

Assessment of Reservoir Water Quality Using Water Quality Indices: A Case Study from Jordan.

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Abstract

This study was conducted to evaluate the water quality of King Talal Dam (KTD) in Jordan and its suitability for irrigation purposes based on the measurements of several physicochemical parameters and water quality indices. Surface water was sampled from seven different locations in the dam. The values of electrical conductivity (EC) and total dissolved solids (TDS) indicate that KTD surface water is relatively saline but still falls within the permissible category for irrigation. The dam's water is suitable for irrigation based on the sodium adsorption ratio-(SAR) and magnesium hazard-(MH) data. It lies between permissible to doubtful categories with respect to the results of sodium percentage (Na%) and lies within the marginal category for irrigation based on Kelly's ratio-(KR) values. Therefore, crops that are not sensitive to sodium and soils with light textures and good permeability are recommended. The data of irrigation water quality index (IWQI) showed that KTD water distributed between moderate to high restrictions for irrigation uses, which indicates that the dam's water can be used to irrigate plants with moderate to high salt tolerance and in soils with moderate to high permeability and good leaching of salts. KTD water requires special measures to reduce salinity and sodium hazards.

Keywords: King Talal Dam-Jordan; Physicochemical parameters; Reservoir water quality; Water quality index; Irrigation.

1. INTRODUCTION

Jordan is one of the most water-stressed countries in the world. Water per capita in Jordan is around 150 cubic meters per year, which is much less than the minimum water per capita in the severe water-scarce countries (500 cubic meters per year) [1]. The problem of water scarcity is increasing with time due to several factors such as climate change, rapid population growth, high social and economic development, growing increase in water demand, and lack of water management [2]. Water sources in Jordan are divided into conventional and non-conventional; these sources are depending on rainwater, which is variable and fluctuates spatially and temporally. The conventional sources (surface and groundwater) are the major available sources for all purposes (drinking, agriculture, and industry), whereas non-conventional sources such as treated wastewater are available only for agriculture and industry [2].

Jordan faces many challenges to meet the domestic, industrial and agricultural water needs due to the continuous increase in population growth, dramatic increase in the number of refugees from neighboring countries, especially Syria and Iraq, overuse of water resources as a result of growing water demand and increased agricultural uses (e.g. fertilizers and pesticides), in addition to the dumping of domestic and industrial wastes into the water resources. All these factors led to changes in chemical, physical and biological characteristics of surface and groundwater and deteriorate their quality [2-4].

Chemical and physical characteristics of surface water (e.g. lakes and reservoirs) depend on several factors such as climate changes, geochemistry, and geomorphology of the area that surrounded the water bodies. Generally speaking, the pollution of surface water comes from two main sources; point sources and non-point sources [5]. The non-point sources (diffuse sources), such as anthropogenic activities, atmospheric depositions, automobile exhausts, urban runoff, pesticides and fertilizer applications in agriculture, while the point include discharges from industrial and domestic wastewater plants [6].

The suitability of surface water for irrigation is mainly based on the dissolved substances. One of these substances is the dissolved salts, which should comprise relatively small quantities of dissolved solids to maintain good water quality for irrigation, thus provides higher productivity of the soil-crop. Salinity and sodicity of surface waters play an important role in the propriety of these waters for irrigation. Increasing the amount of the dissolved salts in irrigation water affects the permeability and aeration of the soil, and increases the osmotic pressure, which reduces the availability of water for plant growth, thus affects the soil productivity [7].

The main objective of this study is to assess the water quality of King Talal dam the largest man-made water body in Jordan and check its suitability for agricultural irrigation. Accordingly, several physicochemical parameters were measured, including temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), bicarbonate (HCO_3^-) and chloride (Cl^-). The quality of the dam's water for irrigation purposes was evaluated based on different water quality indices, including irrigation water quality index (IWQI), sodium adsorption ratio (SAR) electrical conductivity (EC), sodium percentage (Na %), magnesium hazard (MH) and Kelly's ratio (KR).

2. DESCRIPTION OF THE STUDY AREA

King Talal Dam (KTD) is one of the largest surface water bodies in Jordan; it was constructed in 1978, with a height of 90 meters, and a storage capacity of 57 million cubic meters (MCM). In a second stage between (1983-1986), the height of the dam was raised to increase the reservoir capacity to 85 million cubic meters in order to meet the increased water demands [8]. The dam was constructed within the Zarqa River basin with an estimated catchment area of 3400 km². The dam was previously used to supply water for municipal use in Amman (Capital of Jordan) region, but due to the high pollution levels in the dam, its water is used now for irrigation in the Jordan Valley [9-11].

Zarqa River and Wadi Rmemeen are the main two sources of water in KTD. Zarqa River is one of the largest rivers in the country, where the water discharges in the river come from natural runoff, major springs and the effluents from Al-Samra wastewater treatment plant (WWTP), which is the largest wastewater treatment plant in Jordan. Wadi Rmemeen is the second source of water in KTD and composed of the effluents from Al-Baqa'a WWTP and some water springs. Wastewater treatment plants (WWTPs) in the Zarqa basin contribute about more than 50 % of the water effluent entering KTD [8, 9, 12]. In addition to the effluents of WWTPs, other sources of pollution that directly or indirectly affect the water quality of the dam include industrial wastewater discharges, reaching the dam via Zarqa River; urban activities including cesspools, runoff, and transportation; agricultural runoff; and leachate from landfills [11, 13-15].

3. METHODOLOGY

Surface water for physical and chemical analyses was sampled during spring 2016 from seven locations (sampling sites) along the main body of King Talal Dam (Fig. 1): site 1 and site 2 in the eastern part of the dam near the entrance of the dam and close to the flowing point of the Zarqa River into the dam. Sites 3 and 4 are in the middle of the dam. Site 5 is

located in the southern part of the dam near the Wadi Rmemeen tributary. Site 6 was selected near the end of the dam and site 7 in the western part at the end of the dam. High-density polyethylene (HDPE) bottles were used to collect water samples. The bottles were rinsed three times with the water of each sampling site before collection. Immediately after sampling, the bottles were kept at 4 °C in an icebox and then transported to be analyzed in the laboratory.

Surface water samples were analyzed for different physical and chemical parameters including temperature, pH, EC, TDS, cations (Ca²⁺, Mg²⁺, Na⁺ and K⁺), anions (HCO₃⁻ and Cl⁻). *In situ* measurements of temperature, pH, EC, and TDS were measured using calibrated portable meters. The concentrations of cations and anions were determined at the laboratory according to the Standard Methods [16].

4. RESULTS AND DISCUSSION

4.1. Temperature and pH

The mean values of temperature in the surface water of KTD (Table 1) varied between 24.7 to 26.2 °C with an average value of 25.4 °C. Whereas, the mean values of pH ranged between 7.86 and 8.26 with an average value of 8.03, which indicates that the surface water of KTD is weakly alkaline and the important major anion; the bicarbonate is present in the water. During the early spring, the temperature and photosynthetic activity increase, the concentration of carbon dioxide decrease and the growth of phytoplankton begin to increase, which increases the pH value of the water. The lowest pH values were recorded in the eastern part of KTD near the Zarqa River which can be attributed to the industrial and wastewater discharges that reach the dam from the river [17, 18].

The pH values in the current study are within the Food and Agriculture Organization (FAO) recommended pH range (6.5-8.4) for irrigation water [19] and within the Jordanian permissible limit for the use of reclaimed water for irrigation purposes [20] (Table 2).

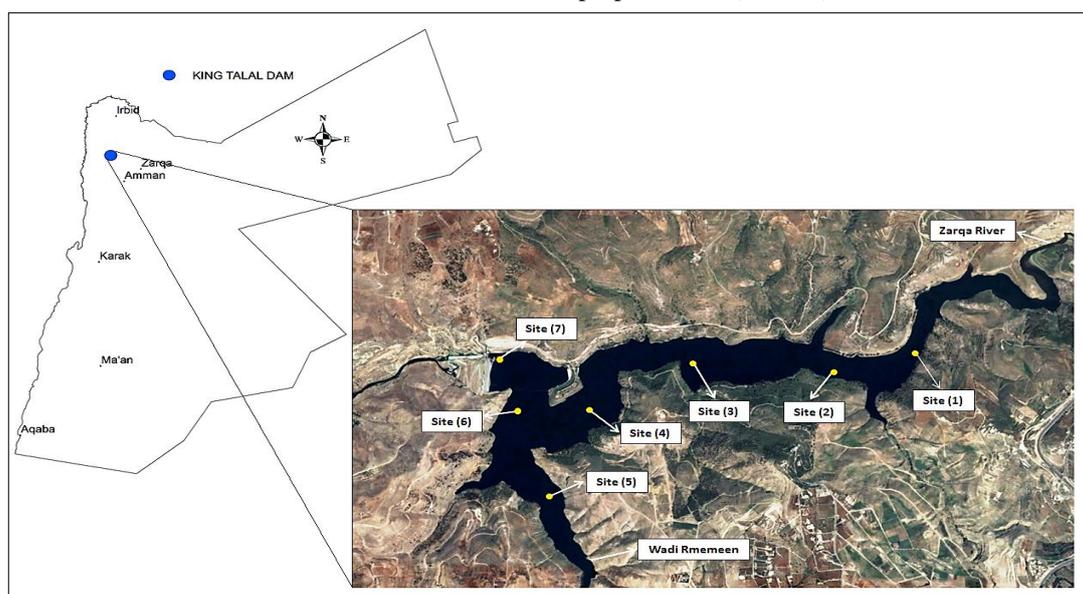


Fig. 1 Location map of water sampling sites in King Talal Dam-Jordan

Table 1. Results of analyses of water collected from King Talal Dam

Site	pH SU	Temp. °C	EC µs/cm	TDS mg/l	Ca ²⁺ mg/l	Mg ²⁺ mg/l	Na ⁺ mg/l	K ⁺ mg/l	HCO ₃ ⁻ mg/l	Cl ⁻ mg/l
Site 1	7.86	24.7	1909.9	1222.3	99.2	33.7	248.0	34.9	150.6	356.2
Site 2	7.90	25.3	1828.4	1170.2	96.5	33.3	239.7	33.8	143.8	347.3
Site 3	7.87	25.6	1675.8	1072.6	91.3	30.8	232.0	32.3	153.0	342.8
Site 4	8.02	25.1	1579.6	1015.3	87.0	29.6	228.7	29.6	144.0	339.1
Site 5	8.11	25.2	1650.3	1056.2	93.7	32.0	219.0	28.9	168.0	325.2
Site 6	8.17	25.5	1490.0	0953.6	87.3	30.5	214.4	28.4	150.4	319.6
Site 7	8.26	26.2	1375.6	0880.4	75.3	24.8	206.3	27.8	137.8	296.4
Min	7.86	24.7	1375.6	0880.4	75.3	24.8	206.3	27.8	137.8	296.4
Max	8.26	26.2	1909.9	1222.3	99.2	33.7	248.0	34.9	168.0	356.2
Mean	8.03	25.4	1644.2	1052.9	90.0	30.7	226.9	30.8	149.7	332.4

Table 2. Comparison of the results of the present study with FAO recommended concentrations for irrigation quality and Jordanian allowable limits for the use of reclaimed water for irrigation purposes (2006)

Parameter	This Study		Jordanian Allowable Limits (mg/l) [20]		FAO guidelines [19]	
	Ranges	Units	Ranges	Units	Ranges	Units
pH	7.86-8.26	SU	6.0-9.0	SU	6.5-8.4	SU
TDS	880.4-1222.3	mg/l	0-1500	mg/l	0-2000	mg/l
EC	1375.6-1909.9	µs/cm	---	µs/cm	0-3000	µs/cm
Ca	75.3-99.2	mg/l	0-230	mg/l	0-20	meq/l
Mg	24.8-33.7	mg/l	0-100	mg/l	0-5	meq/l
Na	206.3-248.0	mg/l	0-230	mg/l	0-40	meq/l
K	27.8-34.9	mg/l	---	mg/l	---	meq/l
HCO ₃	137.8-168.0	mg/l	0-400	mg/l	0-10	meq/l
Cl	296.4-356.2	mg/l	0-400	mg/l	0-30	meq/l
SAR	4.98-5.49	---	0-9.0	---	0-9.0	---

4.2. Cations

The mean concentrations of Ca²⁺, Mg²⁺, Na⁺ and K⁺ ranged between 75.3-99.2, 24.8-33.7, 206.3-248.0, 27.8-34.9 mg/l, respectively, with a mean concentration of 90.0, 30.7, 226.9 and 30.8 mg/l, respectively (Table 1). The maximum mean concentrations of the major cations (Ca²⁺, Mg²⁺, Na⁺ and K⁺) were recorded in the sites near the Zarqa river (sites 1 and 2), whereas the lowest mean concentrations were recorded in the surface water at the far end of the dam (site 7). However, the concentrations of Ca²⁺ and Mg²⁺ were tending to increase slightly in the surface water near the Wadi Rmemeen flowing point into the dam (site 5).

Major cations in water are mainly affected by the nature of the geology of the catchment area and the weathering processes that affect rocks and soils [21]. The concentrations of major elements in water may also be increased by the discharge from wastewater treatment plants. Other sources of major elements are the discharges from industry and drainage water from agricultural lands [22]. The distribution of major cations in this study showed a more or less similar trend, which

indicates that the factors affecting their occurrence and distribution are the same, and include the discharges that enter KTD via Zarqa River and Wadi Rmemeen.

The concentrations of all major cations in the present study lie within the FAO permissible ranges for irrigation water [19] and within the Jordanian permissible limits [20] except for Na concentrations in sites 1, 2, and 3, which were slightly higher than the Jordanian limits (Table 2).

4.3. Anions

4.3.1. Bicarbonate (HCO₃⁻)

The carbonate species (HCO₃⁻ and CO₃²⁻) in surface and groundwater contribute to the total alkalinity; their ratios rely on the hydrogen activity and temperature [23]. The sources of bicarbonate and carbonate in surface water come from atmospheric deposition, biological respiration as well as the weathering of rock, particularly from the carbonate rocks. In dry conditions, high concentrations of carbonate and bicarbonate are precipitated in the form of calcium carbonate

and magnesium carbonate, thus decreasing the concentration of calcium and magnesium relative to the concentration of sodium [23, 24].

The results in (Table 1) showed variations in the distribution of bicarbonate in surface water of KTD. The highest mean concentration of bicarbonate (168 mg/l) was recorded in site 5, which can be attributed to the effluents from the Wadi Rmemeen tributary [17]. The lowest mean concentration of bicarbonate (137.8 mg/l) was recorded in surface water of site 7 at the outlet point of the dam. The bicarbonate distribution in this study is similar to the distribution that has been published by Al-Taani et al. (2018), who found horizontal variations of bicarbonate in surface water of KTD and suggested that the precipitation of CaCO_3 explains the relatively lower concentrations of the bicarbonate in surface water near the end of the dam. However, Table (2) showed that the concentrations of bicarbonate in surface water of KTD are within the Jordanian standards for the use of reclaimed water for irrigation purposes [20] and within the FAO standards for irrigation water [19].

4.3.2. Chlorides (Cl^-)

Chloride is an important anion (component) in irrigation water, it is essential to plants, but in very low concentration, where it can be toxic and hazardous at a high concentration because it cannot be adsorbed by soil, easily moves in soil solution and taken up by the plants and accumulate in the leaves [19].

The results in (Table 1) showed that chlorides concentrations in the surface water of KTD ranged between 296.4 and 356.2 mg/l with a mean value of 332.4 mg/l. Higher mean concentrations of chlorides were recorded in sites (1 and 2) where the water of Zarqa River tributary enters into the dam, compared to those recorded in site (7) at the dam's outlet. Chlorides enter the surface water from several sources, including rocks containing chlorides, agricultural runoff and wastewaters from industrial, and wastewater treatment plants [25]. Accordingly, the high chlorides concentrations during the spring season in the sites near the entrance of the dam can be attributed to wastewater effluents from industrial and wastewater treatment plants that reaching the dam via Zarqa River.

According to the data in (Table 2), the concentrations of chlorides in the present study are within the Jordanian [20] and FAO [19] standards for irrigation water.

4.4. Salinity

The salinity of water can be identified based on total dissolved solids (TDS) or electrical conductivity (EC). TDS is the total amount of dissolved substances in the water, which includes inorganic salts in addition to a small amount of organic matter. The most common inorganic salts in water are Ca^{2+} , Mg^{2+} , Na^+ , and K^+ , which defined as major cations and HCO_3^- , Cl^- and SO_4^{2-} defined as major anions.

Electrical conductivity (EC) is one of the important parameters to assess the quality of surface and groundwater. It

is defined as the capacity of water to transfer electrical flow. EC is directly related to the amount of TDS and major ions in water, where the more TDS and major ions present, the higher water conductivity.

EC value in water is affected by temperature and pH changes as well as chemical reactions and physical changes in water. Elevated salinity in irrigation water causes a high osmotic potential, where the salts in solution and in the soil are competing with the plants for the available water. Therefore, the salts will increase in the soil and result in a drought condition [19, 26, 27]. The possible sources of dissolved solids in surface water are from weathering and erosion of rocks, urban and agricultural runoff, and industrial and wastewater discharges [28].

Table (1) showed that the TDS values in the present study varied between 880.4 and 1222.3 (mg/l), with a mean value of 1052.9 (mg/l), Whereas, the EC values ranged between 1375.6 and 1909.9 ($\mu\text{s}/\text{cm}$), with a mean concentration of 1644.2 ($\mu\text{s}/\text{cm}$).

According to the classifications of USDA salinity laboratory for irrigation water based on EC and TDS values [29] (Table 3), all samples collected from the KTD surface water are lying within the permissible category (C3: high salinity water) for irrigation. Water in the permissible category (C3) is likely to damage the crops with low salinity tolerance even with good drainage soils. Therefore, excess irrigation for leaching or periodic use of low salinity water and good drainage are needed to improve the plant's growth [19].

The values of TDS and EC in the present study are within the Jordanian allowable limits for the use of reclaimed water for irrigation purposes [20] and within the FAO standards for irrigation [19] (Table 2).

4.5. Sodium Adsorption Ratio (SAR)

Sodium adsorption ratio (SAR) is the ratio of sodium ion to calcium and magnesium ions in a water sample, where calcium and magnesium ions reduce the effect of sodium on the soil. SAR is an important extensively used parameter to determine the suitability of water for irrigation, which evaluates the sodium adsorption rate by the soil. SAR is also termed as sodium hazard or sodicity hazard. Irrigation water with high sodium content is particularly important because of the destructive effect of sodium on the soil structure by reducing water movement and the soil infiltration rate due to soil dispersion thereby affecting plant growth [30].

SAR was computed based on the following Equation [29].

$$\text{SAR} = \frac{\text{Na}}{\sqrt{(\text{Ca} + \text{Mg})/2}} \quad (\text{ions units in meq/liter}) \quad (1)$$

SAR values in the surface water of KTD (Table 4) varied between 4.98 and 5.49, with an average value of 5.27. The classifications of irrigation water based on the SAR values [29] (Table 5) showed that the collected surface water samples from the KTD fall in (S1) category and indicate excellent quality for irrigation. The water in this category is with low sodium hazard and suitable for all types of soils and all types

of crops except for crops that are highly sensitive to sodium.

Table 3. USDA salinity laboratory classifications of irrigation water based on EC and TDS values [29]

Water Class	Water Quality	EC (µs/cm)	TDS mg/l
C1	Low-Salinity Water (Excellent for Irrigation)	< 250	< 150
C2	Medium-Salinity Water (Good for Irrigation)	250 – 750	150 – 500
C3	High-Salinity Water (Permissible for Irrigation)	750 – 2250	500 – 1500
C4	Very High-Salinity Water (Unsuitable for Irrigation)	> 2250	> 1500

Table 4. Water quality results for the collected water samples from King Talal Dam

Site	SAR meq/l	EC µs/cm	Na %	Mg Hazard	Kelly's Ratio
Site 1	5.49	1909.9	60.2	35.9	1.40
Site 2	5.37	1828.4	59.9	36.3	1.38
Site 3	5.36	1675.8	60.6	35.7	1.42
Site 4	5.40	1579.6	61.2	35.9	1.47
Site 5	4.98	1650.3	58.4	36.0	1.30
Site 6	5.03	1490.0	59.4	36.6	1.36
Site 7	5.27	1375.6	62.5	35.2	1.55
Min	4.98	1375.6	58.4	35.2	1.30
Max	5.49	1909.9	62.5	36.6	1.55
Mean	5.27	1644.2	60.3	36.0	1.41

Table 5. Classification of irrigation water based on SAR values [29]

Water Class	Water Quality	SAR
S1	Low Sodium hazard (Excellent for Irrigation)	0-10
S2	Medium Sodium hazard (Good for Irrigation)	10 -18
S3	High Sodium hazard (Permissible for Irrigation)	18-26
S4	Very High Sodium hazard (Unsuitable for Irrigation)	> 26

4.6. Sodium Percentage (Na %)

The Sodium percentage (Na %) is one of the water quality parameters used to determine the suitability of water for irrigation, Na % was calculated using the following equation [31] and expressed in meq/l:

$$\text{Na \%} = \frac{(\text{Na}+\text{K})}{(\text{Na}+\text{Ca}+\text{Mg}+\text{K})} \times 100 \text{ (ions units meq/liter)} \quad (2)$$

Based on the data in (Table 4), the values of Na % in the surface water of KTD range between 58.4 and 62.5, with an average value of 60.3. According to the classifications of irrigation water based on Na % [31, 32] (Table 6), the collected samples in the current study distributed between permissible to doubtful categories for irrigation, where 43 % of the samples fall under the category of permissible for irrigation and 57 % under the doubtful category for irrigation.

Table 6. Classifications of irrigation water based on Na % values [31, 32]

Water Quality	Na %
Excellent for Irrigation	< 20
Good for Irrigation	20-40
Permissible for Irrigation	40-60
Doubtful for Irrigation	60-80
Unsuitable for Irrigation	> 80

4.7. U.S. Salinity Laboratory's diagram for the classification of irrigation waters [29].

The U.S. Salinity Laboratory's (USSL) (1954) developed a diagram to determine the viability of water for irrigation purposes based on the values of the electrical conductivity and the sodium adsorption ratio, USSL diagram is also known as

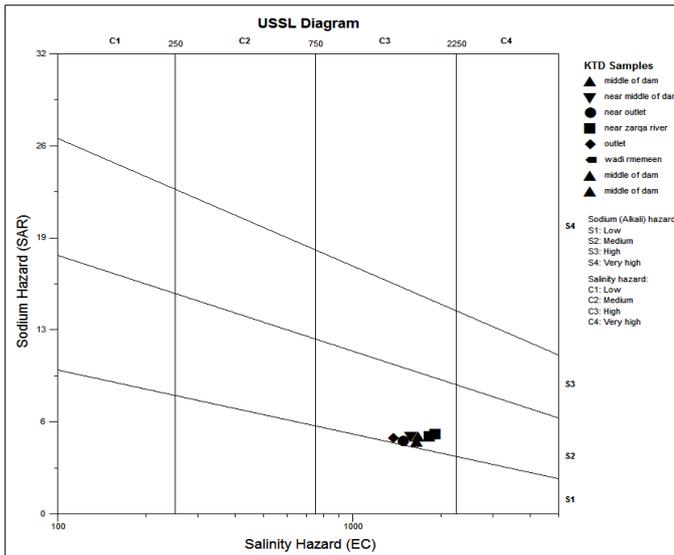


Fig. 2 USSSL diagram of the collected surface water samples from KTD (using Aquachem program version 4.0)

Wilcox diagram. Simply, the diagram is a plot of salinity hazard (EC) on the X-axis versus the sodium or sodicity hazard (SAR) on the Y-axis. USSSL diagram (Fig. 2) classifying the waters into four types on the basis of salinity hazard [29]: C1 (low salinity hazard), C2 (medium salinity hazard), C3 (high salinity hazard), and C4 (very high salinity hazard) (EC), and into four types on the basis of sodium hazard (SAR): S1 (low sodium hazard), S2 (medium sodium hazard), S3 (high sodium hazard), and S4 (very high sodium hazard).

The USSSL diagram (Fig. 2) showed that all the collected samples from the surface water of KTD belong to the category of moderate water quality for irrigation (C3S2), where the water of this category is with high salinity hazard and medium sodium hazard. Accordingly, it is suggested that the water of KTD needs a kind of treatment to reduce salinity and sodium hazards. However, with its present qualities, it can be used to irrigate crops with good salt-tolerance and soils with good drainage. Therefore, the soils with restricted leaching conditions and crops with low salt-tolerance are not suitable and not recommended.

4.8. Magnesium Hazard (MH)

The elevated concentrations of magnesium in irrigation waters will unfavorably affect the quality of the soil and changing it to alkali soil and reduce crop production [19]. Magnesium hazard (MH) or magnesium ratio (MR) can be calculated using the following equation [33].

$$MH = \frac{(Mg) \times 100}{(Ca+Mg)} \quad (\text{ions units meq/ liter}) \quad (3)$$

If the value of MH is less than 50, the water is suitable for irrigation, while the water is considered unsuitable for irrigation when the value of MH is greater than 50. The results in (Table 4) indicated that the MH values in the present study ranged between 35.2 and 36.6, with a mean value of 36. Consequently, the water of KTD is suitable for irrigation and can be used safely.

4.9. Kelley's Ratio (KR)

Water can be classified for irrigation based on Kelley's ratio (KR), where KR measures the Na concentration against the concentrations of Ca and Mg [34].

$$KR = \frac{Na}{(Ca+Mg)} \quad (\text{ions units meq/ liter}) \quad (4)$$

If the KR value is more than 1 indicates an excess concentration of Na in water, where the elevated concentrations of Na in irrigation water can adversely affect the soil structure and features and reducing permeability [35]. The water is considered safe and suitable for irrigation with the KR value of less than 1. When the KR value is more than 3, then the water is unsuitable for irrigation.

The KR value of this study (Table 4) ranges between 1.3 and 1.55, with a mean value of 1.41. According to the classification of irrigation water based on the KR value, water of KTD lies within the marginal category for irrigation, which indicates an excess level of sodium in the waters.

4.10. Irrigation Water Quality Index (IWQI)

IWQI was used and applied to the data of the current study based on the model developed by Meireles et al. (2010). The IWQI was determined through two main steps. The first step: identifying the important physicochemical parameters for irrigation water, including EC, Cl⁻, Na⁺, and HCO₃⁻, where these parameters are required to produce the adopted model [36]. The second step: defining the water quality measurement value (Q_i) and aggregation weights (W_i) for each parameter [36]. Values of (Q_i) were determined based on the observed value of each parameter and according to irrigation water quality parameters proposed by the University of California Committee of Consultants - UCCC and based on the criteria established by Ayers and Westcot (1999) as shown in (Table 7), water quality parameters were represented by a non-dimensional number, where the higher value indicates the better quality of water and vice versa [36].

Values of Q_i were calculated using the Equation (5) and based on the tolerance limits given in (Table 7) and the laboratory results of the analyzed parameters [36].

$$Q_i = Q_{i\max} - [(X_{ij} - X_{inf}) \times Q_{iamp}] / X_{amp} \quad (5)$$

Where, Q_{i_{max}} is the maximum value of Q_i for the class; X_{ij} is the observed value of each parameter; X_{inf} is the corresponding value to the lower limit of the class to which the parameter belongs; Q_{iamp} is class amplitude; X_{amp} is the class amplitude to which the parameter belongs, to determine the value of X_{amp} of the final class of each parameter, the uppermost limit was selected to be as the maximum value obtained from the analysis of the water samples [36].

The values of the aggregation weights (W_i) for the parameters used in the calculation of IWQI were adopted from [36], where (W_i) values were normalized and their sum equals one (Table 8).

The irrigation water quality index (IWQI) was calculated as the following equation.

$$IWQI = \sum_{i=1}^n Q_i \times W_i \quad (6)$$

WQI is a dimensionless parameter ranging from 0 to 100; Q_i is the quality of the ith parameter, a number from 0 to 100,

function of the concentration or measurement; W_i is the normalized weight of the i^{th} parameter, which is a function of the parameter importance in the irrigation water quality [36].

Table 7. Parameter limiting values for quality measurement (Q_i) calculation

Q_i	EC $\mu\text{s}/\text{cm}$	SAR	Na meq/l	Cl meq/l	HCO_3 meq/l
85-100	$200 \leq \text{EC} < 750$	$2 \leq \text{SAR} < 3$	$2 \leq \text{Na} < 3$	$1 \leq \text{Cl} < 4$	$1 \leq \text{HCO}_3 < 1.5$
60-85	$750 \leq \text{EC} < 1500$	$3 \leq \text{SAR} < 6$	$3 \leq \text{Na} < 6$	$4 \leq \text{Cl} < 7$	$1.5 \leq \text{HCO}_3 < 4.5$
35-60	$1500 \leq \text{EC} < 3000$	$6 \leq \text{SAR} < 12$	$6 \leq \text{Na} < 9$	$7 \leq \text{Cl} < 10$	$4.5 \leq \text{HCO}_3 < 8.5$
0-35	$\text{EC} < 200$ or $\text{EC} \geq 3000$	$\text{SAR} < 2$ or $\text{SAR} \geq 12$	$\text{Na} < 2$ or $\text{Na} \geq 9$	$\text{Cl} < 1$ or $\text{Cl} \geq 10$	$\text{HCO}_3 < 1$ or $\text{HCO}_3 \geq 8.5$

Table 8. Weights for the IWQI parameters [36]

Parameter	Weight (W_i)
EC	0.211
Na^+	0.204
HCO_3^-	0.202
Cl^-	0.194
SAR	0.189
Total	1.000

Table 9. Values of IWQI of the surface water samples collected from King Talal Dam

Site	IWQI
Site 1	52.83
Site 2	53.84
Site 3	54.33
Site 4	55.02
Site 5	55.40
Site 6	56.66
Site 7	58.54
Min	52.83
Max	58.54
Mean	55.23

IWQI values in the current study ranged between 52.83 and 58.54 (Table 9), based on the classifications of water for irrigation with respect to IWQI values [36] (Table 10), the surface water of KTD is distributed between moderate to high restriction categories for irrigation uses. Therefore, the dam's surface water can be used in soils with moderate to high

permeability and with good leaching of salts as well as moderate to high salt tolerant plants should be selected. In addition to that, some kind of treatment is needed to control salinity [36].

The lowest values of IWQI were found in the eastern part of KTD near the Zarqa River (sites 1 and 2), whereas the highest values were observed in the western part of the dam near the outlet point (site 7). The lower water quality in the eastern part of the dam compared to the western part can be attributed to natural, agricultural, industrial and wastewater discharges from the Zarqa River.

4.11. Comparison of the results of the current study with the related studies

Many previous studies have been conducted on the waters of King Talal Dam and the Zarqa River, while some of these studies have focused on the chemical and physical properties of the dam's water [11, 17, 37, 38]. The comparison of the results of this study with the studies conducted on the water of King Talal dam (Table 11) indicated that the measured parameters (pH, Ca^{2+} , Mg^{2+} , Na^+ , K^+ , HCO_3^- and Cl^-) and quality indices (EC, TDS and SAR) in the current study are in agreement with the previously listed results by RSS (2003-2004).

The values of pH, Ca^{2+} , Mg^{2+} , Na^+ , K^+ , Cl^- and SAR in this study are within the ranges published by (Al-Taani et al. 2018), whereas TDS values are slightly higher than the ranges published by the same authors. Table (11) showed that the results of EC and pH values of the present study are within the ranges documented by Fandi et al. (2009), whereas Ca and Na values are lower than their ranges.

By comparing the results of the present study with those reported for Zarqa River water by Hind et al. (2018) (Table 11), all the major cations (Ca^{2+} , Mg^{2+} , Na^+ and K^+) and values of EC and MgH in this study are in agreement with their results [39], while the values of the quality indices SAR, Na % and KR are slightly higher than their results.

Table 10. Irrigation Water Quality Index Characteristics [36]

IWQI	Water use restrictions	Recommendation	
85-100	No restriction (NR)	May be used for the majority of soils with low probability of causing salinity and sodicity problems, being recommended leaching within irrigation practices, except for in soils with extremely low permeability.	No toxicity risk for most plants
70-85	Low restriction (LR)	Recommended for use in irrigated soils with light texture or moderate permeability, being recommended salt leaching. Soil sodicity in heavy texture soils may occur, being recommended to avoid its use in soils with high clay.	Avoid salt sensitive plants
55-70	Moderate restriction (MR)	May be used in soils with moderate to high permeability values, being suggested moderate leaching of salts.	Plants with moderate tolerance to salts may be grown
40-55	High restriction (HR)	May be used in soils with high permeability without compact layers. High frequency irrigation schedule should be adopted for water with EC above 2000 $\mu\text{s}/\text{cm}$ and SAR above 7.0.	Should be used for irrigation of plants with moderate to high tolerance to salts with special salinity control practices, except water with low Na, Cl and HCO_3 values.
0-40	Severe restriction (SR)	Should be avoided its use for irrigation under normal conditions. In special cases, may be used occasionally. Water with low salt levels and high SAR require gypsum application. In high saline content water soils must have high permeability, and excess water should be applied to avoid salt accumulation.	Only plants with high salt tolerance, except for waters with extremely low values of Na, Cl and HCO_3 .

Table 11. Comparison of the water quality results of this study with related studies on King Talal Dam, and with FAO recommended maximum concentration for irrigation quality and Jordanian allowable limits for the use of reclaimed water for irrigation purposes

Parameter	This Study Mean	[38]. KTD water	[11]. KTD surface water	[17]. KTD surface water	[39]. Zarqa River
pH	8.03	7.4-8.7	7.76-8.24	8.23-9.79	-----
EC $\mu\text{s}/\text{cm}$	1644.2	1198-2783	1420	-----	670-2189
TDS mg/l	1052.9	680-1424	-----	896-966	-----
Ca mg/l	90.0	82-163	116-152	90.66-116.91	57-140
Mg mg/l	30.7	19-56	49.2-58.6	30.23-40.33	23-57
Na mg/l	226.9	92-288	242-263	192.6-260.84	59-269
K mg/l	30.8	20-48	-----	22.17-31.47	4-33
HCO_3 mg/l	149.7	266-717	-----	97.6-136.64	-----
Cl mg/l	332.4	173-452	-----	320.18-368.02	-----
SAR	5.27	2.5-5.5	-----	4.27-5.42	1.38-5.2
Mg hazard	36.0	-----	-----	-----	27.2-45.8
Kelly's Ratio	1.41	-----	-----	-----	0.36-1.39
Na %	60.3	-----	-----	54.35-58.53	26.2-58.1

5. CONCLUSIONS

The distribution of the measured parameters in this study showed a more or less similar distribution trend, where the highest concentrations of the parameters were recorded in the eastern part (near Zarqa River flow) and southern part (near Wadi Rmemeen flow) of the dam, whereas the lowest concentrations were recorded in the western part of the dam near the outlet point, which indicate that their sources are similar to some extent and include discharges from industrial and wastewater treatment plants that enter KTD via Zarqa River and Wadi Rmemeen tributaries in addition to the natural discharges from the surrounding catchment areas such as weathering products of rocks and soil erosion.

The values of EC and TDS indicate that the surface water of KTD is fairly saline but still falls within the permissible category for irrigation based on the USDA salinity laboratory classifications of irrigation water. Therefore, the water of KTD can be used for irrigation in soils with good drainage and leaching processes, moreover plants with moderate to high salt tolerance should be selected.

The SAR of KTD indicates that the surface water of the dam is suitable for irrigation, whereas the results of Na % showed that the dam's water distributed between permissible to doubtful categories for irrigation. KR values of the present study show that the water of the dam lies within the marginal category for irrigation and indicate an excess level of sodium in the waters. Consequently, the surface water of KTD can be used to irrigate plants that are not sensitive to sodium, and that soils with light texture or good permeability are recommended. However, based on the data of magnesium hazard in this study, the dam's surface water is safe and suitable for irrigation.

The USSL diagram in this study indicates that water of KTD belongs to the category of (C3S2) high salinity hazard and medium sodium hazard, which means that the water of the dam is with the moderate quality for irrigation and can be used to irrigate crops with good salt tolerant and soils with good drainage and good leaching conditions.

The results of the irrigation water quality index (IWQI) show that the water of the dam is distributed between moderate to high restriction categories for irrigation uses. Therefore, the surface water of KTD can be used to irrigate plants with moderate to high salt tolerance and soils with moderate to high permeability and good leaching of salts.

All the analyzed parameters in this study lie within the Jordanian permissible limits for irrigation [20] and within the FAO recommended ranges for irrigation water [19].

Based on the data results of the present study it can be concluded that the water of KTD required special procedures and practices to reduce salinity and sodium hazards.

The application of irrigation water quality index (IWQI) and other indices (EC, SAR, Na %, KR and MgH) will be always useful to evaluate the KTD water quality for irrigation purposes, where these indices can be considered as effective tools to provide the decision-makers and related institutions with the observed data in order to be able to understand the status of the water quality of KTD.

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