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The Effect of Utilizing Microbiological Parameters on Water Quality Index Values Implemented at Wadi Al-Arab Dam Reservoir, North-Jordan.

Habes Mohammad Al-Mashakbeh[1*], Sura Taha Al-harahsheh[2]

1,2. Institute of Earth and Environmental Science, Al - albayt University, Al-Mafraq, Jordan

Abstract
The aims of this study are to investigate the effect of using microbiological parameters, particularly *Escherichia coli* on water quality index values that has been implemented at Wadi Al-Arab Dam Reservoir (WADR) in Northern Jordan and to evaluate its water suitability for domestic purposes. For these purposes, the study period from January 2009 through December 2014, one sample on a monthly basis was used in the calculation of WQI. Firstly, computed the WQI for the seventy two samples that were analyzed for different physico-chemical parameters such as pH, Electrical Conductivity, Total Dissolved Solids, Total Suspended Solids, ions of Sodium, Potassium, Calcium, Magnesium, Chloride, Sulfate, Bicarbonate, Ammonium, Nitrite and Nitrate in various seasons (winter, spring, summer and autumn). Secondly, performing the previous calculations taking into account the *Escherichia coli* (species of bacteria) counts. The analyzed results (by WQI method) have been used to depicting water quality for the two approaches. Based on physico-chemical parameters, the calculated values for WQI over the 6-year study period from 2009 to 2014 were 83.4, 80.6, 59.33, 78.0, 89.3, and 85.4, respectively. On the other hand, the WQI values were 41.7, 40.1, 43.5, 44.2, 51.0 and 44.7, respectively, as a result of incorporated microbiological parameters in WQI calculations that significantly contribute to decrease the WQI values over the 6-year study period. The analysis shows that the water quality rank of the (WADR) is varies from good to marginal based on physico-chemical parameters only, and from poor to marginal based on physico-chemical and microbiological parameters. In comparison with the World Health Organization (WHO) and Jordanian Standards (JS 286:2008). The results signify that the (WADR) is not polluted based on the physical and chemical characteristics of water. However, from microbiological perspective the water is not safe for domestic use and needs further treatment.
Keywords: reservoir, seasonality, Irbid, Wadi Al-Arab Dam, Water Quality Index, microbiology, Jordan.

1. Introduction

Jordan relies mainly on ground and surface water for its supply (54 and 37 percent, respectively) (Albuquerque, 2014). Currently, the deteriorating regional conditions and turmoil a round Jordan have led to waves of hundreds of thousands of refugees flowing into Jordan, pushing it over time from being one of the world's 10 water-poorest countries in the world, to the fourth and to the second, according to ranking by the United Nations (Namrouqa, 2014, MWI, 2009). Jordan is classified as semi-arid to arid region with annual rainfall of less than 200 mm over 90% of the land, Jordan suffers a harsh water situation. Jordanian per capita share of water dropped during the past 60 years from 3600 to 140 cubic meter in 2012 (El-Naser et al., 2014). Not only the quantity of water supplied per capita has been reduced but the quality of water have also decreased, with concerns raised over the contamination of water sources due to more cesspits and septic tanks in use at increased frequency (REACH, 2014). According to the Falkenmark Water Stress Indicator, when annual water supplies drop below 1,000 m^3 per person, the population faces water scarcity; below 500 m^3, they face "absolute scarcity" (Falkenmark et al., 1989). Water scarcity has been exacerbated by drought, depletion of groundwater reserves, overuse by agriculture, population growth, inflow of migrant workers and climate change, combined with an influx of refugees resulting from several conflicts in the region, the latest being the conflict in the Syrian Arab Republic (Albuquerque, 2014). Jordan's water challenges, including scant resources and variable rainfall, require the exploration of alternative water resources and better management of existing resources (Namrouqa, 2012). Total dams capacity in Jordan is estimated at 350 MCM, including the desert dams. There are seven dams that are constructed in the north and middle Jordan valley with a total storage capacity of 270 MCM. These dams are include Arab, Ziglab, King Talal, Karameh, Shueib, Kafrein and Al Wehdah Dam. Moreover there are three dams in southern Ghors: Wala, Mujib and Tannur with storage capacity of 30 MCM (MWI, 2006).

Potable water is one of our most vital resources, and when our water is polluted, it is not only disturbing to the environment , but also to human health. According to a study conducted by the WHO, the majority of the diseases in human beings are water produced (Tiwari & Mishra, 1985). Monitoring the quality of surface water will help protect our waterways from pollution, so the more we monitor our water, the better we will be able to recognize and prevent contamination problems (Bartram & Balance, 1996) . In view of the complexity of factors determining water quality, and the large choice of variables used to describe the status of water bodies in quantitative terms, it is difficult to provide a simple definition of water quality. Furthermore, our understanding of water quality has evolved over the past century with the expansion of water use requirements and the ability to measure and interpret water characteristics (Chapman, 1996).

The main reason for the assessment of the quality of the aquatic environment has been, traditionally, the need to verify whether the observed water quality is suitable for intended uses (Chapman, 1996). A water quality index basically consists of a simpler expression of more or less complex parameters, which serve as water quality measurements. A number, a range, a verbal description, a symbol or a color could be used to represent the index. A water quality index provides a single number (like a grade) that expresses overall water quality at a certain location and time based on several water quality parameters. Water quality index is used to differentiate between polluted and unpolluted water and describe the overall water quality status in a single term. The water quality index (WQI) has emerged as a central way to convey water quality information to policy makers and the general public (Tiwari & Mishra, 1985, Walsh & Wheeler, 2012).

The purpose of the present study is twofold: (a) to investigate the effect of using microbiological parameters, particularly *Escherichia coli* on water quality index values; and (b) to evaluate the suitability of Wadi Al-Arab Dam Reservoir for human use.

2. Material and Methods

2.1. Study Area

Wadi Al-Arab Dam Reservoir (Figure.1) is a vital source of water in the northern part of Jordan (JVA, 1976, 1979). Its located in the northern part of Jordan Valley, at the south of Yarmouk River and on the east bank of the Jordan Rift Valley, about 10 km south of the lake Tiberies and about 25 km west of the Irbid City. It lies between latitudes 32^{o} 36' 51" - 32^{o} 37' 22"N and longitudes 35^{o} 37' 50"- 35^{o} 38' 60" E. The altitude of the Wadi ranging from about 300 m above sea level to 220 m below sea level. Wadi Al-Arab Dam was constructed in 1987 of a rock fill with a maximum water storage capacity of 20 million cubic meters (MCM) to collect flood water and base flows. The volume of the reservoir is 3 100 000 m^3 and the estimated sedimentation rate is 70 000 m^3 /yr (JVA, 1976). The annual average flow in the Wadi has been estimated at 28.8 million cubic meters (MCM) (JVA ,1995-2002, Al-Taloudy, 2001). The reservoir catchment's area is nearly 262 km^2. The reservoir water comes mainly from the Wadi Arab and the Yarmouk River through King Abdullah Canal and partially from precipitation. The reservoir water is used as drinking water source in periods of water shortage by draining to King Abdullah Canal, also to irrigate about 12,500 donums from Al Shuna to Al Baqura (JVA ,1995-2002). Most of annual precipitation starts in October and ends in May, and months from June to September can be considered as a dry summer season. Climate of the region is considered as a Mediterranean, which is characterized by hot and dry summer, cool and wet winter. Relative humidity ranges from 49% in June to 67% in February. Frost and snowfall occur occasionally in January and February. Sunshine hour ranges from 5.0 hours in January to 12 hours in June (Ghrefat, 1999).

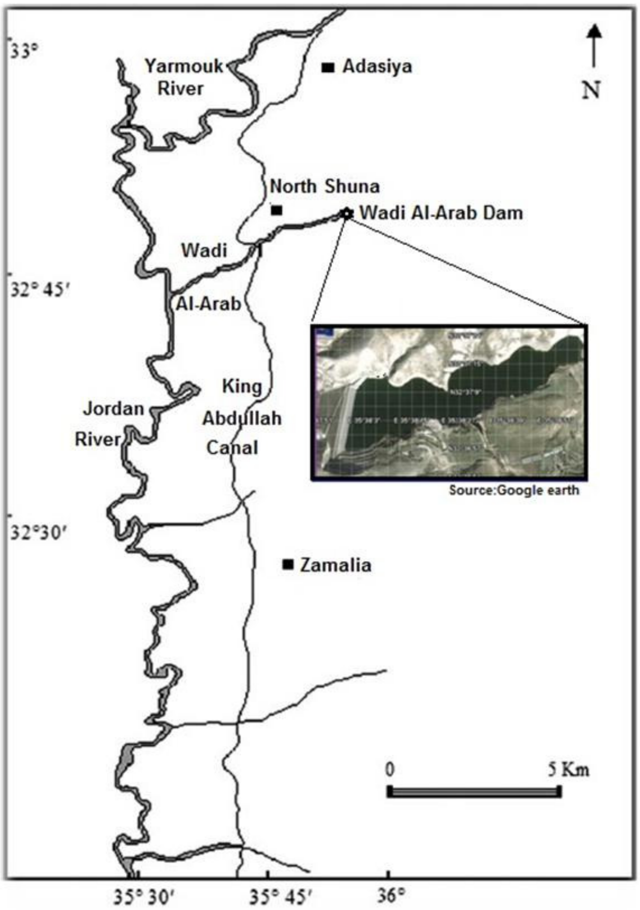

Figure 1. The location of the Study area (Modified after Ghrefat & Yusuf, 2006)

The average annual rainfall in the Wadi Al-Arab is approximately about 400 mm (JVA ,1995-2002). Wind is light to moderate and predominantly from west to southwest. Daily evaporation causes a decrease in water level varies from 4.8 mm in January to 8.9 mm in July. Wadi Al-Arab originates in the neighborhood of Irbid City and runs westward to discharge into the Jordan River. The deep V-shaped is formed in the mid and upstream parts, whereas the Wadi meanders in a wide open valley in the downstream part, forming river terraces, 100 – 150 m wide (Ghrefat & Yusuf, 2006). The reservoir receives the water from the eastward via two main valleys, and some smaller valleys from the north and southward. The Wadi Zahar, mainly a straight valley trending north north-west toward the south south-east, is the main tributary of the Wadi Al-Arab. The geology of the dam site mainly consists of Mesozoic to Cenozoic marl, and limestone as base rock (JVA, 1976, 1982b). Weathered and fissures limestone, marl and chalky marl form the main rocks of the Wadi Al-Arab Dam Reservoir sides. The length of the reservoir ranging from 1.55 to 1.78 km extending east-west with a width ranging between 0.21 to 0.43 km. The southern part of the reservoir is marked by gentle slopes or less steeper than the northern slopes. Irbid city is gradually transgressing westward onto the catchment area, which may put increasing pressure on the quality of the water stored in the reservoir; therefore, that is thought to have a range of possibly harmful consequences. During the rainy season, floodwater enter the wastewater treatment plant of Irbid city, and wash out its contents along Wadi Al-Arab into the dam reservoir, negatively affecting its water quality. Although the effluent of the treatment plant is piped to bypass the dam (Al-harahsheh, 2007).

2.2 WQI Calculation

A Water Quality Index (WQI) is a mathematical method of summarizing multiple parameters into a single value. Usually, a WQI ranges between 0 and 100, with higher values indicating higher quality water. Water Quality Indices are useful tools for comparing dissimilarities in water quality across an area, and for monitoring variations in water quality over trial period. Moreover, These indices utilize various physico-chemical and biological parameters and have been implemented globally by different government agencies and scientists in this field. In spite of that, no index has so far been universally accepted, and search for more useful and universal

water quality index is still going on, so that water agencies, users, and water managers in different countries may use and adopted different indices with little modifications (Tyagi et al., 2013).
In this study, the water quality index is calculated using the equations developed by Canadian jurisdictions which is known globally as the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI). A CCME WQI is considered as a tool for simplifying the reporting of water quality data due to its merits, including their ability to represent measurements of a variety of parameters in a single number, flexibility in the selection of input parameters and objectives, statistical simplification of complex multivariate data, the ability to combine various measurements in a variety of different measurement units in a single metric, and the facilitation of communication of the results (Terrado et al., 2010, Abbasi & Abbasi, 2012).
CCME WQI provides a reliable method that summaries of overall water quality and trends, which was formulated by Canadian jurisdictions to communicate the water quality information for both senior managers and the public. Furthermore, a committee established under the Canadian Council of Ministers of the Environment (CCME) has developed WQI, which can be applied by many water agencies in various countries with slight modification (CCME, 2001; Khan et al., 2004; Lumb et al., 2006). This method has been developed to evaluate surface water for protection of aquatic life in accordance to specific guidelines. The parameters related with various measurements may vary from one station to the other, and sampling protocol requires at least four parameters, sampled at least four times (Khan et al., 2005, Kankal et al., 2012). The calculation of index scores in CCME WQI method can be obtained by using the following relation:

$$CCMEWQI = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right) \quad (1)$$

Where, Scope (F1) = Number of variables, whose objectives are not met.

$$F1 = \left(\frac{Number\ \ of\ failed\ \ variables}{Total\ \ number\ \ of\ variables} \right) X100 \quad (2)$$

Frequency, (F2)= Number of times by which the objectives are not met.

$$F2 = \left(\frac{Number\ of\ failed\ tests}{Total\ number\ of\ tests} \right) x100 \quad (3)$$

Amplitude (F3) = Amount by which the objectives are not met.

(a) $$excursioni = \left(\frac{FailedTestValuei}{Objectivej} \right) - 1 \quad (4)$$

(b) $$nse = \frac{\sum_{i=1}^{n} excursioni}{\#\ of\ \ tests}$$ (nse); normalized sum of excursions. (5)

(c) $$F3 = \left(\frac{nse}{0.01nse + 0.01} \right) \quad (6)$$

Therefore, five categories have been suggested to categorize the water qualities which are summarized in Table 1.

The CCME WQI has been applied on data into two comparative approaches , excluded the microbiological parameters in the first application, and utilized the various physico-chemical and microbiological parameters in the second, then comparing the different outcomes over the 6-year study period (Figure 2).

Table 1. Water Quality Rating as per CCMEWQI (CCME, 2001).

WQI Value	Rating of Water Quality	Categorization of Index Values
95-100	Excellent water quality	water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels. These index values can only be obtained if all measurements are within objectives virtually all of the time.
80-94	Good water quality	water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.
60-79	Fair water quality	water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.
45-59	Marginal water quality	water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.
0-44	Poor water quality	water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

2.3 Data Analysis

This study is generally about what is in water rather than water itself. The major and minor ions whose behavior forms the basis for the chemical composition of natural waters. To obtain an understanding of the chemical behavior of a water body and to know if it is fit for human use or various ecosystem services, seven ions (four cations and three anions), and ammonium, nitrite, and nitrate ions as well as several physical and microbiological parameters should be taken into consideration. The seven ions are as follows: Major cations (Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}) , Major anions($HCO3^{-}$, $SO4^{-2}$, Cl^{-}) and one un-ionized species (silica, Si(OH)4) represent 95–99% of the total dissolved inorganic solutes of natural waters (Brezonik & Arnold, 2011). Natural weathering processes, the role of atmospheric transport and transformation processes, and human activities are described as sources of those ions (Brezonik & Arnold, 2011).

The data used in this study were provided by Jordan Valley Authority (JVA) and cover the period from January 2009 to December 2014. A total of 72 samples were analyzed (12 samples for each year/on a monthly basis) from 2009 to 2014 using the standard procedures of Standard Methods for the Examination of Water, and Wastewater (APHA, 2005).

Fifteen parameters were measured for each sample (pH, Electrical Conductivity(EC), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), $NH4^{+}$, $NO3^{-}$, $NO2^{-}$, $HCO3^{-}$, $SO4^{-2}$, Cl^{-}, Ca^{+2}, Mg^{+2}, Na^{+}, K^{+} and *Escherichia coli*). The maximum, minimum and mean values of different selected physico-chemical and microbiological parameters of 72 surface water samples of the study area for the 6-year study period are shown in Table 2, while the seasonal means of Wadi Al-Arab reservoir data are arranged in Table 3.

Primarily, Fourteen physico-chemical parameters were involved in water quality index calculations then included the microbiological parameters, namely *Escherichia coli*. The results show that, the value of water quality index for each year were reduced dramatically wherever used the microbiological parameters within physico-chemical parameters in water quality index calculations. For the purposes of clarification and interpretation of the results using charts (Figure 2), the results of the analysis for the twelve samples of each year in the reservoir were seasonally, and annually averaged. This means that 24, and 6 seasonally, and annually representative averages respectively were used instead of 72 samples over the period from 2009 to 2014.

Table 2. The mean, minimum and maximum values for water quality parameters used in this study, over the 6-year study period.

Year	Parameter/ Function	pH (SU)	EC (µs/cm)	TDS (mg/l)	TSS (mg/l)	NH4+ (mg/l)	NO3- (mg/l)	NO2- mg/l	HCO3- (mg/l)	SO4-2 mg/l	Cl- (mg/l)	Ca+2 (mg/l)	Mg+2 mg/l	Na+ (mg/l)	K+ (mg/l)	E.coli (MPN/100ml)
2009	Mean	8.48	1023	594.98	6.71	0.33	0.16	0.04	175.07	121.12	169.03	56.96	33.49	101.27	8.54	20.13
	Max	9.12	1117	688.00	25.00	2.28	7.61	0.54	234.00	158.08	181.00	70.00	39.00	116.00	9.80	1300.00
	Min	7.91	940	535.00	1.80	0.07	0.00	0.00	112.00	98.25	149.00	42.00	27.00	92.00	7.47	1.70
2010	Mean	8.48	1003	573.57	13.97	0.21	1.02	0.02	162.65	107.58	160.44	58.11	28.08	93.62	7.87	32.85
	Max	9.14	1108	662.00	121.00	0.77	6.73	0.18	239.00	139.57	179.00	80.00	39.20	104.00	8.54	3500.00
	Min	7.95	890	496.00	1.80	0.06	0.09	0.00	94.10	62.72	148.00	38.00	19.00	76.20	6.16	1.70
2011	Mean	8.61	1035	592.49	16.41	4.63	1.75	0.03	160.07	116.71	172.67	50.47	34.58	101.84	8.13	39.37
	Max	9.52	1136	718.00	147.00	4.63	6.81	0.35	239.00	150.02	189.00	78.50	39.20	112.00	9.48	350.00
	Min	7.93	961	532.00	1.80	4.63	0.97	0.00	95.50	85.88	149.00	33.00	29.70	84.30	7.11	4.50
2012	Mean	8.31	972	557.31	11.72	4.63	1.49	0.03	164.74	112.06	156.46	47.87	36.48	89.79	7.39	29.91
	Max	8.88	1119	641.00	497.00	4.63	5.40	0.44	230.00	281.17	186.00	62.40	85.10	107.00	8.69	490.00
	Min	7.73	839	437.00	1.80	4.63	1.02	0.00	129.00	81.10	127.00	34.20	30.50	73.80	6.20	1.80
2013	Mean	8.44	829	430.01	7.86	NM*	3.57	0.03	158.84	60.61	122.56	53.92	24.30	66.84	6.19	25.43
	Max	9.18	1110	598.70	41.00	0.00	12.65	0.19	292.00	115.00	189.00	74.50	33.10	95.40	9.57	220.00
	Min	7.95	667	300.37	2.00	0.00	1.00	0.00	85.50	7.45	89.00	29.10	19.30	51.90	4.62	4.00
2014	Mean	8.06	1013	532.97	7.88	NM*	2.22	0.04	155.63	106.56	153.27	55.26	29.73	87.54	8.13	56.80
	Max	8.54	1114	595.06	34.00	0.00	6.24	1.19	224.00	112.00	180.00	75.00	38.40	99.70	9.95	900.00
	Min	7.50	936	458.24	2.00	0.00	1.00	0.00	20.70	99.60	127.00	39.10	16.00	76.30	7.25	2.00

NM; Not measured.

Table 3. The seasonal average values for water quality parameters used in this study, over the 6-year study period.

Year	Parameter/ Season	pH (SU)	EC (µs/cm)	TDS (mg/l)	TSS (mg/l)	NH4+ (mg/l)	NO3- (mg/l)	NO2- mg/l	HCO3- (mg/l)	SO4-2 mg/l	Cl- (mg/l)	Ca+2 (mg/l)	Mg+2 mg/l	Na+ (mg/l)	K+ (mg/l)	E.coli (MPN/100ml)
2009	Winter	8.25	1082	637.39	6.46	0.25	1.86	0.21	218.24	115.25	176.64	67.68	33.83	107.49	9.26	191.36
	Spring	8.71	973	575.55	12.65	0.24	3.67	0.14	169.98	139.89	154.61	58.10	33.10	97.79	7.80	40.37
	Summer	8.62	984	556.38	4.72	0.69	0.02	0.01	136.69	126.21	169.63	46.31	32.47	102.28	8.75	1.79
	Autumn	8.35	1055	613.97	5.24	0.28	0.00	0.01	185.26	105.77	176.23	57.83	34.61	97.83	8.41	11.85
2010	Winter	8.14	1053	606.83	7.58	0.20	4.93	0.05	227.82	105.04	158.16	72.52	28.41	96.00	8.21	23.02
	Spring	8.81	923	535.54	26.31	0.22	0.72	0.04	136.08	78.01	151.28	50.60	23.04	81.22	7.28	35.46
	Summer	8.74	975	540.60	13.90	0.24	0.20	0.00	122.33	125.36	158.88	53.84	25.33	95.33	7.72	91.80
	Autumn	8.24	1068	616.05	13.75	0.18	1.55	0.01	184.53	130.39	174.28	57.74	37.48	103.33	8.30	15.53
2011	Winter	8.15	1099	636.14	5.27	4.63	3.11	0.15	233.64	115.29	166.12	70.51	32.90	103.65	8.49	18.84
	Spring	8.95	970	547.81	63.59	4.63	3.19	0.07	133.96	134.67	157.00	47.23	33.16	96.54	7.38	21.94
	Summer	8.85	1001	558.62	9.02	4.63	0.97	0.01	121.53	117.44	182.98	40.23	35.71	102.51	7.84	109.39
	Autumn	8.52	1075	633.03	23.96	4.63	0.97	0.00	172.62	101.75	186.29	48.41	36.69	104.84	8.88	53.18
2012	Winter	7.93	1091	629.99	4.02	4.63	1.97	0.16	221.77	91.17	176.20	61.87	36.80	96.12	8.11	248.19
	Spring	8.47	876	496.10	16.55	NM	2.35	0.07	161.53	111.96	131.29	47.62	31.23	80.71	6.95	10.03
	Summer	8.60	903	510.38	9.17	NM	1.02	0.01	133.28	96.39	150.31	37.66	32.35	85.66	6.96	22.79
	Autumn	8.26	1036	604.77	31.01	NM	1.03	0.01	154.24	160.26	172.33	47.32	47.63	97.83	7.59	14.09
2013	Winter	8.17	798	485.06	8.99	NM	9.73	0.14	193.97	82.24	105.51	65.57	22.23	60.10	5.82	21.25
	Spring	8.77	710	399.30	15.16	NM	4.50	0.05	131.26	77.39	95.13	46.04	20.71	57.92	5.49	24.40
	Summer	8.53	756	322.07	5.68	NM	1.25	0.01	140.04	22.28	120.21	40.18	24.10	61.43	5.64	11.60
	Autumn	8.30	1103	548.13	4.93	NM	2.98	0.02	178.55	95.19	186.99	69.69	31.45	93.31	8.13	69.56
2014	Winter	7.96	1031	545.19	3.68	NM	4.43	0.04	215.12	103.16	144.06	61.59	26.39	83.33	8.49	34.52
	Spring	8.37	940	513.87	20.55	NM	2.31	0.13	174.94	108.28	140.59	52.87	30.97	81.79	7.34	116.57
	Summer	8.00	1019	509.08	8.23	NM	1.12	0.03	84.83	106.90	158.73	52.99	30.14	90.52	7.60	23.39
	Autumn	7.91	1067	565.73	6.20	NM	2.11	0.03	183.75	107.98	171.66	54.03	31.72	95.18	9.21	110.58

3. Results and Discussion

3.1 Water Quality Index Variation

The CCMEWQI equations were applied on the results of water analysis data of Wadi Al-Arab reservoir. Based on physico-chemical parameters, the WQI over the study period from 2009 to 2014 for the water samples have the following values 83.4, 80.6, 59.33, 78.0, 89.3, and 85.4, respectively, as shown in Figure 2. These WQI levels indicate that water quality in the Wadi Al-Arab reservoir was good over the years: 2009, 2010, 2013, and

2014, while has declined to fair during the year 2012, and also during the year 2011 the WQI level has declined to marginal. The good water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels, and the fair water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural, or desirable levels. While the marginal water quality is frequently threatened or impaired; conditions often depart from natural, or desirable levels. The low level of WQI of (WADR) during the year 2012 and 2011 can be attributed to number of variables, and test that exceed, or less than the objectives. The pH, Electrical Conductivity(EC), Total Suspended Solids(TSS), and $NH4^{+}$ were exceeded the objective along the two years.

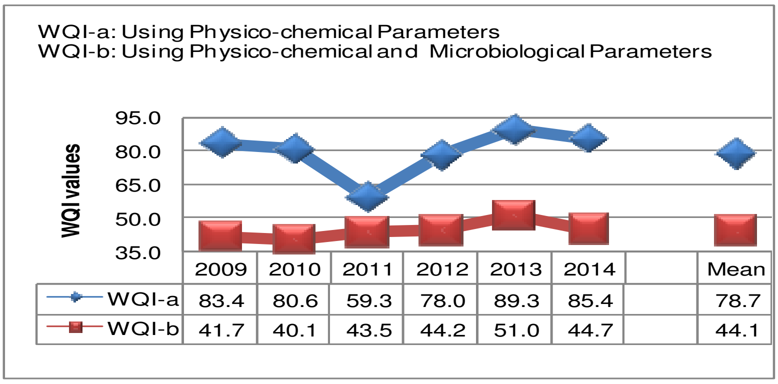

Figure 2. Comparative WQI values; WQI-a values wherever using only the Physico-chemical parameters and WQI-b values based on Physico-chemical and microbiological parameters in WQI calculations.

Table 4. Jordanian Standards (JS 286:2008), guidelines for drinking water quality WHO (2011), for physico-chemical and microbiological parameters used in this study.

Parameter	Unit	Jordanian Standards	WHO Standards
pH	unit	6.5 - 8.5	6.5 - 8.5
EC	µs/cm	700	<1400
TDS	mg/L	1000 - 1300	600
TSS	mg/L	25	25 - 40
NH4+	mg/L	0.2	1.5
NO3-	mg/L	50-70	50
NO2-	mg/L	2	3
HCO3-	mg/L	100 - 500	125 - 350
SO4-2	mg/L	200 - 500	250
Cl-	mg/L	200 - 500	250
Ca+2	mg/L	75 - 200	75
Mg+2	mg/L	50 - 150	<125
Na+	mg/L	200 - 300	200
K+	mg/L	12	12
E.coli	MPN/100ml	0	0

On the other hand, incorporated microbiological parameters with physico-chemical parameters in WQI calculations were significantly contribute to decrease the WQI over the same period (2009-2014) to the following values: 41.7, 40.1, 43.5, 44.2, 51.0, and 44.7, respectively, as shown in Figure 2. These WQI levels indicate that water quality in the Wadi Al-Arab reservoir was poor, during the following years: 2009, 2010, 2011, 2012, and 2014, While the WQI level indicates that water quality was marginal, during the year 2013. The poor water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels. The 〃 poor 〃 quality during the following years: 2009, 2010, 2011, 2012 and 2014, and marginal during 2013, can be attributed to the existence of the *Escherichia coli* (species of bacteria) that exceeded largely the objective and its excursion was large and reflects the intervention between effects of natural, and those of anthropogenic activities. This might be due to increasing pollution of water from urban wastes, and anthropogenic activities in Irbid city located partially at the catchment area. In comparison with the World Health Organization (WHO), and Jordanian Standards (JS 286:2008) as shown in Table 4. The WQI results showed that the (WADR) is not polluted based on its physico-chemical characteristics. However, from microbiological perspective the water is not safe for domestic use, and needs further treatment as shown in Figure 2 and classified in Table 1.

3.2 Surface Water Quality Variation

The results of this study reveal that there are temporal variations in the water quality of the (WADR) over the 6-year study period. Eleven chemical, three physical and one microbiological parameters were analyzed on a monthly basis over the study period (2009-2014) to fulfill the objectives. The annual average for different parameters over the study period is shown in Figure 3-8. The variations of water quality in the present study were discussed below:

3.2.1 Chemical Parameter

Major ions (Ca^{2+}, Mg^{2+}, Na^+ , K^+ , Cl^- , $SO4^{2-}$, $HCO3^-$) are naturally very variable in surface and groundwaters due to local geological, climatic and geographical conditions(Chapman, 1996).

Most calcium in surface water comes from valleys, gullies, or streams flowing over limestone, gypsum, and other calcium-bearing rocks and minerals. Calcium compounds are stable in water when carbon dioxide is present, but calcium concentrations can fall when calcium carbonate precipitates due to increased water temperature, photosynthetic activity by algae or loss of carbon dioxide due to increases in pressure (Chapman, 1996). Ca concentrations ranged from 29.1 to 80 mg/l with an average of 53.64 mg/l (Table 2, and Figure 3). In the study area, all the Ca concentrations in the surface water samples were found within the acceptable limit of WHO, and Jordanian standards (JS). Ca concentrations are significantly declined during the summer over the study period (Table 3), suggesting that calcium carbonate precipitates due to increased water temperature.

Magnesium arises principally from the weathering of rocks containing ferromagnesium minerals and from some carbonate rocks (Chapman, 1996). In calcareous regions the dissolution of limestone and dolomite, $CaMg(CO3)_2$, is an important source of divalent cations and bicarbonate (Brezonik & Arnold, 2011). Magnesium concentration is varying from 16 to 85.1 mg/l with an average value of 30.82 mg/l (Table 2, and Figure 3) and is found within the acceptable limit of WHO, and JS. Unusual elevated in Mg concentrations were recorded in the autumn seasons compared to that of other seasons (Table 3) may be attributed to sewage disposed.

Increased Na concentrations in surface waters may arise from sewage, and industrial effluents and from the use of salts on roads to control snow and ice (Chapman, 1996). Na content fluctuated between 51.9 to 116.0 mg/l with an average of 89.3 mg/l (Table 2, and Figure 3). All the Na concentrations in the surface water samples were found within the acceptable limit of WHO, and JS. During the autumn seasons, the Na concentrations are higher than the values recorded in the other seasons (Table 3) that may be due to high evaporation, and illegal discharges of raw sewage. However, precipitation of carbonate minerals and subsequent dominance of Na cannot be excluded. On the contrary, in 2009, during the winter months, Na concentrations are significantly elevated than those observed in the other seasons, that may be due to the use of salts on roads to control snow, and ice, weathering of sodium bearing minerals and dissolution of rock salts.

Potassium (as K^+) is found in low concentrations in natural waters since rocks which contain potassium are relatively resistant to weathering (Chapman, 1996). The Potassium was ranging between 4.62 to 9.95 mg/l with an average value of 7.7 mg/l (Table 2, and Figure 3). K concentrations in the surface water samples were found within the acceptable limit of WHO, and JS. Megatons of potassium compounds are produced annually (Schultz et al., 2006) which are used to saponify fats and oils, in industrial cleaners, in hydrolysis reactions, glass, soap, color TV tubes, fluorescent lamps, textile dyes, and pigments (Schultz et al., 2006, Toedt et al., 2005) as well as an important agricultural fertilizer. Elevated in K concentrations 8.3, 8.88, 8.13, and 9.21, respectively, were recorded in the autumn seasons compared to that of other seasons over the years 2010, 2011, 2013, and 2014 (Table 3) may be attributed to fertilizer, sewage, and industrial effluents.

Bicarbonate alkalinity is introduced into the water by CO_2 dissolving carbonate-containing minerals (Udeh, 2004). In the present study the dissolution of carbonate rocks such as, limestone and dolomite, is the main source of bicarbonate. Bicarbonate content in water samples ranged from 20.7 mg/l to 292.0 mg/l with a mean value equal to 162.7 mg/l (Table 2, and Figure 4). All the bicarbonate concentrations in the surface water samples were found within the acceptable limit of WHO, and JS. $HCO3^-$ concentrations were declined during the summer seasons, suggesting that calcium carbonate precipitates due to increased water temperatures and evaporation, however, their concentrations were elevated in winter seasons (Table 3) in response to soil washing out, and carbonate dissolution during intense rainfall and runoff.

The sulphate in all samples of the reservoir has a range from 7.45 to 281.2 mg/l with an average value of 101.6 mg/l (Table 2, and Figure 4). Sulphate concentrations in the surface water samples were found within the acceptable limit of WHO and JS. Slightly elevated of sulphate concentrations were detected in the spring seasons during the years: 2009, 2011 and 2014 and also in the autumn seasons during the years: 2010, 2012 and 2013 (Table 3) which may be due to discharge from waste domestic waste (Rajurkaret al., 2003).

Chloride (Cl^-) enters surface waters with the atmospheric deposition of oceanic aerosols, with the weathering of some sedimentary rocks (mostly rock salt deposits) and from industrial and sewage effluents, and agricultural and road run-off (Chapman, 1996). Chloride exhibited a significant concentrations varying between 89.0 and 189.0 mg/l with an average of 154.8 mg/l (Table 2, and Figure 4). Cl^- concentrations in the surface water samples were found within the acceptable limit of WHO, and JS. During the years: 2010, 2011, 2013 and 2014, an increase in chloride concentrations were recorded in the autumn seasons compared to that of other seasons (Table 3) may be attributed to industrial, sewage effluents, and agricultural flow off.

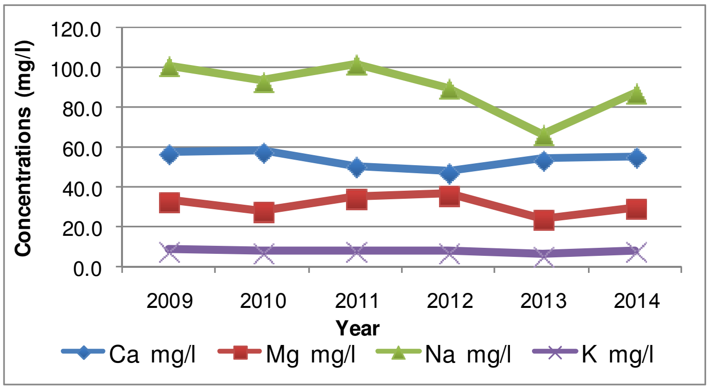

Figure 3. Annual average of major cations concentrations (mg/l) in (WADR).

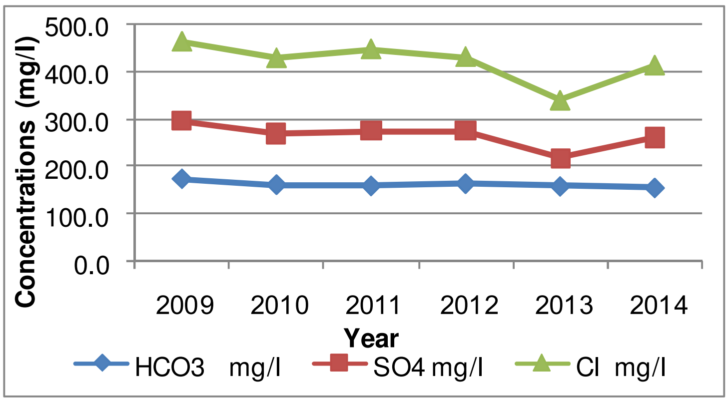

Figure 4. Annual average of major anions concentrations (mg/l) in (WADR).

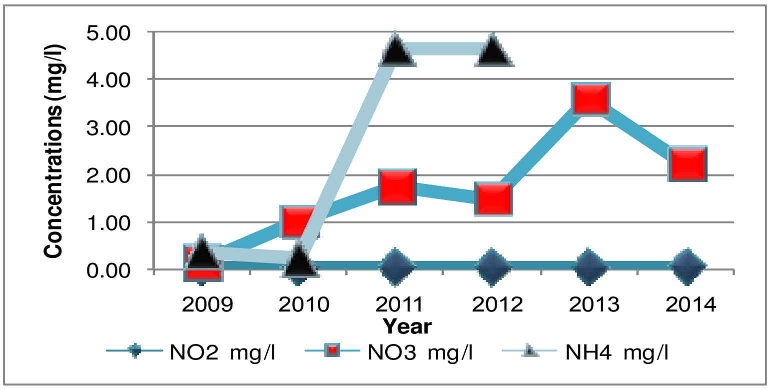

Figure 5. Annual average of nutrients concentrations (mg/l) in (WADR).

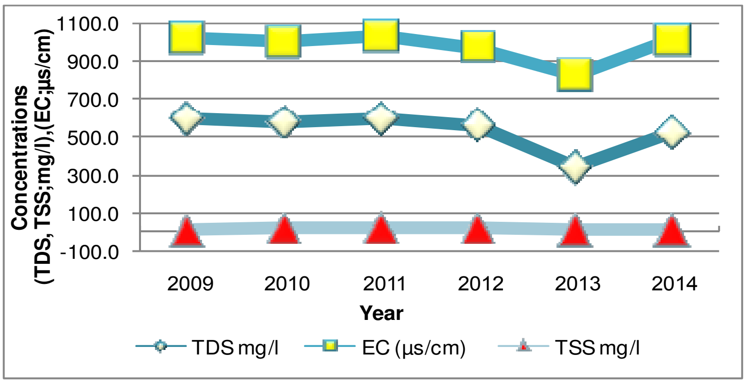

Figure 6. Annual average of EC values, TDS and TSS concentrations (mg/l) in (WADR).

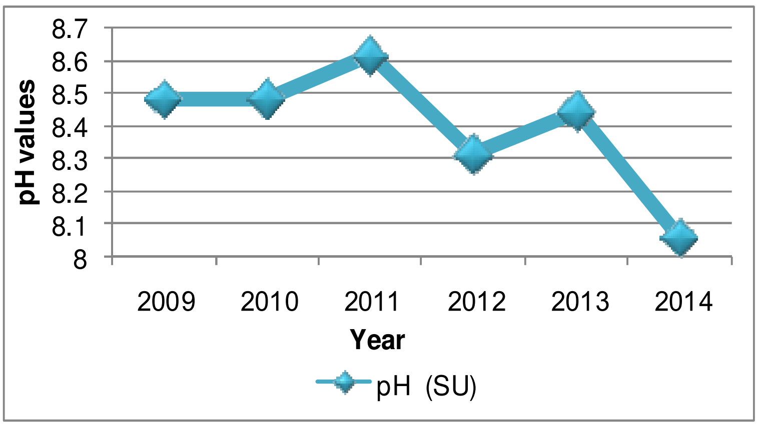

Figure 7. Annual average of pH values (SU) in (WADR).

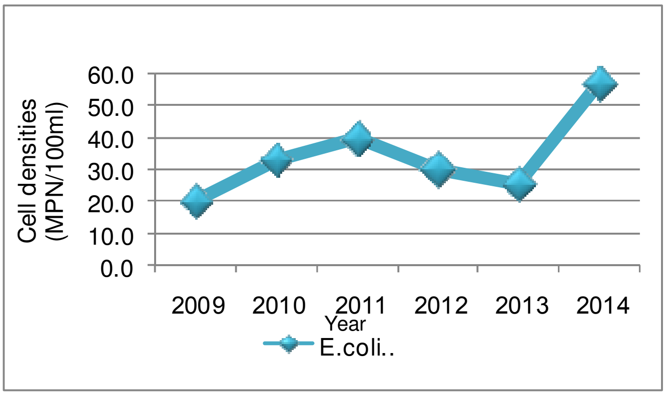

Figure 8. Annual average of cell densities (MPN/100ml) in (WADR).

In the environment, inorganic nitrogen occurs in a range of oxidation states as nitrate ($NO3^-$) and nitrite ($NO2^-$), the ammonium ion ($NH4^+$) and molecular nitrogen (N2) (Chapman, 1996). The atmosphere is an important proximate source, via rainfall and dry deposition, of inorganic nitrogen (ammonium ($NH4^+$), and nitrate ($NO3^-$)) to surface waters, primarily from human activities. In other word, volatilized NH3 reacts with sulfuric and nitric acid in the atmosphere to form ammonium sulfate and ammonium nitrate aerosols, which settle onto terrestrial surfaces by "dry deposition" or act as nuclei for raindrop formation (Brezonik & Arnold, 2011). The ammonium level of the measured samples was high particularly over the years: 2009, 2010, 2011 and 2012, namely overcome the acceptable limit of WHO, and JS, which was 0.2 mg/l NH4, ammonium content in the water samples ranged from 0.0 mg/l to 4.63 mg/l with a mean value equal to 1.0 mg/l (Table 2, and Figure 5). Higher concentrations of ammonium could be attributed to organic pollution such as from domestic sewage, industrial waste and fertilizer flow-off. Ammonium concentrations were not measured during 2013 and 2014.

Nitrates and nitrites concentrations fluctuated between 0.0, 0.0 to 12.65, 1.19 mg/l with an average of 1.2, 0.029 mg/l, respectively, (Table 2, and Figure 5). Nitrate and nitrites concentrations in the surface water samples were found within the acceptable limit of WHO, and JS. An increase in nitrate were detected in winter seasons during the years: 2010, 2013 and 2014, compared to the other seasons (Table 3), which may be related to contamination of animal waste, soil erosion, and the domestic waste from floodwater that enter the wastewater treatment plant of Irbid city, and wash out its contents along Wadi Al-Arab into the dam reservoir. Nitrogen fixation microbes may be responsible for increasing nitrate content in spring seasons during the years: 2009, 2011 and 2012. However, agricultural flow off, and fertilizer over-application from planted crops cannot be excluded.

The pH of a solution indicates its acidity (pH ranging from 0.0 to 6.9) or basicity (pH ranging from 7.1 to 14.0). Extremes in pH in either direction from less than 6.5 or more than 8.5 are usually considered unfavorable to life. The pH is a critical parameter determining the health of a water. The pH values ranged from 7.50 to 9.52 with an average of 8.39 (Table 2 , and Figure 7). and varied from season to season over the 6-year study period. The seasons average of the pH values in the surface water samples were found within the acceptable limit of WHO, and JS. Though, the pH values of the summer and spring seasons over the years: 2009, 2010, 2011 and 2013 and also the autumn of 2011 and summer of 2012 (Table 3) were beyond the acceptable limit of WHO, and JS. The highest pH values were recorded in the spring followed by summer seasons. That could be attributed to increased photosynthetic activities by algae in response to higher temperature, still-flowing water, abundant sunlight and sufficient levels of nutrients. On the contrary, relatively, the lowest pH values were detected in the winter seasons (Table 3) that may be related to the slightly acidic rainfalls discharged into the reservoir (Al-Taani, 2011), from decomposing plants, and organic matter.

3.2.2 Physical Parameter

Electrical Conductivity(EC) is known as a rapid method of estimating the dissolved-solids content of a water sample by determining the capacity of a water sample to carry an electrical current (Lee, 2005). The amount of conductivity is directly proportional to the amount of mineral and salt impurities in the water, which is called total dissolved solids (TDS). Some TDS values were estimated based on the following equation:

$$[(TDS)\, ppm = Conductivity\, \mu S / cm x 0.67] \quad (1)$$

In the present study, EC values are varying from 667.0 to 1136.0 µs/cm with an average value of 976.5 µs/cm (Table 2), which were higher than the acceptable limit of JS (700mg/l), but were found within the acceptable limit of WHO (<1400 mg/l). This increase in conductivity may be due to the high content of soluble salts in the reservoir.

The TDS and EC values were seasonally fluctuated over the 6-year study period (Table 3), where highest values were recorded in winter seasons over the years; 2009, 2011 and 2012, also in autumn seasons over; 2010, 2013m and 2014. Total Dissolved Solids (TDS) values are varying from 300.4 to 718.0 mg/l with an average value of 543.7 mg/l (Table 2, and Figure 6), which were found within the acceptable limit of JS (1000-1300 mg/l), but some seasons were not found within the acceptable limit of WHO (600 mg/l). The increase in TDS values in winter seasons (Table 3) may be due to the high content of soluble salts in the reservoir as a consequence of weathering of the carbonate rocks in the catchment area. A considerable elevated levels of Ca, Mg, HCO3, Na, Cl, and K were observed in autumn correspond with an increase of TDS and EC over; 2010, 2013m and 2014, that may be due to re-dissolution of precipitated salts during withdrawal processes from the reservoir to cover the increased demands for irrigation or domestic uses.

Total suspended solids (TSS) are organic and inorganic materials, mostly small particles larger than 2 microns, regarded as the most visible indicators of water quality. TSS values are varying from 1.80 to 497.0 mg/l with an average value of 10.2 mg/l (Table 2, and Figure 6), which were as an annual average found within the acceptable limit of WHO, and JS (25 mg/l), but the average of some seasons were not found within the acceptable limit of WHO, and JS. The increase in TSS values in spring seasons may be due to the high content of organic matter, dead plants, and algae.

3.2.3.Microbiological Parameter

Escherichia coli (commonly abbreviated *E. coli*), is a Gram negative rod-shaped bacterium that is commonly found in the lower intestine of warm-blooded organisms (endotherms) (Brenner et al., 2005). *E. coli* is a member of the faecal coliform group, which is considered as the best specific indicator for the detection of faecal contamination in drinking water. The microbiological quality of drinking water is necessary to consumers, water suppliers, regulators and public health authority. Human, livestock and wild animals are all sources of faecal contamination; in general, human faecal waste gives rise to the highest risk of waterborne disease (Craun & Argentina, 1996). *E. coli*, with some exceptions, generally does not survive well outside of the intestinal tract, its presence in environmental samples, food, or water usually indicates recent faecal contamination or poor sanitation practices in food-processing facilities (Feng et al., 2002). Studies suggest that *E. coli* survives between 4 and 12 weeks in water containing a moderate microflora at a temperature of 15-18°C (Kudryavtseva, 1972; Filip et al., 1987; Edberg et al., 2000).

E. coli counts varied from 1.7 to 3500 MPN/100 ml with an average value of 32.25 MPN/100 ml (Table 2, and Figure 8) over the 6-year study period. *E. coli* counts exceeding acceptable limit is indicative of pollution from domestic wastes. In the study area, all the surface water samples exceeded the maximum acceptable limit (0.0 MPN/100 ml) as far as it is concerned. Seasonal variation in the population density of waterborne *E. coli* was observed without particular trend (Table 3), over the years 2009, and 2012, the greatest cell densities were found in the winter months, over the years, 2010, and 2011, the greatest cell densities were found in the summer months, over the year 2013, the greatest cell densities were found in the autumn months, over the year 2014, and the greatest numbers, occurred during the spring months. Effluents from sewage treatment plants, runoff water from agricultural and pasture lands, and urban areas can be a source of contamination of surface waters with fecal bacteria. The application of animal manure to agricultural lands as fertilizer cannot be excluded as an important source of contamination of surface water, especially during periods of rainfall. For calculations purposes, the maximum acceptable limit had raised in the present study to (1.0 MPN/100 ml) instead of (0.0 MPN/100 ml), the acceptable limit of WHO, and JS.

4. Conclusion

The findings are based on the results of data analysis. According to the objectives of this study, which mainly attempt to present a picture of the failings of excluding the microbiological parameters wherever WQI is computed. The conclusions are:

1- The computed WQI values for 72 water samples were 83.4, 80.6, 59.33, 78.0, 89.3, and 85.4, respectively, for the period from 2009 to 2014, based on physical and chemical characteristics of reservoir water, while the computed WQI values for same 72 water samples were dramatically declined to 41.7, 40.1, 43.5, 44.2, 51.0, and 44.7, respectively, for the period from 2009 to 2014, based on physical, chemical, and microbiological characteristics of reservoir water. The high lowering of WQI values for these samples was found to be mainly from the utilizing the microbiological parameters (e.g., *Escherichia coli*) in WQI calculations.

2- The quality of water was classified as good for the human uses over the years 2009, 2010, 2013 and 2014, and was classified as fair and marginal over the years 2012 and 2011, respectively, wherever using only the physico-chemical parameters in WQI calculations.

3- The quality of water was classified as poor for the human uses over the years 2009, 2010, 2011, 2012, and 2014 and was classified as marginal over the year 2013, wherever using the microbiological parameters with physico-chemical parameters in WQI calculations. Microbiological analysis of drinking water should be given priority.

4- The bacteriological analysis of water samples showed that the water was contaminated with animal and human wastes and based on the WHO, and JS. So, the Wadi Al-Arab reservoir water was definitely not suitable for drinking purpose without any form of treatment (e.g., disinfection), and it also suggested to be protected from faecal contaminations or sewage.

5- The average values of all major ions concentrations were fluctuated in the reservoir, mainly due to following reasons: (a) the geology of the catchment area; (b) the influences of prevailing climatic conditions; (c) geographical conditions.

6- The concentrations values of all major ions, nitrate and nitrite in the surface water samples were found within the acceptable limit of WHO, and JS. The averages of the Electrical Conductivity, and *Escherichia coli* had completely exceeded the Jordanian standards JS.

7- Ammonium were occasionally exceeded the JS, suggesting that the most considerable source of pollution occurred as outfalls discharging directly through the Wadis, canals, or other watercourses, and through run-off where increasing population and a wide variety of anthropogenic activities.

8- The pH of the reservoir water indicated that it is mildly alkaline varying from pH 7.5 to 9.52 with an average value of 8.4. The higher pH values were noticed during the spring seasons, that may be mainly related to the photosynthesis.

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