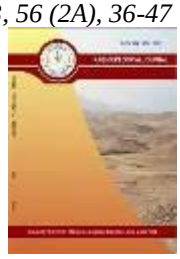
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Monitoring of Surface Water Quality in King Talal Dam Using GIS: A Case Study

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Abstract

King Talal Dam is the largest surface water reservoir in Jordan. Zarqa River and some springs are the major flow contributors to this dam. The other inflow comes in the form of effluents from Al-Samra, Baqa'a, and Jerash wastewater treatment plants, and industries located in Amman and Zarqa. These effluents dramatically deteriorate the water quality of the dam. This study applied Geographical Information System to monitor the temporal and spatial changes in the water quality of King Talal Dam. The parameters included toxicity and infiltration risks, clogging in irrigation systems (drip), soil degradation through soluble salt accumulation, and excessive nitrogen-associated issues. The study expanded from winter 2014 to summer 2016. The final integrated maps revealed two suitable and unsuitable classes for irrigation purposes. The study also provided essential information about the main water quality parameters and pollution sources such as EC, and E. coli. They were recorded throughout the study period in unsuitable zones whereas TSS and bicarbonate (HCO_3^-) were found in the spring of 2015 and spring of 2016, respectively. Autumn 2014 was found to be the worst season among all the study years. During that season, the unsuitable area expanded up to 93% of the total reservoir area. Then, the unsuitable zone reached up to 68.4% of the total area during the winter of 2016. The mapping results indicated that site 100 remained polluted during all the study seasons. This was expected as site 100 is in Zarqa River where Al-Samra and Jerash wastewater treatment plants are discharged.

Keywords: Water Quality; King Talal Dam; Geographic Information System; Spatial analysis; Temporal analysis

1. Introduction

The elements of hydrologic processes must be analyzed within the area of interest to tackle water management issues (Ghoraba, 2015). Irrigation is the major global water-consuming field. Approximately 17% of the cultivated areas are irrigated consuming more than 70% of global water resources (Wolff, 1999). Irrigation enhances crop production in semi-arid and arid lands but it could lead to their salinization (Corwin et al., 2007). There should be a suitable salt balance in the soil for sustainable irrigated agriculture. This balance depends upon the irrigation water quality and filtration, which can restrict salt accumulation around the plant roots. However, these practices can reduce crop incomes and deteriorate the soil structure (Letey et al., 2011).

Geographic information system (GIS) can effectively map the water quality, and detect environmental changes (Kumar, 2013). GIS is widely used to retrieve spatial data and overlay analysis

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in the spatial register domain to represent spatially varying phenomena. GIS and water quality indices could change water quality data into a simple understandable design. It facilitates in summarizing overall water quality conditions for the policymakers. Several studies have used the water quality Index (WQI) for the assessment of water quality (Abdulla and Eshtawi, 2015; Yan et al., 2015; Tiwari et al., 2015; Kumar et al., 2013; Batarseh et al., 2013; Abu Hilal and Abu Alhaija, 2010; Shuai et al., 2010; Zhongwei et al., 2009; Al-Harahsheh, 2007). King Talal Dam (KTD) is a major surface dam in northern Jordan that mainly serves irrigation purposes in the Jordan Valley. KTD water irrigates agricultural projects and farms in the southern and central regions of the Jordan Valley (World Bank, 2001).

Zarqa River is the main source of KTD. The Flow also contains the discharge of treated domestic and industrial wastewater, which constitutes almost all the summer flow and significantly damages the water quality. KTD water quality significantly deteriorated after the construction of the largest sewage treatment plants. The plants were constructed in 1985 in Al-Samra, which is approximately 42 km upstream of the reservoir. The treated wastewater from the Al-Samra plant is discharged into the Zarqa River reaching KTD followed by the Jordan Valley area where it is mainly used for agricultural irrigation. Consequently, river pollution contaminates the dam and affects the quality of agricultural products in the Jordan Valley (Shatanawi and Fayyad, 1996). KTD water is mixed (70 MCM/Year) with the treated wastewater coming from the Al-Samra WWTP (Water Authority of Jordan, 2003). The treated sewage water from WWTP is mixed with fresh water coming from Zarqa River Basin (113 MCM/Year) (Hilal et al., 2010; Ammary, 2007).

This study primarily monitored the KTD surface water quality using GIS. Maps were generated for different types of hazards resulting from KTD surface water irrigation. The hazards mainly included soil quality deterioration, tank problems, plant nutritional disorders, and clogging of irrigation systems. The results (water properties and indices) were subjected to generate the maps using open-source GIS software for the identification and comparison of seasonal and spatial water quality trends (winter 2014 to summer 2016). The study mapped different types of risks after the usage of KTD surface water for irrigation (soil degradation, reservoir problems, plant malnutrition, and clogging of the irrigation system). The study also investigated the impacts of sources and tributaries on the KTD water quality.

2. Materials and Methods

2.1. Study Area

KTD is located in the Jerash Governorate (Fig. 1) at 32°11′24″N and 32°19′89″N to 35°48′05″E, 35°80 13″E (Fig. 2). KTD construction was started in 1972 and completed in 1978. The reservoir's active capacity is 78 MCM whereas the total capacity is 85 MCM. Dam’s lake is 7.50 kilometers long and 450 meters wide with a total surface area of 3.375 km2 (RSS reports, 2005). Zarqa River with a catchment area of 3468 Km² and some springs are the main source of KTD inflow (RSS, 1981). Zarqa river is the third largest river in the region in terms of its annual flow rate. The water of the Zarqa river is mainly used for irrigation and industrial purposes. Small springs, effluents from Al-Samra and Jerash treatment plants, and industrial water from Amman and Zarqa also contribute to the river inflow. The effluents from industrial facilities contribute almost half of the water inflow (Numayr, 1999; Salameh, 1991; Bandel and Salameh, 1981; RSS, 1984-2004). Al-Baqa'a wastewater treatment plant and local springs serve as the water source for Wadi Rmemeen drainage, which is the second most important source of dam water (RSS, 2005). Industrial and AL-Samra effluent water contains high concentrations of heavy metals (ammonia and phosphorous), which negatively affect the KTD water quality (Al-Jassabi and Khalil, 2006; RSS, 2005).

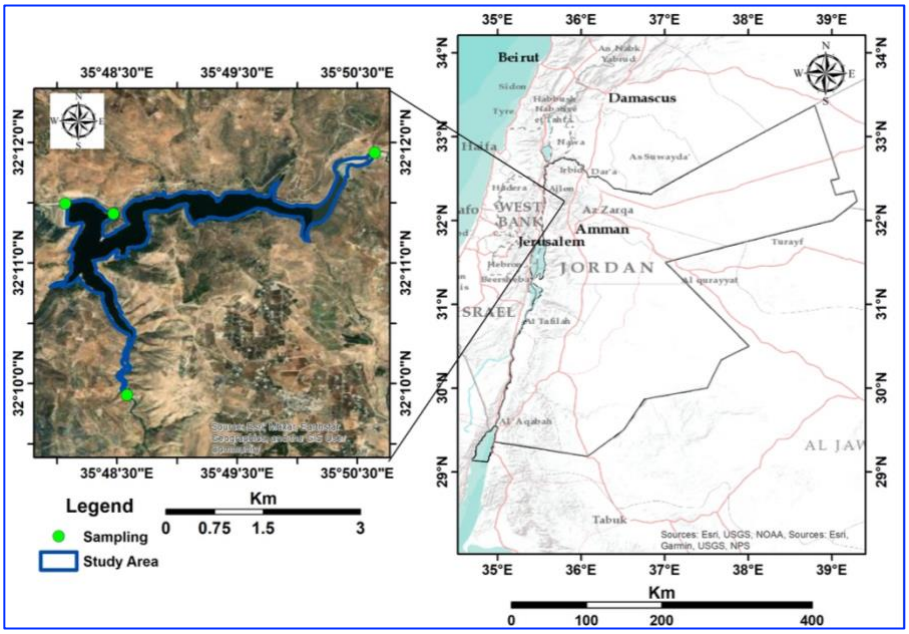


Fig. 1. Location of King Talal Dam

Data related to biological, physical, and chemical parameters were obtained from the Ministry of Water and Irrigation for the years 2014, 2015, and 2016 (January to May) to study the four sites (Ministry of Water and Irrigation reports, 2014-2016). These data represented the monthly results of water parameters from four sites along with the KTD (Fig. 2). Water properties such as electrical conductivity (EC), pH, Total Suspended Solids (TSS), Na^{+}, B, Mg^{+2}, Cl^{-}, and Ca^{2+}concentrations, Sodium Adsorption Ratio (SAR), Nitrate (NO_3^{-}), Ammonium (NH_4^{+}), Total Nitrogen (TN), Bicarbonate (HCO_3^{-}), Phosphorus (PO_4^{3-}), and *Escherichia coli* were investigated during the study.

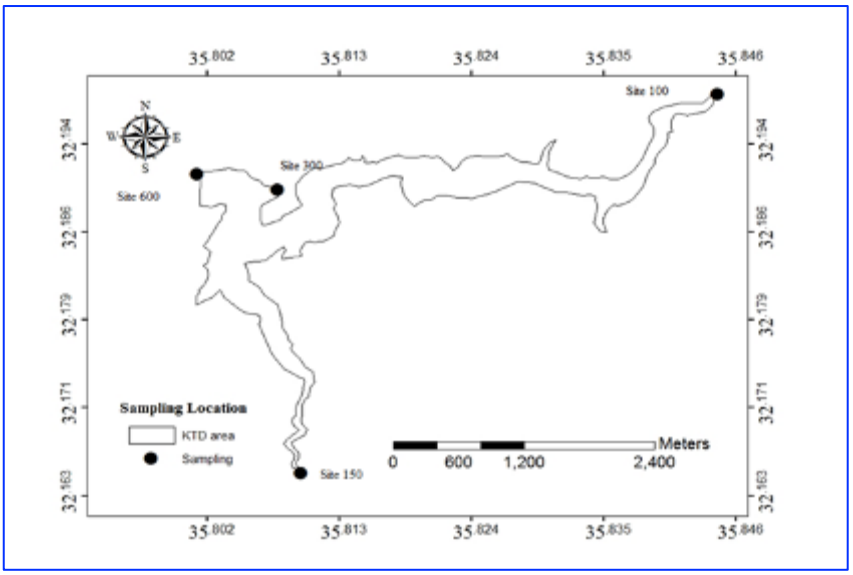


Fig. 2. KTD reservoir and sampling sites

Table 1. Description and coordinates of KTD sampling sites.

Site	Description	Coordinate
100	The inlet to the reservoir from the Zarqa River	N 32 12 .973, E 35 52.979
150	Wadi Rmemeen drainage	N 32 9.905, E 35 48.582
300	Dam body	N 32 11.432, E 35 48.482
600	Dam outlet	N 32 11 .472 E 35 47.803

Monthly data were converted to seasons such as winter (December, January, and February), spring (March, April, and May), summer (June, July, and August), and autumn (September, October, and November). The water properties were compared with the prescribed Jordanian irrigation water standards (JS, 893, 2006).

2.2. GIS Database

The shape files were created in GIS software (ArcMap10) using tabulated (attributes) water quality data of the study area. GIS-based spatial interpolation was employed through Inverse Distance Weighted (IDW) approach to assess the distribution of water contaminants in the study area. IDW is an interpolation approach, which assigns values to the locations based on the nearby values and specified mathematical methods for the identification of the resulting surface smoothness (Selvam et al., 2015). The method uses a distinct or selected set of sample points to assess the output grid cell.

2.3. Surface Water Quality Index (SWQI) for Irrigation Purposes

The water quality index merges complex water quality data into a single value. This study improved a new index known as the Surface Water Quality Index (SWQI) to efficiently indicate the suitability of irrigation water.

The proposed index method utilizes various categories ((a) salinity risk, (b) infiltration and permeability problems, (c) risk of toxicity, and (d) various problems) according to Ayers and Westcot (1985) with a few adjustments in the classification categories for the assessment of irrigation water quality. The conversion of actual concentration values into SWQI was carried out using the following mathematical equation 1.

$$SWQI = \sum Ri*Wi = R\ pH\ *W\ pH + R\ EC*W\ EC + R\ TSS\ *W\ TSS + R\ T\text{-}P\ *W\ T\text{-}P + R\ NH4\text{-}N\ *W\ NH4\text{-}N + R\ NO3\text{-}N\ *W\ NO3\text{-}N + R\ T\text{-}N\ *W\ T\text{-}N + R\ HCO3*W\ HCO3 + R\ SAR\ *W\ SAR + R\ B\ *W\ B + R\ Cl\ *W\ Cl + R\ \textit{E. coli}\ *W\ \textit{E. coli}. \quad (1)$$

Where (R) refers to Ranking, 1 represents suitable and 2 represents unsuitable (Table 2), (i) represents an incremental water quality parameter, and (W) represents the weightage value of the water quality parameter.

Each parameter of all the seasons in 2014, 2015, and 2016 was assigned a ranking value of 1. The value of 2 was assigned if the parameter value was less than the permitted limit according to Jordanian irrigation water standards (JS, 893:2006). If the parameter value was over the permitted limit then it was presented as weightage (%). Weightage value remained higher in the case of high-water parameter hazards. The weightage values were tabulated according to previous studies (Kumar, 2013; Kumar, 2012; Simsek, 2007) with minor modifications based on the available data (Table 2).

Table 2. Criterion table demonstrating weightage and ranking of water quality parameters based on the Jordanian Standard for irrigation water (JS893/2006).

No.	Criteria	Parameter Range	Ranking	Weightage
1	pH	6-9	1	20%
		<6	2	
		>9		
2	EC	<1700	1	
		>1700	2	
3	TSS	<50	1	15%
		>50	2	
4	T-P	<30	1	
		>30	2	
5	NH4-N	<16	1	5%
		>16	2	
6	NO3-N	<30	1	
		>30	2	
7	T-N	<45	1	10%
		>45	2	
8	HCO3	<400	1	
		>400	2	
9	Cl	<400	1	5%
		>400	2	
1	SAR	<9	1	20%
		>9	2	
1	B	<1	1	5%
		>1	2	
1	*E. coli* (MPN/100mL)	<100	1	20%
		>100	2	

3. Results

Table 3, Table 4, and Table 5 present the multiplied ranking and weightage for the water parameters during 2014, 2015, and 2016, respectively. Then GIS-based spatial interpolation and Inverse Distance Weighted (IDW) approach were used for the determination of water contaminant distribution in each season from winter 2014 to summer 2016. The resulting maps were classified into two regions (suitable zone and unsuitable zone) by following Natural Break (Jenks) classification. The Jenks method clusters the data into groups to minimize the within-group variance and maximize the between-group variance. This is carried out by minimizing the average deviation of each class from the class mean and maximizing the deviation of each class from the means of other groups. The method seeks to reduce the variance within classes and maximize the variance between classes.

Table 3. Water parameters for all seasons and sites during 2014 (ranking *weightages).

Site	pH	EC	TSS	T-P	NH4-N	NO3-N	T-N	HCO3	Cl	SAR	B	*E.coli*
Winter												
100	20	30	15	15	5	10	10	10	5	20	5	40
150	20	15	15	15	5	10	10	10	5	20	5	40
300	20	30	15	15	5	10	10	10	5	20	5	20
600	20	30	15	15	5	10	10	10	5	20	5	20
Spring												
100	20	15	15	15	5	10	10	10	5	20	5	40
150	20	15	15	15	5	10	10	10	5	20	5	40
300	20	15	15	15	5	10	10	10	5	20	5	20

600	20	30	15	15	5	10	10	10	5	20	5	40
Summer												
100	20	30	30	15	5	10	10	10	5	20	5	40
150	20	15	15	15	5	10	10	10	5	20	5	40
300	20	30	15	15	5	10	10	10	5	20	5	20
600	20	30	15	15	5	10	10	10	5	20	5	20
Autumn												
100	20	30	15	15	5	10	10	10	5	20	5	40
150	20	15	15	15	5	10	10	10	5	20	5	40
300	20	30	15	15	5	10	10	10	5	20	5	40
600	20	30	15	15	5	10	10	10	5	20	5	40

Table 4. Water parameters for all seasons and sites during 2015 (ranking *weightages).

Site	**pH**	**EC**	**TSS**	**T-P**	**NH4-N**	**NO3-N**	**T-N**	**HCO3**	**Cl**	**SAR**	**B**	***E.coli***
Winter												
100	20	30	15	15	5	10	10	10	5	20	5	40
150	20	15	15	15	5	10	10	10	5	20	5	40
300	20	30	15	15	5	10	10	10	5	20	5	20
600	20	30	15	15	5	10	10	10	5	20	5	40
Spring												
100	20	30	30	15	5	10	10	10	5	20	5	40
150	20	15	15	15	5	10	10	10	5	20	5	40
300	20	15	15	15	5	10	10	10	5	20	5	40
600	20	15	15	15	5	10	10	10	5	20	5	40
Summer												
100	20	30	15	15	5	10	10	10	5	20	5	40
150	20	15	15	15	5	10	10	10	5	20	5	40
300	20	30	15	15	5	10	10	10	5	20	5	20
600	20	30	15	15	5	10	10	10	5	20	5	20
Autumn												
100	20	30	15	15	5	10	10	10	5	20	5	40
150	20	15	15	15	5	10	10	10	5	20	5	40
300	20	30	15	15	5	10	10	10	5	20	5	20
600	20	30	15	15	5	10	10	10	5	20	5	40

Table 5. Water parameters for all seasons and sites during 2016 (ranking *weightages).

Site	pH	EC	TSS	T-P	NH4-N	NO3-N	T-N	HCO3	Cl	SAR	B	*E. coli*
Winter												
100	20	30	15	15	5	10	10	10	5	20	5	40
150	20	15	15	15	5	10	10	10	5	20	5	40
300	20	30	15	15	5	10	10	10	5	20	5	40
600	20	30	15	15	5	10	10	10	5	20	5	20
Spring												
100	20	30	15	15	5	10	10	10	5	20	5	40
150	20	15	15	15	5	10	10	10	5	20	5	40
300	20	30	15	15	5	10	10	10	5	20	5	20
600	20	30	15	15	5	10	10	20	5	20	5	20
Summer												
100	20	30	15	15	5	10	10	10	5	20	5	40
150	20	15	15	15	5	10	10	10	5	20	5	40
300	20	30	15	15	5	10	10	10	5	20	5	20
600	20	30	15	15	5	10	10	10	5	20	5	20

4. Discussion

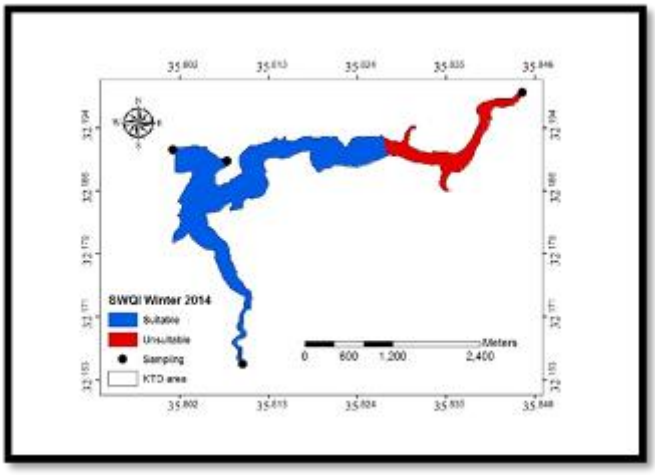
The proposed Surface Water Quality Index (SWQI) is based on the linear combination of different parameters of irrigation water quality, which could potentially exert harmful impacts or risks on soil quality and crop yield. This method counts, analyzes, and combines all the parameters to form a single index value, which determines the suitability of irrigation water. The linear combination of the index provided SWQI index maps for each season to represent the spatial distribution of suitable areas in KTD. The blue color presents the suitable areas whereas unsuitable areas are presented in red color. The maps cover a period from winter 2014 to summer 2016.

4.1. Analysis of 2014 Data

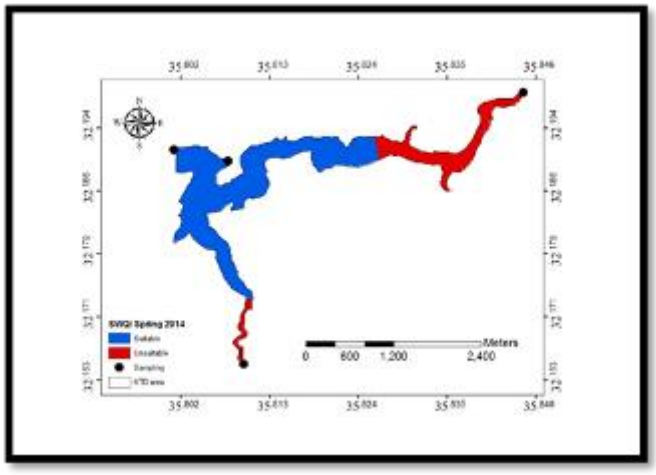
The spatial distribution map (winter 2014) of the Surface Water Quality Index (SWQI) in the KTD is shown in Fig. 3. The map depicts a larger suitable zone area (80%) than the unsuitable zone (20%) in KTD. The unsuitable zone was near the KTD inlet site 100 due to the high EC value (1947 µS/cm). The value was quite high than the recommended value (1700 µS/cm) of the Jordanian standard for irrigation water (JS893/2006). Contrarily, the presence of *E. coli* remained at 1550 MPN/100mL, which is also higher than the permitted Jordanian standards for irrigation water (less than 100 MPN/100mL). These results (EC and *E. coli*) were expected because the inlet site 100 represents the Zarqa River that carries the discharge of Al-Samra and Al- mearad WWTP. The map shows a larger suitable area (75%) in spring as compared to the unsuitable area (25%). The unsuitable zone was again near site 100 where a high *E. coli* pollution was noted (6867 MPN/100mL).

High *E. coli* counts (1033 MPN/100mL) were also found near site 150 (Wadi Rememen) where the effluents of AL-Baqaa WWTP are discharged. The suitable zone also occupied a larger area (80%) during the summer in comparison to the unsuitable zone (20%). The unsuitable zone was located near site 100, which is a polluted inlet of the dam. High EC (1978 µS/cm) and TSS (86 mg/l) values polluted this area. The permitted TSS limit is 50 mg/l according to Jordanian standards (JS893/2006). High TSS value might be due to runoff and erosion during rainfall, which mostly happens in the spring season. A high *E. coli* value (1257 MPN/100mL) was also observed. Autumn 2014 was the worst season among

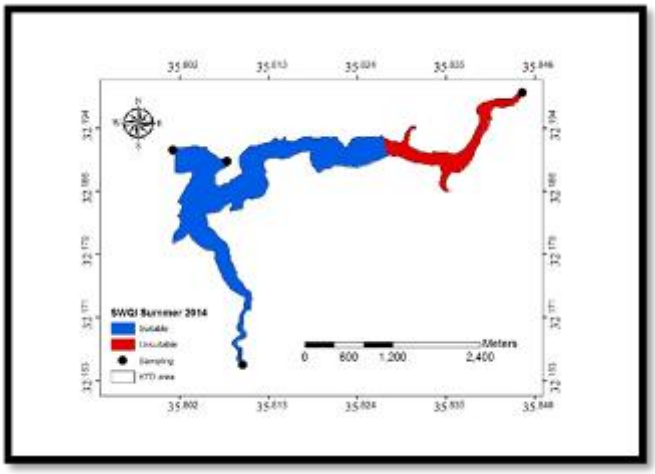
all the study years (Fig. 3) when the unsuitable zone area was expanded to almost 93% of the total reservoir area. This is a serious indicator representing the pollution of all the sites except site 150, which occupied only 7% of the total reservoir area. Multiple factors contributed to such extreme pollution including high EC values at the sites 100 (1986 µS/cm), 300 (2017 µS/cm), and 600 (2008 µS/cm). *E. coli* values were also high at the sites 100 (8767 MPN/100mL), 300 (388 MPN/100mL), and 600 (537 MPN/100mL).



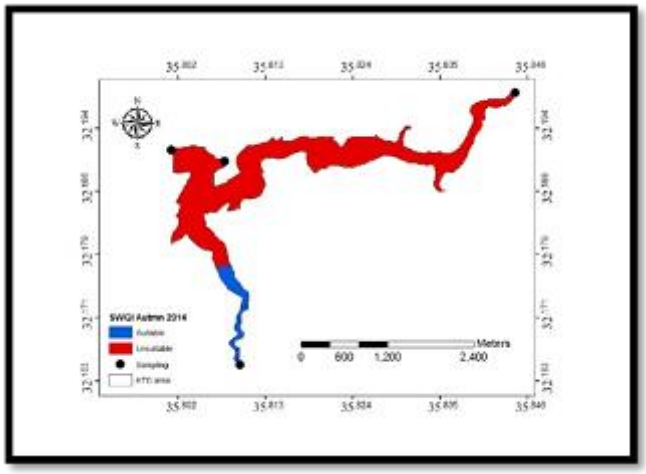
(a) Surface water quality index map of winter 2014.



(b) Surface water quality index map of spring 2014.

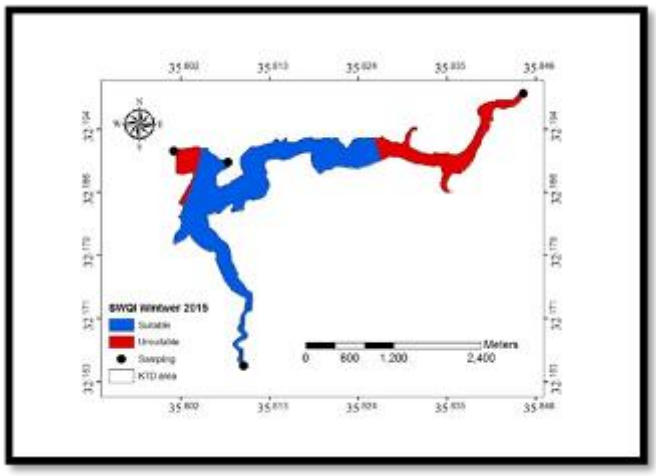


(c) Surface water quality index map of summer 2014.

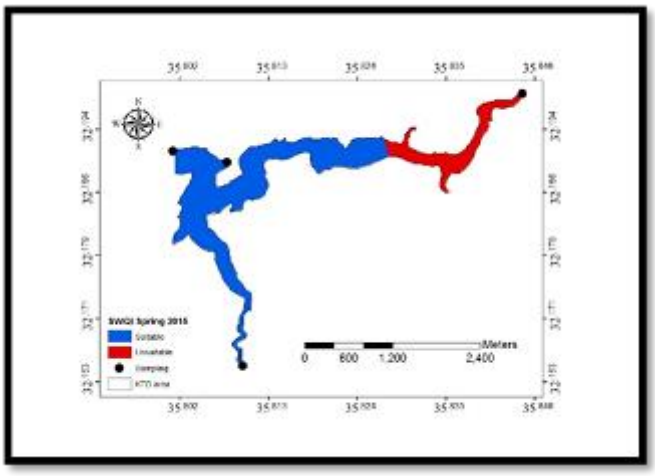


(d) Surface water quality index map of autumn 2014.

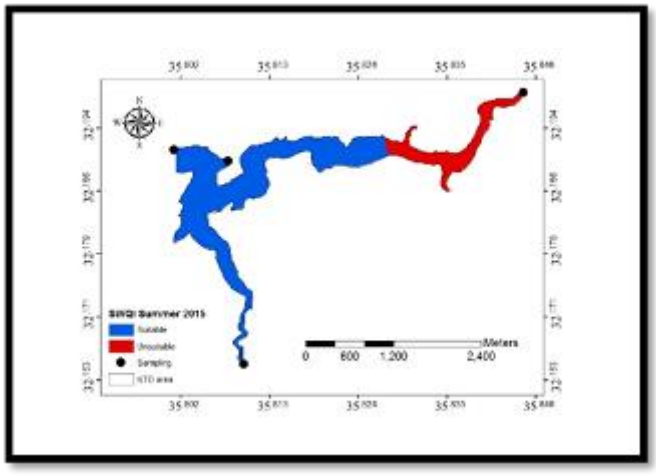
Fig. 3. Surface water quality index maps of 2014



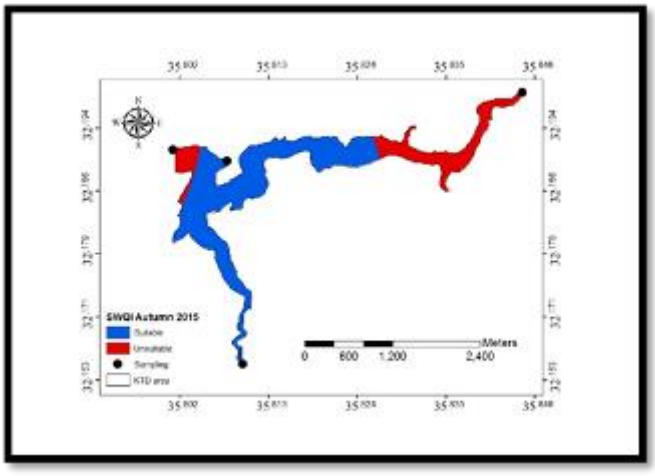
(a) Surface water quality index map of winter 2015.



(b) Surface water quality index map of spring 2015.



(c) Surface water quality index map of summer 2015.

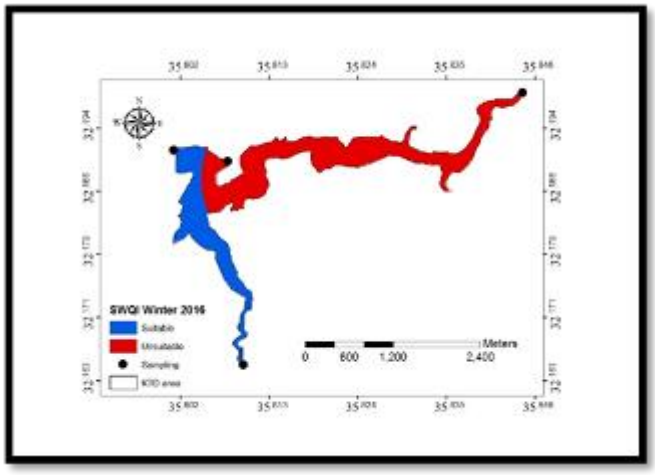


(d) Surface water quality index map of spring 2015.

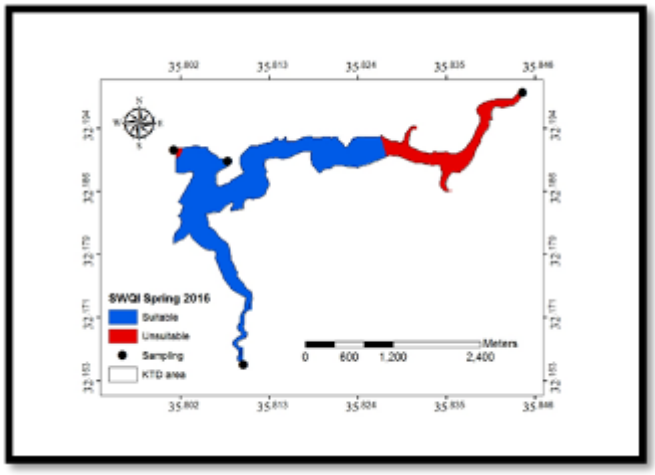
Fig. 4. Surface water quality index maps of 2015

4.2. Analysis of 2015 Data

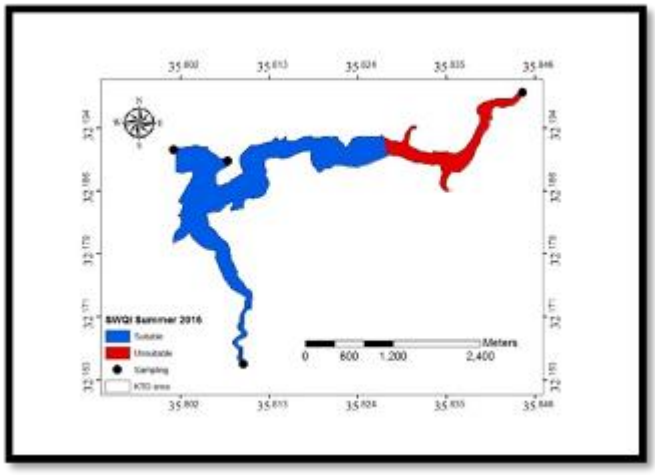
During the winter of 2015, the unsuitable zone area constituted 27.7% of the total reservoir area whereas the suitable area covered 72.3% of the total reservoir area (Fig. 4). The unsuitable zones were located near sites 100 (reservoir inlet), and 600 (reservoir outlet). High values of EC (1857 µS/cm) and *E. coli* (1950 MPN/100mL) were observed at site 100 whereas these values remained at 1876 µS/cm and 404 MPN/100mL at site 600. The map of spring 2015 revealed a seasonal change as compared to the winter season. During this season, the unsuitable zone area was located only near site 100 constituting an area of 19.8% whereas the suitable zone covered an area of about 80.2%. Higher values of EC (1914 µS/cm), TSS (164 mg/l), and *E. coli* (4497 MPN/100mL) were the main reasons of pollution at site 100. There was no difference between the spring and summer seasons and areas of suitable (80.2%) and unsuitable (19.8%) zones remained the same. EC and *E. coli* values in the unsuitable area near site 100 were noted as 1935 µS/cm and 6933 MPN/100mL, respectively. In autumn, the suitable zone consisted of 72.3% of the total reservoir area whereas 27.7% area constituted the unsuitable zone. The unsuitable zone was located near two sites (100 and 600). EC and *E. coli* values were noted as 1991µS/cm and 2270 MPN/100mL, respectively at site 100 whereas EC and *E. coli* values at site 600 remained at 1978 µS/cm and 282 MPN/100mL, respectively.



(a) Surface water quality index map of winter 2016



(b) Surface water quality index map of spring 2016



(c) Surface water quality index map of spring 2016

Fig. 5. Surface water quality index maps of 2016

4.3. Analysis of 2016 Data

Winter 2016 was the second worst season of all the years (Fig. 5). The unsuitable zone was extended from the inlet point 100 to the body of the dam (300) covering 68.4% of the total area. The pollution at sites 100 and 300 was associated with higher EC and *E. coli* values. A similar EC value of 1794 µS/cm was observed at sites 100 and 300 whereas *E. coli* values remained at 16733 and 120 MPN/100mL at these sites, respectively. The suitable zones near points 150 and 600 covered 31.6% of the overall reservoir area. The situation was better in the spring as compared to the winter season (Fig. 5). In spring, the suitable zone area was expanded to 79% of the total area whereas the unsuitable zone was divided into two distant areas. The first unsuitable zone near the inlet had an area of 20% and EC and *E. coli* values of 1932 µS/cm and 5047 MPN/100mL, respectively. The second unsuitable zone had an area of 1% near the outlet. The pollution at this point was because of high EC (1763 µS/cm) and bicarbonate

(555 mg/l) values. The acceptable bicarbonate value according to Jordanian standards for irrigation water (JS 893, 2006) is less than 400 mg/l. In summer, the suitable zone occupied about 80.7% of the total reservoir area whereas the unsuitable area was about 19.3%. This unsuitable zone was near the inlet point 100 and had high EC (1910 µS/cm) and *E. coli* (3500 MPN/100mL) values.

5. Conclusions

SWQI is a good tool for farmers, industrialists, and decision-makers. The developed technique was applied to assess the irrigation water quality of KTD. This study facilitated in better understanding of KTD water quality. It could further help in developing suitable management practices for the protection of water resources. GIS is a powerful tool for assessing water quality and developing solutions for water resources-related problems. This study provides essential information about the water quality parameters, which are the root cause of pollution. EC and *E. coli* were found in unsuitable zones during the complete study period. However, TSS was noted only in the summer of 2014 and spring of 2015 whereas bicarbonate was only found in the spring of 2016. Autumn 2014 was the worst season in the complete study period followed by winter 2016. The maps reveal that site 100 was polluted during the complete study period. Site 100 is an inlet site for the Zarqa River carrying the discharge from Al-Samra and Al-Mearad WWTP. The discharge of effluents increased the levels of *E. coli* and EC in the water. The reservoir outlet was mostly in the suitable zone except for autumn 2014, winter 2015, autumn 2015, and spring 2016.

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