A Review of the Water Quality of the Mesopotamian (Southern Iraq) Marshes Prior to the Massive Desiccation of the Early 1990s

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Abstract

The marshes of southern Iraq range from in size from 8,000 to 30,000 km^2. Delivery of freshwater to this system has been affected by the construction of water control structures both within Iraq and in neighboring countries. In the early 1990s, the Government of Iraq drained a large portion of this system and burned extensive stands of *Phragmites*. Less than 10% of these marshes were functioning normally by 2000 (Partow 2001, Brasington 2002).

This review summarizes the existing data on water quality of this vast and unique ecosystem prior to the Iraqi government's decision to drain these marshes. These data come from numerous graduate theses and other investigations not readily accessible by the scientific community. Water quality variables considered included salinity, ionic composition, and a number of variables related to nutrient status.

These data show that salinity has increased over time, adversely affecting agriculture in southern Iraq. Dissolved oxygen concentrations have generally been high, waters are typically slightly alkaline, and extensive submerged aquatic vegetation facilitates the settling of suspended solids. Nitrates are the predominant form of inorganic nitrogen, and the concentrations were low compared to other water bodies in Iraq. Nutrient limitation experiments indicated that the phytoplankton were nitrogen limited.

Key words: water quality; Iraq; Mesopotamia; marshes; salinity; nutrients; anions; cations

1- Introduction

The southern Iraqi marshes occupy the south and southeastern parts of the Mesopotamian Valley (32.7557^o N,

48.0128^o E) (Figure 1). The climate of the area has long hot summers and short, rather cold winters; the prevailing north-westerly winds have a pronounced influence on the area (Yuaqub and Salman 1992). These marshes are the most important geographical unit in southern Mesopotamia and form a complex lacustrine sedimentary environment (Yuaqub and Seikian 1992). The areal extents of this marsh system were not fixed. These wetlands have ranged from 8,000 to 30,000 km^2, making them the largest wetland system in the region (Maltby 1994, Partow 2001, Nicholson and Clark 2002). Sources of water for this marsh system include several rivers, precipitation, and groundwater. Flow from the Tigris and Euphrates rivers almost wholly regulate the area of the marshes since local rainfall averages <100-mm year$^-$^{1} (Yuaqub and Salman 1992).

Regulation of flows from the Tigris and Euphrates by Turkey, Iran, and Syria, primarily for agriculture, has contributed to the reduction of these wetlands. Additionally, within Iraq, construction of impoundments, increased irrigation for agriculture as well as the draining of wetlands for agriculture, has also affected the quantity and timing of water delivery to these wetlands (IUCN 2005). During the Iran-Iraq War of the 1980s, the marshes were often the scene of intense fighting, which facilitated their destruction. Then, in the early 1990s, the Government of Iraq constructed a large network of water control

structures, drained an extremely large portion of the marsh system, and burned extensive stands of *Phragmites*. The consequence of all these modifications to the system, particularly those of the Hussain regime beginning in the early 1990s, was that <10% of these marshes were functioning as they should be by 2000 (Partow 2001; Brasington 2002).

The remaining wetlands include both permanent and seasonal marsh systems. The permanent marshes include expanses of open water ("burkahs") and channels used for both transportation and fishing (Al-Kayat 1975). The Al-Kharka River contributes a limited amount of freshwater flow to the Al-Huwayza marsh. The Tigris River contributes the greatest volume of water to the marshes near the city of Amarra and Qurna (Figure 1), whereas the Euphrates feeds the Al-Hammar marsh. The Shatt Al-Arab River also contributes water to the eastern part of the Al-Hammar marsh.

These marshes once served as a natural filter for suspended particles and pollutants translocated by the Tigris and Euphrates rivers. This filtering process diminished sedimentation and pollutant loadings to the coastal marine environment of the Gulf (Maltby 1994, Saeed *et al*. 1999, Partow 2001; Al-Yammani *et al.* 2007).

Central to the function of the marshes are the role of vegetation. Emergent vegetation, including dense stands of *Phragmites australis, Typha domengensis*, and *Schoenoplectus litoralis* (Al-Mayah

1978; Al-Mayah 2005; IUCN 2005) are refuges and rookeries for migratory waterfowl. Juvenile fishes may also move into these areas. Decomposition of emergent vegetation yields detritus that is a key to energy cycling. These plants are also important in nutrient recycling and removal of contaminants.

Ceratophyllum demersum, Vallisneria spiralis, *Potamogeton crispus, Myriophyllum verticilatum*, *Chara* sp., *Najas spp.,* and *Salvinia* sp. are the typical submerged aquatic vegetation (SAV) in these marshes (Al-Mayah 1978; IUCN 2005). SAV provides habitat for fishes and epiphytic macroinvertebrates. Furthermore, they attenuate water velocities, facilitating

the settlement of suspended particles, thereby increasing water clarity. SAV also absorbs nutrients from the water column. Planktonic and epiphytic algal productivity is also enhanced by this marsh system (Al-Zubaidi 1985; Al-Lammi 1986; Al-Aarjy 1988).

2-The objectives of this review are to:

- Summarize the results of previous studies of this extensive marsh ecosystem, many of which are unpublished and not readily accessible to the scientific community; and

- To highlight key water quality factors affecting the structure and functions of this unique ecosystem.
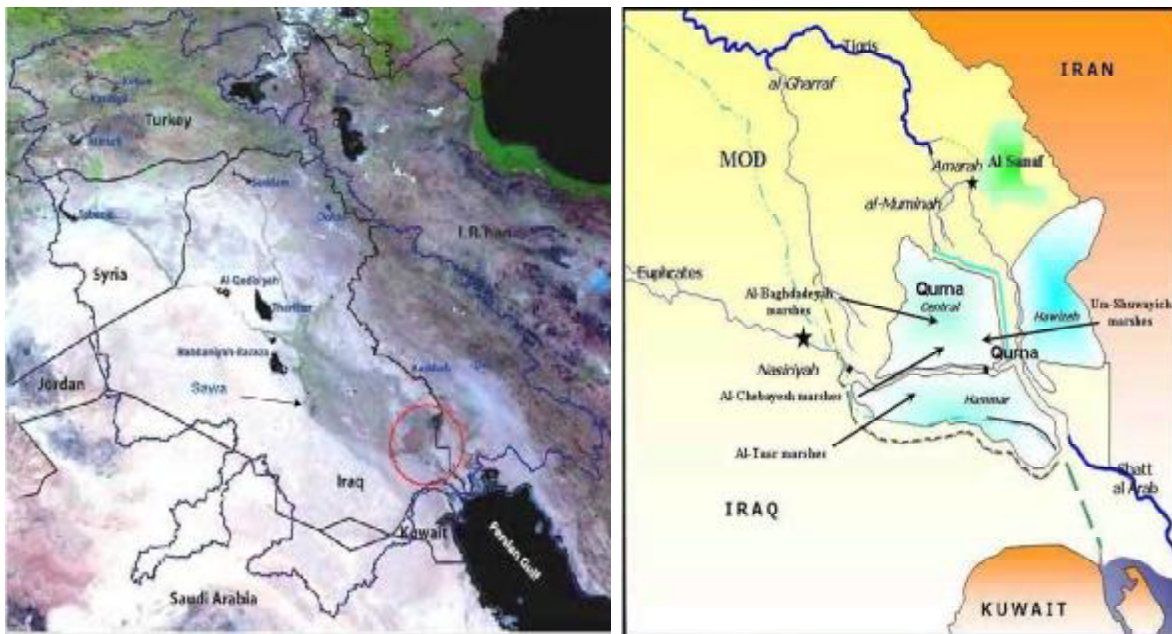

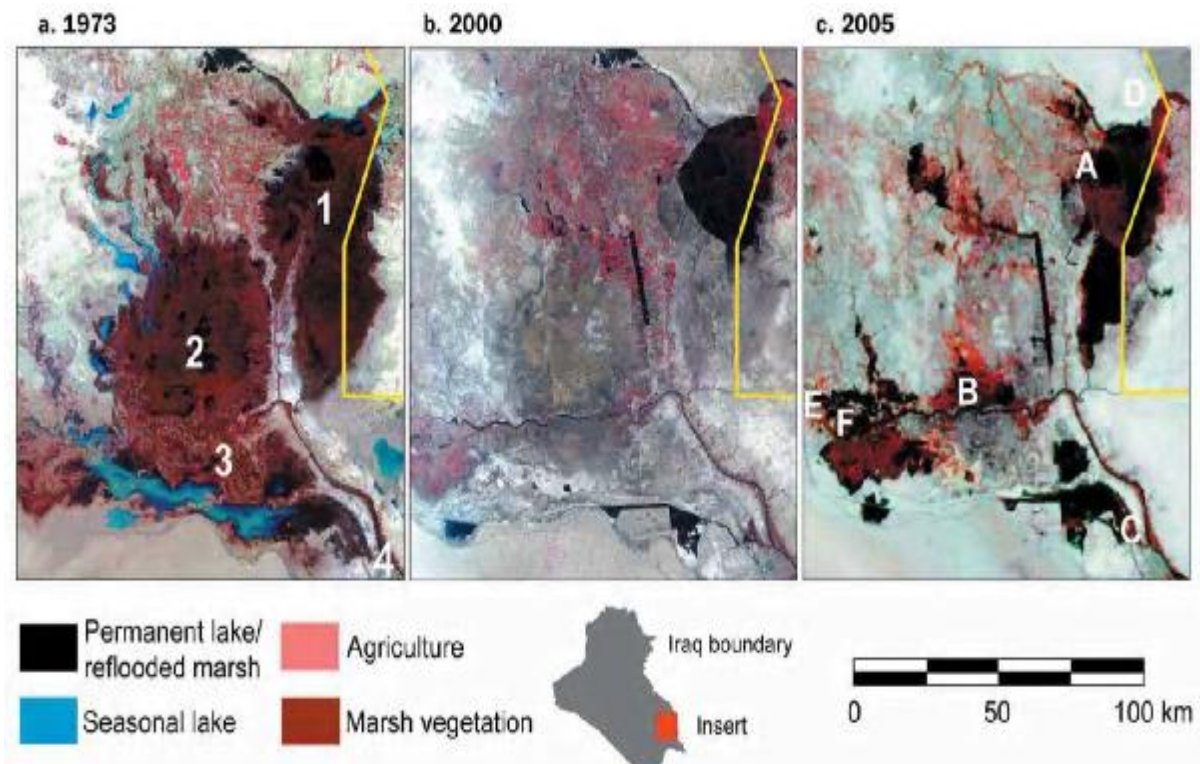**Figure 1. Map of Iraq (1a) and the Mesopotamian marshes (1b).**

Figure 2. (a) A composite view of the Mesopotamian marshlands from four Landsat 1 images and two false-color, near-infrared images, 1973–1976. The three main marsh areas are Al-Hawizeh, Central, and Al-Hammar, labeled 1, 2, and 3, respectively. The city of Basrah is located at number 4.Modified from Richardson *et al*. (2005). (b) A Landsat 7 Enhanced Thematic Mapper mosaic taken in 2000. Most of the drained marshes appear as grayish-brown patches, indicating dead marsh vegetation or low desert shrubs and dry ground. The white and gray patches indicate bare areas with no vegetation and sabkah (salterns) or shells covering the bottoms of former lakes. (c) False-color image of the remaining Mesopotamian marshlands, taken 2 September 2005. Black= areas newly reflooded since 2003. Reflooded areas adjacent to Al-Hawizeh, the western area of Al-Hammar, and waterways in the northern and southern parts of the Central marsh are also visible in black. Al-Hawizeh straddles the Iraq–Iran border (yellow line). Sampling sites: A, Al-Hawizeh; B, Central; C, Al-Hammar; D, Al-Sanaf; E, Abu Zarag; F, Suq Al-Shuyukh. MODIS satellite image courtesy of the United Nations Environment Programme, Iraq Marshlands Observation System (From: Richardson and Hussain, 2006).

3-Results

Water Temperature

Water temperatures of the marshes of southern Iraq experienced large seasonal fluctuations, with monthly averages ranging from 13.3 to 33.3°C (Figure 3). Due to the shallowness of the marshes, the seasonal cycle of water temperature closely followed that of the air temperature. The lowest water temperature (9.9°C) was observed during January 1988 in the Al-Hammar marsh (Al-Aarjy 1988; Hassan 1988). Variability was also greatest during the winter months. Maulood *et al.* (1979) reported little evidence of thermal stratification as surface and bottom temperatures usually differed by <0.5°C.

Salinity

Each of the marshes showed some evidence of saline intrusion (Figure 2). Salinities were generally in the oligohaline (0.5 to 5.0 PSU) range, although even low mesohaline salinities were reported from the Al-Hammar marsh (Table1& 2).Banat *et al.* (2006) found that spatial and temporal differences existed between parts of Al-Hammar marsh but in general salinity increase toward the south .

Dissolved Oxygen

Dissolved oxygen (DO) concentrations were generally high (Figure 3). Hypoxia was rarely observed and then only in remote areas. DO concentrations ranged from 1.67 mg l^{-1} (Al-Zubaidi 1985) to 11.95 mg l^{-1} (Al-Laami 1986). Percent saturation ranged from 23.2% to 136.7%. A seasonal cycle was evident, in which the highest values occurred in winter and the lowest in summer (Figure 3). This cycle suggests that temperature, perhaps more so than biological processes, regulates the DO cycle in the marshes.

DO showed little relationship to depth. For example, Maulood *et al.* (1979) measured 4.2 mg l^{-1} at the surface and 5.03 mg l^{-1} at 3m (Table 3). Regionally, Al-Aarjy (1988) recorded 9.1 mg l^{-1} in Al-Chebayesh/Qurna marshes, 8.30 mg l^{-1} in Al-Hammar, and 8.1 mg l^{-1} in the Al-Taar marsh during March and April of 1988 (Table 1). Seasonal changes in DO were less evident in the open marsh areas ("burkah") and more pronounced in the littoral areas of the marsh, where changes in water levels were proportionately greater (Al-Zubaidi 1985; Al-Lammi 1986).

Carbon Dioxide

Few of the historical investigations dealt with direct determination of CO_2. Pankow *et al*. (1979) reported concentrations ranging from 2.2 to 11.8 mg

l^{-1} in a Baghdad burkah (Qurna marshes); Al-Saadi *et al.* (1981) measured values between 15.0 and 26.0 mg l^{-1} in the Al-Hammar marsh.

Several studies showed that the total available inorganic carbon (including free CO_2 and HCO_3) ranged between 88.6 and 160.2 mg l^{-1} (Al-Zubaidi 1985; Kassim 1986; Al-Lammi 1986; Al-Arajy1988).

Total Suspended Solids

Total suspended solids (TSS) concentrations in the Al-Hammar marsh ranged between 1.3 to 4.4 mg l^{-1} (October 1987 to August1988(Al-Aarjy 1988).

Phytoplankton Abundance

The open water marshes were generally characterized by low concentrations of phytoplankton. Cell counts ranged from 0.97×10^3 cells l^{-1} in February 1987 to 44.5×10^3 cells l^{-1} in September 1979 (Maulood *et al.* 1981). In isolated areas cell counts did exceed 1.0×10^6

cells l^{-1} (Al-Zubaidi 1985; Al-Laami 1986). By comparison, Al-Saadi *et al.* (1981) recorded 6.0 $\times 10^6$ cells l^{-1} in a Baghdad area burkah (Qurna marshes) during April and May 1987.

Light Penetration

Secchi disk depth is a common method

used to determine the depth of light penetration in the water column (Lind 1979) and most of the previous marsh investigations employed this technique. Light generally penetrated to the bottom in open areas of the marshes (Table 1). Sediments were more easily disturbed in channels off the main body of the marshes and light penetration was diminished. For example, Maulood *et al.* (1979) recorded a Secchi depth of 50 cm near Um-Shuwayich (Qurna marshes), in an area affected by boat traffic and currents. In contrast a Secchi disk depth >3m was recorded in an open water area of the marsh.

Within the Al-Hammar marsh, Al-Aarjy (1988) and Hassan (1988) showed that there were regional differences in light penetration (Table 1). Secchi disk depths were greater in the Al-Hammar marsh than in the Al-Chebayesh (Qurna marshes) and Al-Taar marshes. Light penetration also varied seasonally (Figure 3), with the greatest depths in summer and fall and shallower depths in winter and spring.

Anions and Cations

Maulood *et al.* (1979) found that the concentrations of Na and K ranged from 60 to 232 mg l^{-1} and 2.2 to 3.4 mg l^{-1} respectively in Qurna marshes but Banat et al(2006) recorded higher values in Al-

Hammar 179 to795 mg/l and 3-13 mg/l for Na and K respectively. These values were higher than those recorded in Lake Al-Habania, south of Baghdad (Al-Kaisi 1964). Al-Saadi *et al*. (1981) recorded SO_4 concentrations between 78 and 126 mg l^{-1}. Chloride concentrations ranged between 60 to 80 mg l^{-1} in Qurna marshes (Baghdad burkah) during April and May.

Abdullah (1982) measured concentrations of the cations Na, Ca, Mg, and K in Al-Hammar marsh as 289, 89, 100, and 7 mg l^{-1} respectively. Al-Saadi and Al-Mousawi (1988) recorded much higher values (849, 573, 209, and 47 mg l^{-1} respectively). Concentrations of the anions Cl, HCO_3, SO_4, and CO_3 in the Hammar marsh were measured as 283 to 1284, 64, 278, and 2 mg l^{-1} respectively (Abdullah 1982,Antoin 1984; Banat *et al.* 2006).

Hydrogen ion concentration (pH)

Mean pH in the three different marsh systems was slightly alkaline (Table 1). pH varied by depth (Table 2), with highest values near the surface. Highest pH occurred during the winter months and values during the other seasons were similar (Figure 3).

Total Alkalinity

Total alkalinity ranged between 72 and 336 mg $CaCO_3$ l^{-1}. Alkalinity was generally highest during winter and lowest during summer and autumn (Figure 3).

Mean alkalinity was similar between the two sub-areas of the Al-Hammar marshes and the Al-Chebayesh marsh (Qurna marshes) (Table 1). Al-Zubaidi (1985) reported 26 mg $CaCO_3$ l^{-1} in the Qurna marshes while Al-Laami (1986) recorded values of ranging between 8 and 136 mg $CaCO_3$ l^{-1} in the Al-Hammar marshes

Total Hardness

Waters in the marsh system were defined as hard to very hard according to the Reid scale (Reid 1961), with values ranging from 452 to 1339 mg $CaCO_3$ l^{-1} (Figure 3). Lower values were recorded in winter and autumn with highest values during summer .Spatial variations of HCO3 concentration coincides with other ions. its average concentration in Al-Hammar marsh ranged 40-125 mg/l(Banat *et al*,2006)

There was a difference between total hardness and the hardness due to Ca and Mg (Figure 3). Total hardness reflected contributions from Cl, SO_4, Na, and K as well as silicates. Large differences in hardness were observed between open water areas of the marshes and the more heavily vegetated areas (Al-Zubaidi 1985, Kassim 1986; Al-Laami 1986). Al-Aarjy

(1988) and Hassan (1988) reported similar values within the Al-Hammar marsh (Table 1).

Nutrients

The earliest studies of nutrients in the marshes dealt with non-organic nitrogen, phosphorus, and silicates. More recent research (late 1980's) examined total and dissolved nitrogen and phosphorus.

Nitrite nitrogen concentrations ranged between 0.001 to 2.07 µmol l^{-1} (Al-Laami 1986, Al-Zubaidi 1985,Al-Aarjy 1988; Al-Rikabi 1992) in different parts of Al-Hammar marsh, although the mean concentrations only ranged up to 0.03 µmol l^{-1} (Table 1). Comparable values were found in the Qurna marshes (Maulood *et al.* 1979). Nitrite nitrogen concentrations were similar at different water depths (Table 2) and between seasons (Figure 5).

Nitrate nitrogen in the marshes ranged between 0.01-3.54 µmol l^{-1}. These values were lower than those of Iraqi lakes (Rzoska *et al.* 1980, Moulood and Al-Mousawi 1984; Al-Tamimi1992).

Seasonality of nitrate concentrations was pronounced (Figure 5). Spatial heterogeneity was particularly evident when littoral areas of Al-Hammar marsh were compared to open water areas (Al-Zubaidi 1985; Al-Laami 1986). Within the Al-Hammar marsh, nitrate concentrations were higher than in the Al-Chebayesh marshes (Qurna marshes) and lower in Al-Taar (Table 1). There was some evidence of vertical stratification with surface waters having higher concentrations than other depths (Table 2).

Ammonia concentrations in this system were generally low (0.001 to 3.23 µmol l^{-1}) (Al-Aarjy 1988). Al-Saadi *et al.* (1981) did, however, record concentrations as high as 14.29 µmol l^{-1} in a Baghdad area burkah in the Qurna marshes. There were seasonal changes in ammonia concentrations, with highest values during the summer and lowest during winter and spring (Figure 5).

Organic nitrogen represented a high percentage of total nitrogen (TN) in the marshes. Historically, TN concentration in the Al-Hammar marsh ranged from 5.6 to 21.4 µmol l^{-1}. Total dissolved nitrogen concentrations of 2.3 to 17.1 µmol l^{-1} were measured during 1987-1988, when water levels were higher than normal (Al-Aarjy 1988). A comparison of TN in flowing and stagnant waters by Al-Rikabi (1992) showed that higher concentrations occurred when velocities were lower (20.7 to 48.9 µmol l^{-1} vs. 67.3 to 90.5 µmol l^{-1}). The lowest concentrations occurred during May with highest values in January. There was little spatial variability in TN

concentrations. Al-Aarjy (1988) and Hassan (1988) reported concentrations of 8.9 to 14.4 µmol l^{-1} in Al-Chebayesh, Al-Hammar and Al-Taar during March and April 1988 (Table 1).

Soluble reactive phosphate (SRP) was often the focus of the historical studies of marsh water quality. Concentrations ranged between 0.08 and 1.14 µmol l^{-1} (Table 11). Seasonality was evident, with the highest values recorded in summer and autumn (Figure 5). Total phosphate (TP) concentrations ranged between 0.33-5.95 µmol l^{-1} in Al-Hammar marsh (Al-Aarjy 1988; Al-Rikabi 1992).

The ratios of inorganic nitrogen: SRP were generally <10:1 and ranged down to 5:1 (Al-Aarjy 1988). TN:TP ratios were somewhat higher (Table 1).

Silicate concentrations in the southern marshes of Iraq were relatively high and were not a limiting nutrient for diatom growth. Concentrations ranged between 11.9 and 242 µmol l^{-1}. Mean concentrations were higher in Al-Taar than in either Al-Hammar or Al-Chebayesh (Table 1).

Table 1. Spatial variations in mean values of selected physical and chemical characteristics of the Al-Hammar marshes (Al-Hammar and Al-Taar) and Qurna marshes (Al-Chebayesh) of southern Iraq. (Adapted from: Al-Aarjy 1988 and Hassan 1988)

Variable	Al-Chebayesh	Al-Hammar	Al-Taar
Water Temperature ($^\circ$C)	18.7	18.8	22.2
Dissolved oxygen (mg/l)	9.0	8.3	8.0
Secchi Disc Depth (cm)	115	280	135
Conductivity (μS cm^{-1})	309	244	173
Salinity (PSU)	1.98	1.56	1.11
pH	7.16	7.28	7.26
Total Alkalinity (mg l^{-1})	102	113	115
Total Hardness (mg l^{-1})	753	564	594
Calcium (mg l^{-1})	148	128	159
Magnesium (mg l^{-1})	95	77	49
Nitrite Nitrogen (NO_2) (μmol l^{-1})	0.03	<0.001	<0.001
Nitrate Nitrogen (NO_3) (μmol l^{-1})	0.55	0.20	0.01
Ammonia Nitrogen (NH_3) (μmol l^{-1})	0.02	0.09	0.08
Total Nitrate Nitrogen (μmol l^{-1})	13.47	11.90	14.40
Total Dissolved Nitrate Nitrogen (μmol l^{-1})	8.30	5.70	10.20
Particulate Nitrate Nitrogen (μmol l^{-1})	5.17	6.20	4.20
Total Phosphate (TPO_4) (μmol l^{-1})	0.90	0.70	0.50
Soluble Reactive Phosphate (SRP) (μmol l^{-1})	0.22	0.50	0.10
Total Phosphate (μmol l^{-1})	0.60	0.20	0.40
Ratio of Total Nitrogen: Total Phosphorus	15:1	15:1	29:1
Total Silicates (SiO_2) (μmol l^{-1})	11.9	11.9	17.0

Table 2. Mean and ranges of salinity (PSU), by region, in the marshes of southern Iraq.

Region	Study Period	Mean (Range)	Source
Al-Hammar Marsh	1969-1972	0.3 (0.2-0.4)	Al-Sahaf (1976)
Al-Hammar Marsh	1983-1984	4.0 (0.6-7.4)	Al-Zubaidi (1985)
Al-Hammar Marsh	1984-1985	2.3 (1.3-4.3)	Kassim (1986)
Al-Hammar Marsh	May 1985	2.2 (1.5-2.8)	Al-Saadi and Al-Mousawi (1988)
Al-Hammar Marsh	1987-1988	2.4 (1.2-4.5)	Al-Aarjy (1988)
Al-Hammar Marsh	1990-1991	5.2 (3.5-6.3)	Al–Rikabi (1992)
Qurna Marsh	October 1977	1.3 (--)	Arndt and Al-Saadi (1975)
Qurna Marsh	April 1977	0.6 (0.5-0.6)	Pankow *et al.*(1979)
Qurna Marsh	February 1978	0.4 (0.3-0.5)	Maulood *et al.*(1979)
Qurna Marsh	April-June 1978	0.4 (0.3-0.5)	Al-Saadi *et al.* (1981);
Qurna Marsh	September 1979	0.6 (0.6-0.6)	Maulood *et al.* (1981)

Table 3. Mean values of selected physical and chemical variables, by depth, in the marshes of southern Iraq (Adapted from: Maulood *et al.* 1979)

| Variable	Near-surface	1-m	2-m
Water Temperature ($^{\circ}$C)	15.3	15.3	15.3
Conductivity (μS cm^{-1})	98	92	91
Dissolved Oxygen (mg l^{-1})	4.2	5.2	5.0
pH	8.40	7.97	8.1
Total Alkalinity (mg l^{-1})	294	301	306
Sodium (mg l^{-1})	148	92	92
Potassium (mg l^{-1})	2.8	2.7	2.9
Nitrite Nitrogen (NO_2) (μmol l^{-1})	0.12	0.13	0.11
Nitrate Nitrogen (NO_3) (μmol l^{-1})	4.51	1.42	3.0
Ammonia Nitrogen (NH_3) (μmol l^{-1})	0.64	0.80	0.64
Total Phosphate (TPO_4) (μmol l^{-1})	0.31	0.37	0.52
Total Silicates (SiO_2) (μmol l^{-1})	65.4	65.4	61.4
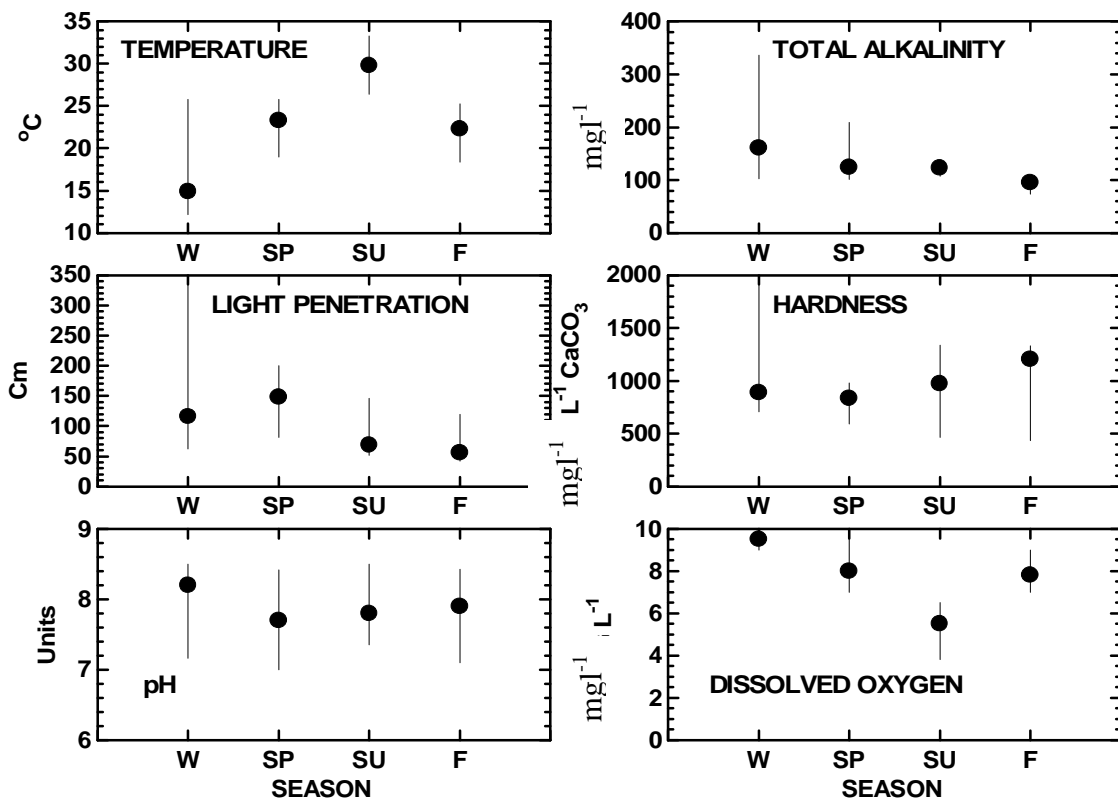
Figure 3. Mean and ranges of water temperature, light penetration, pH, total alkalinity, hardness, and dissolved oxygen, by season, in the marshes of southern Iraq. Adapted from: Arndt and Al-Saadi (1975); Maulood *et al.* (1979 and 1981); Pankow *et al.* (1979); Al-Saadi *et al.* (1981); Al-Zubaidi (1985); Al-Laami (1986); Kassim (1986); Al-Aarjy (1988); Al-Saadi and Al-Mousawi (1988); Al-Sayab (1988); Hassan (1988); Mohammad (1989);Hussein *et al.*(1992).
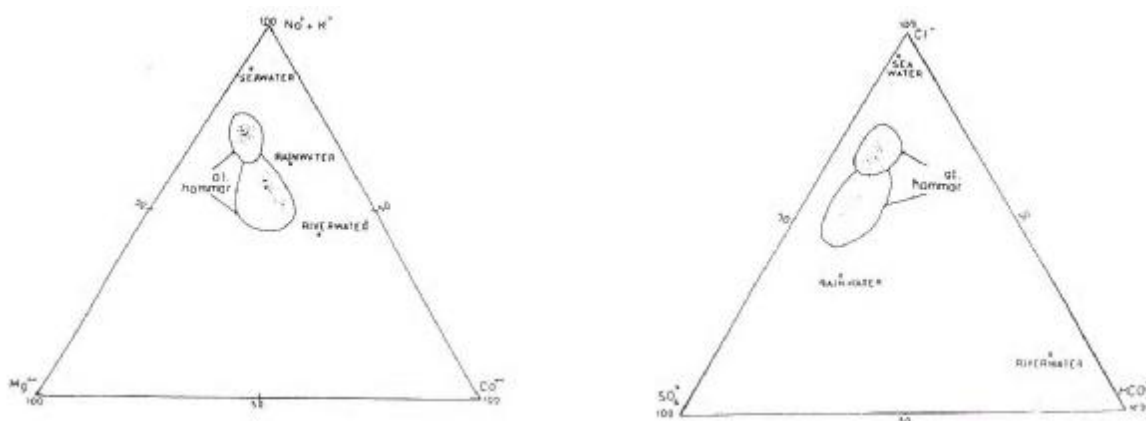

Figure 4. Relative molar distribution of major cations and anions in water samples from the Al-Hammar marsh, compared to seawater, precipitation, and river water (after Livingstone 1963). Adapted from Hussain and Hassan (2003).
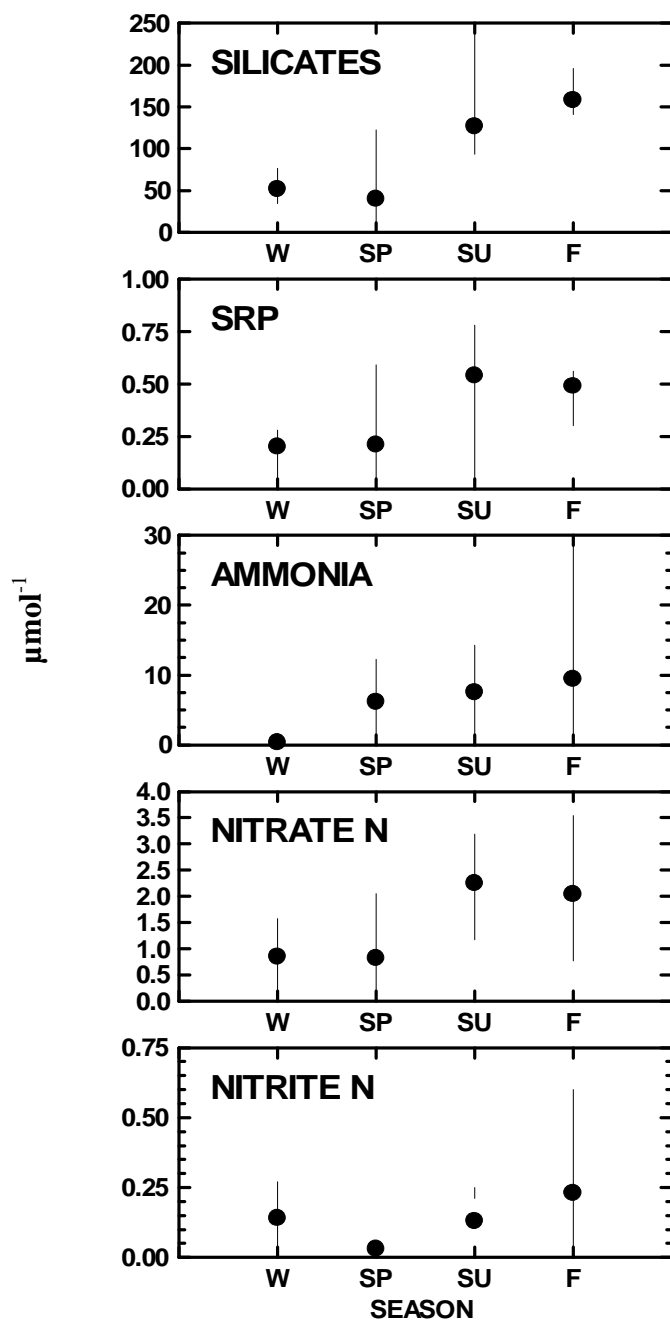
Figure 5. Mean and ranges of nitrite, nitrate, ammonia, soluble reactive phosphorus, an silicates, by season, in the marshes of southern Iraq. Adapted from: Al-Zubaidi (1985); Al-Laami (1986); Kassim (1986); Al-Aarjy (1988); Hassan (1988); Al-Rikabi(1992).

4- Discussion

Investigations of the water quality of Iraq's southern marshes have generally been limited in scope, duration, seasonality, and spatial extents (e.g., Al-Hammar marsh). There have been few studies of the Qurna (central) marshes and none in the Al-Huwayza marshes because of accessibility issues.

Yuaqub and Salman (1992) concluded that, although the southern marshes were relatively large water bodies occupying vast areas, they were affected by the arid climate and its characteristic temperatures, humidity, precipitation and evaporation. Water temperature closely followed the seasonal cycle of air temperature because of the shallow water depths of this ecosystem.

Salinity of the marshes was affected by both the volume of freshwater entering the marsh system and evaporation rates. Salinity was generally quite low when river flows were high (Pankow *et al.* 1979; Al-Saadi *et al*. 1981). During the September through November dry season salinity increased due to diminished freshwater contributions (Arndt and Al-Saadi 1975; Maulood *et al*. 1981; Al-Aarjy 1988; Hassan 1988).

The second factor affecting salinity, evaporation rate, is linked to the higher seasonal temperatures during summer and early fall. Yuaqub and Salman (1992) estimated summer evaporation rates in the southern marshes as 1840 mm year^{-1} whereas Bringh (1960) calculated a higher rate (2450 mm year^{-1}).Banat *et al*.(2006) reach the same conclusion that evaporation play the major role in deciding the salinity of the southern marshes.

Although evaporation is a factor in this seasonal cycle, the diversion of flows from the Tigris and Euphrates to dams and reservoirs in Turkey, Syria, Iran, and Iraq have further reduced the amount of water entering to the marshes. Al-Rikabi (1992) recorded a salinity of 6.3 PSU. This was higher than other lakes, reservoirs, and rivers in Iraq at this time. In fact, the salinity of the southern marshes was higher than that of the Tigris, Euphrates, and Diyala rivers (Al-Mukhtar *et al.* 1985), Al-Habaniya lake, and the Dokan Reservoir (northwest of Sulaymaniyah in Kurdistan) (Al-Hamed 1976, Shaban 1980; Zdanowski *et al*. 2001a). Salinities were still lower than that of Sawa (south of Baghdad), and Al-Razaza (southwest of Baghdad) lakes (Maulood and Al-Mousawi 1984; Al-Tamimi 1992; Zdanowski *et a*l. 2001a).

Salinity values have gradually increased over time, reaching 6.3 PSU in 1991 (Al-Rikabi 1992). Again, this was likely related to the construction of dams and reservoirs in recent decades. Salinities >0.5 PSU are generally considered unsuitable for human consumption and values $\geq$ 1.5 PSU preclude the use of the water in agriculture.

TSS concentrations in Al-Hammar marsh ranged between 1.3 and 4.4 mg l^{-1} (Al-Aarjy 1988). These concentrations are <30th percentile for Florida lakes and streams (Friedeman and Hand 1989). Higher TSS concentrations have been recorded from the Tigris and Euphrates rivers and the Shatt Al-Arab River (Rzóska *et al*. 1980). The intensive macrophyte growth in the marshes effectively reduced current velocities. This, in turn, facilitated the settlement of suspended particles, assuring the role of the southern marshes as a sedimentation bed for suspended particles brought by the Tigris and Euphrates rivers.

Secchi disk depths often reached the bottom in open areas of the marshes. Light penetration in these marshes was typically greater than in Iraqi lakes (Rzóska *et al*. 1980; Al-Tamimi 1992; Zdanowski *et al*. 2001b). Thick aquatic vegetation facilitated the settling of suspended materials, thereby increasing the light penetration of the water

column. Light penetration in shallow areas was restricted because waters were typically colored from the phytoplankton and suspended material (Al-Aarjy 1988; Hassan 1988). Secchi disk depths were more restricted in channelized areas used by boats, which can resuspend fine-grained sediments.

DO concentrations were generally adequate to support aquatic life (i.e., >4 mg l^{-1}) and, in fact, were generally high. This was due to the shallowness of the marshes, its extensive plant coverage, and epipelic phytoplankton. Hypoxia was rarely observed. Rzóska *et al.* (1980) pointed out that in certain areas of the marshes decomposition of vegetation and high organic loads from buffalo and cow feces and urine contributed to hypoxia (cf. Al-Zubaidi 1985).

pH values in the marshes should have been related to the CO_2 content. In summer and autumn, increased CO_2 should have reduced pH due to decomposition of organic material same was reported by Banat *et al.*(2006) that lower pH existed in Al-Shafi marsh. However pH was largely unaffected because the high water temperatures reduced the solubility of CO_2 and let it escape to the air, leading to equilibrium between water and air.

pH was generally been on the alkaline

side with a slight increase in dissolved CO_2 during summer and autumn. Al-Zubaidi (1985) reported a pH of 9.13 in the Qurna marshes that coincided with very high concentrations of phytoplankton during the spring bloom. Al-Kaisi (1976) and Banat et al.(2006), however, recorded values as low as 6.5. The dense macrophyte beds in the marshes contributed to high CO_2 during winter and spring which, in turn, contributed to the reduced pH and also to biological activities of micro-organsims aid in the decomposition of organic sulfer compounds yielding in lowering the pH.

Alkalinity was mainly related to bicarbonate concentrations within marsh waters, which was generally considered to be hard to very hard. Alkalinity values were comparable to those reported by Miller *et al*. (1999) for another large marsh ecosystem, the southern Everglades of Florida (USA).   Total hardness values revealed the importance of sulfate and chloride salts in addition to carbonate hardness.   The   marshes   of   southern Mesopotamia,   then,   appeared   to   be generally similar to other water bodies in Iraq at this time.

pH values between 7 and 8 indicated a slight increase of CO_2 in the water. This was found to be the case in the marshes year-round.   The   high   water   and   air temperatures   accelerated   the   decay   of organic material, leading to the breakdown of $CaCO_3$, increased CO_2, and the formation of carbonic acid.   During periods of high primary productivity (winter and spring) there was increased pH and precipitation of $CaCO_3$.   This $CaCO_3$ precipitate can be recognized as a thin layer on the leaves of macrophytes in the marshes.

Abdullah (1982) pointed out that the concentrations of cations and anions of Al-Hammer exceeded that of the Tigris and Euphrates rivers.   He   showed that the concentrations of these ions were ranked as: Na > Mg> Ca> K> Cl > SO_4 > CO_3, the same was concluded by Banat *et al*,(2006). This ranking is indicative of concentration mid-way   between   marine   and   riverine waters.

Richardson *et al*. (2005) pointed out that all major cations and anions in Iraqi inland waters, except K, exceeded the concentrations reported for the mean of the world's rivers by 1-2 orders of magnitude. These results were similar to other rivers and water bodies in arid regions in which evaporation of significant amounts of water resulted in greater concentrations of ions than non-arid rivers before reaching the ocean (Schlesinger 1997).   Hussain and Hassan (2003) showed that cations and anions concentrations in Al-Hammar marsh

differed in composition from riverine and estuarine waters as well as from wet precipitation.

Nutrient concentrations were never limiting for phytoplankton and macrophyte productivity. The shallowness of the marshes facilitated the release of nutrients from the marsh sediments and the decomposition of submerged and emergent vegetation also contributed to the nutrient load (Maulood *et al.* 1979). Marsh waters were characterized by low nitrite nitrogen concentrations, which suggested that pollution was relatively low. DO depletion at night did lead to some increases in nitrites (Al-Mousawi and Hussain 1992).

Nitrate nitrogen is the most common form of inorganic nitrogen in well-oxygenated waters and is always found in low concentrations in unpolluted waters (Reynolds 1984). In this marsh system nitrate was also the dominant form of inorganic nitrogen with averages between 0.01 and 3.5 µmol l^{-1} .These values were low compared to other water bodies in Iraq, such as the Razaza and Sawa lakes (Rzóska *et al.* 1980, Maulood and Al-Mousawi l984; Al-Tamimi 1992). The low concentrations were likely related to the dense macrophyte growth and the low density of agriculture in this system.

The non-organic phosphorus concentrations in the marshes were within in the range typical of lakes in different parts of the world (Reid 1961). Concentrations tended to be higher during the summer months. High water temperatures accelerate the decay of submerged and emergent vegetation and uptake by plants is low. Concentrations were lower during the cooler months because primary production was higher and rainfall and increased stream flow diluted concentrations of phosphate.

Phosphorus concentrations may remain relatively high in marsh waters because the macrophytes are unable to absorb all of the phosphorus available relative to the available nitrogen pool (Al-Aarjy 1988; Al-Rikabi 1992). In fact, Al-Aarjy (1988) noted that activity of the enzyme soluble alkaline phosphate was relatively low during March and April 1988 in Al-Hammar marsh. Several authors have attributed the presence of this enzyme to be an indicator that the macrophytes were relying upon organic sources of phosphorus (Healey 1982).

Silicate concentrations in the marshes were also similar to that of other water bodies in Iraq at that time (Al-Kaisi (1964), Rzóska *et al.* 1980, Shaban 1980, Al-Laami 1986, Al-Aarjy 1988; Al-Tamimi 1990).

The higher concentrations during summer and fall may be indicative of the release of silicates from the sediments and decomposing diatoms (Reynolds 1984).

These concentrations were never a limiting factor for phytoplankton growth. This is the typical condition for water bodies proximate to arid lands, such as are common in Iraq. Nutrient limitation experiments indicated that the marsh phytoplankton were nitrogen limited. Water quality data showed that the ratio of inorganic nitrogen:SRP was typically ~10:1. Under such conditions (especially where N:SRP ratios are this low), conditions are favorable for the dominance of the phytoplankton by nitrogen-fixing cyanobacteria. Al-Mousawi and Whitton (1983) in fact, found that blue-green algae were abundant in the marshes they studied.

Water quality conditions in the marsh ecosystem of southern Iraq has been investigated for more than 20 years by a variety of researchers and graduate students, each examining a specific problem. These marshes are a valuable resource both ecologically and economically. The waterways, vegetation, waterfowl, shrimp and finfish provide habitat and food resources for the local populace. These water resources and the inhabiting fauna offer the potential for exploitation by populations within southern Iraq. As restoration of this unique and vast system continues

(Iraqi Ministeries of Environment, Water Resources, Municipalities, and Public Works 2006), it is imperative that monitoring of the marsh's water quality and biota continue so that progress can be measured and problems are identified before they become detrimental to the restoration process.

5- Acknowledgements

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استعراض لنوعية المياه في أهوار وادي الرافدين قبل التجفيف الكبير لها في بداية التسعينات

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الخلاصة

تراوحت مساحة الاهوار العراقية الجنوبية ما بين ٨٠٠٠-٣٠٠٠٠ كم ^{٢}. أن وصول المياه العذبــة اليهــا تائرت بإنشاء السدود علي نهري دجلة و الفرات في الدول المتشاطئه لهما. في بداية التـسعينات قامــت الحكومــة العراقية السابقة بتجفيف مساحات شاسعة و رئيسية من هذا النظام البيئي و حرق تجمعات كبيرة وواسـعة لنبــا ت القصب الشائع و ما يبقى من هذه الاهوار يقــدر بأقــل مــن ١٠% مــن مـساحتها الـسابقة بحــدود عــام ٢٠٠٠ (Partow 2001 and Branigston 2002) هذا ا ألاستعراض يلخص المعلومات و النتائج المنشورة عــن نوعيــة المياه في هذا النظام البيئي الفريد قبل قيام الحكومة العراقية السابقة بتدميره من خلال عملية تجفيف منظمه .

أن هذه النتائج جاءت من العديد من الأبحاث المنشورة و رسائل الماجستير والتقارير المحدودة النشر . ان نوعيــة المياه المقصودة تشمل الملوحة والتركيب الايوني وعدد من العوامل المتصلة بحالة المغذيات . بينت النتائج ان درجة الملوحة تزداد مع مرور الزمن. اما تركيز اوكسجين المذاب فبصورة عامة مرتفعة و المياه ذات قاعدية خفيفة وكما ان كثافة النباتات المائية العالية تساعد على ترسيب المواد العالقة. النترات هــي الـشكل الـسائد مــن النتــروجين اللاعضوي وان تركيزها اقل بالمقارنة مع بقية الأجسام المائية الداخلية و تبين أن النترات هي العامل المحدد لنمو الهائمات النباتية .