JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2021, 22(9), 159–175
https://doi.org/10.12911/22998993/141531
ISSN 2299–8993, License CC-BY 4.0

Received: 2021.07.26
Accepted: 2021.08.25
Published: 2021.09.01

# Assessing Water Quality of Kufranja Dam (Jordan) for Drinking and Irrigation: Application of the Water Quality Index

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**ABSTRACT**
The current study was undertaken to assess the physicochemical quality of the Kufranja dam (KD) surface water in northern Jordan during the summer and winter seasons [2019]. The samples were analyzed for temperature, pH, dissolved oxygen, conductivity, major cations, major anions, and heavy metals. Most of the physicochemical parameters exhibited a similar spatial distribution, where the maximum concentrations were observed at the dam's entrance, while the minimum concentrations were recorded at the dam's end. This indicates that the factors affecting their occurrence and distribution are the same, including natural discharges from the surrounding catchment areas, weathering products, agricultural activities, and wastewater effluents that enter the dam via Wadi Kufranja. All the physicochemical parameters and heavy metals in KD water lie below the maximum permissible levels of the Jordanian and international standards for drinking and irrigation, except for EC values that are above WHO standards for drinking. The application of the water quality index (WQI) depicts that the KD water is chemically unsuitable for use in drinking and needs proper treatment before use. The irrigation indices (SAR, Na%, and MH) indicate that the KD water is chemically suitable for irrigation, whereas EC results and USSL diagram showed that the dam's water is suitable for irrigation and belongs to the categories of good to permissible for irrigation. Therefore, KD water is suitable for irrigation of most soils (except soils with low salt tolerance). Crops with good salt tolerance are recommended and a special treatment of salinity might be required.

**Keywords:** Kufranja Dam-Jordan, physiochemical parameters, water quality index, drinking, irrigation.

## INTRODUCTION

One of the countries facing water shortage challenges today is Jordan, the annual water per capita is less than 100 m$^3$/year, far below the international water poverty line of 500 m$^3$/year per capita [MWI, 2017]. The uses of the limited available water resources in the country are expected to increase by 60% in 2025, leading to additional water stress [MWI, 2016]. Moreover, Jordan is an arid and semi-arid country with about 90% of the land classed as drylands; the climate is semi-tropical in the Jordan Valley, Mediterranean in the northern and western highland, and desert in most of the country. Generally, the climate is characterized by hot and dry in summer and wet and cold in winter; the total annual rainfall ranges between 100 mm in the south-eastern desserts to 600 mm in the northern highlands; more than 91% of the country receives less than 200 mm of rainfall [Frenken, 2009; MOENV and UNDP, 2014].

Water scarcity in Jordan has been exacerbated due to rapid population growth, a dramatic increase of refugees, climate change, rainfall fluctuations, and lack of appropriate water management, which lead to increased pressure on the available water resources. In addition, the problem of water scarcity has many socioeconomic effects. The lack of water supply for domestic uses leads to the spread of diseases and epidemics, which raises the bill of health treatment and reduces productivity, thus reflecting negatively on national output. Furthermore, this leads to the inability to achieve the coveted development rates of the plans set by the government, thereby affecting social and economic growth [Karmakar and Musthafa 2012; Strobl and Robillard 2008].

Jordan has faced water shortage challenges by adopting different approaches and strategies such as implementing several strategic plans and water harvesting projects (e.g. dams constructions), reducing water losses, increasing efficiency in water use, reducing the over-extraction of groundwater, expanding wastewater services, treating the wastewater according to the internationally adopted technologies, and developing plans for the optimal use of water.

The importance of finding alternative water resources to fill the gap between supply and demand is as important as protecting the water quality of the available limited water resources and ensuring that they are compatible with different uses, where access to sustained water supply requires the protection of water resources from any possible pollution.

Water resources in Jordan consist of about 27% surface water, 59% groundwater, and 14% treated wastewater [MWI, 2017]. In addition to the current and future threats of over-use and/or misuse of water resources, surface and groundwater are exposed to pollution due to a wide range of human and natural influences, the former being anthropogenic, agricultural, and industrial activities; the important natural influences come from geological, hydrological, and climatic conditions (e.g. weathering and erosion processes). The aforementioned may raise physical, chemical, and microbiological contaminants, thus impairing the quality of water available [Karmakar and Musthafa, 2012; Varol et al., 2012]. Dams, rivers, and lakes are significant fresh surface water resources, are among the most important inland water supply resources used for domestic, irrigation, industry, recreation, and energy production. Therefore, preventing and controlling pollution in these resources as well as making constant reliable studies on water quality is extremely important.

Kufranja Dam (KD) is one of the most prominent development projects in Jordan, which was newly constructed and designed to contribute to solving the water shortage problem in Ajloun city (northern Jordan), one of the cities with the poorest water resources in the country. This research aims to characterize the chemical and physical properties of the KD water to determine the status of the water quality in the dam and the possibility of reusing its water for drinking and irrigation purposes.

This will be the first study concerning the evaluation of the physicochemical parameters of KD in Jordan. Therefore, this study will give initial information about the water quality of the dam and help the decision-makers, water planners, and related institutions to develop effective management of the dam watershed to sustain optimal water quality.

## MATERIALS AND METHODS

### Description of the study area

Wadi Kufranja (or Wadi Ajloun) is a valley extending between Kufranja and Ajloun in northern Jordan, where the rainfall and spring water flows from Ajloun and Kufranja areas into the Jordan River. In 2011, the Jordanian government decided to build a dam in this valley and named it Kufranja Dam. The Jordan Valley Authority (JVA) in the Ministry of Water and Irrigation (MWI) began to construct the dam in the valley to collect spring water and rainfall in a catchment area of about 99 km$^2$ of the Ajloun city in the north of Jordan, where the average precipitation is 600 mm/year. In 2016, the construction of the Kufranja Dam was completed.

The KD is located 70 km northwest of Amman (Figure 1), the capital of Jordan. It was designed as a concrete-face rock-fill dam (CFRD), the first of its kind in Jordan. The dam measuring 80.5 meters in height and 275 meters in length has a storage capacity of about 7.8 MCM. The climate in the catchment area of the KD can be classified as a Mediterranean Sea type with hot summers and relatively mild and wet winters. The topography in the catchment area of the dam is generally hilly with slopes toward the west. The main water resources of the dam are from precipitation and spring waters discharged from the catchment area of the Kufranja Basin (KB). The KD was constructed to receive the base and flood flow from Wadi Kufranja. Moreover, the dam receives effluents from the Kufranja wastewater treatment plant. The dam's water is planned to mainly be used for drinking and irrigation purposes as well as recharging of groundwater.

### Field sampling and analytical procedures

Nine sampling sites (site 1 to 9) in the Kufranja dam (KD) were examined during the summer and winter in the year 2019 (Figure 1).

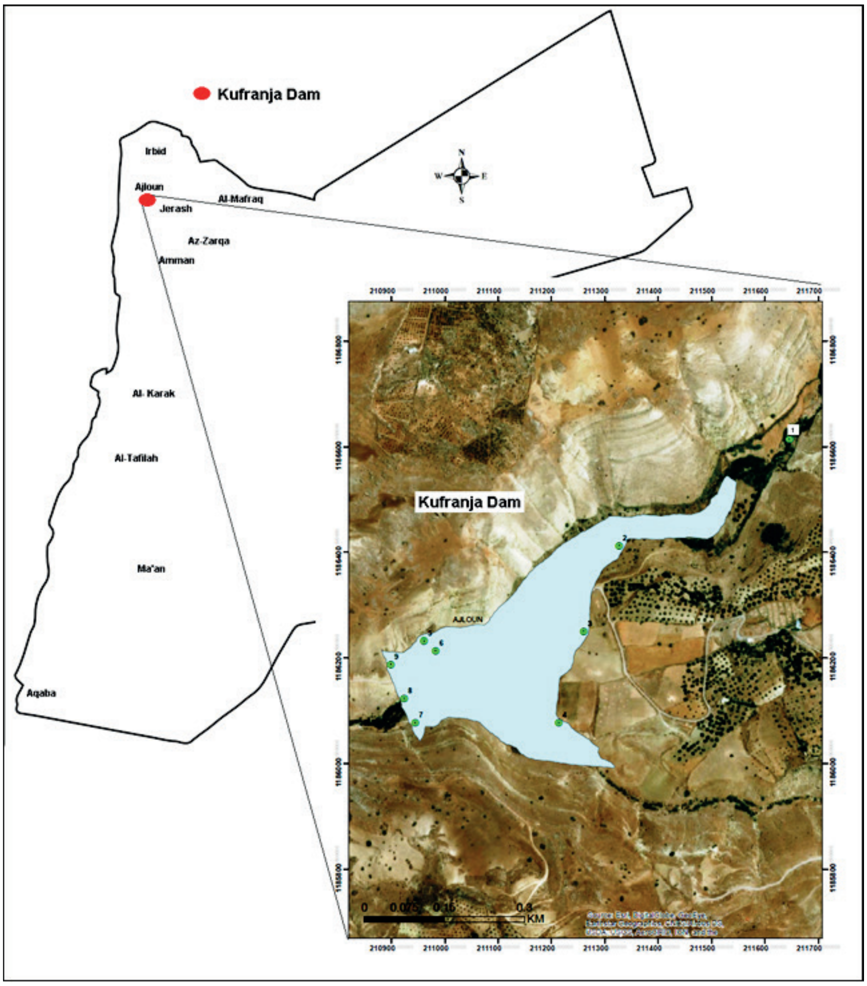

**Figure 1.** Location map of the study area

The sampling locations in this study were selected to represent, to some extent, the entire dam and can be accessed during the fieldwork easily and safely without risk. Some of the sites inside the dam were not selected as we could not access them easily due to the lack of facilities and equipment available inside the dam and that it is newly constructed. Moreover, the unselected sites are dangerous and have steep topography, especially those at the entrance and southern part of the dam.

The samples were collected in polyethylene bottles from the surface water of KD using a PVC Niskin water sampler. The sampler, bottles, and water containers were first rinsed with water (3 times) to reduce the possibility of any contamination; then, they were filled with the dam's water and stored in an icebox until they were transported to be analyzed in the laboratory. Hydrogen ion concentration (pH), temperature (°C), and electrical conductivity (µs/cm) were determined in situ using portable meters (Table 1).

**Table 1.** Analytical and reference methods used for the physicochemical parameters and heavy metals in the water samples

| Test | Unit | Method | References |
|---|---|---|---|
| Temperature, DO, pH, EC | Cº, mg/l, SU, µs/cm | Field meters | Multiparameter waterproof meter<br>(Hanna instruments: HI98194) |
| Cations and anions | mg/l | Ion Chromatography (4110C) | (APHA et al., 2017) |
| Bicarbonate | mg/l | Titration Method (2320B) | (APHA et al., 2017) |
| Heavy metals | mg/l | ICP-OES Method | (APHA et al., 2017) |

The collected samples of the present study were laboratory analyzed for several chemical tests as follows: cations (Calcium – Ca, Magnesium - Mg, Sodium - Na, and Potassium – K); anions (bicarbonate – $HCO_3$, chloride – Cl, Nitrates – $NO_3$, and sulfate – $SO_4$); heavy metals (Iron – Fe, Manganese – Mn, Copper – Cu, Zinc – Zn, Cadmium – Cd, Molybdenum – Mo, and Mercury – Hg). Cations and anions excluded bicarbonate were analyzed using Ion Chromatography (instrument: DIONEX ICS-5000+ DP) equipped with the column (CS12A – 4×250) for cation tests; in addition, the column (AS14A – 4×250) was used for anions tests with a conductivity detector according to the Standard Methods for Examination of Water and Wastewater [APHA and others, 2017]. The bicarbonate test was carried out using the Titration method with the calibrated pH meter (sensodirect 150 Lovibond) [APHA, 2017] (Table 1).

Heavy metal analyses were carried out using the ICP-OES method [APHA and others 2017] (instrument: QUANTIMA-Sequential-GBC); the samples were analyzed by ICP-OES with the following parameters: nebulizer flow 0.5 L/min and the wavelength 259.940 nm for Fe; 257.61 nm for Mn; 324.75 nm for Cu; 213.85 nm for Zn; 228.80 nm for Cd; 202.030 nm for Mo; 253.652 for Hg. The concentrations of Fe, Mn, Cu, and Zn were directly determined by the ICP-OES method. The Cd and Mo concentrations were determined by ICP-OES analysis after sample preconcentration 20 times for the Cd and 25 times for Mo analysis. Trace concentration of Hg was determined after sample preconcentration 10 times using hydride generation technique combined with ICP-OES in a continuous flow system of the acidified samples and reductant to produce gaseous hydrides.

## RESULTS AND DISCUSSIONS

### The physicochemical variables of water quality

The results of physicochemical variables and heavy metals in the surface water of the Kufranja Dam (KD) during the summer (dry) and winter (wet) seasons are presented in Tables 2 and 4 and Figures 2, 3, and 4.

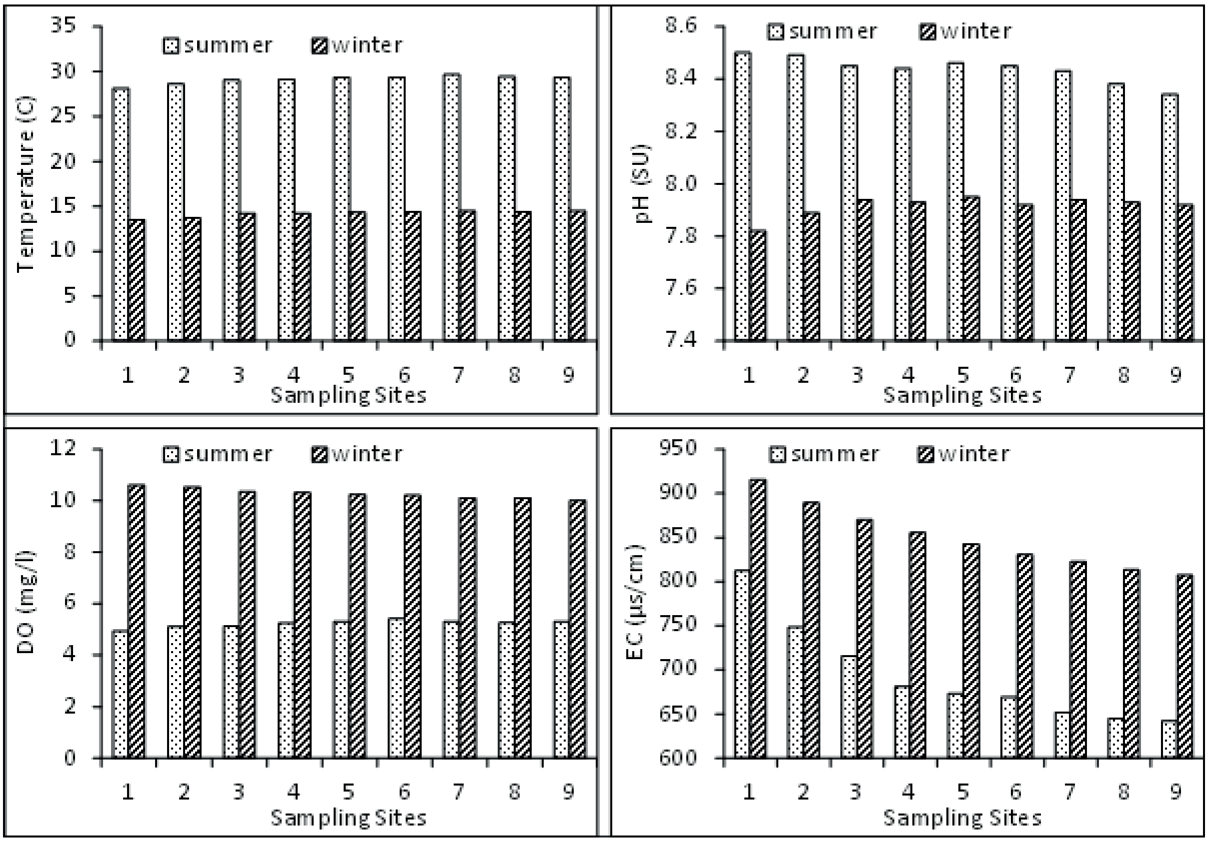

**Figure 2.** Mean concentrations of temperature, pH, DO, and EC in the surface water of the Kufranja dam during the summer and winter seasons

**Table 2.** The values of the measured physicochemical parameters in the Kufranja Dam surface water during the summer and winter seasons

| Summer season | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | Temp. | pH (SU) | DO (mg/l) | EC (µs/cm) | Ca (mg/l) | Mg (mg/l) | Na (mg/l) | K (mg/l) | $HCO_3$ (mg/l) | Cl (mg/l) | $NO_3$ (mg/l) | $SO_4$ (mg/l) |
| Site 1 | 28.1 | 8.50 | 4.92 | 812 | 65.5 | 25.0 | 43.8 | 5.94 | 181 | 90.4 | 25.8 | 79.3 |
| Site 2 | 28.6 | 8.49 | 5.10 | 748 | 59.0 | 24.2 | 39.5 | 5.74 | 155 | 87.2 | 25.4 | 78.0 |
| Site 3 | 29.0 | 8.45 | 5.11 | 715 | 57.0 | 23.6 | 34.7 | 5.97 | 140 | 85.7 | 24.2 | 79.0 |
| Site 4 | 29.1 | 8.44 | 5.23 | 681 | 53.0 | 23.9 | 34.0 | 5.94 | 123 | 85.6 | 23.1 | 82.3 |
| Site 5 | 29.3 | 8.46 | 5.30 | 673 | 51.5 | 23.7 | 33.5 | 6.11 | 121 | 84.5 | 23.6 | 81.0 |
| Site 6 | 29.3 | 8.45 | 5.40 | 669 | 50.0 | 23.9 | 34.0 | 6.24 | 120 | 84.2 | 23.4 | 80.0 |
| Site 7 | 29.6 | 8.43 | 5.30 | 652 | 49.1 | 23.7 | 34.7 | 6.12 | 119 | 80.5 | 22.6 | 78.5 |
| Site 8 | 29.4 | 8.38 | 5.24 | 645 | 48.2 | 23.6 | 34.9 | 6.10 | 118 | 80.3 | 22.7 | 79.3 |
| Site 9 | 29.4 | 8.34 | 5.30 | 642 | 47.9 | 23.4 | 34.5 | 6.04 | 116 | 79.6 | 22.5 | 79.8 |
| Min | 28.1 | 8.34 | 4.92 | 642 | 47.9 | 23.4 | 33.5 | 5.74 | 116 | 79.6 | 22.5 | 78.0 |
| Max | 29.6 | 8.50 | 5.40 | 812 | 65.5 | 25.0 | 43.8 | 6.24 | 181 | 90.4 | 25.8 | 82.3 |
| Mean | 29.1 | 8.44 | 5.21 | 693 | 53.5 | 23.9 | 36.0 | 6.02 | 133 | 84.2 | 23.7 | 79.7 |
| Winter season | | | | | | | | | | | | |
| Site | Temp. | pH (SU) | DO (mg/l) | EC (µs/cm) | Ca (mg/l) | Mg (mg/l) | Na (mg/l) | K (mg/l) | $HCO_3$ (mg/l) | Cl (mg/l) | $NO_3$ (mg/l) | $SO_4$ (mg/l) |
| Site 1 | 13.5 | 7.82 | 10.60 | 915 | 85.7 | 37.0 | 24.1 | 4.89 | 259 | 63.3 | 44.5 | 62.8 |
| Site 2 | 13.7 | 7.89 | 10.52 | 889 | 78.0 | 36.2 | 24.6 | 4.79 | 254 | 61.7 | 42.5 | 65.2 |
| Site 3 | 14.2 | 7.94 | 10.35 | 870 | 73.0 | 34.6 | 24.5 | 4.73 | 249 | 63.6 | 40.9 | 68.8 |
| Site 4 | 14.2 | 7.93 | 10.30 | 855 | 69.0 | 34.9 | 24.9 | 4.79 | 243 | 62.3 | 40.5 | 68.6 |
| Site 5 | 14.3 | 7.95 | 10.24 | 842 | 65.1 | 34.8 | 24.7 | 4.75 | 236 | 62.0 | 40.4 | 68.0 |
| Site 6 | 14.4 | 7.92 | 10.20 | 830 | 64.0 | 34.0 | 25.0 | 4.77 | 236 | 62.1 | 40.0 | 67.2 |
| Site 7 | 14.5 | 7.94 | 10.10 | 822 | 62.0 | 35.0 | 24.7 | 4.95 | 228 | 61.6 | 40.6 | 67.1 |
| Site 8 | 14.4 | 7.93 | 10.10 | 813 | 60.4 | 33.6 | 24.6 | 4.78 | 226 | 61.7 | 40.2 | 68.3 |
| Site 9 | 14.5 | 7.92 | 10.00 | 807 | 60.0 | 33.6 | 24.8 | 4.90 | 225 | 61.4 | 40.7 | 68.1 |
| Min | 13.5 | 7.82 | 10.00 | 807 | 60.0 | 33.6 | 24.1 | 4.73 | 225 | 61.4 | 40.0 | 62.8 |
| Max | 14.5 | 7.95 | 10.60 | 915 | 85.7 | 37.0 | 25.0 | 4.95 | 259 | 63.6 | 44.5 | 68.8 |
| Mean | 14.2 | 7.92 | 10.27 | 849 | 68.6 | 34.9 | 24.7 | 4.82 | 240 | 62.2 | 41.1 | 67.1 |

## Temperature, pH, and dissolved oxygen

Temperature is an important parameter in the surface water quality because it is critical for aquatic life and regulates water dissolved oxygen concentrations as well as influences the rates of the chemical and biological reactions; therefore, it affects the concentration of many variables. The solubility of many gases (e.g., $O_2$, $CO_2$, etc.) decreases with increasing temperature, thus increasing the consumption of dissolved oxygen and decomposition of organic matter.

Temperature values in the surface water of the KD (Figure 2 and Table 2) range between 28.1 and 29.6 °C in the summer with an average value of 29.1 °C and between 13.5 and 14.5 °C in the winter with an average value of 14.2 °C.

Temperature value in the summer and winter increases gradually from the entrance (site 1) to the end of the dam (sites 7, 8, and 9) (Figure 2); this may be due to the high movement of water and aeration at the entrance of the dam. The rising surface water temperature in KD during the summer can be attributed to an overall increase in the atmospheric temperature, which results in a high evaporation rate and a likely decline in water level compared to the wet season.

The pH is a measurement of how acidic/basic water is, an important water quality parameter that determines the solubility and biological availability of different chemical constituents in water. The pH value in the surface water of KD ranges from 8.34 to 8.50 (SU) during the dry season with an average value of 8.44 (SU); from 7.82 and

7.95 (SU) during the wet season with an average value of 7.92 (SU) (Figure 2 and Table 2). The pH values in the summer and winter were similar to those described by Al-Harahsheh and Al-Amoush [2010] in the Mujib Dam-Jordan [Al-Harahsheh and Al-Amoush, 2010]. Higher pH values were recorded in the summer compared to the winter (Figure 2). Lower pH values in the winter are attributed to the limited photosynthetic activity as well as the dilution effect of the dam water with the large amount of slightly acidic water that enters the dam during the rainy season [Al-Taani, 2013], which may explain the slightly lower pH values at the sites near the entrance. The relatively higher pH values during the summer can be ascribed to $CO_2$ removal via algal photosynthesis due to increased temperature, sunlight, and nutrients; thus, it increases algal blooms that cause the precipitation of calcium and magnesium carbonates. Moreover, agricultural runoff could be the reason for the increased pH values during the dry season especially at the sites near the dam's inlet [Abu-Hilal and Abualhaija 2010; Al-Taani 2013].

Dissolved oxygen (DO) is one of the most important parameters in evaluating water quality because of its effect on the living organisms existing in the water body where extremely high or low levels of DO can influence the water quality and destroy aquatic life [Wetzel, 2001]. The level of DO in the natural waters is based on several factors such as aeration, temperature, photosynthetic activity, respiration and decomposition processes, salinity, and atmospheric pressure. The solubility of oxygen decreases with temperature and salinity increases. Aquatic life and production in the water body need a DO concentration of more than 5 mg/l, where the concentration below 2 mg/l may lead to the death of most fishes [Chapman, 1996].

The DO in surface water of KD varied between 4.92 and 5.40 mg/l in the summer with an average value of 5.21 mg/l; in the winter, the DO value ranged from 10.0 to 10.6 mg/l with an average of 10.3 mg/l (Figure 2 and Table 2). The maximum concentrations of DO were recorded during the winter due to the decreased temperature of the water compared to the summer; the relatively low values during the summer may be attributed to the increased temperature and/or decaying algal cells that consume the available DO in the surface water of KD. In the winter, the slightly higher DO concentrations at the sites near the entrance of the dam compared to other sites can be linked to the mixing of the dam's low DO water with the oxygenated water inflow from Wadi Kufranja. In contrast, during the summer, lower concentrations at the sites near the Wadi Kufranja inflow (dam's entrance) can be attributed to the higher organic content in the water of these sites compared to that of the other sites.

The levels of DO in water are classified into four classes according to Water Pollution Control Regulation, where waters with a DO level higher than 8 mg/l are considered of high quality and belong to Class I; those with a level between 6–8 belong to Class II; between 3–6 belong to Class III; less than 3 belong to Class IV, which is polluted water. Accordingly, the levels of DO in the water of the Kufranja Dam (Table 2) belong to Class I (high-quality water during the winter) and Class III (moderate-quality water during the summer).

## Electrical conductivity (EC)

The salinity of water can be identified based on electrical conductivity (EC) or the total dissolved solids (TDS). The EC of water is an expression of the ability of water to carry an electric current and directly related to the amount of TDS and major ions. The TDS expresses the presence of inorganic salts and small amounts of organic matter in water. The EC value in water depends on the presence of ions, temperature, and pH. The possible sources of salinity in the surface water come from the nature and geological condition of the catchment area surrounding the water body (i.e. weathering and erosion of rocks); urban and agricultural runoff; industrial and wastewater discharges [Gorde and Jadhav, 2013; Marandi et al., 2013; Temponeras et al., 2000].

The EC value in the surface water of KD during the summer ranged from 642 µs/cm to 812 µs/cm, with an average value of 693 µs/cm), while in the winter from 807 µs/cm to 915 µs/cm, with an average value of 849 µs/cm (Figure 2 and Table 2). The spatial distribution of the electrical conductivity in the surface water of KD during the summer and winter (Figure 2) showed a similar trend, where the highest values were recorded in the eastern part of the dam (sites 1 and 2) near the inflows of Wadi Kufranja; the lowest EC values were observed in the western part of the dam near the outlet point (Sites 8 and 9). The elevated EC values at the sites near the inlet point of the KD compared to the other sites can be attributed to natural discharges from the surrounding catchment areas such as weathering

**Table 3.** Classifications of irrigation water based on EC values [Richards, 1954]

| Water class | Water quality | EC (µs/cm) |
|---|---|---|
| C1 | Low-salinity water (excellent for irrigation) | < 250 |
| C2 | Medium-salinity water (good for irrigation) | 250 – 750 |
| C3 | High-salinity water (permissible for irrigation) | 750 – 2250 |
| C4 | Very high-salinity water (unsuitable for irrigation) | > 2250 |

products of rocks and soil erosion in addition to the agriculture and wastewater effluents that enter the dam via Wadi Kufranja. The higher EC values in the winter season can be ascribed to high rainfall over the KD catchment area, which increases the weathering products and dissolution of rocks and soil erosion, thus increasing the EC values during this cold period, especially at the sites near the dam's entrance.

Depending on the classifications of the USDA salinity laboratory for irrigation water based on EC values (Table 3) [Richards, 1954], the samples collected during the summer fall within the good category for irrigation (C2: water with medium salinity) except for the sample collected from the entrance of dam (site 1) belonging to the permissible category for irrigation (C3: water with high salinity). All the samples collected in the winter belong to the permissible category (C3) for irrigation.

## Major cations

Major cations in the surface water influenced by the nature and geology of the surrounding area as well as weathering processes that affect rocks and soils [Holden, 1970]. The concentrations of calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K) in the surface water of KD during the summer ranged between 47.9–65.5 mg/l, 23.4–25.0 mg/l; 33.5–43.8 mg/l; 5.74–6.24 mg/l, with an average concentration of 53.5 mg/l, 23.9 mg/l, 36.0 mg/l and 6.0 mg/l, respectively. Their concentrations in the winter varied between 60.0–85.7 mg/l; 33.6–37.0 mg/l; 24.1–25.0 mg/l; 4.73–4.95 mg/l, with an average concentration of 68.6 mg/l, 34.9 mg/l, 24.7 mg/l and 4.82 mg/l, respectively (Figure 3 and Table 2).

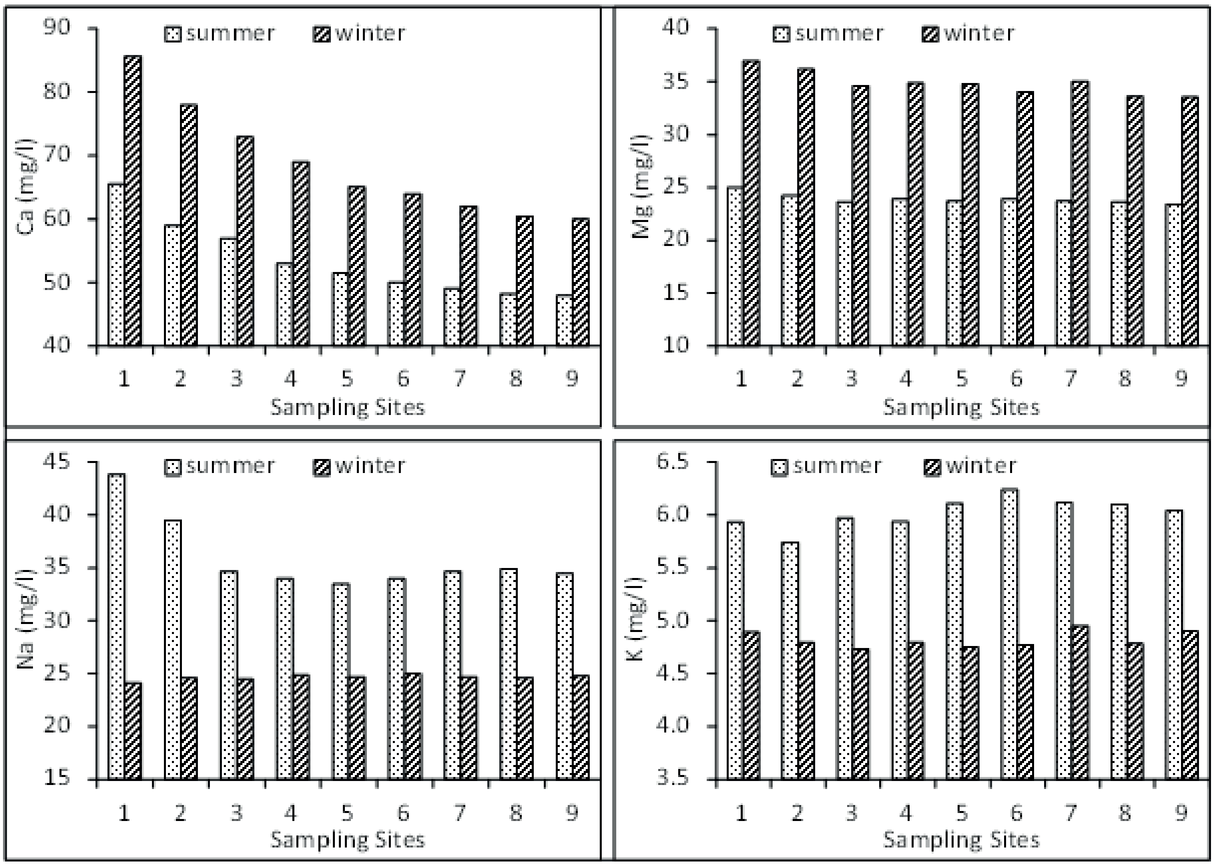

**Figure 3.** Major cations in the study area during the dry (summer) and wet (winter) seasons

Figure 3 showed that Ca was dominant among the cations in the summer and winter, which constitutes the higher proportion of the total cations compared to the other cations; this means that the dolomite ($CaCO_3$) and limestone ($CaMg(CO_3)_2$) rocks prevail in the study area. Ca and Mg are important parameters in water quality due to their joint role in hardening water, which affects the water quality. These two elements are very important from the biological aspect, where Ca is necessary for healthy growth and essential in the foundation of the skeletal structure of living organisms, and Mg for chlorophyll growth. Therefore, low concentrations of Ca and Mg in the water body will affect biological productivity [Dagaonkar and Saksena, 1992].

The higher concentrations of Ca and Mg in the rainy season (Figure 3) can be imputed to the weathering and leaching of rocks in the surrounding area of the KD. In contrast, their concentrations drop during the dry season perhaps due to the precipitation of calcium and magnesium carbonates. Similar results have been reported by Al-Taani in Al-Wehdeh Dam –Jordan [Al-Taani, 2013]. The spatial distribution of Ca and Mg in dry and wet seasons showed a more or less similar trend (Figure 2); their maximum concentrations were recorded at the sites near the Wadi Kufranja inflows, whereas their lower concentrations were recorded at the sites near the end of the dam, indicating that the factors affecting their occurrence and distribution are the same, and include the discharges that enter KD via Wadi Kufranja.

Unlike Ca and Mg, the maximum concentrations of Na and K in the surface water of KD were observed in the summer and the minimum concentrations in the winter. Similar results were observed by Al-Taani in Al-Wehdeh Dam –Jordan [Al-Taani, 2013]. High evaporation rate, agricultural activities (e.g., Fertilizers), livestock waste in Wadi Kufranja as well as effluents from the Kufranja wastewater treatment plant may be the cause of the high concentrations of Na and K in the summer season. In addition, the precipitation of calcium and magnesium carbonates could be also the cause of the elevated concentrations of Na and K during the dry season. Lower concentrations of Na and K in the rainy season can be attributed to the dilution effect of the dam's water with the rainwater. Data (Figure 3 and Table 2) showed that the higher Na concentration in the summer was observed at the sites near the Wadi Kufranja inflows; Na concentration was relatively consistent in all sites during the winter. No spatial trend of K concentration was observed during the summer and winter seasons.

## Major anions

The concentrations of anions (bicarbonate ($HCO_3$); chloride (Cl); nitrates ($NO_3$); and sulfate ($SO_4$)) in the surface water of KD (Figure 4 and Table 2) during the summer varied between 116.0–181.0 mg/l; 79.6–90.4 mg/l; 22.5–25.8 mg/l; 78.0–82.3 mg/l, with an average concentration of 132.6 mg/l, 84.2 mg/l, 23.7 mg/l and 79.7 mg/l, respectively. The concentrations in the winter ranged between 225.0–259.0 mg/l; 61.4 –63.6 mg/l; 40.0–44.5 mg/l; 62.8–68.8 mg/l, with an average concentration of 239.6 mg/l, 62.2 mg/l, 41.1 mg/l and 67.1 mg/l, respectively.

The highest $HCO_3$ concentrations were recorded during the rainy season as a result of high rainfall, runoff, and weathering processes; this explains the high concentration of $HCO_3$ at the sites near the Wadi Kufranja inflow (Figure 4). The lowest concentrations of $HCO_3$ were observed in the summer at the far end of the dam, which can be attributed to the high evaporation rate and precipitation of carbonates [Al-Taani, 2013]. Similar to Ca in the cations, bicarbonate is the dominant anion during the summer and winter; hence, the surface water of KD is mild alkaline.

Nitrate ($NO_3$) is an important nutrient for aquatic plants and microorganisms, which might limit phytoplankton growth. The sources of $NO_3$ in the natural waters include decaying of organic matter, sewage, fertilizers, and manures. Elevated concentrations of $NO_3$ in rivers, lakes, and dams promote the microorganisms (like algae) and produce undesirable taste and odor in water [Chapman, 1996; Mutlu et al., 2016; Provin and Pitt, 2002]. The $NO_3$ concentrations were higher during the wet season (Figure 4) at the sites near the dam's entrance in response to high rainfall and runoff, the influx of nutrients from the Wadi Kufranja catchment area, animal wastes, and agricultural activities where the high rainfall events mobilize more nutrients and sediments [Basnyat and others, 2000; Errahmani and others, 2015]. The lower concentration of $NO_3$ in the dry season at the sites near the outlet point of the dam may be due to the biological activity and denitrification process [Al-Taani, 2013].

Chloride (Cl) in natural waters originates from geological formations as a result of

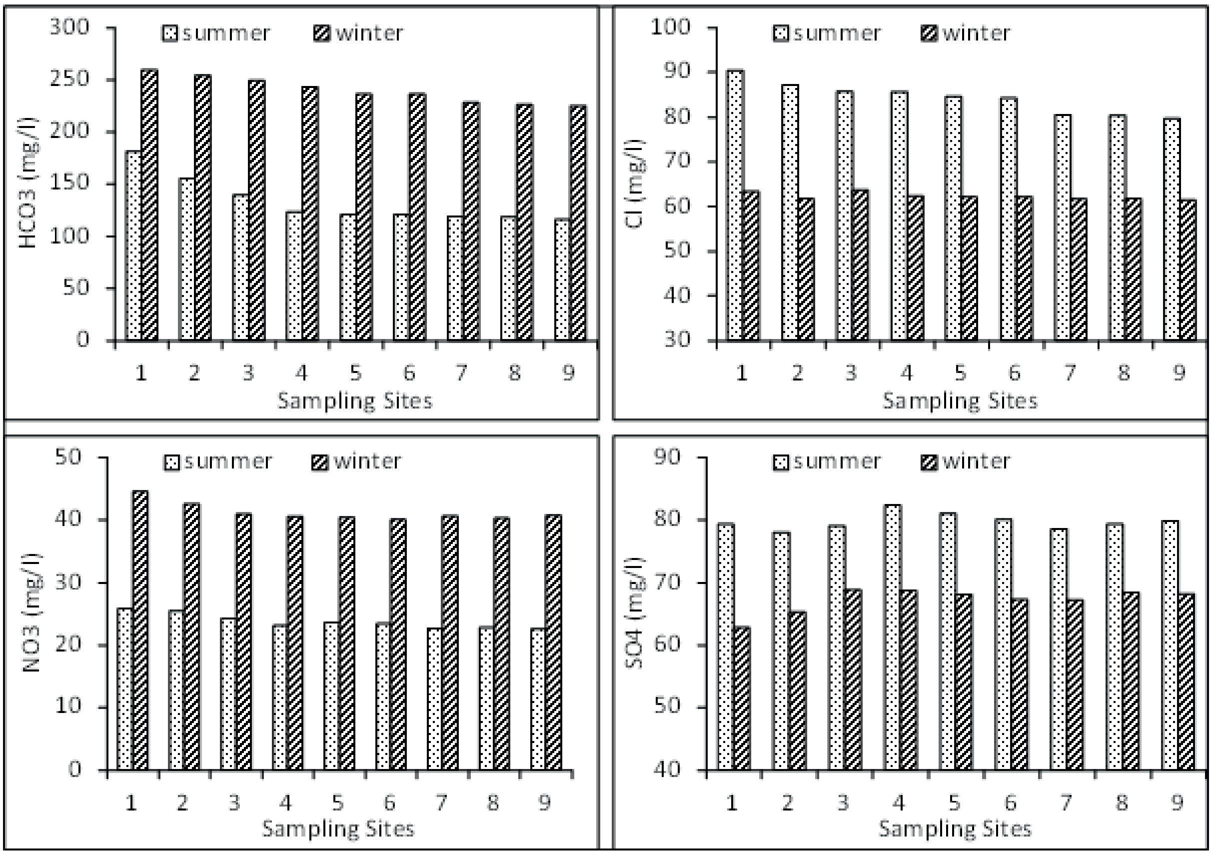

**Figure 4.** Major anions in the study area during the summer and winter seasons

dissolving minerals and industrial wastes, fertilizers, road salts, and sewage; sulfates ($SO_4$) in the surface water come from rocks and soils (containing gypsum, sulfides, and other sulfur compounds), and industrial wastes and sewage [Provin and Pitt, 2002]. Figure 4 shows that the highest concentrations of Cl and $SO_4$ were observed in the summer, which can be attributed to effluents from the Kufranja wastewater treatment plant in addition to the natural runoff from the surrounding springs. Precipitation of calcium and magnesium carbonates might also be responsible for the increased concentrations of Cl and $SO_4$ in the dry season [Al-Taani, 2013]; the lowest concentrations of Cl and $SO_4$ in the winter can be due to the dilution effect with the rainwater. The spatial distribution of Cl is almost similar to the spatial distribution of $HCO_3$ and $NO_3$, whereas the $SO_4$ concentrations during the study period fluctuate among all sites.

## Heavy metals

The study of heavy metals in natural water is of great importance since they affect the water quality and may cause water pollution at certain concentrations. Heavy metals can enter the aquatic environments from both natural and anthropogenic sources; natural sources mainly come from the weathering of soils and rocks; anthropogenic sources come from industrial plants, sewage effluents, and agricultural activities (fertilizers) [Jackson, 1979; Mortvedt, 1996; Wu at al., 2014]. Heavy metals in the aquatic system can remain for some time as they are not readily degraded. Naturally, heavy metals are found at low concentrations in the natural waters, where their high concentrations in water and sediments indicate that they come from anthropogenic rather than geogenic origin [Nriagu, 1996; Tylmann at al., 2011].

Seven heavy metals were selected and examined in this study due to their great importance in surface water, especially rivers, lakes, and dams. The concentrations of the investigated heavy metals (Iron (Fe), Manganese (Mn), Copper (Cu), Zinc (Zn), Cadmium (Cd), Molybdenum (Mo), and Mercury (Hg)) in the surface water of KD during the summer and winter were not detectable and below the detection limits of the analytical methods (Table 4). Therefore, they do not

**Table 4.** Heavy metals concentrations in the surface water of the Kufranja Dam during the summer and winter seasons

| Summer season | | | | | | | |
|---|---|---|---|---|---|---|---|
| Site | Fe (mg/l) | Mn (mg/l) | Cu (mg/l) | Zn (mg/l) | Cd* (mg/l) | Mo** (mg/l) | Hg*** (mg/l) |
| Site 1 | < 0.05 | < 0.025 | <0.1 | < 0.05 | < 0.0025 | < 0.01 | < 0.001 |
| Site 2 | < 0.05 | < 0.025 | <0.1 | < 0.05 | < 0.0025 | < 0.01 | < 0.001 |
| Site 3 | < 0.05 | < 0.025 | <0.1 | < 0.05 | < 0.0025 | < 0.01 | < 0.001 |
| Site 4 | < 0.05 | < 0.025 | <0.1 | < 0.05 | < 0.0025 | < 0.01 | < 0.001 |
| Site 5 | < 0.05 | < 0.025 | <0.1 | < 0.05 | < 0.0025 | < 0.01 | < 0.001 |
| Site 6 | < 0.05 | < 0.025 | <0.1 | < 0.05 | < 0.0025 | < 0.01 | < 0.001 |
| Site 7 | < 0.05 | < 0.025 | <0.1 | < 0.05 | < 0.0025 | < 0.01 | < 0.001 |
| Site 8 | < 0.05 | < 0.025 | <0.1 | < 0.05 | < 0.0025 | < 0.01 | < 0.001 |
| Site 9 | < 0.05 | < 0.025 | <0.1 | < 0.05 | < 0.0025 | < 0.01 | < 0.001 |
| Winter season | | | | | | | |
| Site 1 | < 0.05 | < 0.025 | <0.1 | < 0.05 | < 0.0025 | < 0.01 | < 0.001 |
| Site 2 | < 0.05 | < 0.025 | <0.1 | < 0.05 | < 0.0025 | < 0.01 | < 0.001 |
| Site 3 | < 0.05 | < 0.025 | <0.1 | < 0.05 | < 0.0025 | < 0.01 | < 0.001 |
| Site 4 | < 0.05 | < 0.025 | <0.1 | < 0.05 | < 0.0025 | < 0.01 | < 0.001 |
| Site 5 | < 0.05 | < 0.025 | <0.1 | < 0.05 | < 0.0025 | < 0.01 | < 0.001 |
| Site 6 | < 0.05 | < 0.025 | <0.1 | < 0.05 | < 0.0025 | < 0.01 | < 0.001 |
| Site 7 | < 0.05 | < 0.025 | <0.1 | < 0.05 | < 0.0025 | < 0.01 | < 0.001 |
| Site 8 | < 0.05 | < 0.025 | <0.1 | < 0.05 | < 0.0025 | < 0.01 | < 0.001 |
| Site 9 | < 0.05 | < 0.025 | <0.1 | < 0.05 | < 0.0025 | < 0.01 | < 0.001 |

* The detection limit for Cd is < 0.05 (samples preconcentrated 20 times). ** Detection limit for Mo is < 0.25 (samples preconcentrated 25 times). *** Detection limit for Hg is < 0.01 (samples preconcentrated 10 times).

pose any health or environmental issues. The detection limits of the heavy metals Fe, Mn, Cu, Zn, Cd, Mo, and Hg usage in the analytical methods (in the methods section) are 0.05, 0.025, 0.1, 0.05, 0.05, 0.25, and 0.01, respectively.

## Water quality of the Kufranja Dam and its suitability for drinking and irrigation

The KD was designed and newly built to collect spring and rainwater; the collected water in the dam is planned to use for drinking and agricultural purposes as well as to relieve the pressure on the water supply in Ajloun city, north of Jordan. Accordingly, it is important to conduct chemical, physical, and biological studies to assess the water quality of the newly constructed dam and its suitability for different uses.

The water quality of the KD has been assessed based on different water quality parameters and indices, including physicochemical parameters, metal composition, water quality index (WQI) (using the weighted arithmetic method), sodium adsorption ratio (SAR), sodium percentage (Na%), magnesium hazard (MH), total hardness (TH) and USSL Diagram.

The comparison of the results of the physicochemical parameters in this study with the Jordanian and international standards for drinking and irrigation water (Table 5) showed that the values of the physicochemical parameters (pH, DO, EC, Ca, Mg, Na, K, $HCO_3$, Cl, $NO_3$, $SO_4$, and TH) and heavy metals (Fe, Mn, Cu, Zn, Cd, Mo, and Hg) are within the standard values published by Jordan standard and metrology organization [JSMO, 2015] and World Health Organization [WHO, 2011] for drinking water, except for EC values above WHO standards for drinking. Moreover, all the results of the physicochemical parameters and heavy metals are within the Jordanian standards for irrigation [JSMO, 2006] and the Food and Health Organization (FAO) for irrigation water [Ayers and Westcot, 1985].

## Water quality index (WQI)

The WQI was computed using the weighted arithmetic index method, which has been broadly used by several researchers [Bouslah at al., 2017; Chauhan and Singh, 2010; Chowdhury and others, 2012; Ewaid and Abed, 2017; Ibrahim, 2019; Imneisi and Aydin, 2016; Rao at al., 2010]; the weighted arithmetic index method

**Table 5.** Quality evaluation of KD water with respect to Jordanian and WHO standards for drinking and with Jordanian and FAO standards for irrigation

| Components | This study | | Jordanian standards for drinking (JSMO, 2015) | WHO guidelines for drinking (WHO, 2011) | Jordanian standards for irrigation (JSMO, 2006) | FAO guidelines for irrigation (Ayers and Westcot, 1985) |
|---|---|---|---|---|---|---|
| | Summer | Winter | | | | |
| pH (SU) | 8.34–8.50 | 7.82–7.95 | 6.5-8.5 | 6.5-8.5 | 6-9 | 6.0–8.5 SU |
| DO (mg/l) | 4.92–5.40 | 10.0–10.6 | – | < 5.0 | – | – |
| EC (µs/cm) | 642–812 | 807–915 | 1500 | 400 | 2340 | 3000 (µs/cm) |
| Ca (mg/l) | 47.9–65.5 | 60.0–85.7 | 200 | 150 | 230 | 0–20 (meq/l) |
| Mg (mg/l) | 23.4–25.0 | 33.6–37.0 | 50 | 100 | 100 | 0–5 (meq/l) |
| Na (mg/l) | 33.5–43.8 | 24.1–25.0 | 200 | 200 | 230 | 0–40 (meq/l) |
| K (mg/l) | 5.74–6.24 | 4.73–4.95 | 50 | 10 | | 0–0.05 (meq/l) |
| HCO3 (mg/l) | 116–181 | 225–259 | 500 | 350 | 400 | 0–10 (meq/l) |
| Cl (mg/l) | 79.6–90.4 | 61.4–63.6 | 500 | 250 | 400 | 0–30 (meq/l) |
| NO3 (mg/l) | 22.5–25.8 | 40.0–44.5 | 50 | 50 | 70 | 0–10 (meq/l) |
| SO4 (mg/l) | 78.0–82.3 | 62.8–68.8 | 500 | 250 | 500 | 0–20 (meq/l) |
| TH (mg/l) | 216–266 | 288–366 | 500 | 500 | 985 | 0–25 (meq/l) |
| Fe (mg/l) | < 0.05 | < 0.05 | 1.0 | 0.3 | 5.0 | 5.0 (mg/l) |
| Mn (mg/l) | < 0.025 | < 0.025 | 0.4 | 0.4 | 0.2 | 0.2 (mg/l) |
| Cu (mg/l) | < 0.1 | < 0.1 | 2 | 2.0 | 0.2 | 0.2 (mg/l) |
| Zn (mg/l) | < 0.05 | < 0.05 | 4.0 | 5.0 | 5.0 | 2.0 (mg/l) |
| Cd (mg/l) | < 0.0025 | < 0.0025 | 0.003 | 0.003 | 0.01 | 0.01 (mg/l) |
| Mo (mg/l) | < 0.01 | < 0.01 | 0.09 | 0.07 | 0.01 | 0.01(mg/l) |
| Hg (mg/l) | < 0.001 | < 0.001 | 0.006 | 0.006 | 0.002 | – |

was firstly proposed by [Horton, 1965] and developed by [Brown at al., 1972]. WQI was calculated as the following formula:

$$WQI = \sum_{i=1}^{n} W_i Q_i \Big/ \sum_{i=1}^{n} W_i \qquad (1)$$

where: WQI is the water quality index using the weighted arithmetic index method, n is the number of parameters or variables included, $W_i$ is the unit weight of the i^th^ parameter and $Q_i$ is the water quality rating of the i^th^ parameter.

The calculation of WQI requires four steps:

1) The selection of the monitored parameters; in this study, 12 variables were selected to calculate the WQI using the drinking water quality standards recommended by Jordan Standards and Metrology Organization (JSMO) and the World Health Organization (WHO) [JSMO, 2015; WHO, 2011].
2) The computation of the water quality rating ($Q_i$), where $Q_i$ was calculated according to [Brown at al., 1972]:

$$\mathrm{Q_i} = 100\ [(\mathrm{V_i} - \mathrm{V_{id}})/(\mathrm{S_i} - \mathrm{V_{id}})] \qquad (2)$$

where: $V_i$ is the observed or monitored value of the $i^{th}$ parameter at a given sample station, $V_{id}$ is the ideal value of the $i^{th}$ parameter in pure water, $S_i$ is the standard permissible value of the $i^{th}$ parameter. All the ideal values ($V_{id}$) are considered as zero (0) for drinking water parameters except for pH and dissolved oxygen, where ($V_{id}$) for pH is 7 and 14.6 for DO [Chowdhury at al., 2012; Tripathy and Sahu, 2005].

3) The computation of the unit weight ($W_i$), $W_i$ is inversely proportional to the recommended standard value ($S_i$) for the $i^{th}$ parameter as the following:

$$W_i = K/S_i \qquad (3)$$

where: K is the constant for proportionality and $S_i$ is the standard value for the $i^{th}$ parameter.

4) The categorization of WQI, where the values of WQI are classified into five categories [Brown at al., 1972; Chaterjee and Raziuddin, 2002; Tyagi at al., 2013] as shown in

**Table 6.** Categories and rating of water quality and possible usage of the water samples

| WQI range | Rating of water quality | Possible usage |
|---|---|---|
| 0–25 | Excellent water quality | Drinking, irrigation and industrial purposes |
| 26–50 | Good water quality | Drinking, irrigation and industrial purposes |
| 51–75 | Poor water quality | Irrigation and industrial purposes |
| 76–100 | Very poor water quality | Irrigation purposes |
| Above 100 | Unsuitable for drinking and propagation of fish culture | Proper treatment required before use |

(Table 6); the low range of WQI represents the best water quality whereas the higher number gives a bad quality.

Calculated values of WQI in the KD water range from 80.8 and 86.8 during the summer and 54.6 and 57.0 during the winter (Table 7). According to the classifications of WQI in (Table 6), WQI results in the KD showed that the water of KD falls under the categories of very poor water quality for drinking during the summer and poor water quality for drinking during the winter; therefore, the surface water of the dam required treatment before use for drinking, but it can be used for irrigation purposes.

## Sodium adsorption ratio (SAR)

Sodium adsorption ratio (SAR), also known as sodium or alkali hazard, is an important index in assessing the water quality for irrigation. SAR is the ratio of Na concentration to Ca and Mg concentration.

SAR was calculated based on the following equation [Richards, 1954]:

$$\mathrm{SAR} = \frac{\mathrm{Na}}{\sqrt{\frac{\mathrm{Ca}+\mathrm{Mg}}{2}}} \left(ions\ units\ in \frac{meq}{liter}\right) \tag{4}$$

SAR value in irrigation water is significantly related to the amount of sodium absorbed by the soils; high Na content in irrigation water affects

**Table 7.** The values of the water quality indices of the different sites in the Kufranja Dam

| Site | WQI | SAR | Na% | MH | TH |
|---|---|---|---|---|---|
| Summer season | | | | | |
| Site 1 | 86.77 | 1.17 | 27.9 | 38.6 | 266.4 |
| Site 2 | 84.75 | 1.09 | 27.4 | 40.4 | 246.9 |
| Site 3 | 84.00 | 0.98 | 25.8 | 40.6 | 239.5 |
| Site 4 | 83.08 | 0.97 | 26.1 | 42.7 | 230.7 |
| Site 5 | 83.12 | 0.97 | 26.3 | 43.1 | 226.1 |
| Site 6 | 82.72 | 0.99 | 26.9 | 44.1 | 223.2 |
| Site 7 | 82.53 | 1.02 | 27.5 | 44.3 | 220.1 |
| Site 8 | 81.95 | 1.03 | 27.8 | 44.7 | 217.5 |
| Site 9 | 80.79 | 1.02 | 27.7 | 44.6 | 215.9 |
| Min | 80.79 | 0.97 | 25.8 | 38.6 | 215.9 |
| Max | 86.77 | 1.17 | 27.9 | 44.7 | 266.4 |
| Mean | 83.31 | 1.03 | 27.0 | 42.6 | 231.8 |
| Winter season | | | | | |
| Site 1 | 54.55 | 0.55 | 13.8 | 41.6 | 366.3 |
| Site 2 | 55.24 | 0.58 | 14.8 | 43.4 | 343.8 |
| Site 3 | 56.00 | 0.59 | 15.5 | 43.9 | 324.7 |
| Site 4 | 56.01 | 0.61 | 16.0 | 45.5 | 315.9 |
| Site 5 | 56.35 | 0.61 | 16.4 | 46.9 | 305.8 |
| Site 6 | 55.80 | 0.63 | 16.8 | 46.7 | 299.7 |
| Site 7 | 57.01 | 0.62 | 16.7 | 48.2 | 298.9 |
| Site 8 | 56.18 | 0.63 | 17.1 | 47.8 | 289.1 |
| Site 9 | 56.64 | 0.64 | 17.3 | 48.0 | 287.9 |
| Min | 54.55 | 0.55 | 13.8 | 41.6 | 287.9 |
| Max | 57.01 | 0.64 | 17.3 | 48.2 | 366.3 |
| Mean | 55.98 | 0.61 | 16.0 | 45.8 | 314.7 |

the soil permeability and reduces the infiltration rate; Na replaces Ca and Mg adsorped by the soil and causes dispersion of soil particles, thus affects the plant growth [Fipps, 2003].

Table 7 showed that the SAR values in the surface water of KD ranged from 0.97 to 1.17 during the summer with an average value of 1.03; in the winter the values varied between 0.55 and 0.64, with an average of 0.61. According to the classifications of irrigation water based on the SAR values [Richards, 1954] (Table 8), all the collected samples in this study belong to category (S1), indicating that the surface water of KD is with low sodium hazard and excellent for irrigation.

Table 8. Classification of irrigation water based on SAR values [Richards, 1954]

| 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 |

### Sodium percentage (Na%)

Sodium percentage (Na%) is one of the water quality parameters, used extensively to determine the suitability of water for irrigation, where water with a high percentage of Na affects the soil structure and reduces crop yield [Ayers and Westcot, 1985]. The Na% was calculated using the following equation [Wilcox, 1955]:

$$\text{Na}\ \% = \frac{(\text{Na} + \text{K})}{(\text{Na} + \text{Ca} + \text{Mg} + \text{K})} \times 100 \quad (ions\ units\ in \frac{meq}{liter}) \tag{5}$$

Data in (Table 7) revealed that the value of Na % during the summer varied between 25.8 and 27.9; during the winter from 13.8 to 17.3. Based on the classifications of irrigation water concerning Na% [Wilcox, 1955] (Table 9), the surface water of KD is distributed between good (during summer season) and excellent (during the winter season) categories for irrigation.

### Magnesium hazard (MH)

Magnesium hazard (MH) is also an important parameter in the categorization of water for irrigation uses [Szabolcs and Darab, 1964]. The higher levels of Mg in the irrigation water will influence the soil structure by converting the soil into alkaline, which reduces crop production [Ayers and Westcot, 1985]. MH is calculated using the following equation [Szabolcs and Darab, 1964].

$$\text{MH} = \frac{(\text{Mg})\ \times 100}{(\text{Ca} + \text{Mg})}\ (ions\ units\ in \frac{meq}{liter}) \tag{6}$$

The value of MH in water used for irrigation should not exceed (50); water with an MH value greater than (50) is considered unsuitable for irrigation [Szabolcs and Darab, 1964]. Data in Table 7 revealed that the value of MH in the surface samples of KD varied between 38.6 and 48.2 during the summer and winter, which indicates that the water of KD falls under the suitable category and can be used safely for irrigation.

### Hardness

Total hardness (TH) represents the quantity of divalent cations (calcium and magnesium) in water. It is calculated by the sum of Ca and Mg concentration and expressed in mg/l with $CaCO_3$ equivalent as follows [Todd, 1980]:

$$\text{TH (CaCO3)} = (2.5 \times \text{Ca}) + (4.1 \times \text{Mg}) \tag{7}$$

Excessive amounts of TH will build up on surfaces of plug pipes and irrigation lines and may cause the closure of irrigation systems. On

Table 9. Classifications of irrigation water based on Na % values [Wilcox, 1955]

| Na % | Water quality | This study | | | |
|---|---|---|---|---|---|
| | | Summer season | | Winter season | |
| | | % | No. of samples | % | No. of samples |
| < 20 | Excellent for irrigation | Nil | Nil | 100 | All samples |
| 20–40 | Good for irrigation | 100 | All samples | Nil | Nil |
| 40–60 | Permissible for irrigation | Nil | Nil | Nil | Nil |
| 60–80 | Doubtful for irrigation | Nil | Nil | Nil | Nil |
| > 80 | Unsuitable for irrigation | Nil | Nil | Nil | Nil |

the contrary, water with high TH levels and low SAR values will make a good soil structure; thus the water moves into and through the soil easily (good infiltration) [Hopkins and others, 2007].

The value of TH in the present study ranged from 216 to 266 in the dry season and 288 to 366 in the wet season (Table 7). Sawyer and McCarty [1967] have classified water based on TH as follows: soft water (<75 mg/l), moderately hard water (75–150 mg/l), hard water (150–300 mg/l), and very hard water (>300 mg/l) [Sawyer and McCarty, 1967]. Accordingly, the samples collected from KD during the dry season are in the category of hard water, while in the wet season the samples are distributed between hard and very hard water.

### USSL diagram for the classification of irrigation waters

The USSL (or Wilcox) diagram is a plot of EC as a salinity hazard on the X-axis with SAR as sodium or alkali hazard on the Y-axis as shown in Figure 5. This diagram is developed by the United States salinity laboratory in 1954 to determine the suitability of water for irrigation purposes [Richards, 1954]. This diagram classifying water based on salinity hazard (EC) into four categories: C1 (low salinity hazard), C2 (medium salinity hazard), C3 (high salinity hazard), and C4 (very high salinity hazard). Whereas the classifications of water based on sodium hazard (SAR) are S1 (low sodium hazard), S2 (medium sodium hazard), S3 (high sodium hazard), and S4 (very high sodium hazard).

Data obtained from the USSL diagram (Figure 5) showed that the collected samples from the surface water of KD during the summer belonged to the (S1C2) category except for the sample that was collected from site 1 at the entrance of the dam, which belonged to the category (S1C3). All the samples collected during the winter are classified in the (S1C3) category. Accordingly, and based on the obtained data from the USSL diagram (Figure 5), the collected samples from KD water fall into categories medium to high salinity hazard and low sodium hazard; hence, the dam's water is suitable for irrigation of the majority of soils (except soils with low salt tolerance) with little danger of the emergence of harmful levels of exchangeable sodium. Therefore, special management of salinity and choice of crops with good salt tolerance might be required.

## CONCLUSIONS

This study was conducted on the Kufranja Dam (KD) in the north of Jordan, recently constructed to utilize its water for drinking and irrigation purposes and relieve pressure on the water supply in the north. This study aims to determine the water quality of the dam, find out if there is any source of pollution, and assess the water quality of the dam to identify its suitability for different uses. The results of the present study showed that most of the physicochemical parameters in the water of KD have a similar spatial trend, where the maximum concentrations of

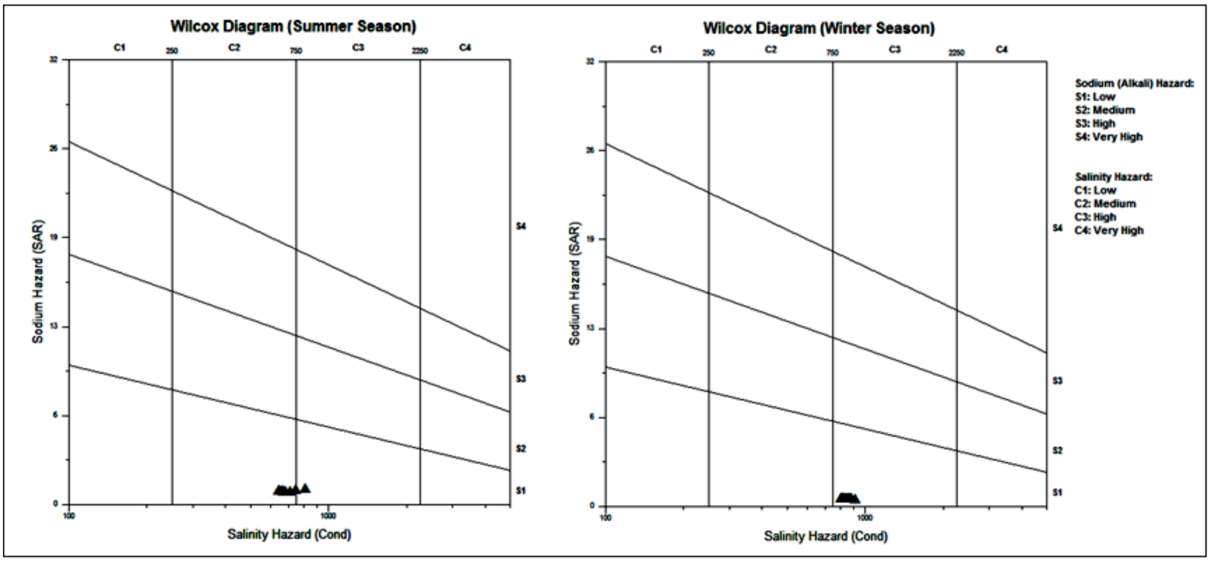

**Figure 5.** USSL diagram of the collected water samples from the Kufranja Dam (software: AquaChem)

these parameters were observed at the sites near the dam's entrance; their minimum concentrations were recorded at the sites near the end of the dam, which can be attributed to natural discharges from the surrounding catchment areas such as weathering products of rocks and soil erosion in addition to the agriculture and wastewater effluents that enter the dam via Wadi Kufranja.

The highest concentrations of EC, Ca, Mg, $HCO_3$, and $NO_3$ were recorded during the winter at the sites near the entrance of the dam, which can be ascribed to the weathering products and dissolution of rocks and soil erosion during the wet season; their lower concentrations during the summer are in response to high evaporation, precipitation of calcium and magnesium carbonates, biological activity, and denitrification process.

The maximum concentrations of Na, K, Cl, and $SO_4$ were recorded during the summer; this can be linked to the high evaporation rate and precipitation of carbonates, agricultural activities (e.g. Fertilizers), livestock waste in Wadi Kufranja, effluents from the Kufranja wastewater treatment plant, and the natural runoff from the surrounding springs. In contrast, the dilution effect with the rainwater might be responsible for the lower recorded values of these parameters during the rainy season. The concentrations of Na and Cl exhibited a similar spatial trend to EC, Ca, Mg, $HCO_3$, and $NO_3$, whereas the concentrations of K and $SO_4$ revealed no spatial trends, and their concentrations have fluctuated among all sites. The investigated heavy metals (Fe, Mn, Cu, Zn, Cd, Mo, and Hg) in this study during the summer and winter seasons are not detectable and below the detection limit of the analytical methods; thus, they do not cause any health or environmental concerns.

All the studied physicochemical parameters and heavy metals in KD water are within the standards published by Jordan standard and metrology organization [JSMO, 2015], World Health Organization [WHO, 2011] for drinking water, Jordan standard and metrology organization [JSMO, 2015], and Food and agriculture organization (FAO) [Ayers and Westcot, 1985] for irrigation water, except for EC values that are above the WHO standards [WHO, 2011] for drinking water.

The computations of the water quality index (WQI) using the weighted arithmetic index method indicated that the surface water of the KD distributed between the very poor water quality for drinking during the summer and poor water quality for drinking during the winter, but the dam's water possibly can be used for irrigation. Therefore, there must be a proper treatment of water before it can be used for drinking.

The results of the irrigation water quality indices SAR, Na%, MH, and TH indicate that the KD water is suitable for irrigation. EC values in the present study indicated that the surface water of KD is distributed between good to permissible categories for irrigation water quality. The USSL diagram revealed that the surface water samples of the KD during the summer and winter belong to the categories (S1C2; medium salinity, and low sodium hazard) and (S1C3; high salinity, and low sodium hazard), respectively. Thus, the dam's water is suitable for irrigation of most soils (except soils with low salt tolerance) with little danger of the emergence of harmful levels of exchangeable sodium. Soils and crops with good salt tolerance are recommended and a special treatment of salinity might be required.

## Acknowledgments

The authors would like to express their gratitude to the Deanship of Scientific Research at the University of Jordan for financially supporting this project. The authors would also like to thank the manager and technical staff of Kufranja Dam for their help and for providing us with all facilities during the sampling and fieldwork. Further thanks are extended to the editors and reviewers for their review and commitment to the publication process.

## REFERENCE

1. Abu-Hilal A.H., Abualhaija M.M. 2010. Nutrients in water and sediments of King Talal Dam-Jordan. Jordan Journal of Biological Sciences, 147, 1–14.
2. Al-Harahsheh S.T., Al-Amoush H.R. 2010. Eutrophication Process in the Mujib Dam. Jordan Journal of Earth and Environmental Sciences, 3.
3. Al-Taani A.A. 2013. Seasonal variations in water quality of Al-Wehda Dam north of Jordan and water suitability for irrigation in summer. Arabian Journal of Geosciences, 6, 1131–1140.
4. APHA, AWWA, WEF. 2017. Standard Methods for the Examination of Water and Wastewater. Washington: American Public Health Association, American Water Works Association and the Water Environment Federation.
5. Ayers R.S., Westcot D.W. 1985. Water quality for agriculture. Rome, Italy: Food and Agriculture Organization of the United Nations.

6. Basnyat P., Teeter L., Lockaby B.G., Flynn K.M. 2000. Land use characteristics and water quality: a methodology for valuing of forested buffers. Environmental Management, 26, 153–161.
7. Bouslah S., Lakhdar D., Larbi H. 2017. Water quality index assessment of Koudiat Medouar Reservoir, northeast Algeria using weighted arithmetic index method. Journal of water and land development, 221–228.
8. Brown R., Mccleiland N., Deiniger R., O'Connor M. 1972. A water quality index-crossing the physical barrier. Proceedings of the International Conference on Water Pollution Research.
9. Chapman D.V. 1996. Water quality assessments: a guide to the use of biota, sediments and water in environmental monitoring: CRC Press.
10. Chaterjee C., Raziuddin M. 2002. Determination of water quality index (WQI) of a degraded river in Asanol Industrial area, Raniganj, Burdwan, West Bengal. Nature Environment and Pollution Technology, 2, 181–189.
11. Chauhan A., Singh S. 2010. Evaluation of Ganga water for drinking purpose by water quality index at Rishikesh, Uttarakhand, India. Report and opinion, 2, 53–61.
12. Chowdhury R.M., Muntasir S.Y., Hossain M.M. 2012. Water quality index of water bodies along Faridpur-Barisal road in Bangladesh. Global Engineers and Technology Review, 2, 1–8.
13. Dagaonkar A., Saksena D. 1992. Physico-chemical and biological characterization of a temple tank Kailasagar, Gwalior, Madhya Pradesh. Journal of Hydrobiology, 8, 11–19.
14. Errahmani M., Hamaidi-Chergui F., Hamaidi M. 2015. Physico-chemical parameter variability relative to seasonal dynamics and community structure of plankton in the Boukourdane lake dam (Algeria). Applied ecology and environmental research, 13, 1121–1139.
15. Ewaid S.H., Abed S.A. 2017. Water quality index for Al-Gharraf river, southern Iraq. The Egyptian Journal of Aquatic Research, 43, 117–122.
16. Fipps G. 2003. Irrigation water quality standards and salinity management strategies. Texas FARMER Collection.
17. Frenken K. 2009. Irrigation in the Middle East region in figures AQUASTAT Survey-2008. Water Reports.
18. Gorde S., Jadhav M. 2013. Assessment of water quality parameters: a review. Journal of Engineering Research and Applications, 3, 2029–2035.
19. Holden W.S. 1970. Water treatment and examination. London: J. & A. Churchill.
20. Hopkins B.G., Horneck D.A., Stevens R.G., Ellsworth J.W., Sullivan D.M. 2007. Managing irrigation water quality for crop production in the Pacific Northwest, PNW 597-E.
21. Horton R.K. 1965. An index number system for rating water quality. Journal of Water Pollution Control Federation. 37, 300–306.
22. Ibrahim M.N. 2019. Assessing groundwater quality for drinking purpose in Jordan: application of water quality index. Journal of Ecological Engineering, 20.
23. Imneisi I.B., Aydin M. 2016. Water quality index (WQI) for main source of drinking water (Karaçomak Dam) in Kastamonu City, Turkey. Journal of Environmental and Analytical Toxicology. 6, 2161–0525.
24. Jackson T.A. 1979. Sources of heavy metal contamination in a river-lake system. Environmental Pollution (1970), 18, 131–138.
25. JSMO. Jordan standards and metrology organization: Standard Specification "Water- Reclaimed Domestic Wastewater", No. 893/2006. Jordan, 2006
26. JSMO. Jordan standards and metrology organization: Standard Specification "Water-Drinking Water", No. 286/2015. Jordan; 2015.
27. Karmakar S., Musthafa O. 2012. Lakes and Reservoirs: Pollution. Encyclopedia of Environmental Management, Four Volume Set: CRC Press.
28. Marandi A., Polikarpus M., Jõeleht A. 2013. A new approach for describing the relationship between electrical conductivity and major anion concentration in natural waters. Applied geochemistry, 38, 103–109.
29. MOENV UNDP. Jordan's Third National Communication on Climate Change. Ministry of Environment (MOENV) and United Nations Development Programme (UNDP) Amman, Jordan, 2014.
30. Mortvedt J. 1996. Heavy metal contaminants in inorganic and organic fertilizers. Fertilizers and environment: Springer.
31. Mutlu E., Demir T., Yanık T., Anca Sutan N. 2016. Determination of environmentally relevant water quality parameters in Serefiye Dam-Turkey. Fresenius Environmental Bulletin. 25, 5812–5818.
32. MWI. 2016. Jordan National Water Strategy 2016–2025. Jordan: Ministry of Water and Irrigation.
33. MWI. 2017. Jordan water Sector: Facts and Figures. Jordan: Ministry of Water and Irrigation.
34. Nriagu J.O. 1996. A history of global metal pollution. Science. 272, 223–223.
35. Provin T., Pitt, J. 2002. Description of water analysis parameters. Texas A&M Agrilife Extension Texas.
36. Rao C.S., Rao B.S., Hariharan A., Bharathi N.M. 2010. Determination of water quality index of some areas in Guntur District Andhra Pradesh. International Journal of Applied Biology and Pharmaceutical Technology.
37. Richards L. 1954. Diagnosis and improvement of saline and alkali soils. Handbook, 60.
38. Sawyer C.N., McCarty P.L. 1967. Chemistry for sanitary engineers. New York: McGraw Hill.
39. Strobl R.O., Robillard P.D. 2008. Network design for water quality monitoring of surface freshwaters:

A review. Journal of environmental management. 87, 639–648.

40. Szabolcs I., Darab C. 1964. The influence of irrigation water of high sodium carbonate content of soils. Proceedings of 8th international congress of ISSS, Trans, II.
41. Temponeras M., Kristiansen J., Moustaka-Gouni M. 2000. Seasonal variation in phytoplankton composition and physical-chemical features of the shallow Lake Doïrani, Macedonia, Greece. in: Reynolds C.S., Dokulil M., Padisák J., eds. The Trophic Spectrum Revisited. Dordrecht: Springer Netherlands.
42. Todd D. 1980. Groundwater Hydrology, 2nd edn. New York: John Wiley and Sons.
43. Tripathy J., Sahu K. 2005. Seasonal hydrochemistry of groundwater in the Barrier Spit system of the Chilika Lagoon, India. Journal of Environmental Hydrology, 13.
44. Tyagi S., Sharma B., Singh P., Dobhal R. 2013. Water quality assessment in terms of water quality index. american Journal of water resources. 1, 34–38.
45. Tylmann W., Łysek K., Kinder M., Pempkowiak J. 2011. Regional pattern of heavy metal content in lake sediments in Northeastern Poland. Water, Air, & Soil Pollution. 216, 217–228.
46. Varol M., Gökot B., Bekleyen A., Şen B. 2012. Spatial and temporal variations in surface water quality of the dam reservoirs in the Tigris River basin, Turkey. Catena. 92, 11–21.
47. Wetzel R.G. 2001. Limnology: lake and river ecosystems: San Diego: Academic Press.
48. WHO. 2011. Guidelines for drinking-water quality. Geneva, Switzerland World Health Organization.
49. Wilcox L. 1955. Classification and use of irrigation water. United States Department of Agriculture, Washington, DC, 19.
50. Wu B., Wang G., Wu J., Fu Q., Liu C. 2014. Sources of heavy metals in surface sediments and an ecological risk assessment from two adjacent plateau reservoirs. PLoS One, 9:e102101.