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INDEX AND STATISTICAL METHODS IN WATER MANAGEMENT. A CASE STUDY FROM THE MESOPOTAMIAN MARSHES, IRAQ

Water quality status of marshes within Mesopotamia has been investigated, and temporal and spatial changes determined by examining causes and effects. Data gathered from pre-desiccation and after re-flooding periods were subjected to index and statistical analysis. The quality of waters in the region was assigned to polluted class, regarding specific salinity related parameters. Total dissolved solids, chloride and sulfate were main variables negatively impacting the water quality. The main quality parameters creating spatial differences between the selected marshes were electrical conductivity and total dissolved solids. Temporal differences in dissolved oxygen, salinity, nitrate and phosphate concentrations between the 1980's and 2000's reflected the impact of desiccation and water shortage on the marshes. Salinity and nutrient concentrations generally increased after desiccation compared to their historical levels. These findings indicated that the Mesopotamian marshes had poor water quality due to increase in the concentration of salinity. The study revealed that the index and statistical methods are useful tools identifying water quality and fingerprinting pollution. This will help decision makers to establish strategic and comprehensive water management plans.

1. INTRODUCTION

Water quality is largely affected by natural processes such as weathering and soil erosion and also by anthropogenic inputs. Spatial and temporal variations in quality

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should be investigated by assessing biological, physical and chemical properties. One of difficult tasks facing environmental managers is how to transfer complex environmental data into information that is understandable by technical and non-technical recipients.

The water quality index (WQI) improves understanding of water quality issues by integrating complex data and generating a score that describes water quality status and evaluates water quality trends. The concept of the WQI is based on the comparison of water quality parameters (WQPs) with respective regulatory standards. The output is a numerical value that corresponds to a categorical description of water quality [1–3]. The index method was initially proposed by Horton [4]. Since then, the formulation and use of indices has been strongly advocated by agencies responsible for water supply and control of water pollution.

Multivariate statistical methods are also useful tools to identify groups of similarity-dissimilarity between data sets, detect hidden factors responsible for the data structure, reveal discriminating parameters, etc. [5].

In the study, WQI and multivariate statistical methods were applied to interpret water quality of the Mesopotamian marshes. A significant reduction in the quantity of freshwater entering the Mesopotamian marshes after re-flooding in April 2003 is one of the largest problems impeding the ecosystem function. Water shortage is considered a major issue directly and indirectly affecting the hydrological status of wetlands [6, 7]. The re-flooded marshes are currently receiving water intermittently and in reduced quantities [8, 9]. Additionally, marshes have been exposed to several anthropogenic activities (e.g., construction of dams, exposure to untreated sewage, oil field activities, and exposure to agricultural discharge). Therefore due to such hydrological challenges and anthropogenic activities water quality of the marshes has been deteriorated in the region [7, 10–13].

Water quality has been assessed through specific water quality parameters (WQPs), including pH, dissolved oxygen (DO), nitrates (NO_3^-), phosphates (PO_4^{3-}), total dissolved solids (TDS), biochemical oxygen demand (BOD), sulfates (SO_4^{-2}), chlorides (Cl^-), electrical conductivity (EC), total suspended solids (TSS), and salinity. In this scope, water quality variables were subjected to index (Canadian Council of Ministry of Environment Water Quality Index, CCME-WQI) and statistical calculations (Mann–Whitney U test, cluster analysis, Mann–Kendall test).

The main objectives of this study were: to report on the current water quality status of some marshes within Mesopotamia, and to investigate temporal and also spatial changes in the region by examining causes and effects. The scope of such study was to enable decision makers to address changes and trends caused mainly by desiccation. Identification of the status, changes and trends in water quality may contribute to the establishment of a strategic and comprehensive water management plans.

2. EXPERIMENTAL

In the study, water quality data obtained from The Mesopotamian marshes over the period 1983–2008 (generally on monthly basis) were assessed using the WQI and statistical methods.

Site description. The Mesopotamian marshes (29°55′00″ N to 32°45′00″ N and 45°25′00″ E to 48°30′00″ E) are among most distinctive ecosystems in Iraq. These marshes support several important habitats that provide resources for local communities and preserve significant populations of wildlife, including endemic and endangered species [14, 15]. The Mesopotamian marshes are divided into three main regions: the Al-Hawizeh, Central, and Al-Hammar marshes (Fig. 1). The Tigris and the Euphrates Rivers are the main water suppliers to the marshes. A general description of the marshes is given in Table 1.

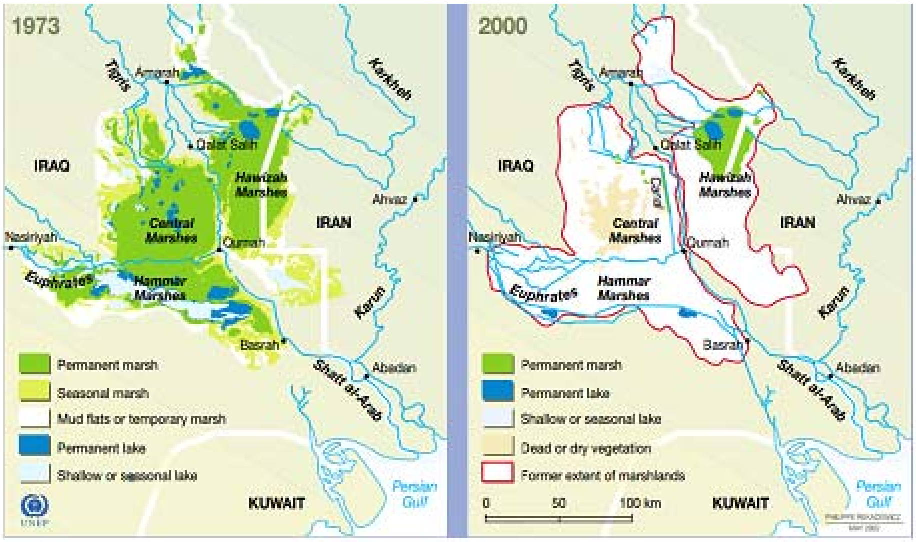

Fig. 1. Location of the Mesopotamia and its major marshlands
(the Central, Al-Hawizeh, and Al-Hammar) [16]

Data sources. WQPs including salinity, DO and pH were measured *in situ* using a WTW multi-meter model 350i. Water samples were collected in triplicate from 0.3 m below the water surface using a horizontal van Dorn sampler. Water samples analyzed for NO_3^-, SO_4^{2-} and Cl^- were filtered immediately in the field using pre-weighted Whatman GF/F 0.7 μm pore-size filters and some of which were filtered through Whatman GF/C 1.2 μm pore size filters. The filtrate (500 cm^3) was transferred into translucent polyethylene screw-cap plastic bottles pre-rinsed twice with the filtrate. Filters used for TSS measurements were individually stored in petri dishes at 4 °C until analysis.

Table 1

General description of the marshes water quality monitoring locations

Location	Status[a]	Water source	General description
Al-Hawizeh Marshes			
Al-Udhaim	never dried	direct water input from the Tigris River	shallow open water with high vegetation cover
Al-Souda north	semi-dried	water flows from Al-Udhaim marsh	shallow open water with slight vegetation cover
Um Al-Niaaj	semi-dried	two direct water inputs from the Tigris River	deep open water with high vegetation cover, partially influenced by agricultural activities
Um Al-Warid	completely dried	direct water input from the Tigris River	deep open water with high vegetation cover, partially influenced by agricultural activities
Al-Souda south	completely dried	water flows from surrounding marshes	shallow marsh with high vegetation cover
Al-Baydha	completely dried	water flows from surrounding marshes	shallow open water with seasonal-slight vegetation cover
Lissan Ijerda	completely dried	water flows from surrounding marshes	shallow marsh with seasonal-slight vegetation cover
Mjnoon	completely dried	water flows from surrounding marshes	shallow marsh with seasonal-slight vegetation cover
Central Marshes			
Abu Zirig	completely dried	direct water input from the Tigris River	shallow open water with high vegetation cover partially influenced by agricultural activities
Al-Baghdadia	completely dried	water flows from the surrounding marshes	deep open water with seasonal-slight vegetation cover
Al-Hammar Marshes			
Al-Kirmashia	completely dried	direct water input from the Euphrates River	shallow marsh with seasonal-high vegetation cover
Al-Burka	completely dried	Water flows from the surrounding marshes	deep open water with seasonal-slight vegetation cover
Al-Naggara	completely dried	Water flows from the surrounding marshes	shallow marsh with seasonal-high vegetation cover

[a]Status refers to the hydrological condition of the selected marshes during the desiccation period.

The concentration of major ions, BOD and TDS were determined according to the standard procedures described in *Standard Methods for Examination of Water and Waste Water* (American Public Health Association APHA), Incubation bottles and air incubators were used for the BOD analysis. Total suspended solids were measured gravimetrically by weighing the fraction remaining on a glass fiber filter (dried) after vacuum filtration of a measured volume of the sample.

Water quality index. In the study, the Canadian Council of Ministry of Environment Water Quality Index (CCME-WQI) was used to describe the surface water quality of the re-flooding marshes for the protection of freshwater's aquatic life. Since the CCME-WQI has a flexibility to select the appropriate parameters and guidelines for the investigated purposes it was preferred in the study [17, 18].

The CCME-WQI allows measurements of the frequency and extent to which parameters exceed the guidelines at each monitoring station. The calculation of the indices is based on a combination of three factors:

- F_1 – the number of variables whose objectives are not met (scope),
- F_2 – the frequency with which the objectives are not met (frequency),
- F_3 – the amount by which the objectives are not met (amplitude) [19].

According to the *Canadian Water Quality Index 1.0. Technical Report* [19, 20], the formulation of the WQI is as follows:

- The measure for F_1 represents the extent of water quality guideline non-compliance over the time period of interest:

$$F_1 = \left[\frac{\text{Number of failed variables}}{\text{Total number of variables}} \right] \times 100\%$$

- F_2 represents the percentage of individual tests that do not meet objectives (so-called failed tests):

$$F_2 = \left[\frac{\text{Number of failed tests}}{\text{Total number of tests}} \right] \times 100\%$$

- F_3 represents the amount by which failed test values do not meet their objectives. It is calculated in three steps.

The number of times by which an individual concentration is higher than (or lower than, when the objective is a minimum) the objective is termed an excursion and is expressed as follows. When the test value must not exceed the objective:

$$\text{Excursion}_i = \left[\frac{\text{Failed test value}}{\text{Objective}_j} \right] - 1$$

For the cases in which the test value must not fall below the objective:

$$\text{Excursion}_i = \left[\frac{\text{Objective}_j}{\text{Failed test value}} \right] - 1$$

The collective amount by which individual tests are out of compliance is calculated as:

$$\mathrm{nse} = \frac{\sum_{i=1}^{n} \mathrm{Excursion}_i}{\#\ \mathrm{of\ tests}}$$

nse is referred to as the normalized sum of excursions.

F_3 is calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (nse) to yield a range between 0 and 100.

$$F_3 = \frac{\mathrm{nse}}{0.01\mathrm{nse} + 0.01}$$

The WQI is then calculated as:

$$\mathrm{CCME} - \mathrm{WQI} = 100 - \left[\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right]$$

Turkish Water Pollution Control Regulation (Turkish WPCR) [21] (classification of inland waters according to quality) which has a quite similar categorization scheme with supranational standard – European legislation (concerning the quality required of surface water intended for the abstraction of drinking water in the Member States [22] 75/440/EEC) was chosen as reference objective [18]. Since these guidelines are used to classify inland water according to quality by evaluating about 45 water quality variables and not only targets specific beneficiary uses, it was preferred. The CCME-WQI categorization scheme proposes five quality classes (excellent, good, fair, marginal and poor). Since the referenced objective (Turkish WPCR) used in the study classifies waters into four categories, assignment of the water into one of these categories was required. In the study, a modified categorization scheme by Boyacioglu [18] has been used for this purpose.

Classification of water quality in the referenced objective is based on the assessment of 45 parameters including but not limited to pH, DO, TDS, Cl^-, SO_4^{2-}, NO_3^- and BOD. Threshold values for each class for these parameters are given in Table 2. Modified categorization scheme is also presented in Table 3.

In the study, the WQI technique was used to investigate:

- water quality status,
- spatial differences between water quality of marshes in three marshlands (the Hammar, Al-Hawizeh and Central marshlands),

• temporal differences in the Al-Hammar (Al-Burka), Al-Hawizeh (Majnoon) and Central marshlands (Al-Baghdadia) between two monitoring periods (1980 and 2000)

Table 2

Classification of inland waters according to quality [21]

Variable	Class I	Class II	Class III	Class IV
pH	6.5–8.5	6.5–8.5	6–9	6 > 9
Dissolved oxygen, DO, mg/dm^3	8	6	3	<3
SO_4^{2-}, mg/dm^3	200	200	400	>400
Cl^-, mg/dm^3	25	200	400	>400
NO_3^--N, mg/dm^3	5	10	20	>20
Total dissolved solids, TDS, mg/dm^3	500	1500	5000	>5000
Biochemical oxygen demand, BOD, mg/dm^3	4	8	20	>20

Table 3

Modified CCME-WQI categorization scheme [18]

Water quality class	Index score	Characterization of waters
Class I	95–100	high quality
Class II	55–94	moderate quality
Class III	35–54	polluted
Class IV	0–34	highly polluted

Index calculations were performed for two monitoring periods (1980's and 2000's) and using three groups of index components

- pH, DO, NO_3^--N (index component I)
- pH, DO, NO_3^--N, TDS, BOD (index component II)
- pH, DO, NO_3^--N, TDS, BOD, SO_4^{2-}, Cl^- (index component III)

Statistical analysis. The Mann–Whitney U test was used to analyze the difference between the medians of two stations in each marshland. This is a nonparametric alternative to the two-sample independent *t*-test, which tests whether the two samples come from distributions with the same mean on the assumption that the distributions have the same shape [23]. Variables having frequent observations (e.g., pH, DO, TDS, concentrations of NO_3^-, PO_4^{3-}, etc.) were selected to evaluate the difference within marshes.

Furthermore, classification of marshes according to quality was performed by the use of cluster analysis (between groups of the linkage method and squared Euclidean distance as a similarity measure). The cluster analysis organizes sampling entities (e.g., species, sites, observations) into discrete classes or groups, such that within-group similarity is maximized and among-group similarity is minimized according to some objective criteria [24]. Based on the water quality index, the results of the Mann–Whitney U test and considering the characteristics of the data sets and variables, the following parameters were chosen to classify marshes with similar properties among the three marshlands: DO, TSS, SO_4^{2-}, Cl^-, TDS, and EC. Cluster analysis was performed using Statistical Package for the Social Sciences Software – SPSS 10.0 for Windows.

To detect temporal trends, water quality data were assessed using the non-parametric Mann–Kendall analysis and to evaluate whether a significant increase or decrease for each water quality parameters (DO and NO_3^-) occurred. Since both parameters were water quality index components and also had continuous observations compared to other variables, they were chosen for the analysis. The advantage of using Mann–Kendall analysis is that it is less sensitive to missing data, data gabs, and data that are not normally distributed [25].

DO, salinity, NO_3^- and PO_4^{3-} concentrations were observed more regularly than other data in three marshlands. Therefore they were used to investigate temporal differences between the 1980's and 2000's. This enabled one to understand impact of desiccation on water. The Wilcoxon signed ranks test was performed to investigate whether differences in water quality parameters between 1980's and 2000's were statistically significant or not.

3. RESULTS AND DISCUSSION

Water quality index scores for selected marshes are presented in Table 4. The whole monitoring period (comprising monthly observations of the variables in general) was used for the analysis. WQI scores of the Al-Hammar, Al-Hawizeh, and Central marshes based on the index component I (pH, DO, NO_3^--N) were generally ranged from 55 to 75, which represented moderate water quality. Quality classes of the marshes determined for the index component II (pH, DO, NO_3^--N, TDS, BOD) were moderate or polluted. However inclusion of SO_4^{2-} and Cl^- concentrations to index calculations (index component III) lowered water quality index scores. Quality classes were polluted or highly polluted in the region.

Temporal differences in the Al-Hammar (Al-Burka), the Al-Hawizeh (Majnoon) and the Central marshlands (Al-Baghdadia) between two monitoring periods (1980' and 2000's) were also investigated. Depending on the data availability the index components I were chosen for the comparison. The results revealed that in the Al-Burka mash (Hammar) water quality assigned to moderate quality in the historical state and after desiccation. In the Majnoon marsh (Al-Hawizeh) despite the fact that the index score increased after desiccation, the water quality represented moderate quality in two time periods. In the Al Baghdadia marsh (central) water quality assigned to the same quality class (moderate) and resulted in the similar index score (ca. 67) in two periods. In summary, water quality in three marshes showed quite similar characteristics and represented moderate quality class (by evaluating pH, DO and NO_3^-) in the historical state and after desiccation.

Table 4

Water quality indices for the selected marshes within Al-Hawizeh, Central, and Al-Hammar based on various water quality parameters

Marshland	Marsh	Period	Index components	WQI	Water quality class
Al-Hammar	Al-Burka	1985	I	74.6	moderate
		2005–2008	I	74.6	moderate
			II	50.9	polluted
			III	29.5	highly polluted
	Al-Kirmashia	2004–2008	I	66.6	moderate
	Al-Naggara	2006–2007	II	74.3	moderate
			III	33.1	highly polluted
Al-Hawizeh	Majnoon	1983–1984	I	65.4	moderate
		2006–2008	I	75.0	moderate
			II	64.4	moderate
	Al-Udhaim	2005–2008	I	73.9	moderate
			II	65.5	moderate
	Um Al-Niaaj	2005–2008	I	75.7	moderate
			II	54.5	polluted
			III	35.5	polluted
	Lissan Ijerda	2005–2008	I	77.4	moderate
			II	57.7	moderate
	Um Al-Warid	2005–2008	I	78.5	moderate
			II	50.2	polluted
			III	37.1	polluted
	Al-Souda north	2006–2008	I	72.0	moderate
			II	63.7	moderate
	Al-Baydha	2006–2008	I	73.4	moderate
			II	65.2	moderate
	Al-Souda South	2006–2008	I	53.6	polluted
			II	50.8	polluted
Central	Al-Baghdadia	1983–1984	I	67.5	moderate
		2005–2008	I	66.3	moderate
			II	56.3	moderate
			III	33.0	highly polluted
	Abu Zirig	2004–2005	I	64.6	moderate

3.1. SPATIAL DIFFERENCES

The non-parametric Mann–Whitney U test was used to analyze the differences between the medians of two stations in each marshland. Since the data sets have not met the assumption of normality, this method was used to test the null hypothesis that two samples come from the same population (i.e., have the same median) or, alternatively, whether observations in one sample tend to be larger than observations in the other. Variables, having frequent observations (e.g., pH, DO, TSS, NO_3^-, PO_4^{3-}, etc.) were selected to evaluate the difference within marshes. The results of the Mann–Whitney U test showed significant differences between marshes within the same marshlands (Tables 5–7).

Table 5

p-values from the Mann–Whitney U test for the Al-Hammar marshes

Variable	Marsh	Al-Kirmashia	Al-Naggara
pH	Al-Burka	0.048	0.088
	Al-Kirmashia		0.859
DO	Al-Burka	0.004	0.345
	Al-Kirmashia		0.046
TSS	Al-Burka	0.019	0.428
	Al-Kirmashia		0.192
Salinity	Al-Burka	0.012	0.509
	Al-Kirmashia		0.042
NO_3^-	Al-Burka	0.000	0.185
	Al-Kirmashia		0.151
PO_4^{3-}	Al-Burka	0.001	0.382
	Al-Kirmashia		0.003
EC	Al-Burka	0.020	0.379
	Al-Kirmashia		0.025

- In Al-Hammar marshland, water quality differences between the Al-Burka marsh and Al-Kirmashia marsh were statistically significant ($p < 0.05$, Table 5). In contrast, water quality differences between the Al-Burka marsh-Al-Naggara and Al-Kirmashia, Al Naggara marshes were statistically not significant.
- In the Al-Hawizeh marshland, the results of the Mann–Whitney U test showed statistically significant differences ($p < 0.05$) in water quality among the tested marshes (Table 6). The salinity and EC were the main water quality variables creating difference among the Al-Hawizeh marshes. Similarly pH, NO_3^- and PO_4^{3-} levels were generally different from one marsh to another in the region.

The results of the Mann–Whitney U test also showed significant differences ($p < 0.05$) between the Central marshes, Al-Baghdadia and the Abu Zirig (Table 7), especially in TSS, PO_4^{3-} concentration and salinity.

Table 6

p-values from the Mann–Whitney U test for the Al-Hawizeh marshes

Variable	Marsh	Al-Udhaim	Um Al-Niaaj	Lissan Ijerda	Um Al-Warid	Souda North	Al-Baydha	Souda South
pH	Majnoon	0.009	0.004	0.081	0.006	0.005	0.001	0.000
	Al-Udhaim		0.290	0.045	0.102	0.758	0.965	0.004
	Um Al-Niaaj			0.092	0.579	0.067	0.063	0.000
	Lissan Ijerda				0.297	0.009	0.004	0.000
	Um Al-Warid					0.018	0.014	0.000
	Souda north						0.762	0.004
	Al-Baydha							0.004
DO	Majnoon	0.615	0.333	0.244	0.071	1.000	0.765	0.000
	Al-Udhaim		0.707	0.649	0.330	0.555	0.432	0.000
	Um Al-Niaaj			0.978	0.553	0.372	0.119	0.000
	Lissan Ijerda				0.399	0.253	0.176	0.000
	Um Al-Warid					0.091	0.060	0.000
	Souda north						0.800	0.000
	Al-Baydha							0.000
Salinity	Majnoon	0.000	0.000	0.042	0.000	0.000	0.003	0.010
	Al-Udhaim		0.005	0.000	0.057	0.509	0.008	0.011
	Um Al-Niaaj			0.000	0.990	0.001	0.000	0.000
	Lissan Ijerda				0.000	0.000	0.000	0.001
	Um Al-Warid					0.021	0.000	0.000
	Souda north						0.034	0.037
	Al-Baydha							0.977
NO_3^-	Majnoon	0.793	0.003	0.931	0.008	0.758	0.441	0.666
	Al-Udhaim		0.001	0.885	0.002	0.644	0.356	0.666
	Um Al-Niaaj			0.003	0.427	0.005	0.008	0.004
	Lissan Ijerda				0.004	0.785	0.369	0.870
	Um Al-Warid					0.006	0.011	0.009
	Souda north						0.525	0.931
	Al-Baydha							0.564
PO_4^{3-}	Majnoon	1.000	0.000	0.931	0.000	0.951	0.951	0.758
	Al-Udhaim		0.000	0.931	0.000	0.975	0.902	0.805
	Um Al-Niaaj			0.000	0.182	0.000	0.000	0.000
	Lissan Ijerda				0.000	0.935	0.828	0.978
	Um Al-Warid					0.000	0.000	0.000
	Souda north						0.977	0.931
	Al-Baydha							0.954
EC	Majnoon	0.000	0.000	0.066	0.000	0.000	0.006	0.054
	Al-Udhaim		0.030	0.000	0.003	0.597	0.048	0.016
	Um Al-Niaaj			0.000	0.215	0.010	0.001	0.000
	Lissan Ijerda				0.000	0.001	0.001	0.013
	Um Al-Warid					0.002	0.000	0.000
	Souda north						0.161	0.018
	Al-Baydha							0.713

Table 7

p-values from the Mann–Whitney U test for the Central marshes

Variable	Marsh	Abu Zirig
pH	Al-Baghdadia	0.594
DO		0.599
TSS		0.026
Salinity		0.008
NO_3^-		0.061
PO_4^{3-}		0.005

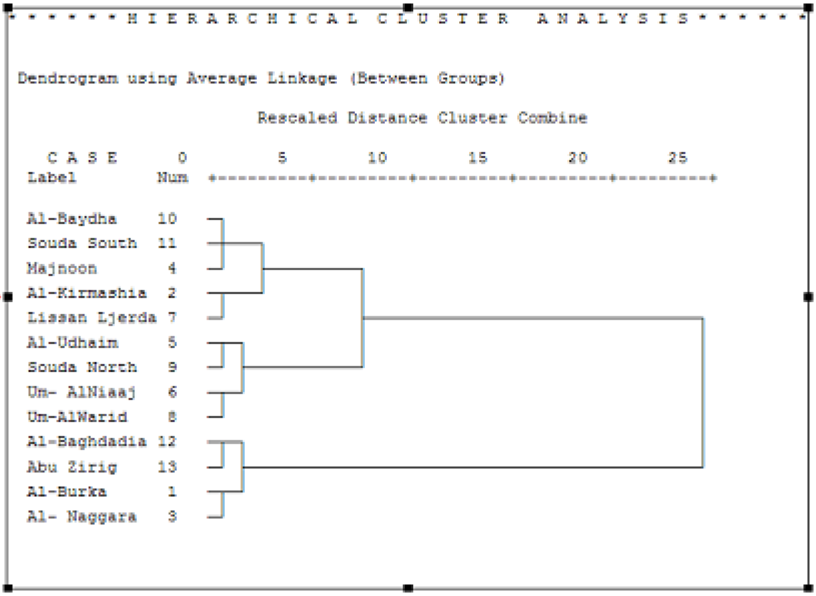

Fig. 2. Dendrogram using groups of the linkage method (performed based on DO, TSS, SO_4^{2-} Cl^-, TDS, and EC)

Cluster analysis (performed based on DO, TSS, SO_4^{2-}, Cl^-, TDS, and EC) investigated special differences among the selected marshes within the three marshlands (Fig. 2). Three major groups were formed by treating all data by clustering (Table 8). It should be noted that cluster analysis performed for the variables Cl^-, TDS, EC and Ca produced the same classification pattern. The results revealed that in general the water quality characteristics of the Central and the Al-Hammar marshes were similar (cluster III). However, Al-Hawizeh marshes were divided into two groups (clusters I and II) and showed different water quality characteristic from the Central and the Al-Hammar marshes.

Table 8

Marshes grouped in classes

Cluster I	Cluster II	Cluster III
Al-Baydha (HZ)	Al- Udhaim (HZ)	Al-Baghdadia (CM)
Souda South (HZ)	Souda North (HZ)	Abu Zirig (CM)
Majnoon (HZ)	Um-AlNiaaj (HZ)	Al-Burka (HM)
Al Kirmashia (HM)	Um- AlWarid (HZ)	Al-Naggara (HM)
Lissan Ljerda (HZ)		

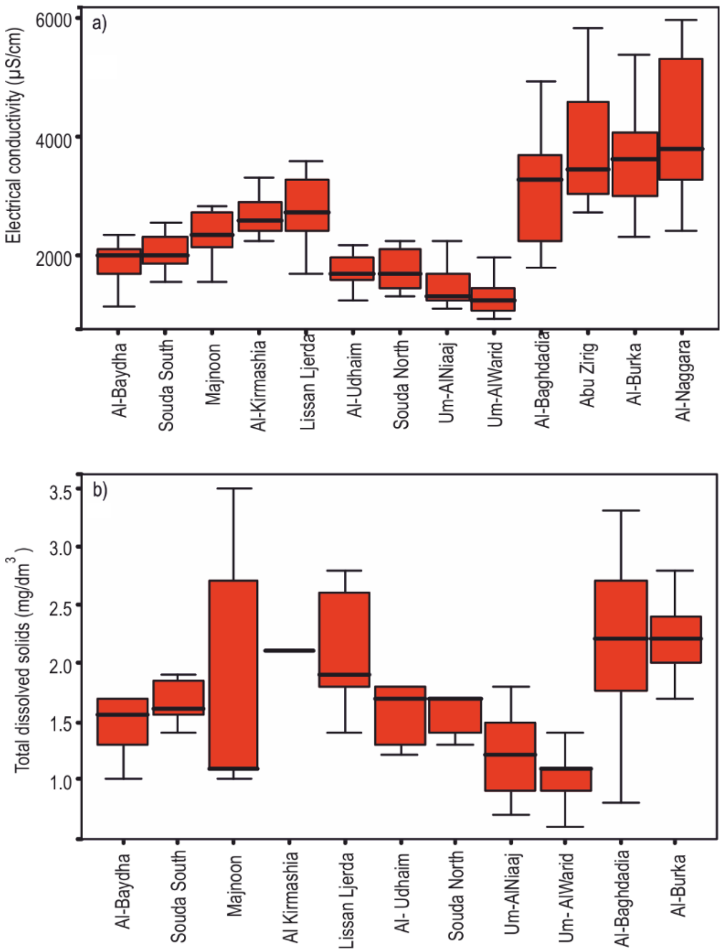

Fig. 3. Box plot showing the shape of the underlying distributions for the examined variables (a) EC, b) TDS) which created difference between the marshes within the three marshlands

Box plots were plotted to provide a visual impression of the location and shape of the underlying distributions for the EC and TDS (Fig. 3). Based on the shape of the underlying distributions for EC and TDS and the results of the cluster analysis, it was concluded that the main water quality parameters that caused spatial differences between the selected marshes within the three marshlands were EC and TDS. Based on this result, it can be concluded that

- cluster III represented high level saline waters,
- cluster I represented medium level saline waters,
- cluster II represented low level saline waters.

3.2. TEMPORAL DIFFERENCES

In the study, the Mann–Kendall test was used to evaluate whether a significant change of each water quality parameter (DO and NO_3^-) occurred. Since both parameters were the components of the water quality index and also had continuous observations in contrast to other variables, they were chosen for the analysis. The results presented in Table 9 revealed that, there was no significant trend over the time for DO ($z < 1.645$). On the other hand NO_3^- levels in Al-Burka and Al-Baghdadia marshes increased over the time ($z > 1.645$)

Table 9

Mann Kendall trend analysis for the Al-Hammar, Al-Hawizeh, and Central marshes based on DO and NO_3^- parameters

Marshland	Marsh	Variable	Calculated z	$z_{0.95}$	Trend
Hammar	Al-Burka	DO	0.087	1.645	–
		NO_3^-	4.356		yes, upward
Al-Hawizeh	Majnoon	DO	0.874		–
		NO_3^-	0.563		–
Central	Al-Baghdadia	DO	1.258		–
		NO_3^-	1.927		yes, upward

Since DO, salinity, NO_3^- and PO_4^{3-} levels were observed more regularly than others in three marshlands, they were used to investigate temporal differences between the 1980's and 2000's by the Wilcoxon signed ranks test (Table 10). In the Al-Burka marsh (Al-Hammar), NO_3^- and PO_4^{3-} levels in two periods were statistically significant ($p < 0.05$). While medians of NO_3^- and PO_4^{3-} data sets were 1.2 and 0.3 μg/dm^3 in 1985, levels increased up to 8.3 and 4.25 μg/dm^3 in 2005–2006, respectively. In Majnoon marsh (Al-Hawizeh), the salinity showed temporal differences between 1983–1984 and 2006–2008), while the median of the data sets decreased from 6.45 to 1.15 mg/dm^3. In contrast, PO_4^{3-}

levels increased (from 0.6 to 4.5 μg/dm^3). The salinity levels in Al-Baghdadia marsh (Central) showed temporal difference between 1978–1984 and 2005–2007, and the median of the data sets increased from 0.75 to 1.6 mg/dm^3.

Table 10

Wilcoxon signed ranks test results for the selected marshes within the Al-Hammar, Al-Hawizeh, and Central Marshes

Marshland (Marsh)	Compared monitoring periods	Water quality variable	*p*
Hammar (AlBurka)	1985 and 2005–2006	DO	0.516
		salinity	0.103
		NO_3^-	0.011
		PO_4^{3-}	0.000
Al-Hawizeh (Majnoon)	1983-1984 and 2006–2008	DO	0.779
		salinity	0.028
		NO_3^-	0.092
		PO_4^{3-}	0.012
Central (Al-Baghdadia)	1978–1984 and 2005–2007	DO	0.844
		salinity	0.023
		NO_3^-	0.260
		PO_4^{3-}	0.071

4. CONCLUSION

The Canadian Council of Ministry of Environment Water Quality Index (CCME--WQI) was applied to describe the surface water quality of the re-flooding marshes. The non parametric Mann–Whitney U test, and cluster analysis has been performed to investigate spatial differences in the region. To assess temporal trends, the non-parametric Mann–Kendall analysis has been applied. Application of the WQI to the selected re-flooded marshes of Iraq indicated that salinity related parameters (TDS, Cl^-, and SO_4^{2-} levels) were negatively impacting the water quality of the marshes assessment of water quality based on DO, NO_3^-, and pH showed that the water quality of the re-flooded marshes was approaching the quality of the marshes prior to desiccation. It is recommended to take measures reducing salt intrusion to the Mesopotamian marshes. Statistical analysis results also showed that the main water quality parameters that caused spatial differences between the selected marshes within the three marshlands were EC and TDS. The Central and the Al-Hammar marshes represented high level saline waters comparing to the Al-Hawizeh marshes. This can be highly related to the impact of the salinization during the desiccation period and the frequent flushing period between marshes when Al-Hawizeh marshes received frequent and large amount of water than the other marshes. The significant differences in salinity level among the Al-Hawizeh marshes were mostly related to the differences in the hydrological status during the desiccation period. It was obvious to observe high salinity level within the completely dried marshes comparing to the ever wet marsh within the Al-Hawizeh. Furthermore, the results of the cluster analysis performed based on Ca, Cl^-, EC, and TDS parameters strongly indicated that salinity and salinity-related water quality parameters were the main factors tclassifying the Mesopotamia marshes. Temporal differences in DO, salinity, NO_3^- and PO_4^{3-} concentrations between the 1980's and 2000's generally reflected the impact of desiccation and water shortage on the Mesopotamian marshes. Salinity and nutrients concentrations were increased after desiccation in contrast to their historical values. The study revealed that the index and statistical methods are useful tools for identifying water quality status/changes and fingerprinting pollution. This will help decision makers to contribute to the establishment of a strategic and comprehensive water management plans.

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