# Restoration Assessment: I- Phosphorus and Nitrogen dynamics versus phytoplankton biomass in Al-Hawizeh marshland, Iraq

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***Abstract***
*Inundation of the Mesopotamian marshlands, southern Iraq, brings the anticipation of restoring the destroyed habitat to life again. It is important from the restoration point of view to study the relationship between water quality parameters and marshland's productivity. Al-Hawizeh, one of the three main marshlands of the Mesopotamia, has been studied intensively after re-flooding in April 2003. During the desiccation period, the marshland features three significant parts: never dried, semidried, and completely dried areas. The main goal of this study is to find whether the newly re-flooded marshes in Al-Hawizeh exhibit healthy nutrient dynamics in contrast to their primary production biomass.Water quality parameters and chlorophyll-a concentrations were monitored on a monthly basis from May 2006 to April 2007 ineight marshes in Hawizeh. The result indicates significant differences ($P > 0.005$) between the selected marshes in Al-Hawizeh, whichsuggest that Al-Hawizeh marshland system is not a one homogeneous ecosystem as used to be pre desiccation period. Also, there was a relationship between chlorophyll-a and both TP and TN concentrations;however, the relationship between chlorophyll-a and TN was stronger than TP. In conclusion, the overall water quality assessment suggests a good prospective recovery ability of the semi dried marshes and marshes has a river water input comparing to the completely dried marshes in Al-Hawizeh.*

**Key words:** Mesopotamian marshes, restoration assessment, water quality assessment; phosphorus variation, nitrogen variation, chlorophyll-a.

## 1.1 Introduction

Thirteen years after the desiccation of the Mesopotamian marshlands, and the beginning of their re-inundation in April 2003, still there is a hopeful expectation that these ecosystems will return to their natural condition. This study focused on variation in Phosphorus (P)and nitrogen (N), and their implication for the restoration process of Al-Hawizeh marshland specifically as a part of the Mesopotamian marshlands. P and N are two of the most important nutrients for plant growth and they represent two of the most common limiting factors for the aquatic systems (Mitsch & Gosselink, 2000). Therefore, they tend to be the most limiting nutrients for the production of the organic matter via photosynthesis (Wetzel, 2001). Their variation also plays a role in the distribution and diversity of the phytoplankton, periphyton, and macrophytes (Dillon &Rigler, 1974; McCauley *et al*., 1989; Radwan, 2005; Panigrahi*et al*., 2007). It is important from the restoration point of view to study P and N availability and distribution in the newly inundated marshes in Al-Hawizeh marshland. The main goal ofthis study is to find whether the newly re-flooded marshes in Al-Hawizeh exhibit healthy nutrient dynamics in contrast to their primary production biomass. Normally, phytoplankton standing crop increases when there is enough nutrient supply (Dillon &Rigler, 1974). This study attempt to compare the total P (TP) and total N (TN) distribution and their correlation with phytoplankton biomass, represented by chlorophyll-*a*, in eight marshes inAl-Hawizeh marshland and test the differences of physical-chemical and nutrients variation among the selected station in Al-Hawizeh marshland.

## 1.2 Study site descriptions

Al-Hawizeh is a mix of permanent and seasonal open water, mudflats, and inundated plains of fresh water marshes, dominated by emergent aquatic plants such as *Phragmites* and *Typha*. Since the desiccation of the Mesopotamia in 1993, the north part of the Al-Hawizeh (Al-Udhaim marsh) retained water from the Iranian side that share part of Al-Hawizeh under their territories. Al-Udhaim kept its original size and environmental features; and therefore it is important for the restoration assessment point of view. Also, the seasonal water flow from Al-Udhaim into the south west allows a grate portion of North West Al-Hawizeh to be partially wet. In contrast, the rest of the Al-Hawizeh marshes were completely dried. Historically, the Al-Hawizeh marshland was a one unique and homogeneous ecosystem. The damage caused by desiccation processes left remarkable effects on, especially in the central and southern parts of the marshland. For example, the construction of embankments disturbed the land sediment by moving it to create these embankments and still affects the flow of water.

## 1.3 Material and methods

**Field sampling:**Fieldwork was carried out on a monthly basis starting in May 2006 to April 2007. The monthly variation of TP, TN, and chlorophyll-

*a* were studied ineight marshes in Hawizeh (Figure 1, Table 1). The sampling stations were selected to represent different hydrological status of Al-Hawizeh from desiccation to inundation. According to the hydrological status, the marshes were divided into three groups: the first group includes Al-Udhaim the ever-wet marsh, the second group includes the marshes that has water supply from rivers and partially dried, the third group include the southern marshes that completely dried and became a desert.At each station, triplicate surface water samples (30 cm bellow the water surface) and triplicate bottom water samples (30 cm above the sediment surface)were collected from two depths using aVan Dorn bottle sampler. Physical and chemical parameters including water temperature, salinity, dissolved oxygen, and pH were measured using the WTW Multi-meter model 350i. Water column depth was measured using an extendable ruler. Light penetration was measured using a Secchi disk.The water samples were filtered immediately in the field using pre-weighed GF/F 0.7 µm pore-size filters. The filtrate (500 ml) was transferred into translucent polyethylene screw-cap bottles. Bottles were pre-rinsed with the filtrate twice. Filtrates used to determine nitrite ($NO_2$), nitrate ($NO_3$), and orthophosphate ($PO_4$) were preserved with 5 drops of chloroform (Staintonet *al.*,1977). Another 50 ml of filtrate was transferred into screw-cappedtest tubes and digested with 1.5 ml of 3% potassium persulfate for the determination of total dissolved P (TDP) concentrations (Menzel& Corwin, 1965). To determine total dissolved N (TDN) concentrations, 30 ml of the filtrate was transferred into a screw-capped test tube and digested with 4 ml of oxidation reagent (Valderrama, 1981). Filters with particulate matter were transferred immediately to disposable Petri-dishes and stored at 4 °C (Staintonet *al.*, 1977; Wetzel & Likens, 1991) in order to determine particulate P (PP)particulate N(PN). Filters used to determine chlorophyll-*a* were preserved by adding 5 ml of 1% magnesium chloride to each filter and were transferred immediately to dark amber scintillation vials and stored at 4 °C until the time of analysis (Staintonet *al.* 1977).

**Laboratory analysis:** The ascorbic acid method described by Staintonet *al.* (1977) was used to determine $PO_4$concentrations. $PO_4$ samples were measured using a 1 cm quartz cell in a Shimadzu spectrophotometer at 885 nm.The concentrations of DP in the water samples and PP on the filters were determined according to the method described by Staintonet *al.*(1977). The sum of DP and PP is the TP concentration.The pink azo dye method described by Stanintonet *al.* (1977) was used to determined $NO_2$ concentrations in the water. Samples used to determine $NO_3$ concentration were reduced to$NO_2$ by passing them through a cadmium-copper column and measured as described by Stanintonet *al.* (1977). The DN concentrations in the water were measured by the method described by Valderrama (1981). The PN samples were packed in 7 x 5 mm nickel capsules. The elemental analysis developed by Zimmermann & Keefe (1997) was used to determine the particulate organic N (PON) concentration in the water. The concentration of dissolved organic N (DON) was calculated approximately by subtracting the concentrations of $NO_2$ and $NO_3$ from the concentrations of DN as the previous studies presented in Hussain (1994)found very low concentrations of $NH_4$ in the Iraqi marshes(less than 1 µg N/l), the TN concentrations then were calculated by the summation of DN and PON in the water samples.TSS concentrations were determined according to the gravimetrically method that described by Staintonet *al.*(1977) using a Sartorius balance.Chlorophyll-*a* concentrations were measured according to the monochromatic method described in Lorenzen (1967).

**Data analysis:**The General Linear Model (GLM) in Systat was used to test the relationships between chlorophyll-*a* and TP and TN (Smith, 1982; Prairie *et al.*, 1989; Kufel, 2001). The analysis of covariance (ANCOVA) in Systatwas used to identify the relationship between chlorophyll-*a* concentration and TP and TN concentration in the selected marshes in order to find which nutrient is the main factor control the phytoplankton production in these marshes.*t*-test analysis was used to determine the difference of water physical and chemical parameters, TP concentrations, TN concentrations, and chlorophyll-*a* concentrations in the surface water samples and near bottom.

## 1.4 Results

Comparison of water physical and chemical parameters, TP concentrations, TN concentrations, and chlorophyll-*a* concentrations in the surface water samples and near bottom water samples in the eight marshes of Al-Hawizeh revealed no significant differences (paired *t*-test $P$> 0.005). As a result, the data within the marshes were averaged to show one value per station.

TP and TN concentrations in Al-Hawizeh underwent both spatial and temporal variation (Table 4, Figure 3). TP and TN were high during the summer and winter. The average concentrations of TP and TN were 30.9 µg/l and 245.0 µg/l, respectively. The highest average concentration of TP was 68.4 µg/l recorded in Umm Al-Warid, while the lowest average concentration of TP was 18.6 µg/l found in Al-Udhaim. The highest average concentration of TN was 711.7 µg/l found in Majnoon, while the lowest average concentration was 123.6 µg/l found in Al-Souda south.

Chlorophyll-*a* concentration in Al-Hawizeh also underwent seasonal variation (Table 5, Figure 3).

Among all of the eight marshes, chlorophyll-*a* concentration was high during the summer and early fall then its concentration dropped during winter. During the study period, Majnoon had the highest chlorophyll-*a* among the other marshes. Its concentrations ranged from 1.6 µg/l to 26.2 µg/l. On the other hand, the Al-Baydha marsh had the lowest chlorophyll-*a* concentrations among the other marshes, its concentration ranged from <0.1 µg/l to 3.2 µg/l.

The correlations between chlorophyll-*a* and water physical and chemical parameters, as well as with TP and TN concentration, are differ among the selected marshes if Al-Hawizeh(Table 6).In the Al-Udhaim, chlorophyll-*a* variation was strongly influenced by the light penetration and dissolved oxygen rather than P and N concentrations. However, P and N were the main factors that influenced the chlorophyll-*a* variation in the marshes that are close to the rivers. P and N concentrations were also the main factors that correlated with the variation of chlorophyll-*a* in the Al-Souda south marsh. In the southern marshes, chlorophyll-*a* varied according to both water quality parameters and P and N concentration. Chlorophyll-*a* variation in the selected marshes were positively correlated to the water temperature. It is worth mentioning that cholrophyll-*a* variation in the Al-Baydha marsh is not correlated to any water quality parameter or nutrient.The GLM analysis shows a significant relationship between chlorophyll-*a* and TP ($P$= 0.006) and TN ($P$= 0.000). However, the relationship between chlorophyll-*a*and TN was stronger (Figure 4; Table 7). In addition, the GLM was also used to look at the effect of marsh and month on the variation of TP and TN. In this case the analyses revealed no significant relationships (Table 7).

Based on the history of the eight marshes the *t*- test analysis shows that the three groups of marshes are different based on some water physical and chemical parameters, TP and TN concentrations (Table 8). The analysis shows that the undisturbed marsh (Al-Udhaim) is significantly different from the marshes that are close to the rivers and partially dried (Al-Souda north, Um Al-Niaaj, and Um Al-Warid) in light penetration, TSS, and TP. In addition, Al-Udhaim is also significantly different from the completely dried marshes (Al-Souda south, Al-Baydha, Lissan Ijerda, and Majnoon) in salinity, LP, TSS, TN, and chlorophyll-*a*.

The variation of TP and TN between the selected marshes indicates that the southern marshes are high in TN comparing to the undisturbed marsh (Figure 5). On the other hand, the partially dried marshes have the highest concentration of TP among the other marshes. As a result, the phytoplankton productivity as it presented by chlorophyll-*a* is higher in the southern marshes than the undisturbed marsh.

## 1.5 Discussion

### 1.5.1 Phosphorus and nitrogen dynamics

Natural and artificial impacts likely influenced the TP and TN variation within Al-Hawizeh marshland. Rivers are the main natural factors influenced the TP and TN variation within Al-Hawizeh, especially in the marshes that have direct water supply (Hussain, 1994). For example, the high concentration of TP and TN found in the Um Al-Warid marsh is mostly contributed to its direct water inputthat affect by chemical fertilizers, which were applied heavily during the study period, especially when the farmers prepare their farms for sowing crops (IMWR-CRIM, 2006). Vegetation cover is also a main factor that effects the variation of TP and TN in Al-Hawizeh (Alwan, 1994). The density and variation of plants species among the seasons have a major impact on the TP and TN in which P and N concentrations will vary depend on the efficiency by removal plants and/or complexation(Hambright*et al.*, 1998; Zohary*et al.*, 1998; Radwan, 2005; Krak*et al.*, 2006). Constructed embankments are the main artificial factors influencing the P and N variation in Al-Hawizeh marshland. The field observations indicate that these embankments have a major influence on water currents and the circulation of water. These embankments divide the marshland into many parts and isolate them from the wholeecosystem (UNEP, 2001). The embankments can slow water currents and thus lead to inefficient nutrient circulation. This will eventually affect the P and N transportation between the marshes (Mahamed, 2008). The inefficient P and N circulation could affect the vegetation cover and water quality in Hour Al-Hawizeh.

TP and TN concentrations exhibited different seasonal patterns among the marshes during the study period. Temporal variation of P and N fractions in the eight marshes indicates that DIP and DIN concentrations were low in spring, which is mainly due to uptake by plants during the growing season (Gophen2000;Okbah, 2005; Panigrahi*et al*., 2007). DOP and DON are present in high concentrations in late spring and reach their highest level in summer. This is likely because of the increased bacterial decomposition of dead phytoplankton and macrophytes, which is enhanced by the increase in temperature (Gophen, 2000). The increase in evaporation and decrease in water level also affects the TP and TN concentration in summer (Karh*et al*., 2006). In winter, the increase of TP and TN is mainly due to the low plant uptake (Hussain, 1994). PP concentration was lower than the PN concentration within the marshes during the study period. This is could be due to two reasons: first, it might relate to the low amount of P-containing particles actually entering the system, or the suspended particulate matter in top sediment layer is nitrogen rich. It is well known that N content in living organisms is much higher than P and eventually, after the decay of these organisms, the released amount of N will be higher than P. Second, it could be that the rate of PP solubilization into DOP or DIP is higher than for PN solubilization into DOP or DON, which could be true because the concentration of DOP and DIP are also lower than DON and DIN.

In this study, an extremely high concentration of TP and TN was found in some of the marshes. This is mainly because of the differences between marshes location and hydrological history. For example, TP and TN concentrations are likely influences by the rivers, especially in the marshes located close to water inputs. The differences between each inlet in nutrient eventually will have a significant impact on the vegetation cover in these marshes (Mahamed, 2008). For example, the high average concentration of TP and TN in Um Al-Warid marsh was likely due to the impact of its water input; and the high concentration of TN in the southern marshes, especially PN, was either due to the wide fluctuation of the water column depth within the seasons that led to re-suspension the top sediment layer, as I observed in the Majnoon marsh, or due to the density of plankton as I observed in the Lissan Ijerda marsh (Mahamed, 2008).

P and N concentrations in some of the pre-desiccation studies of the Mesopotamian marshes were within the range of P and N concentrations that I found during my study (Hussain, 1994). However, higher concentrations of P and N fractions were found in different pre-desiccation studies (Hussain, 1994). In addition, concentrations of P and N fractions in my study were close to some of the recent studies that were done in the Mesopotamian marshes after re-flooding (USAID, 2006) where some of the pre-inundation studies indicated higher values of P and N within the Mesopotamian marshes than found in this study (Richardson *et al.*, 2005; Richardson &Hussain, 2006, USAID, 2006).

### 1.5.2 Chlorophyll-*a* variation in Hour Al-Hawizeh

The difference in the seasonal variation of the chlorophyll-*a* between the eight marshes of Al-Hawizeh was likely dependent on their location and vegetation cover (Alwan, 1994). It may be also associated with the ability of these marshes to provide appropriate conditions for phytoplankton growth. The temporal variations of chlorophyll-*a*in were strongly influenced by the water temperature. The highest concentration of chlorophyll-*a* was observed in summer (July to September 2006) reflecting the highest peak of phytoplankton mass (Zohary*et al.*, 1998; Benson-Evans *et al.*, 1999). Phytoplankton can tolerate a certain temperature; when the water temperature becomes greater than 35 °C, phytoplankton growth declines (Alwan, 1994). In fall, the slight decrease of the temperature stimulates phytoplankton to grow again and may have led to the increase the chlorophyll-*a* (Alwan, 1993). This situation does not last long, and biomass decreases when the temperature drops to <10 °C in winter. Also the variation of chlorophyll-*a* was influenced by the availability of TP and TN within the marshes. For example, the high amount of chlorophyll-*a* found in the Majnoon and lissan Ijerda marshes is related to the high concentrations of TN, while the low concentrations of TP and TN in Al-Baydha marsh could be a reasons behind the low amount of chlorophyll-*a* in this marsh. Light penetration is also a main factor that could affect the variation of chlorophyll-*a* (Yaqoub, 1994; Radwan, 2005). Turbid water conditions affect the light penetration which is very important for phytoplankton growth, and thus decrease the amount of chlorophyll-*a*. In this study, the average concentrations of chlorophyll-*a* in Al-Hawizeh marshland were low compared to other studies done in the Mesopotamian marshes and other similar wetlands (Zohary*et al.*, 1998; Gophen, 2000; Radwan, 2005).

Chlorophyll-*a* variation in the eight marshes responded differently to TP and TN concentrations. In this study, there was relationship between chlorophyll-*a* and TP and TN, but this relation is relatively weak. This is mainly because the differences between TP and TN within in different parts of Al-Hawizeh (IMWR-CRIM, 2006). Low concentrations of TP and TN and poor water quality conditions could also affect the strength of the relationship. Different studies found significant relationships between phytoplankton biomass (chlorophyll) and P and N concentrations (Gophen, 2000; Kufel, 2001; Panigrahi*et al.*, 2007). Light limitation or grazing could also affect the relationship between chlorophyll-*a* and TP and TN. The study by Radwan (2005) found chlorophyll-*a* concentrations were correlated to water quality parameters (water temperature, transparency, and dissolved oxygen) and P. In Kufel (2001) study, the concentration of chlorophyll-*a* was not correlated to either P or N concentration in the mesotrophic Great Masurian Lakes, while chlorophyll-*a* was correlated to the P and N concentration in the eutrophic lakes. Zooplankton grazing could also be a reason for poor chlorophyll-nutrient relationship (Kufel, 1999, Kufel, 2001).

Since phytoplankton biomass (chlorophyll-*a*)can reflect the productivity of the marshlandit also can reveal the restoration process of the system. The undisturbed marsh is low in chlorophyll-*a*, which means low productive. This is mainly because of the low concentration of P and N in this marsh. The high amount chlorophyll-*a* in some of the completely dried marshes reflect the success of restoration process, especially in the Lissan Ijerda and Majnoon marshes. This is mainly because these marshes have high concentrations of TP and TN (Mahamed, 2008). Rivers also affect the restoration process of the marshes that located close their input by the amount of P and N load. Although TP and TN were available in the Al-Baydha marsh, the amount of chlorophyll-*a* was so low which slow the restoration of this marsh. It is hard to judge whether the low concentrations of chlorophyll-*a* in the Al-Baydha marsh was related to the poor water quality conditions or to the lack of P and N. This issue could be an interesting point to focus on in the future studies.

## 1.6 Conclusions

The study indicate that each marsh within Al-Hawizeh is a well-mixed aquatic system since there are no significant differences between the water quality parameters between surface and near bottom water samples.The temporal and spatial variations of TP and TN concentrations in Al-Hawizeh were likely influenced by natural (water input, vegetation cover) and artificial (constructed embankments) impacts. There was a relationship between chlorophyll-*a* and both TP and TN concentrations;however, the relationship between chlorophyll-*a* and TN concentration was stronger than TP. The success of the restoration process of Al-Hawizeh varied among the different marshes according to the hydrology and the drying history of the marsh.The significant differences among the marshes in Al-Hawizeh suggest that this marshland system is not a one homogeneous system as used to be pre desiccation period and the main reason can be due to the constructed embankments that divide the marshland into several parts and isolate some of these parts completely from being a one active ecosystem as it should be.

## 1.7 References


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**Table 1:** ecological characteristics of the studied marshes of Al-Hawizeh during the study period from May 2006 to April 2007 and the hydrological status of each marsh during the desiccation period.

| Marsh | Coordinates | Size | Hydrology | Physical characteristics | Vegetation | Status during desiccation |
|---|---|---|---|---|---|---|
| **Al-Udhaim** | 31˚41'30" N 47˚46'35" E | 100 km$^2$ | Revrine marsh system | Deep, open water and inundated plains of fresh water | *Potamogetoncrispus, Najas minor, Phragmitesaustralis.* | Ever-wet |
| **Al-Souda north** | 31˚40'23" N 47˚40'0" E | 70 km$^2$ | Revrine marsh system | Shallow inundated plains of fresh water | *Potamogetoncrispus,Ceratophyllumdemersum* | Semi dried |
| **Umm Al-Niaaj** | 31˚36'0" N 47˚37'20" E | 300 km$^2$ | Revrine marsh system | Deep, open water and inundated plains of fresh water | *Phragmitesaustralis, Ceratophyllumdemersum, Potamogetonleucenus, Najas minor* | Semi dried |
| **Um Al-Warid** | 31˚34'47" N 47˚31'7" E | 50 km$^2$ | Revrine marsh system | Deep, inundated plains of fresh water | *Potamogeton sp., Potamogetoncrispus, Phragmitesaustralis* | Completely dried |
| **Al-Souda south** | 31˚25'15" N 47˚36'56" E | 50 km$^2$ | Seasonal water flow | Shallow, seasonal inundated plains of fresh water | *Phragmitesaustralis, Najas minor* | Completely dried |
| **Al-** | 31˚22'1" N | 30 | Annual | Open water | *Myriophyllumspicatum* | Complete |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Baydha** | 47°38'46" E | km$^2$ | water flow | area, seasonal inundated plains of fresh water | | ly dried |
| **Lissan Ijerda** | 31°17'27" N 47°34'37" E | 300 km$^2$ | Annual water flow | Shallow, inundated plains of fresh water | *Phragmitesaustralis, Najas minor* | Completely dried |
| **Majnoon** | 31°7'59" N 47°35'33" E | 200 km$^2$ | Annual water flow | Shallow, inundated plains of fresh water | *Phragmitesaustralis, Myriophyllumspicatum* | Completely dried |

**Table2:**Average and range of monthly water temperature (WT), salinity, dissolved oxygen (DO), pH, total suspended solids (TSS), light penetration (LP), and water column depth (WCD) in the selected marshes of Al-Hawizeh from May 2006 to April 2007.

| | | Udhaim | Souda north | Um Al-Niaaj | Um Al-Warid | Souda south | Baydha | Lissan Ijerda | Majnoon |
|---|---|---|---|---|---|---|---|---|---|
| **WT °C** | **average** | 21.9 | 22.2 | 22.7 | 21.1 | 22.1 | 21.6 | 22.2 | 22.9 |
| | **range** | 10.0-31.9 | 10.1-31.5 | 10.9-31.6 | 9.4-31.1 | 9.8-31.1 | 9.6-31.5 | 9.9-33.0 | 10.7-32.2 |
| **Salinity ppt** | **average** | 0.7 | 0.7 | 0.6 | 0.5 | 0.9 | 0.9 | 1.4 | 1.1 |
| | **range** | 0.5-0.9 | 0.5-1.0 | 0.4-0.9 | 0.2-0.8 | 0.6-1.3 | 0.6-1.1 | 1.0-1.8 | 0.9-1.3 |
| **DO mg/l** | **average** | 7.4 | 6.5 | 9.2 | 7.8 | 2.1 | 7.1 | 7.7 | 7.0 |
| | **range** | 5.2-10.6 | 1.7-9.2 | 6.1-11.8 | 5.4-11.1 | 0.3-7.9 | 4.8-9.0 | 4.1-10.0 | 0.9-11.5 |
| **pH** | **average** | 7.8 | 7.7 | 8.2 | 8.1 | 7.2 | 7.8 | 8.1 | 8.1 |
| | **range** | 7.5-8.3 | 7.3-8.0 | 7.9-8.6 | 7.9-8.6 | 6.6-7.6 | 7.5-8.1 | 7.5-8.5 | 6.7-8.5 |
| **TSS mg/l** | **average** | 1.6 | 2.3 | 1.5 | 10.3 | 4.6 | 3.0 | 4.8 | 70.5 |
| | **range** | 0.3-2.9 | 0.2-7.7 | 0.4-2.7 | 2.0-20.5 | 1.2-24.8 | 1.5-6.7 | 1.5-1.-1 | 0.6-219.3 |
| **LP cm** | **average** | 190 | 250 | 230 | 130 | 50 | 230 | 220 | 140 |
| | **range** | 170-220 | 200-310 | 210-250 | 50-250 | 50-180 | 190-300 | 130-340 | 30-80 |
| **WCD m** | **average** | 2.1 | 2.6 | 2.4 | 2.3 | 2.4 | 2.4 | 1.7 | 1.5 |
| | **range** | 1.7-2.5 | 2.2-3.1 | 2.1-2.7 | 2.0-2.7 | 1.0-2.1 | 1.9-3.0 | 1.3-3.4 | 1.0-2.5 |

**Table 3:** Average and range of monthly P, N fractions and chlorophyll-*a*(µg/l) in the selected marshes of Al-Hawizeh from May 2006 to April 2007.

| | | Al-Udhaim | Al-Souda north | Umm Al-Niaaj | Umm Al-Warid | Al-Souda south | Al-Baydha | Lissan Ijerda | Majnoon |
|---|---|---|---|---|---|---|---|---|---|
| | **Average** | 4.2 | 4.4 | 5.3 | 32.1 | 4.7 | 4.6 | 4.4 | 4.7 |
| **$PO_4$** | **Min** | 0.0 | 0.2 | 0.0 | 6.2 | 1.5 | 2.6 | 2.2 | 2.1 |
| | **Max** | 11.1 | 7.6 | 23.3 | 74.8 | 10.8 | 8.0 | 7.6 | 7.2 |
| | **Average** | 1.8 | 1.8 | 2.3 | 5.9 | 1.6 | 2.0 | 1.6 | 2.5 |
| **$NO_2$** | **Min** | 0.1 | 0.5 | 0.5 | 1.4 | < 0.1 | < 0.1 | 0.1 | < 0.1 |
| | **Max** | 4.6 | 4.7 | 5.1 | 16.2 | 7.0 | 13.8 | 8.9 | 10.2 |
| | **Average** | 12.8 | 13.3 | 15.0 | 36.5 | 13.8 | 16.0 | 14.3 | 13.4 |
| **$NO_3$** | **Min** | 0.1 | 0.6 | < 0.1 | 1.4 | 1.4 | 1.3 | 0.1 | 0.4 |
| | **Max** | 48.4 | 50.1 | 47.4 | 115.9 | 53.1 | 51.8 | 51.1 | 51.6 |
| | **Average** | 11.7 | 16.7 | 14.1 | 27.9 | 20.1 | 18.6 | 15.2 | 20.9 |
| **DOP** | **Min** | 1.3 | 0.9 | 0.9 | 4.7 | 2.0 | 1.0 | 1.9 | 2.4 |
| | **Max** | 48.5 | 67.2 | 67.0 | 165.5 | 117.2 | 80.6 | 83.2 | 71.4 |
| **DON** | **Average** | 69.1 | 94.6 | 98.5 | 80.8 | 84.0 | 72.6 | 110.5 | 79.6 |

| | | Al-Udhaim | Al-Souda north | Umm Al-Niaaj | Umm Al-Warid | Al-Souda south | Al-Baydha | Lissan Ijerda | Majnoon |
|---|---|---|---|---|---|---|---|---|---|
| | **Min** | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 |
| | **Max** | 288.2 | 571.9 | 483.8 | 390.9 | 421.8 | 328.7 | 622.5 | 346.8 |
| | **Average** | 2.6 | 3.1 | 3.4 | 8.5 | 1.8 | 2.0 | 5.2 | 9.8 |
| **PP** | **Min** | 1.0 | 1.3 | 1.7 | 1.1 | 0.5 | 0.0 | 2.2 | 0.6 |
| | **Max** | 4.7 | 12.0 | 9.3 | 16.1 | 3.2 | 4.6 | 10.7 | 20.8 |
| | **Average** | 91.5 | 90.7 | 85.1 | 129.5 | 66.9 | 92.6 | 181.7 | 628.2 |
| **PN** | **Min** | 31.0 | 29.0 | 33.8 | 31.0 | 23.0 | 23.0 | 59.0 | 188.0 |
| | **Max** | 181.0 | 174.0 | 178.0 | 230.0 | 167.0 | 267.0 | 483.0 | 1342.0 |
| | **Average** | 18.6 | 24.0 | 22.4 | 68.4 | 26.6 | 25.1 | 24.0 | 38.3 |
| **TP** | **Min** | 6.9 | 2.0 | 3.6 | 18.5 | 8.4 | 6.0 | 8.1 | 13.6 |
| | **Max** | 57.5 | 72.6 | 76.7 | 184.0 | 122.8 | 89.6 | 100.0 | 89.6 |
| | **Average** | 146.0 | 182.8 | 160.7 | 225.8 | 123.6 | 160.4 | 249.0 | 711.7 |
| **TN** | **Min** | 44.8 | 66.6 | 55.5 | 50.6 | 41.8 | 40.7 | 76.8 | 250.8 |
| | **Max** | 462.4 | 751.8 | 675.9 | 580.4 | 502.6 | 510.2 | 561.3 | 1352.0 |
| | **Average** | 1.7 | 1.9 | 1.4 | 3.7 | 1.0 | 0.8 | 4.2 | 11.7 |
| **Chlorophyll-*a*** | **Min** | 0.3 | 0.3 | 0.4 | 0.1 | 0.1 | <0.1 | 0.4 | 1.6 |
| | **Max** | 5.7 | 8.7 | 2.7 | 14.0 | 3.6 | 3.2 | 11.6 | 26.2 |

**Table 4:**Pearson correlation coefficients between chlorophyll-*a* and water temperature (WT), dissolved oxygen (DO), light penetration (LP), total phosphorus (TP), total nitrogen (TN), orthophosphate ($PO_4$), nitrite ($NO_2$), and nitrate ($NO_3$) in the selected marshes of Al-Hawizeh from May 2006 to April 2007.

| | WT | DO | LP | TP | TN | $PO_4$ | $NO_2$ | $NO_3$ |
|---|---|---|---|---|---|---|---|---|
| **Al-Udhaim** | 0.7 | -0.6 | -0.8 | 0.0 | -0.2 | 0.4 | 0.2 | -0.1 |
| **Al-Souda north** | 0.6 | -0.3 | -0.7 | -0.3 | -0.2 | -0.1 | 0.5 | 0.0 |
| **Um Al-Niaaj** | 0.5 | 0.1 | -0.5 | 0.7 | -0.4 | 0.3 | -0.2 | 0.5 |
| **Um Al-Warid** | 0.6 | 0.4 | -0.1 | 0.1 | 0.3 | -0.4 | 0.5 | 0.8 |
| **Al-Souda south** | 0.4 | -0.3 | -0.2 | 0.1 | -0.2 | 0.4 | -0.3 | 0.6 |
| **Al-Byadha** | -0.4 | 0.1 | 0.4 | 0.3 | 0.1 | -0.3 | -0.3 | -0.3 |
| **Lissa Ijerda** | 0.8 | -0.7 | -0.4 | 0.5 | 0.1 | 0.4 | 0.3 | 0.4 |
| **Majnoon** | 0.4 | 0.1 | -0.5 | -0.1 | 0.8 | 0.3 | -0.4 | -0.2 |

**Table 5:**GLM regression tables of chlorophyll-avs TP (A) and TN (B) in the selected marshes of Al-Hawizeh. $R^2$ for chlorophyll-*a*vs TP is 0.078 and $R^2$ for chlorophyll-*a*vs TN is 0.155. ANCOVA table for the relationship between chlorophyll-*a* and TP in the selected marshes, where (A), the categorical variable (z) in this analysis is marshes and $R^2$ is 0.503 and (B), the categorical variable (z) in this analysis is months and $R^2$ is 0.361.ANCOVA table for the relationship between chlorophyll-*a* and TN in the selected marshes, where (A) the categorical variable (z) in this analysis is marshes and $R^2$ is 0.481 and (B), the categorical variable (z) in this analysis is months and $R^2$ is 0.654.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **GLM Regression** | **(A) Effect** | **Coefficient** | **Std Error** | **StdCoef** | **Tolerance** | **t** | **P (2 Tail)** |
| | **Constant** | 0.050 | 0.0390 | 0.000 | . | 1.298 | 0.197 |
| | **Log TP** | 0.078 | 0.0280 | 0.280 | 1.000 | 2.832 | 0.006 |
| | **(B) Effect** | **Coefficient** | **Std Error** | **StdCoef** | **Tolerance** | **t** | **P (2 Tail)** |
| | **Constant** | -0.074 | 0.056 | 0.000 | . | -1.320 | 0.190 |
| | **Log TN** | 0.099 | 0.024 | 0.394 | 1 | 4.160 | 0.000 |
| **ANCOVA analysis (TP vs Chlorophyll-*a*)** | **(A) Source** | **Sum-of-Squares** | **df** | **Mean-Square** | **F-ratio** | **P** | |
| | **Log TP** | 0.017 | 1 | 0.017 | 3.146 | 0.080 | |
| | **Marshes** | 0.046 | 7 | 0.007 | 1.243 | 0.290 | |
| | **Marshes*Log TP** | 0.031 | 7 | 0.004 | 0.818 | 0.575 | |
| | **Error** | 0.426 | 80 | 0.005 | | | |

| | (B) Source | Sum-of-Squares | df | Mean-Square | F-ratio | P |
|---|---|---|---|---|---|---|
| | **Log TP** | 0.084 | 1 | 0.084 | 11.042 | 0.001 |
| | **Months** | 0.049 | 11 | 0.004 | 0.59 | 0.831 |
| | **Months*Log TP** | 0.058 | 11 | 0.005 | 0.698 | 0.737 |
| | **Error** | 0.548 | 72 | 0.008 | | |

| ANCOVA analysis (TN vs Chlorophyll-*a*) | (A) Source | Sum-of-Squares | df | Mean-Square | F-ratio | P |
|---|---|---|---|---|---|---|
| | **Log TN** | 0.002 | 1 | 0.002 | 0.441 | 0.509 |
| | **Marshes** | 0.014 | 7 | 0.002 | 0.359 | 0.923 |
| | **Marshes*Log TN** | 0.023 | 7 | 0.003 | 0.586 | 0.766 |
| | **Error** | 0.445 | 80 | 0.006 | | |
| | **(B) Source** | **Sum-of-Squares** | **df** | **Mean-Square** | **F-ratio** | **P** |
| | **Log TN** | 0.208 | 1 | 0.208 | 50.461 | 0.000 |
| | **Months** | 0.048 | 11 | 0.004 | 1.066 | 0.401 |
| | **Months*Log TN** | 0.038 | 11 | 0.003 | 0.847 | 0.595 |
| | **Error** | 0.297 | 72 | 0.004 | | |

**Table 6:** Salinity (Sal), pH, dissolved oxygen (DO), water temperature (WT), light penetration (LP), total suspended solid (TSS), total phosphorus (TP), total nitrogen (TN), and chlorophyll-a (chl-*a*) paired t test on the three classes of marshes within Hour Al-Hawizeh: G1= the undisturbed marsh, G2= partially dried marshes, and G3= completely dried marshes.

| | | SD difference | t | df | P |
|---|---|---|---|---|---|
| TP | G1 vs G2 | 19.28 | -3.55 | 11 | 0.005 |
| | G1 vs G3 | 15.77 | -2.19 | 11 | 0.050 |
| | G2 vs G3 | 11.71 | 2.89 | 11 | 0.020 |
| TN | G1 vs G2 | 60.84 | -2.55 | 11 | 0.030 |
| | G1 vs G3 | 97.48 | -6.19 | 11 | **0.000** |
| | G2 vs G3 | 117.03 | -3.83 | 11 | **0.003** |
| Chlorophyll-*a* | G1 vs G2 | 1.63 | -1.36 | 11 | 0.200 |
| | G1 vs G3 | 1.76 | -4.70 | 11 | **0.001** |
| | G2 vs G3 | 2.25 | -2.69 | 11 | 0.020 |

**Figure 1:** Sampling stations in Al-Hawizeh marshlands. Arrows indicate the main water inputs and outlets of the marshland

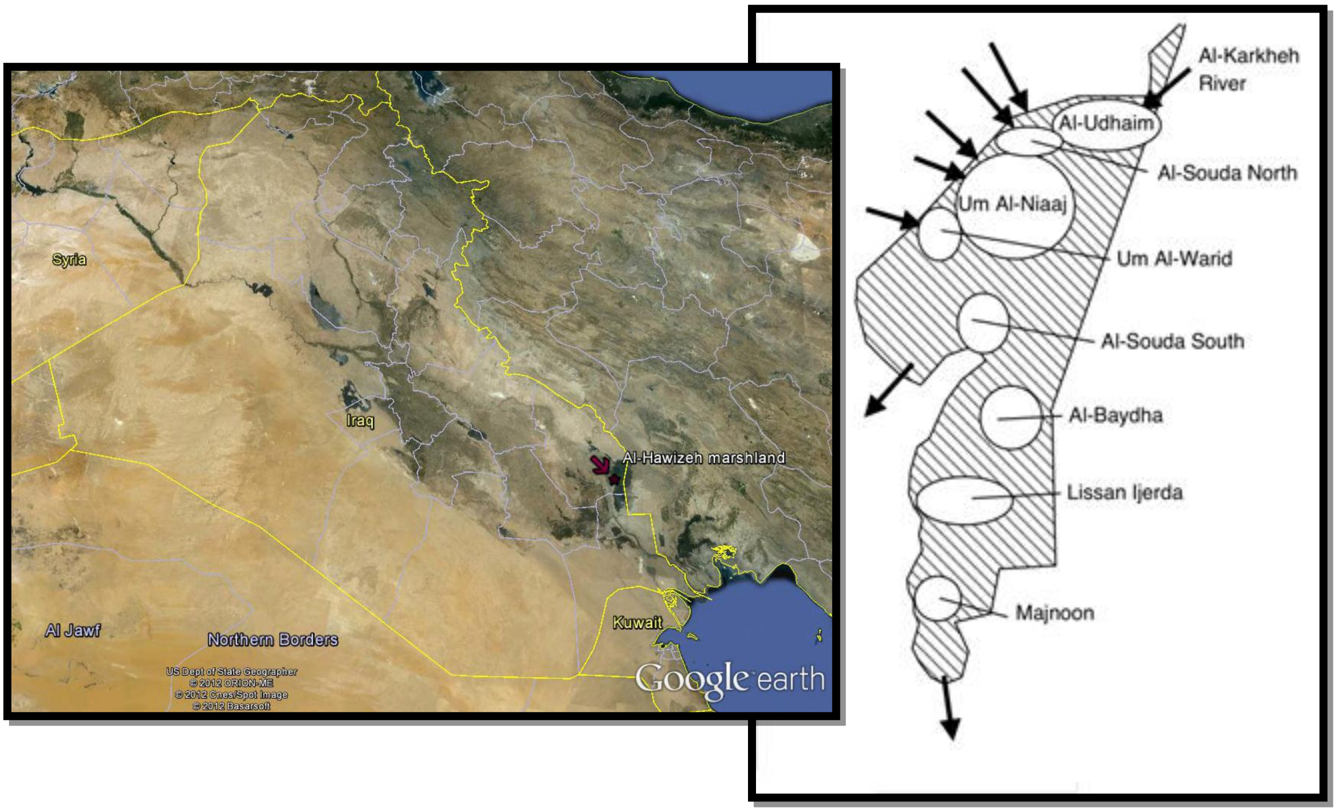
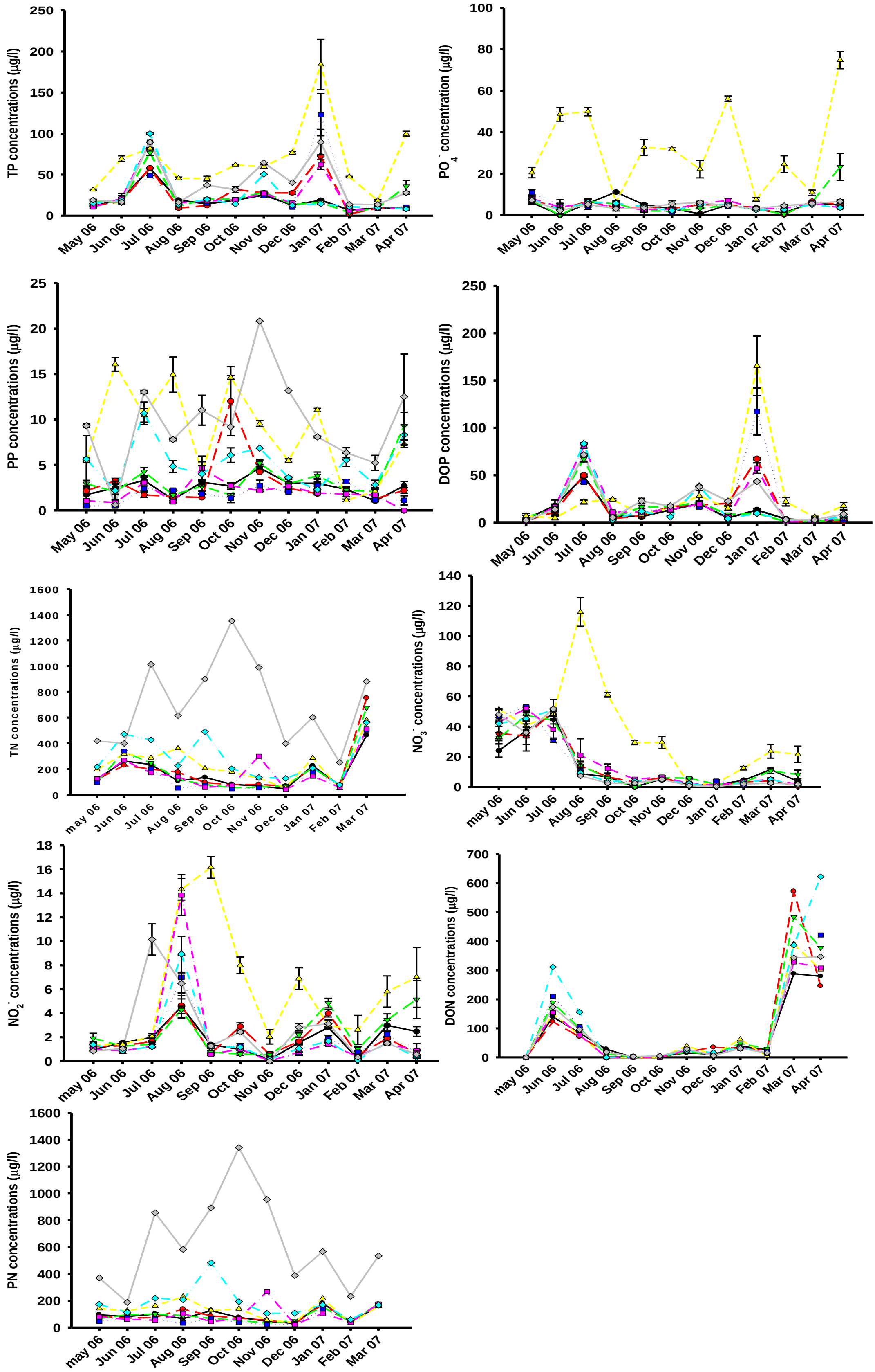

Syria
Iraq
Al-Hawizeh marshland
Kuwait
Al Jawf
Northern Borders
Google earth
Al-Karkheh River
Al-Udhaim
Al-Souda North
Um Al-Niaaj
Um Al-Warid
Al-Souda South
Al-Baydha
Lissan Ijerda
Majnoon

**Figure 2:**Monthly variation of TP, TN and chlorophyll-*a*concentrationsin the selected marshes of Al-Hawizeh (error bars= standard error)




**Continued figure 2**

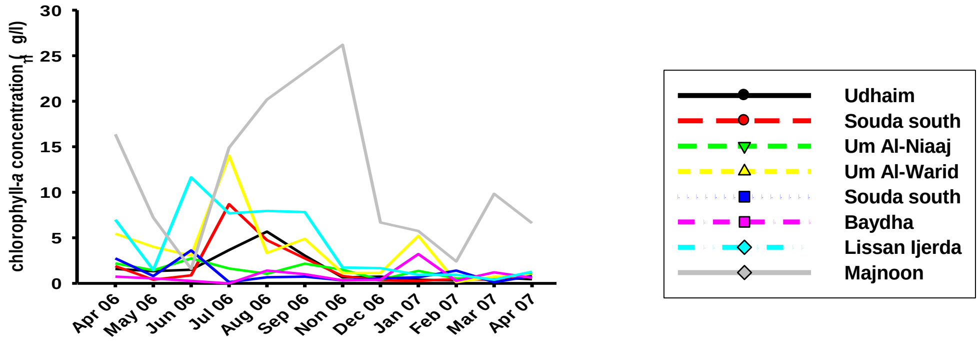



**Figure 4:** The relationships between chlorophyll-a and TP and TN concentrations in the selected marshes of Al-Hawizeh.

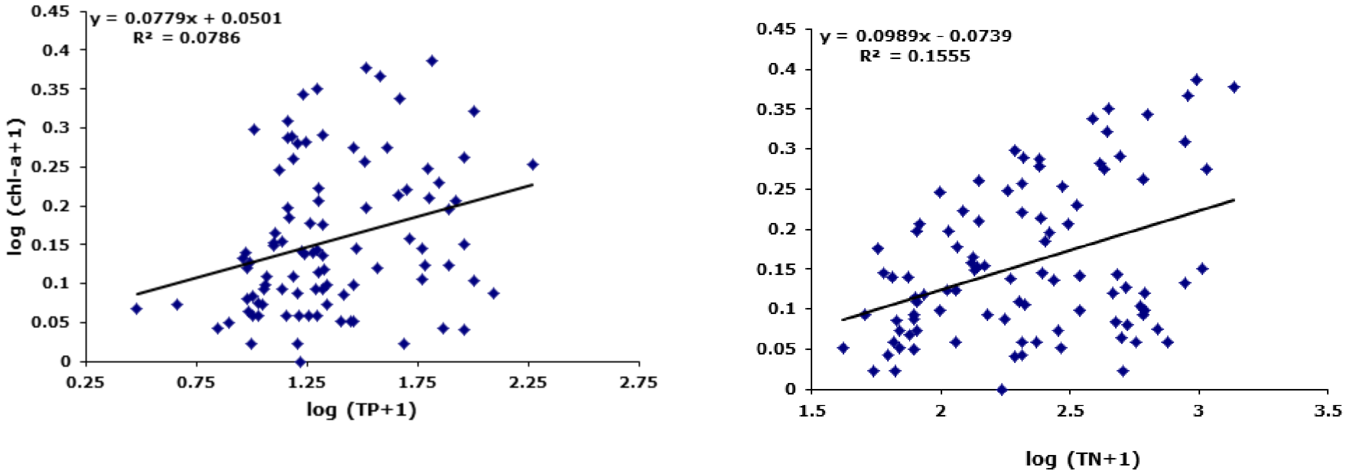



**Figure 5:**Monthly variation of TP, TN, and chlorophyll-*a* in the three marsh groups, ever-wet Al-Udhaim marsh (blue line), semi-dried marshes and has direct water inputs (red line), and completely dried marshes (green line).