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The Primary Production Conditions of Wadi Al-Arab Dam (Reservoir), Jordan

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Abstract

The purpose of this study was to investigate the effect of the primary production of phytoplankton on water quality of Wadi Al-Arab Dam Reservoir in Northern Jordan. Species successive change and composition in addition to increased rain inflow and nutrient loading seems to be the major factors behind fluctuation of total chlorophyll a (chl a) content which, was positively correlated with the phytoplankton primary production ($r = 0.63$-0.68, $P < 0.05$). The major phytoplankton species that contribute to the increase in the primary production were green algae and dinoflagellates. Below water surface, a gradual decrease in chl a concentration was observed with a lowest concentration (3.61 mg/L) being recorded at 10 m during August. Phytoplankton primary production followed a bimodel trend with two clear peaks, the first was in the wet season (March) and the second in summer (September). Total cell counts (mean count = 4040-4636 × 103 ± 1645 cells /L) showed higher values all over the year as attributed to the trophic status of the reservoir with diatoms being the highest proportion of the total counts. Phytoplankton production was significantly correlated with dissolved oxygen concentration ($r = 0.76$ ، $P < 0.05$). However, surface water temperature, pH and electrical conductivity found to be negatively correlated with production ($r = -0.51$, $P < 0.05$; $r = -0.09$, $P < 0.05$ and $r = -0.24$, $P < 0.05$, respectively). Salinity and total alkalinity on the other hand, did not appear to have any particular influence on phytoplankton production.

الملخص

تهدف هذه الدراسة في البحث في أثر الإنتاجية الأولية على نوعية المياه في بحيرة سد وادي العرب. كان التغير الزمني والمكاني للعوالق النباتية بالإضافة إلى ازدياد تدفق المياه و الإثراء الغذائي لمياه البحيرة من أهم العوامل المؤثرة على تذبب تركيز صبغة الكلوروفيل أ وبمعامل ارتباط موجب مع الإنتاجية الأولية للبحيرة (r = 0.63-0.68, P > 0.05) وليصل أقل تركيز لصبغة الكلوروفيل أ تحت سطح الماء بمقدار ٣,٦ مع/لتر وعلى عمق ١٠ متر في شهر أب. وقد لوحظ أن أهم العوالق النباتية في ارتفاع الإنتاجية الأولية للبحيرة هي الطحالب الخضراء والداينوفلاجلات. أبدت الإنتاجية الأولية للعوالق النباتية الشكل المزدوج بارتفاعين واضحين اولهما في فصل الشتاء (أذار) والثاني في الصيف (أيلول). كانت الأعدد الكلية للخلايا (متوسط العدد = ٤٠٤٠ – ٤٦٣٦ × 103 خلية/لتر) ذات قيم مرتفعة على طول السنة بسبب ارتفاع المستوى الغذائي للبحيرة وباحتلال الدايوتومات اعلى نسبة في العدد الكلي. ارتبطت الإنتاجية الأولية للعوالق النباتية بشكل ملحوظ مع تركيز الأكسجين المذاب (r = 0.76, P < 0.05) لكنها ارتبطت عكسيا مع درجة حرارة سطح الماء، درجة الحموضة والموصلية الكهربائية وبمعامل ارتباط سالب (r = - 0.51, P < 0.05; r = - 0.09, P < 0.05 و r = - 0.24, P < 0.05 على التوالي. على النحو الآخر فان الملوحة والقاعدية الكلية لم يكن لها أي أثر على الإنتاجية الأولية للعوالق النباتية.

Keywords: Chlorophyll a; Phytoplankton; Primary Production; Wadi Al-Arab reservoir;

1. Introduction

Primary production by phytoplankton is a main process supporting life in the aquatic ecosystems and plays a prime role in their biological and chemical characteristics. Therefore, knowing the intensity and dynamics of this process for long time scales can help to understand aquatic ecosystems as well as their water quality (Reynolds, 1984).

Reservoir water quality and productivity are to a large extent controlled by the quantity and quality of external nutrient loading. In water affected by human made effluents, such as that of Wadi Al-Arab Reservoir in Northern Jordan, high primary production resulting from excessive load of nutrients may cause problems affecting water quality for human use. Long-term changes in the

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nutrient supply to lakes represent very large-scale shifts in the balance and spectra of resources to which phytoplankton abundance and quality are known to respond (Gray, 1995).

Phytoplankton and nutrient dynamics are closely linked since nutrient uptake during algal growth is the main process that removes dissolved nutrients from the water. Algal growth is a function of temperature, light and nutrients with phosphorus, nitrogen and carbon, in addition to silicate for diatoms are the major growth limiting nutrients (Rhee, 1982).

Long-term studies of phytoplankton productivity and distribution have not been conducted in most Jordanian freshwater bodies. Therefore, the present study was aiming at investigating the biological parameters prevailing in Wadi Al-Arab Dam Reservoir and their potential effects on water quality.

2. Study Area

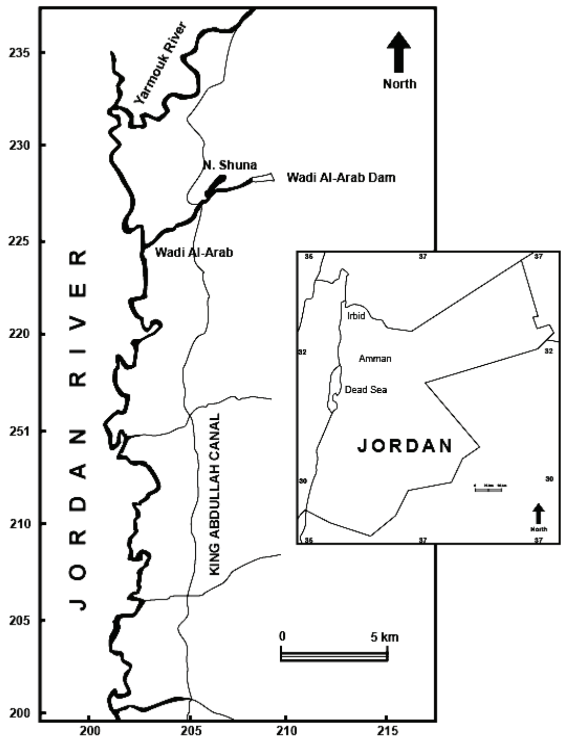
Wadi Al-Arab Dam Reservoir (Fig.1a) is located in the northern part of Jordan Valley, on the east bank of the Jordan Rift Valley, about 10 km south of the lake Tiberies and 25 km from Irbid City. The reservoir water comes partially from the King Abdallah Canal and partly from precipitation. The reservoir water is used to irrigate about 12,500 donums from Al Shuna to Al Baqura. It also serves as drinking water source in periods of water shortage by draining to King Abdallah Canal (Jordan Valley Authority, JVA, 1995-2002). The average annual rainfall in the Wadi Al-Arab is approximately about 400 mm (JVA, 1995-2002). Most of precipitation occurs during October to May, and months from June to September can be considered as a dry summer season. Climate of the region is considered as a Mediterranean, which is characterized by hot and dry summer, cool and wet winter. Relative humidity ranges from 49% in June to 67% in February. Frost and snowfall occur occasionally in January and February. Sunshine hour ranges from 5.0 hours in January to 11.9 hours in June (Ghrefat, 1999). Wind is light to moderate and predominantly from west to southwest. Daily evaporation causes a decrease in water level varies from 4.8 mm in January to 8.9 mm in July.

The principal features of Wadi Al-Arab Dam Reservoir are summarized as follows: the reservoir catchment's area is 262 km^2 with gross, effective and dead storage capacity of 20.0, 16.9 and 3.1 million cubic meters, respectively. The estimated precipitation per year is 7000 m^3 and the annual total discharge is 33 million m^3 (JVA, 1995-2002). The reservoir live storage capacity during the study period (February 2001 to February 2002) maximized in April, 2001 to 13182000 m^3 and the minimized in November, 2001 to 1360000 m^3.

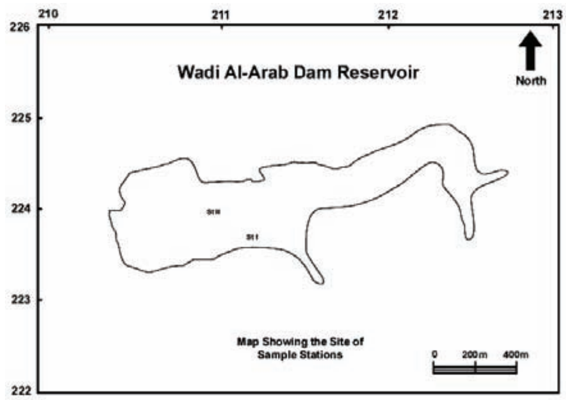
3. Materials and Methods

3.1. Sampling

Two sampling stations (SI and SII) were selected for investigation. Station I was closer to the shore of the lake and station II represents the open area and is located in the middle of the reservoir about 350 m from station I, at a fixed point by a flag planted there where the boat usually reach water (Fig.1.b). Water samples in two plastic bottles of 1 liter volume were carried out monthly from each station during the study period. Primary production was measured at the tow stations and samples for chlorophyll *a* measurements were obtained from a depth of 30 cm below the water surface in each station.



(a)



(b)

Figure 1. a. Location map of the study area; b. Map showing the locations of sample stations in Wadi Al-Arab dam reservoir.

3.2. Biological analysis

3.2.1. Cell count

3.2.1.1. Lackey drop (Microtransect) counting method

One-liter samples were collected from each station and fixed with 5 ml of 40% formaline. Upon return to the lab, samples were transferred to a 1L cylinder and left to settle for 72 hours. This period was found to be enough for all algal cells to settle down. Later, 90 % of the supernatant water was decanted, leaving about 100 ml of phytoplankton concentrate. Cells were counted according to APHA (1998). In brief, the concentrated sample was shaked vigorously then 0.1 ml of the suspension was placed on a blank microscopic slide and covered with a 22 x 22 mm glass cover slip. Organisms were counted in four strips all over the width of the cover slip. Number of cells/ml was calculated according to:

$$Cells\ /\ ml = \frac{C \times A_t}{A_s \times S \times V}$$

C : total number of organisms counted in the counted strips.
A_t : area of the cover slip, mm
A_s : area of one strip = Number of fields counted × area of one field.
S : No. of strips counted, 4.
V : volume of sample under the cover slip, ml = 0.1ml

3.2.1.2. Chlorophyll a and phaeopigment analysis

Samples for chlorophyll *a* and phaeopigments analysis were thoroughly shaken, filtered through GF/C glass fiber filters (25 mm diameter) using Millipore filtration unit and vacuum pump at low pressure. The glass fiber filter was grinded with few drops of 90 % acetone then transferred to glass tubes in which acetone was added to a volume of 15 ml. The filtrate was left over night and was centrifuged at 2500-3000 (rpm) for 10 minutes. Finally the supernatant was measured spectrophotometrically at 665 nm and 750 nm wavelengths (Milton Roy, USA) before and after acidification with 0.1N HCL as described in APHA (1998). The concentration of chlorophyll *a* and other phaeopigments were calculated according to Vollenweider (1974).

3.2.1.3. Primary production measurement: Light / Dark bottles method

Phytoplankton primary production was measured by the oxygen light and dark bottle technique (APHA 1998). Winkler method was followed for the estimation of dissolved oxygen in the incubation bottles.

A measurement of net photosynthesis (photosynthesis in excess of respiration) can be obtained by measuring the gain in oxygen concentration in the transparent bottle. Net photosynthesis is equated with net oxygen evolved and is obtained by subtracting the oxygen content of the water before incubation from oxygen content of the transparent bottle following incubation. A measurement of gross photosynthesis can be obtained by adding the amount of respiratory oxygen to the net oxygen evolved. Respiratory oxygen is calculated by subtracting the oxygen content of the dark bottle after incubation from the oxygen content of water before incubation. With suitable calculations of both net and gross photosynthesis, primary production can be expressed in units of assimilated carbon per unit of time.

In the present study, 6 Winkler bottles (BOD bottles) of 300 ml volume were used in each station. Four bottles were left clear and tow bottles were painted black and wrapped with aluminum foil. Oxygen concentration in one of the clear bottles was determined immediately at the beginning of the experiment and considered as the initial oxygen concentration. The remaining bottles were incubated in situ for 3 hours. After the incubation period, oxygen concentration was determined in all bottles as the following and average values for light and dark bottles were recorded

3.3. Primary production calculation

Gross primary production (mg O_2 / L) was measured by substracting the concentration of dissolved oxygen (DO) in the dark bottle from that in the transparent bottle. However, net primary production was measured by substracting (DO) in the initial bottle from that in the transparent bottle. To convert (mg O_2 / L) into (mg C / m^3 / hr) the following formula was used:

$$\left(\text{mg C} \backslash \text{m}^3 \backslash \text{hr}\right) = \frac{\text{mg O}_2 / \text{m}^3 / \text{hr} \times \left(12/32\right) \times 1000}{\text{time of incubation}}$$

12/32: factor to convert oxygen to carbon; 1000: to convert ml to m^3.

3.4. Physical and chemical analysis

3.4.1. Physical and chemical parameters

Water temperature, pH, salinity and conductivity were measured in situ upon sampling using a multiparameter portable instrument (WTW, Multiline F / SET-3, Germany).

3.4.2. Dissolved oxygen (DO)

Dissolved oxygen concentration in the incubation bottles was measured following Winkler method as described in APHA (1998).

4. Statistical analysis

Analyses of variance for all data were performed using statistical analysis system (SAS Institute Inc., 2000). Means were separated by the least significant differences (LSD) at $\alpha = 0.05$.

5. Results and Discussion

Fluctuation of water level at Wadi Al-Arab reservoir is a combined result of an irregular variation of inflow and outflow. The main source of water to the reservoir is precipitation, which is confined to short period in winter. On the other hand, water outflow from the reservoir increased during summer owing to an increasing demand of water for irrigation and drinking. It is estimated that about 65,000 m^3 of water is pumped daily from the reservoir for agricultural uses in Al-Shuna and nearby villages (JVA, 2000). A wide fluctuation in water level, however, is a common feature in reservoirs and has some effect on their ecology through, for example, an enhanced nutrient exchange between pelagic and littoral zones of the reservoir (Andrew and Pfiester, 1995).

Total cell counts showed higher values all over the year with diatoms being the highest proportion of the total counts. The mean cell count through the study period was $4040 \times 10^3 \pm 1410$ cell /L at station I and $4636 \times 10^3 \pm 1645$ cell /L at station II (Fig. 2a). Maximum cell count recorded at station I was 7103×10^3 cell in December and the minimum was 1857×10^3 cell /L in July. At station II, the maximum cell count recorded was 8810×10^3 cell /L in December and the minimum was 1606×10^3 cell /L in February 2002.

Changes in cell counts provide good indication of phytoplankton succesional pattern. Taxonomical uncertainty, however, may limit the full understanding of successional changes (Hart, 1996). The irregularity in cell count changes in the reservoir can not be related to any particular environmental parameter. It is most likely to be a combined effect of a transmissible distribution (Fogg and Thake, 1987) and succession interruption. Succession interruption, however, is a common feature of warm reservoirs which caused by changes in the depth of mixed layer (Lewis, 1996). Growth strategies on the other hand play a major role in the observed variation of species peaks.

Nutrient concentrations have not been measured in this study, but it was shown erarlier (Saadoun et al., unpublished data) that Wadi Al-Arab reservoir is eutrophic with high nutrients loads all of the year round. Therefore, it is unlikely that nutrients in the reservoir are limiting factors for phytoplankton cell densities. It is most likely that temperature, light limitation and physiological status of species play a more influencing role in species succession. Furthermore, the absence of a detailed study on the phytoplankton of Wadi Al-Arab reservoir makes it difficult to extract comparison of species occurrence and distribution both within and between years.

Species composition seems to be the major factor behind fluctuation of total chlorophyll *a* content in the reservoir. In March 2001, chl *a* concentration was 29.38 mg/L where phytoplankton was mostly dominated by the dinoflaggelate *Peridinium sp.* Phytoplankton species composition had changed remarkably in the next month (April) where the chlorophytes *Chlorella sp*. and *Chlamydomonas sp.* became more common. This successive change of species was accompanied with a rapid increase in chl *a* concentration reaching 107.79 mg/L. Similar conditions, however, have also been noted in other reservoirs (Reynolds, 1984). From May to the end of the year, fluctuations in concentration of chl *a* were rather low with its minimum in November when diatoms dominate the population.

Significant and abrupt increase in chl *a* concentration was observed in February 2002 at both stations. Chlorophyll *a* concentrations were rather high in Wadi Al-Arab reservoir with a seasonal change that was related to water inflow to the reservoir in the wet season (September to February) as compared to a marked decrease in summer months (May to August) (Fig. 2b). Chl *a* mean concentrations over the study period were (39.62 mg / m^3) and (46.34 mg / m^3) at station I and II, respectively, with the highest level (120.42 mg / m^3 and 107.97 mg / m^3) recorded in February, 2002, at station I and in April, 2001 at station II, respectively. However, the lowest chl *a* concentration recorded at station I was 15.83 mg / m^3 in August where cell densities were rather low resulting in a relatively more transparent water. At station II, the minimum concentration recorded was 19.56 mg / m^3 in November. In February 2002, elevated level of chl *a* was correlated with the increased rain inflow, nutrient loading and species distribution. In general, the factors which are known to decrease chl *a* in lakes and reservoirs such as light availability (Desortova, 1981; Hunter and Laws, 1981; Kotut et al. 1999) and algal size (Malone, 1980) seem to be of less importance in highly eutrophic water bodies like Wadi Al-Arab reservoir.

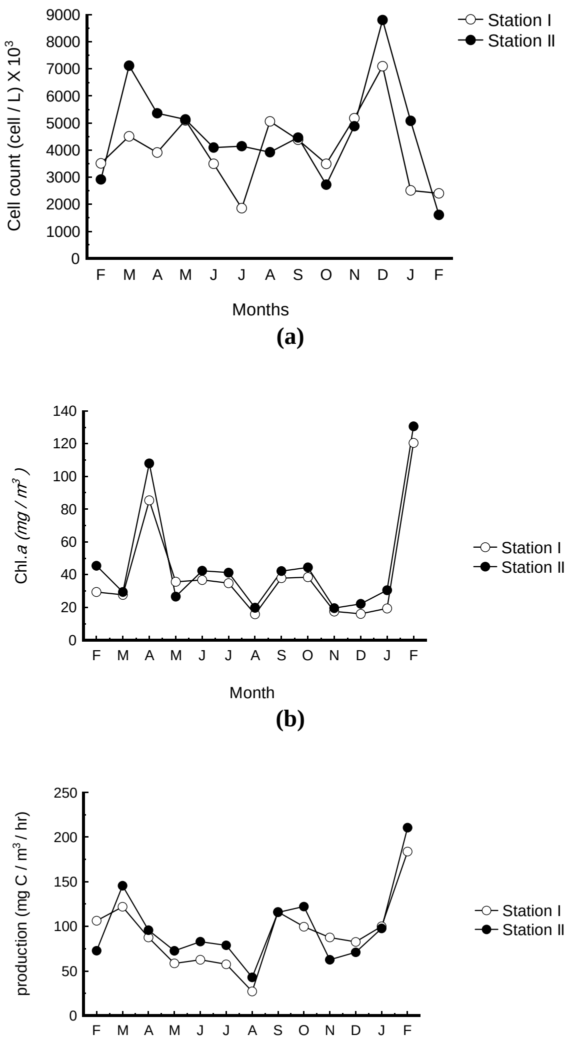


Figure 2. Total cell count (cell/L) (a), chlorophyll *a* (mg/m^3) concentration (b) and phytoplankton primary production (mg C/m^3/hr) (c) at stations I and II.

Chl *a* concentration was determined at the water surface and at 1, 5 and 10 m below the water surface for the period April to August. A gradual decrease in chl *a* concentration with depth was observed with the highest values always at the surface (Fig. 3). The lowest concentration recorded (3.61 mg/L) was at 10 m below the water surface and during August (Fig. 3e). Depletion of chl *a* values with depth was observed all the year round and may be attributed to the low cell densities under water surface.

Results of phaeopigment concentration (data not shown) revealed no seasonal pattern. The maximum concentration (39.57 mg / m^3) recorded was in May at station I, while at stationII, the maximum concentration (18.84 mg/m^3) was recorded in April. The lowest concentration (1.1 mg/m^3) was recorded in September at station II and (0.52 mg/m^3) in October at station I. Phaeopigments which reflect concentration of non-functional chl *a* were rather low in surface water of the reservoir with minor fluctuations throughout the period of study. Increased levels of phaeopigments were observed below the water surface during May-July period, which is attributed to the rapid sinking of dead phytoplankton cells.

Phytoplankton primary production of the reservoir showed a seasonal pattern with an increase in the wet season and a decrease in summer. The mean primary production at station II was higher than that at station I with values of 97.72 mg C $m^{-3}hr^{-1}$ and 91.60 mg C $m^{-3}hr^{-1}$ at station II and I, respectively. Phytoplankton primary production was generally high and followed a bimodel trend with two clear peaks, the first was in the wet season (March) and the second in summer (September) at both stations. In February 2002, elevated levels of primary production were recorded with 210.55 mg C $m^{-3}hr^{-1}$ at station II and 183.75 mg C $m^{-3}hr^{-1}$ at station I. The maximum production recorded in February 2002 at both stations, coincided with the marked increase in nutrient loading to the reservoir. However, a considerable decrease in the primary production rate was observed in Summer with a minimum of 27.08 mg C $m^{-3}hr^{-1}$ at station I. The lowest production recorded at station II was 42.90 mg C $m^{-3}hr^{-1}$ in August (Fig. 3e). The minimum productivity of the reservoir was in August at both stations, which is correlated with a lower chl *a* concentration.

The major phytoplankton groups that contributed to winter rise of primary production were green algae and dinoflaggelates (Saadoun et al. 2008). A positive correlation was found between chl *a* and primary production at both stations (r = 0.66, $P < 0.05$). In discussing the correlation of different parameters with primary production, chl *a* appears to be the closest factor in this regard and is widely used as an indirect measure of phytoplankton productivity (Voros and Padisak, 1991). Such close relation results from the fact that chl *a* is the most abundant pigment in plant living material. Chl *a*, on the other hand, was found to decline with reduced nutrients levels (Hunter and Laws, 1981), but such condition was not found in the reservoir since nutrient were above normal concentration all of the time. Therefore, a strong correlation between primary production and chl *a* concentration in Wadi Al-Arab reservoir is predictable. Minimum chl *a* concentration at station I in August 2001 coincided with the lowest production of the reservoir, also when chl *a* peaked in February 2002, it was accompanied with a peak of phytoplankton production. Positive correlation was evident between chl *a* and primary production at the two stations ($r_1 = 0.63$, $r_2 = 0.68$, $P <$ 0.05, respectively).

Many factors are well known to affect the primary production of the phytoplankton including nutrients loading, species composition, light and temperature. The data of water temperature, pH, salinity, dissolved oxygen and conductivity are not shown (Saadoun et al. unpublished data). The relation between temperature and primary production showed a degree of correlation in terms of seasonality as primary production increased in winter months and decreased in summer months.

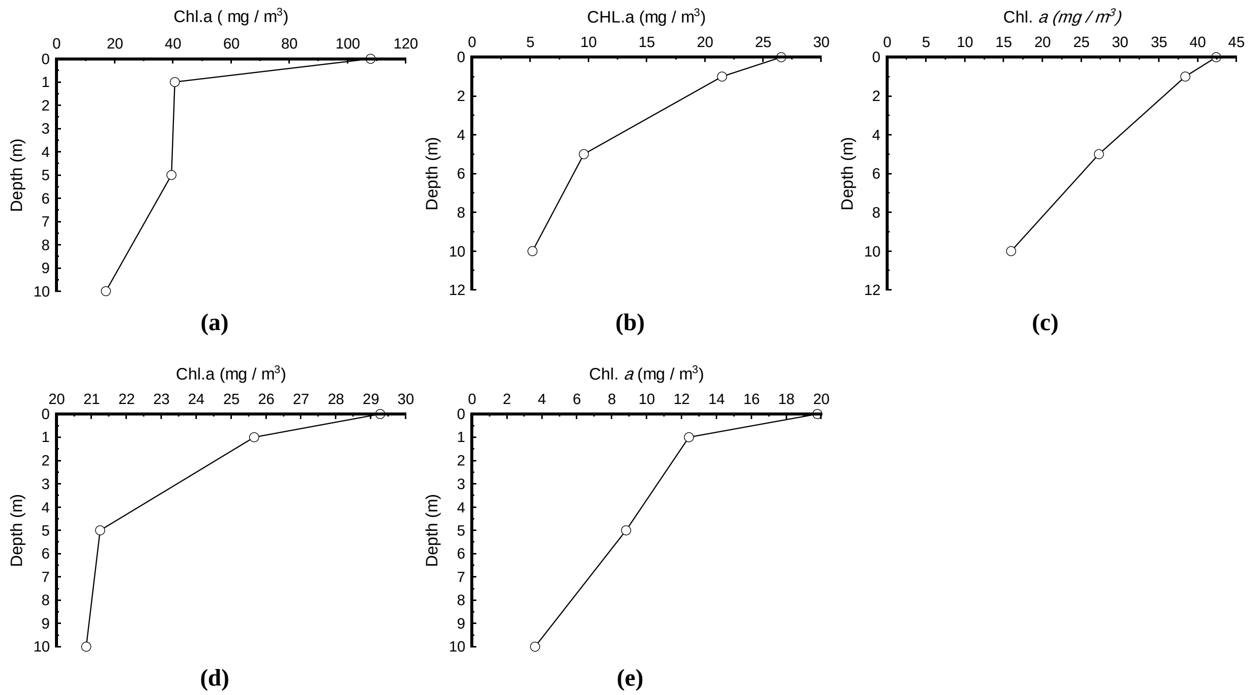


Figure 3. Vertical profile of chlorophyll *a* (a: April, b: May, c: June, d: July and e: August) at station II.

However, negative correlation (r = - 0.51, $P < 0.05$) was recorded between primary production and surface water temperature. This, however, can be reffered to the photoinhibition as light intensity is coniderably high during summer in this part of the world. Photoinhibition is known to occur in *in situ* incubated bottles in shallow waters during warm seasons (Coldman and Dennett 1984). As primary production estimation depends mainly on the rate of photosynthesis reaction, and as the pH of the water correlated with CO_2 consumption by phytoplankton population, one can relates the pH of the water to its productivity. But in the reservoir, values of pH showed no seasonality with a mean of 7.92 at the two stations and was negatively correlated with productivity (r = - 0.09, $P < 0.05$) (Saadoun et al., unpublished data).

Also, the electrical conductivity of the reservoir showed high values without any pattern of variation. This stability of the reservoir salts levels reduce its influence on the productivity of the phytoplankton, so it was found to be negatively correlated with production (r = - 0.24, $P > 0.05$). Variation of total alkalinity in the reservoir is similar to that of electrical conductivity, the two parameters were highly correlated (r = 0.92) and have no obvious influence on phytoplankton production. Salinity, on the other hand, did not appear to have any particular influence on production (Saadoun et al. unpublished data).

6. Conclusion

Primary production in Wadi Al-Arab Dam reservoir during the study period was generally high and showed pattern of seasonally characterized by increase in wet season and a decrease in summer months. It was significantly correlated to dissolved oxygen concentration, but, negatively correlated with the surface water temperature and pH. As chlorophyll *a* is the most abundant pigment in plant living material, chlorophyll *a* appears to be the closest factor to be correlated to primary production. Positive correlation was evident between chlorophyll *a* and primary production at both stations.

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