	<7Cl4 ≤	<6Na3 ≤	<6SAR3 ≤	≥750Ec1500>	85 - 60
<8.5$HCO_3$4.5≤	<10 Cl7≤	<9Na6 ≤	<12SAR6 ≤	≥1500Ec3000>	60 - 35
HCO_3< 1or≥8.5	Cl<1or≥10	Na<2or≥9	SAR<2or≥12	≥3000or<200 Ec	35 -0.0

*[24]

Table 3: Weights (Wi) for the water quality index parameters.

Parameters	Wi*
Electrical conductivity (EC_{25})	0.211
Sodium ion (Na^+)	0.204
Chloride ion (Cl^{-1})	0.194
Bicarbonate ion (HCO_3^{-1})	0.202
Sodium Adsorption Ration (SAR)	0.189
Σ	1.000

*[24]

Table 4: Classification of Water Quality Manual (WQI)

WQI values	Water-use restriction	Recommendation	
		Soil	Plant
85≤100	No restriction (NR)	Used for most soil with a low probability of salinization problem and sodicity	There is no toxicity risk for most plants
70 ≤ 85	Low restriction (LR)	Used to irrigate the sandy and medium permeability soils and recommend washing salts and sodicity may occur in heavy soils while avoiding use to irrigate high clay content soils.	Avoid irrigation sensitive salts plants.
55 ≤ 70	Moderate restriction (MR)	Used to irrigate the soil with medium and high permeability, and it is proposed to conduct medium salt washing processes	Avoid irrigation sensitive salt plants.
40 ≤55	High restriction (HR)	Used to irrigate high soil permeability and non-compact layers, with a high frequency of irrigation within the specific dates of the program when using water EC 2.0 dS. cm^{-1} and SAR> 7.0.	Irrigation plants are medium to high tolerant salts, action required to control salts, except low water content of Na, Cl, HCO_3.
0.0 ≤ 40	Severe restriction (SR)	High tolerant plants for salts except for water with very low content of Na, Cl, HCO_3.	It is used to irrigate high tolerant plants for salts except water with very low content of Na, Cl, HCO_3.

Sources [24]

3. RESULTS AND DISCUSSION

3.1 Salinity Hazard

Electrical conductivity values represented by salinity damage are very important factors in deciding the quality of water used for irrigation due to its impact on the osmotic pressure of the soil solution and the capacity of plants to absorb water by their roots [25]. Table 5 indicated a high electrical conductivity value which ranged between (2591-5369) µS. cm^{-1} and at rates ranging between (3091-4396) µS. cm^{-1}. These values are higher than the values obtained by Al- Shanona et al, [26] in their study of groundwater of Abu Maria village, district of Tal-Afar, which ranged between (2125-3129) µS. cm^{-1}, while they are compatible with the results obtained by Al-Saffawi (2007) for groundwater of Alkonsia village, Hamidat subdistrict, which ranged between (2000-5500) µS. cm^{-1}. The elevated values are likely due to the nature of the geological formations of the study area, which is characterized by the presence of the lower Faris Formation containing evaporated salts, gypsum and dolomite, leading to the deterioration of the water quality which passing through it [27].

3.1.1 Infiltration hazards

The most important characteristics affecting permeability and water filtration in the soil are salinity and Sodium Adsorption Rate (SAR). Table 5 shows that SAR values ranged between (0.45-3.31); these relatively low values, despite the high concentration of sodium ions, which reached an average of 15.17 meq.l^{-1}, were due to the average increase in calcium and magnesium ion concentrations which reach to (34.0, 18.0) meq. l^{-1} sequentially.

3.1.2 Specific ion toxicity

The high concentration of sodium ion in irrigation water has a toxic effect on the plants and show burns and death of tissues along with the paper and adjacent to the outer edge. This increase leads to the replacement of calcium and magnesium ions and thus increases the soil content of sodium which reflected in the increased damage to irrigated plants (expressed by SAR). Water is of good quality for irrigation when the values of SAR < 3, so the groundwater of the studied wells are good quality except for groundwater of well No. 4 [11]. Also, chloride ions cause toxicity when present in high concentrations in irrigation water and show the symptoms of toxicity at first burns in the tops of the leaves and then develop to the edges and in advanced cases, defoliation occurs. Overall, water is a good quality for irrigation in terms of toxicity when the chloride concentration is less than 3.95 $meq.l^{-1}$ (140 $mg.\ l^{-1}$) as presented in Table 5. Consequently, the studied groundwater quality ranged between suitable to unsuitable for irrigation according to Ayers and Westcot, [10] rating.

3.1.4 Miscellaneous effects

Table 5 also shows that pH values of the samples are near the equilibrium state, which ranged between (6.89 - 7.43). This means all the groundwater samples are within the permissible irrigation limits. As for the bicarbonate ions, they play a role in the acidity equation when they are formed, and this ability is called Acid Neutralization Capacity (ANC). Without this ability, the negative effects would have been worse [8]. The rates ranged from 3.4 to 3.99 $meq.l^{-1}$, as shown in Table 5. This high concentration could be due to the reaction of calcite and magnesium calcite with carbonic acid as given in equation 1, 2 and 3 [28, 12]:

$CO_2 + H_2O \rightarrow H_2CO_3$ ....(1)
$CaCO_3 + H_2CO_3 \rightarrow Ca^{+2} + 2HCO_3^{-1}$ ....(2)
$CaMg(CO_3)_2 + 2H_2CO_3 \rightarrow Ca^{+2} + Mg^{+2} + 4HCO_3^{-1}$.(3)

In general, the groundwater samples of Kasik in terms of bicarbonates effect are moderately suitable for irrigation based on the views of Ayers and Westcot [10]. As for NO3-N ions. although they are essential nutrients for plant growth, increasing their concentration in water has serious effects on plants and the consumers [29]. Table 5 indicates that the concentration of NO_3–N ranged between (0.004 - 0.08) and at a rate not exceeding (0.046) $meq.l^{-1}$. Thus, the water quality of the samples analysed is suitable for irrigation according to the classification of Ayers and Westcot [10]. For sulphate ions, no specific damage to soil and vegetation has been identified yet, but it contributes to soil salinity [1]. Table 5 also indicates high levels of sulfur ions in the studied groundwater with value as high as 28.9 $meq.\ l^{-1}$. This high value may be attributed to the nature of the geological formation of the study area which is rich in sulphate salts [8], which is also reflected in the values of potential salinity (P.S) of about 30.7 $meq.l^{-1}$ and therefore will lead to deterioration of irrigation water quality as shown in Table 5.

As for SSP ratio and the permeability index (PI), both were within suitable limits for irrigation. Also, no concentration of residual sodium carbonate (RSC) was recorded in the sampled groundwater due to the high concentration of calcium and magnesium ions compared with the concentration of bicarbonate ions. The relative decrease in Kelley Ratio values (KR) was also observed due to higher levels of calcium and magnesium ions than sodium ions.

3.2 Water quality assessment:

Groundwater analysis of the parameters of individual wells based on their electrical conductivity, sodium adsorption and concentration of sodium ions, chlorides, and bicarbonates in the calculation of the IWQ index, well water 1 and 2 is of high restriction (HR) and the water of well 4 is severe restriction (SR), while well water 5 is moderate restriction (MR) when used for irrigation as described in Table 6 and based on the classification of Meireles et al., [24].

The water quality salinity is considered to be of very high salinity type (C_4) according to the classification of the American salinity laboratory USSL, which are suitable for the irrigation of plants that are highly tolerant to salts in well-scrubbed soils and with heavy wash [22]. Water is also suitable for irrigation for each of (SSP, PI, KR) but generally unfit (except for well no. 3) based on potential salinity (PS) as described in Table 6.

Table 5: Analysis results of groundwater in Al- Kasik subdistrict. (meq.l⁻¹, except Electrical conductivity µS. cm-1)

Wells Parameters	1		2		3		4		5	
EC_{25}	Max. Min. 4716 -3380	Mean 4122	Max. Min. 4789-3558	Mean 4243	Max. Min. 3540-2591	Mean 3091	Max. Min. 5369-3540	Mean 4396	Max. Min. 4154-3058	Mean 3851
pH	7-7.09.27	7.52	7.43– 7.0	7.23	7.17 – 7.01	7.09	7.18– 6.9	7.07	6.93– 6.89	6.91
Ca	34.0–30.0	31.8	33.0 –30.0	30.97	33.0 –28.0	30.33	34.0–30.0	31.33	32.0– 27.0	30.10
Mg	18.0–12.0	15.00	16.0–15.0	15.45	10.0 –7.0	8.500	16.0–11.0	13.20	13.0– 10.7	12.23
Na	10.8-9.80	10.20	11.0–10.2	10.60	2.90– 2.0	2.543	15.3–15.0	15.17	6.78– 5.26	5.92
K	0.38–0.13	0.22	0.38 –0.26	0.30	0.51 –0.38	0.42	0.33–0.10	0.24	0.26– 0.12	0.14
HCO_3	4.15–3.57	3.84	3.92–3.44	3.72	4.10 –3.17	3.89	3.50–3.30	3.40	4.10– 3.80	3.99
Cl	10.3–6.40	8.70	15.8 –8.90	11.34	2.70 –2.30	2.54	18.0–14.5	15.9	6.70– 6.10	6.42
SO_4	26.4–21.0	23.2	28.9–17.0	22.4	17.0 –11.5	14.1	29.3–24.0	25.8	18.5– 12.4	16.1
NO_3-N	0.05-0.01	0.034	0.08–0.01	0.06	0.03–0.01	0.021	0.08-0.01	0.046	0.05-0.004	0.045
SSP	20.5–17.2	18.45	19.5-18.0	19.00	8.25 –6.1	7.200	26.9–23.5	25.69	15.0– 10.8	12.37
SAR	2.32–2.14	2.14	2.30–2.08	2.20	0.66 –0.45	0.775	3.31–3.06	3.23	1.36– 1.12	1.23
KR	0.25-0.20	0.222	0.24–0.21	0.231	0.076-0.05	0.065	0.37–0.31	0.343	0.16– 0.12	0.183
PI	14.4–13.1	13.77	14.5–13.6	14.04	7.83-6.86	7.39	19.0–18.1	18.47	10.4– 9.33	9.77
P,S	23.5–18.0	21..1	23.3–17.8	20.2	4.16-3.59	3.81	30.7–26.5	28.13	15.8– 12.3	14.53
RSC	0.0		0.0		0.0		0.0		0.0	

Table 6: Results of water wells for irrigation purposes rating according to internationally approved classifications [22,1]

Wells	IWQI		EC_{25}	SAR	SSP	P. S	RSC	PI	KR
	Values	Rating							
1	49.43	H.R	C_4	S_1	Suitable	Unfit	Safe	Good	Suitable
2	44.51	H.R	C_4	S_1	Suitable	Unfit	Safe	Good	Suitable
3	76.59	L.R	C4	S_1	Suitable	Good	Safe	Good	Suitable
4	36.43	S.R	C_4	S_1	Suitable	Unfit	Safe	Good	Suitable
5	60.07	M.R	C_4	S_1	Suitable	Marginal	Safe	Good	Suitable

4. CONCLUSIONS

The studied groundwater was characterized by the rise of concentrations of most parameters analysed. In particular, the electrical conductivity values, the concentration of sodium, calcium, chloride and sulfate ions are high which negatively affects the groundwater quality for irrigation. The quality of water according to the classification of quality (IWQ index) ranged between moderate restriction (MR) to a severe restriction (HR) when used for irrigation purposes while of suitable quality for each of (SSP, RSC, PI, KR) parameters. Therefore, we recommend the cultivation of resistant plant species to salts, taking into account the use of scientific modern methods in irrigation operations.

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