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Investigation of short-time artificial aeration on water quality parameters and phytoplankton structure: a case study "Mamloo Reservoir"

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A B S T R A C T

Thermal stratification accompanied by a release of nutrients from sediment is a serious problem for the management of water quality. Water aeration and mixing technology can be widely used to control endogenous pollution and algae growth in reservoirs and lakes by water quality managers. In this research, a diffuser aeration system, was installed in a water column, in the Mamloo stratified Reservoir; and the impact of artificial aeration was brought under extensive assessment in relevance with the qualitative and biological parameters of the water, during the preliminary 6 d of aeration. The results showed that the thermal stratification was remarkably disturbed. After aeration, the amount of dissolved oxygen in the hypolimnion incremented from 0.55 to 3.46 mg/L. Nevertheless, a noteworthy correlation was not observed between the modification in the concentration of dissolved oxygen and the internal release of nutrients from the sediment in the hypolimnion. The advection generated by the circulated flow from the diffused air system can effectively transport algae between the surface and lower layers. The mixing function of diffuser can resist cyanobacteria flotation and decreased their distribution from 51,728 to 22,600 Cells/L. During the 6 d aeration, a significant factor, regarding modifications in water quality parameters and algae structure is the artificial flow generated by the diffuser.

Keywords: Thermal stratification; Nutrients; Phytoplankton structure; Artificial circulation; Reservoir

1. Introduction

Thermal stratification plays a crucial role in the qualitative and ecological condition of lakes and reservoirs [1–3]. During thermal stratification in water bodies, they experience a depletion of dissolved oxygen (DO) (of less than 2 mg/L) in the hypolimnion, thereby, causing an anoxic condition in the lower layers, favoring the release of nutrients from sediment which leads to the deterioration of water quality [4,5]. The stratified reservoir, with calm waters and a prolonged hydraulic retention time has created a suitable artificial environment for extreme algae growth [2]. However, since the resources required for algae growth in reservoirs may be potentially limited, the change in phytoplankton communities is strongly influenced by the available nutrients such as, (N, P and C) including the penetration of light [6]. As an internal management method, aeration of the reservoir was able to reduce the hypolimnion anoxic conditions and prevent the release of nutrients into the water body [5,7]. Two major countermeasures are

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available for the aeration of the reservoir; one strategy is the absolute combination of water and prevails over stratification; and in the aeration of the hypolimnion, the oxygen required in the hypolimnion is bestowed directly, without disturbing the thermal gradient associated with the stratification [7–9].

During artificial mixing an excessive growth of algae and the predominance of destructive species like cyanobacteria are prevented, by limiting access to light; and instead, are replaced by other species such as, diatoms, which are less harmful in terms of water quality [6]. Several different kinds of technologies for the recovery of water quality were applied in studies, including (i) Application of the water lifting aerator to control the growth of algal blooms and effective physicochemical parameters [10–13]; (ii) Artificial aeration to resolve water quality concerns including unpleasant odors and tastes, blue-green algae bloom, and particularly the existence of heavy metals [14,15]; (iii) Application of mixed oxygenation technology reduced ammonia-nitrogen release from the sediment in the Fenhe Reservoir [16]; (iv) Artificial mixing in the Nieuwe Meer Lake in Amsterdam by bubble plume installation to reduce the growth of green algae bloom [17]; (v) Operation of diffused air system in the small eutrophic impoundment to decreased the amount of total algae biomass [18]; And (vi) the full and partial lifting of the hypolimnetic aerator used in the Medical Lake to enhance water quality parameters [19].

Although artificial aeration in reservoirs and lakes has been widely utilized as an effective technique to alleviate quality problems caused by stratification and eutrophication [12,20,21], but, almost all of the studies have assessed the different effects of artificial aeration on water quality and its biological parameters over long time-periods; and a survey of these modifications, in the initial days of the aeration implementation, displays a lack in studies, in accordance with prior research. The objectives of this study, is to investigate and assess as to the manner of changes in water quality parameters and the structure of the phytoplankton community on a widespread field basis, in the first 6 d of diffused aeration exploitation, in a water column located in the Mamloo stratified Reservoir (MLOR), where it was executed. A scrutinizing and detailed survey of the modifications in water quality parameters and also the changes which have taken place in the abundance and structure of the phytoplankton, during the initial aeration can render more precise clues to the experts, so as to analyze the accurate occurrences within the duration of intensive aeration in the reservoirs.

2. Material and methods

2.1. Site study

MLOR (35° 35′ 11″ N and 51° 46′ 58″ E) is located 45 km away from Tehran city, the capital of Iran, as shown in (Fig. 1). The reservoir was built in 2002, began to supply water to Tehran in November 2010, and has comprehensive benefits such as urban water supply, irrigation for agricultural purpose, and generating electricity, as well as preventing flood [22]. The storage capacity of MLOR

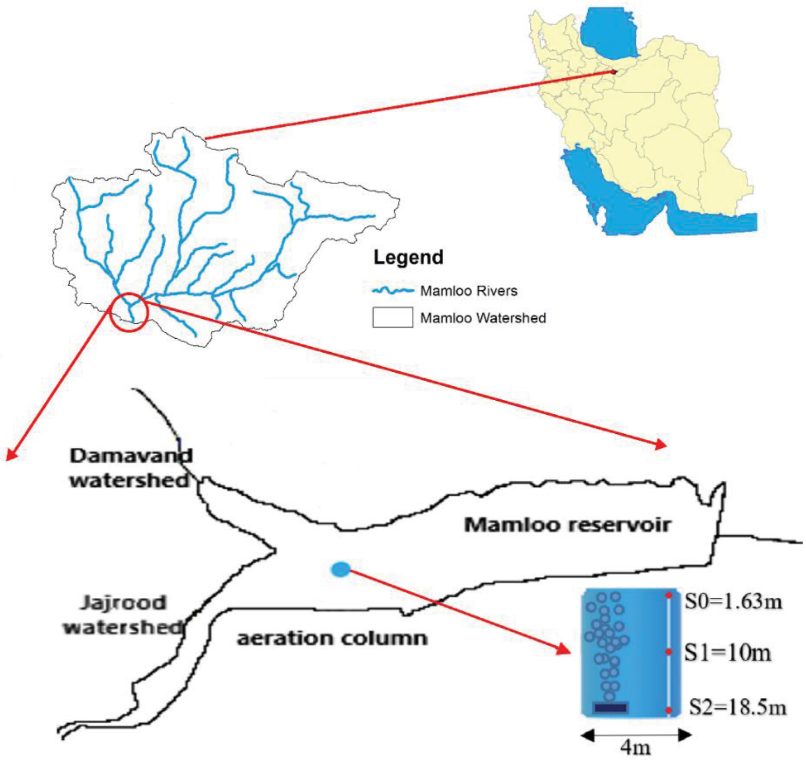

Fig. 1. The map of the study area: The watershed and Mamloo Reservoir, and the schematic aeration column with the monitoring stations.

is 250 million m^3 with an area of 8 km^2. The Jajrood River with a length of 165 km and a catchment area of 1,180 km^2 and an average inflow of 3.503 m^3/s, and Damavand River with a length of 33 km and an inflow of 0.898 m^3/s are the mainstreams to supply the MLOR in Tehran Province. The basin area is 1,750 km^2, and the average annual rainfall is 369 mm. The study area has a cold and humid climate in a mountainous region and a relatively moderate climate in the non-mountainous part, with a mean temperature of 10°C–20°C. Surrounding landscapes and the upstream of the MLOR is mainly rich in organic matter and phosphorus; However, it is limited for agriculture due to mountainous, and in major, a significant agricultural drainage is not observed in the MLOR Basin. Despite this, there are many industrial units and several residential areas in the Jajrood catchment, which can be considered as a potential source for pollutants entering the reservoir.

MLOR is characterized by a large depth (with a maximum depth of 70 m), stable thermal stratification, fast depletion of DO in the hypolimnion, also increased chlorophyll concentration in summer (especially in a euphotic zone) and up to 40 μg/L, which indicates a high potential for the occurrence of eutrophication. A diffused air system was installed in the MLOR for the experimental study of change water quality at the beginning of aeration. A water column with a depth of 20 m and a radius of 4 m was considered as a pilot with three monitoring stations located at the Shushtari Wharf (X = 0568990, Y = 3942851). Sampling stations were selected at three depths S0 (Secchi disk depth = 1.63 m), S1 = 10 m from the surface, and S2 = 18.5 m from the surface and1.5 m above the sediment (Fig. 1). All samples were collected daily from 10/22/2019 to 10/28/2019; moreover, all studied parameters were evaluated a day before operating the aeration equipment inside the sampling column. The hydro physiochemical parameters of MLOR before operation of the diffused air system are shown in (Table 1).

2.2. Artificial mixing

MLOR was mixed artificially with compressed bubbled air, which was connected with a network of four tubes, each of which, were half a meter long, creating a 90° angle with each other, and situated at almost 18.5 m (to prevent disturbing the sediment) depth. Air was pumped through pipes, which were perforated every 5 cm with holes of 3 mm in diameter. The compressed air was continuously delivered to the air-releasing tubes in these techniques. Subsequently, the rising bubbles tend to lift the lower layer of the water to the surface resulting in the induction of a turbulent mixing [23]. Injection of compressed air at a maximum depth usually results in the highest mixing rate, as the water flow is a function of depth of release and air-flow rate (Fig. 2). Lorenzen and fast concluded that an air-flow rate per lake surface area of 9.2 $m^3/km^2/min$ should provide adequate surface re-aeration and other circulation benefits. According to the Lorenzen and fast criterion, the supplied rate of the diffused air system in MLOR was considered to be 0.5 $m^3/m^2/hr$ [24].

Table 1
Qualitative parameters of MLOR before commencing the operation of artificial mixing at the three stations S0, S1 and S2

No.	Parameters	S0	S1	S2
1	Temperature, °C	22.00	21.61	15.12
2	Dissolved oxygen, mg/L	8.22	6.36	0.55
3	pH	8.80	8.53	7.31
4	Electrical conductivity, μs/cm	470	470	470
5	Chlorophyll, μg/L	22.39	17.62	1.30
6	Secchi disk, m	1.63	–	–
7	Nitrate, mg/L	2.20	0.81	0.03
8	Nitrite, mg/L	0	0.01	0
9	Ammonium, mg/L	0.08	0.08	0.52
10	Total nitrogen, mg/L	2.67	4.66	7.83
11	Soluble reactive phosphorus, mg/L	0.11	0.14	0.19
12	Total phosphorus, mg/L	0.18	0.23	0.36

2.3. Chemical and physical measurement

Two sets of samples were collected using a Niskin water sampler in polyethylene containers with a volume of 1 L. One bottle was used for physical and chemical measurement, and another one was used to identify and count the phytoplankton community (Olympus Microscope, Japan), where; the contents of this bottle was immediately preserved with 5% of formalin and 1% of Lugol's solution [25]. Nutrients such as nitrate (NO_3–N; mg/L), nitrite (NO_2–N; mg/L), and the soluble reactive phosphorus (PO_4–P; mg/L) were determined by the Spectrophotometric Method with a single reagent. Moreover, ammonium (NH_4–N; mg/L) was analyzed by the Ion Chromatography Method and total nitrogen (TN; mg/L) as well as total phosphorus (TP; mg/L) were also estimated by the Digestion Acid Persulfate Method.

Some parameters such as pH, dissolved oxygen (DO), temperature (T) and water transparency were measured in situ by using standard devices with high accuracy [pH and DO heck portable analyzer and heck digital thermometer (accuracy ±0.1%)] and the standardized Secchi disk. All samples were stored at 4°C and dispatched to the laboratory immediately to be were analyzed within 72 h by following the standard method procedure [26].

3. Result and discussion

3.1. Temperature, dissolved oxygen, and pH change of MLOR

Fig. 3a illustrates the MLOR temperature profile during the different months in 2019. The reservoir experienced a stratified condition for several months, while, the water body became completely mixed in January and February. Due to a rapid increase of temperature on the surface, stratification began to intensify in April, and the temperature gradient was the maximum in July to September. Stable stratification restricts the transfer of oxygen from the surface to the lower layers and the hypolimnion turns anoxic (Fig. 3b), [27]. An anoxic condition in the hypolimnion leads to the release of nutrients from the sediment into the hypolimnion [28,29].

The thermal gradient is a significant factor, which lays an impact on the mixing depth of the diffuser system. [12,30]. When the gradient temperature decreased, the

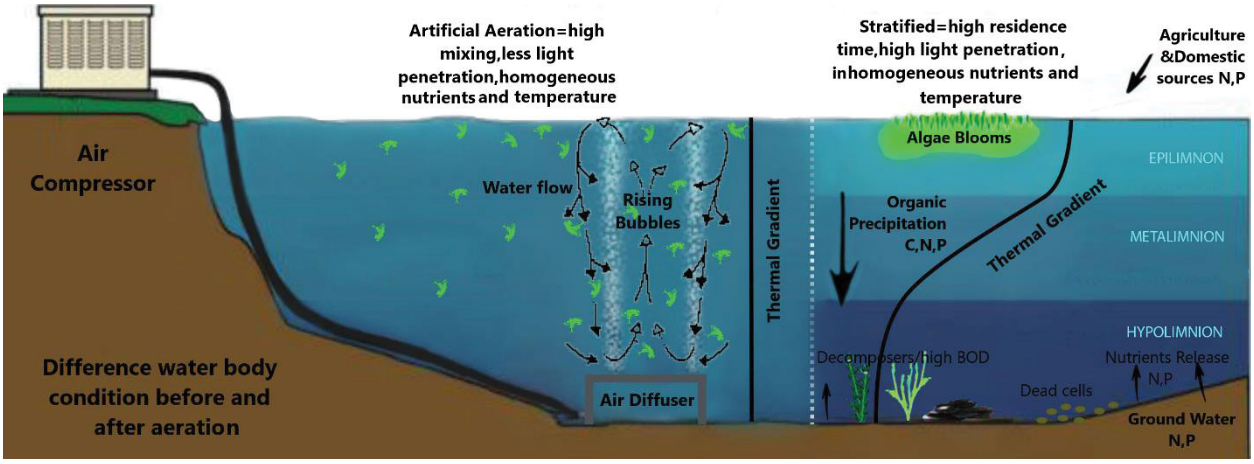

Fig. 2. Schematic diagram of artificial mixing and stratified condition in reservoir.

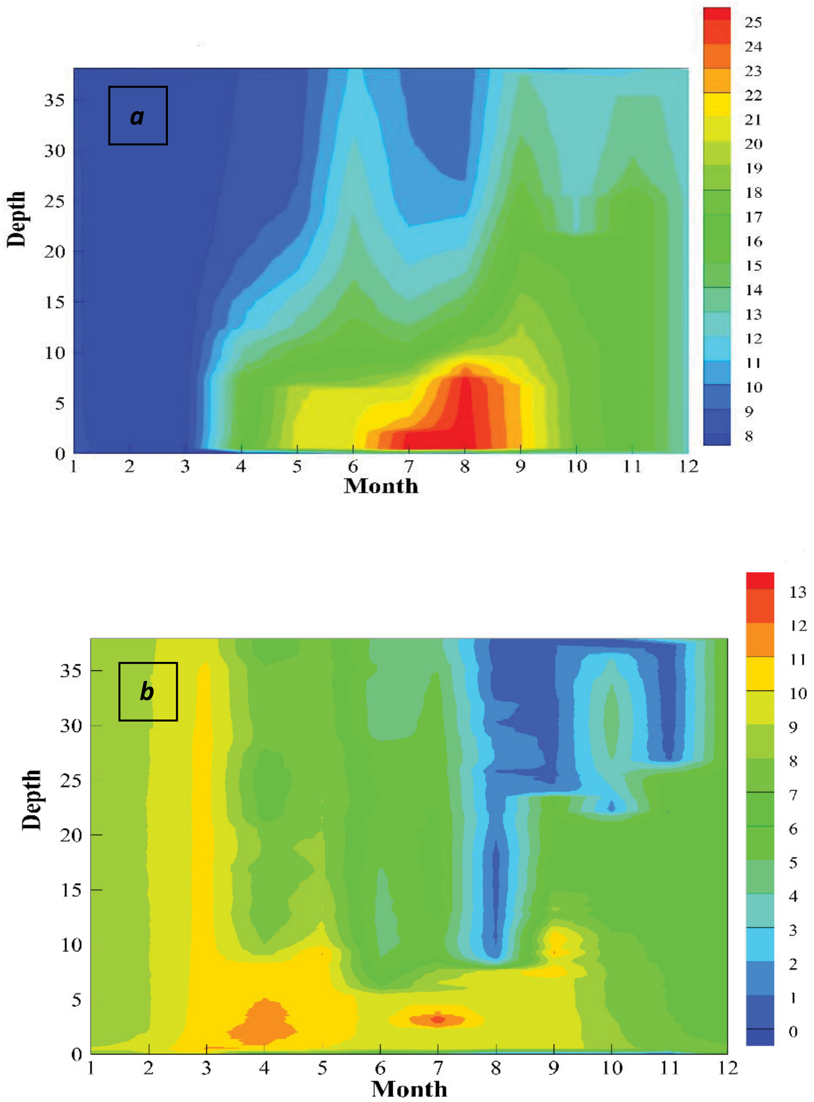

Fig. 3. Vertical variation of (a) water temperature (°C) and (b) dissolved oxygen (mg/L) in MLOR at the different months of 2019, at the depth of 37 m.

resistance of the buoyancy decreased, which increased the mixing depth [12]. The temperature gradient at the sampling site, till a depth of 13 m from the surface, in MLOR was less than 0.1°C/m and the mean was approximately 0.9°C/m, between 13 m and 20 m. The maximum temperature gradient was noted at a depth of 15–19 m. The water temperature gradient is an important index to measure the mixing impact of the diffuser system in MLOR [12]. The daily change in the MLOR thermal profile, during the 6 d of aeration is shown in Fig. 4. After 3 d of diffuser operation, the water temperature in the upper layer (up to 8 m from the surface) began to reduce, and at the end of the period, water temperature in the surface decreased from 22.61°C to 18.93°C. An increase in temperature at the deeper layers showed a slower trend. The temperature in the over-layer in sediment (S2) showed an increase in temperature from 15.11°C to 16.81°C (Fig. 4).

Oxygen can enter a reservoir in two different ways. The main mechanism is through atmospheric diffusion; where oxygen in the air is absorbed by surface water due to the various concentrations. Secondly, the aquatic plant photosynthesis mechanism releases oxygen into the water reservoir [9]. The concentration of dissolved oxygen in MLOR during the thermal stratification from (April to November) and turn over condition (end of December until mid-March) are given in Fig. 3b. The diffuser system can improve the concentration of dissolved oxygen of water body in the hypolimnion in two varied ways; (i) by mixing the upper and lower layers and destroying the thermal stratification, which increases the concentration of DO in the hypolimnion; and (ii) by directly oxygenating water body by rising bubbles [17]; and in most cases, artificial mixing and de-stratification increases the concentration of DO in the water body immediately [15,19]. The result of the survey of the vertical gradient of DO in MLOR within the duration of aeration, depicted a decrease in DO from 8.21 to 3.77 mg/L in surface and an increase from 0.55 to 3.46 mg/L in the hypolimnion (S2) (Fig. 4). On the fundaments of Smith et al. [31], oxygen transfer between air bubbles and water is insignificant except in very deep waters of (60) meters. Since, the mixing time was short and mixing depth was less than 60 m, in MLOR, it seems that the main reason for the change in DO content at the different stations (S0–S2) was de-stratified and the mixing of oxygen-enriched surface water with oxygen with meager oxygen water in the hypolimnion, due to the artificial flow generated by the diffused air system. Moreover, a decrease in DO at the sampling column surface can be related to a certain extent to the reduction in photosynthesis and the mixing of hypolimnetic water with high biochemical oxygen demand (BOD) in the upper layers [32,33].

The vertical modifications in the value of pH in the sampling column throughout aeration and a day before commencing the aeration is demonstrated in Fig. 4. The pH value in the water body depends on the intensity of mixing, respiration, and photosynthesis [34]. At the end of the sixth day of aeration, surface (S0) values of pH decreased from 8.88 to 8.18, and conversely, the pH in the hypolimnion at the S2 station elevated slightly and from 7.31 increased to 8.11.

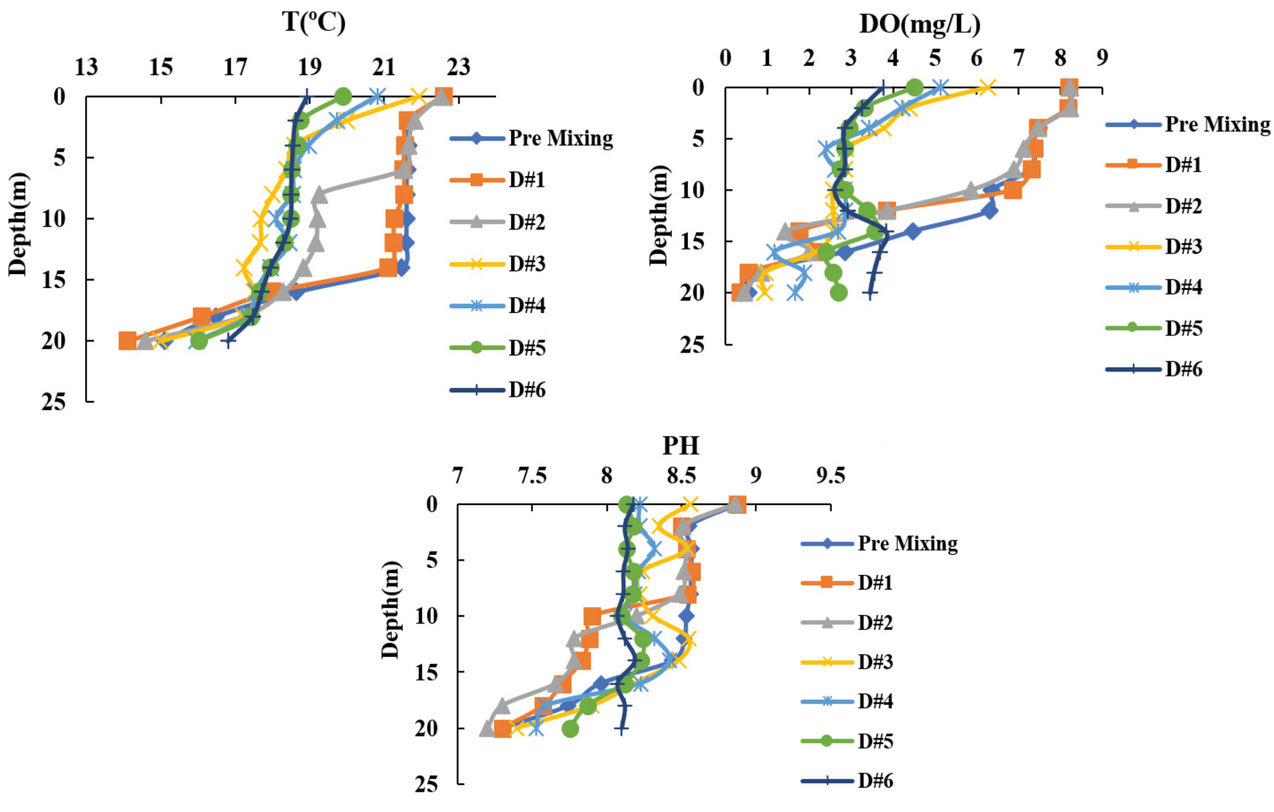

Fig. 4. Daily vertical variation of water temperature, DO, and pH value, during the aeration.

(Fig. 4). The reduction of pH in the surface can be attributed to the impact of mixing on the change in the abundance of algae and a reduction in the amount of photosynthesis. Moreover, the transfer of CO_2 accumulated in hypolimnion in respect to the upper layers could be effective in the modification of pH in the sampling column [35].

3.2. Nutrient

In the stratified MLOR, NH_4–N has a negative clinograde distribution, whereas, NO_3–N is almost deficient in the hypolimnion. In addition, NO_2–N occurs in the narrow layers, between the upper oxygen-enriched water and the lower oxygen-poor water [36]. The concentration of nutrients strongly depends on bottom anoxic conditions in the reservoir [5,7]. The results indicate that in the stratified MLOR, with a hypolimnetic DO of less than 2 mg/L, the release of nutrients from the sediment into hypolimnion was noticeable; and the concentration of nutrients in the different layers was heterogeneous. As the diffuser system operated in the sampling column, the concentration of nutrients modified in the different depths of MLOR (Figs. 5 and 6).

The concentration of NO_3–N decreased in all the three depths; with a decrease in the amount of DO in the upper layers, the reduction in the concentration of NO_3–N is capable of being foreseen. Upon artificial destratification, the distribution of NH_4–N and PO_4–P was interrupted and their concentrations increased in the upper layers [35,37], (Fig. 5). On the basis of the research performed by Cong et al. [16], under anaerobic conditions, when the concentration of DO drops to less than 2 mg/L, nitrification becomes static; and NH_4–N accumulates in the lower layer, alongside the sediment. In addition to which, under neutral alkaline conditions (such as, MLOR at the time of sampling) with DO being

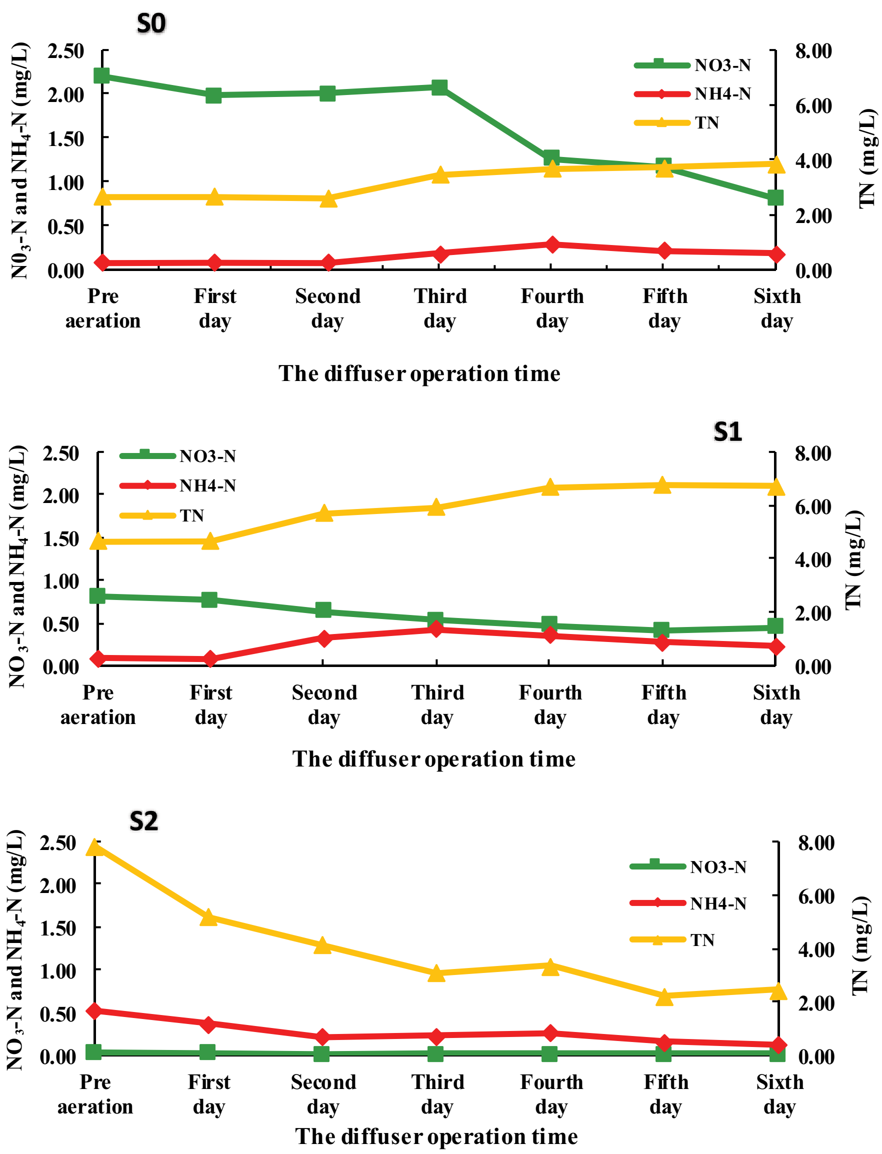

Fig. 5. Dynamic change of ammonium (NH_4–N), nitrate (NO_3–N) and total nitrogen (TN) during the aeration in S0–S2.

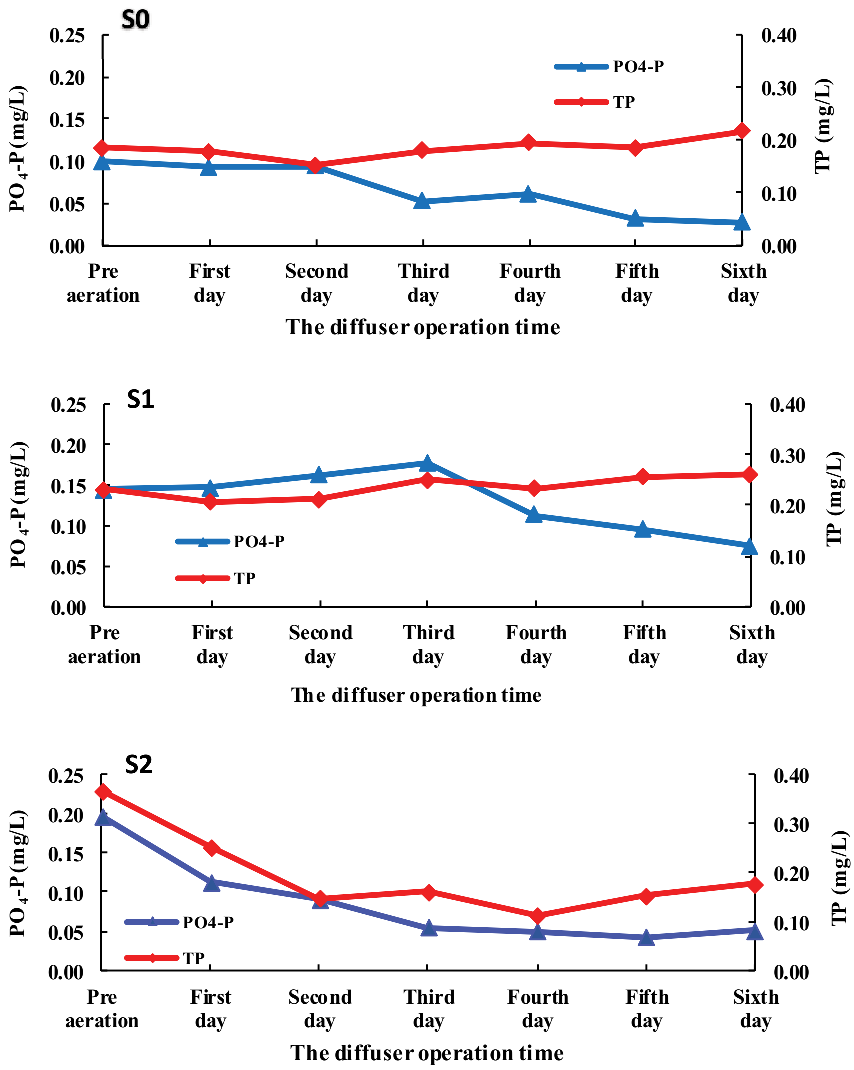

Fig. 6. Dynamic change of soluble reactive phosphorus (PO_4–P) and total phosphorus (TP), during the aeration in S0–S2.

<2 mg/L, PO_4–P is released into the water body from the sediment [15]. A significant reduction in the concentration of NH_4–N (from 0.52 to 0.12 mg/L) and PO_4–P (from 0.19 to 0.05 mg/L) in the hypolimnion (S2) during the 6 d aeration (despite the maintenance of the anaerobic condition until the termination of the 4th day) is inconsistent with that of the results, rendered by Cong (Figs. 5 and 6). The result obtained from the modifications of NH_4–N and PO_4–P concentrations in the hypolimnion during aeration showed that, there is no consequential correlation between the change of dissolved oxygen concentrations and the internal release of nutrients from sediment. The concentration of NH_4–N, increased from 0.08 to 0.19 mg/L and from 0.08 to 0.23 mg/L in the two other stations of S0 and S1, respectively (Fig. 5). An increment of NH_4–N concentration at the upper stations (S0 and S1) occurred after mixing, when the water containing the accumulated NH_4–N was conveyed to the upper layers or during the fatality of the algae community, which will be discussed later [35,38]. During the aeration period, the NO_2–N concentration in all the monitoring stations was zero.

The vertical distribution of PO_4–P and TP during the aeration in different depths is shown in (Fig. 6). In MLOR the epilimnion PO_4–P concentration was extremely low, because of the intense competition for this substrate among autotrophs, as well as a chemical reaction or precipitation, which expels it from the euphotic zone [34]. During the operation of the diffuser, the concentration of phosphate at the surface showed an erratic trend of change, but at the end of aeration, it reduced to 0.07 mg/L compared to the initial amount. In the first 3 d of aeration, phosphate accumulated in the hypolimnion was distributed in the upper layer (S1) and the concentration of phosphate increased from 0.14 to 0.17 mg/L, but then, the concentration of phosphate decreased in S1, from 0.17 to 0.07 mg/L until the end of aeration, which, could be due to the rapid absorption by algae [39].

After aeration, an increase of TN and TP at the upper sampling stations (S0 and S1) and a decrease in the bottom station (S2) were observed (Figs. 5 and 6). Some researchers have shown that during the aeration, TP decreases in the water body, probably because of a decrease in phosphorus release from the sediment together with an increase in the redox potential at the sediment surface [32,40]. In other cases, TP incremented and this is possibly due to the entrainment of nutrient-rich hypolimnetic water into the upper layers [41,42]. The daily variation in TP concentration in (S2) have not shown a strong correlation with alleviation of the hypolimnetic conditions (Fig. 6). Therefore, this implies that the main reason for variation of content of TP and TN in the stations (S0, S1 and S2), is the mixing flow generated by the diffuser system. In general, the accumulation of the lifeless remains of algae on the water surface and a re-suspension of organic matter which is presented as a sub-factor; can have an impact on the TP and TN in the sampling stations [40,43].

3.3. Effect on phytoplankton

The phytoplankton in MLOR displayed the typical seasonal pattern observed in the mesotrophic lake term. Seasonal variation of chlorophyll concentration in MLOR in the three depths of the reservoir in 2019 is illustrated in (Fig. 7).

At the beginning of autumn, the chlorophyll a concentration decreases significantly, in MLOR; which can be attributed to the unfavorable conditions for the growth of phytoplankton; such as, a decrease in surface temperature and light penetration due to the access to flood, as a result of precipitation in autumn [38]. The abundance of algae (based on the cell numeral) prior to artificial mixing, which was mainly concentrated in the upper layer. However, after mixing, the abundance of algae decreased in station S0 and increased in the stations S1 and S2 in the sampling column of MLOR. Modifications in algae dominance and a Secchi disk transparency variation (m), during the aeration period are demonstrated in (Fig. 8).

Several recent publications have documented the correlation of the change in the abundance of phytoplankton with artificial de-stratification [44–46]. Ma et al. [12] reported that the phytoplankton distribution decreased on the surface, in just three weeks after the performance of the aerator in the Shibianyu Reservoir in China. Prior to the artificial mixing in MLOR, the number of algae cells on the surface was 811,219 cells/L, and 6%, 63%, and 1.5% of which, these pertain to the cyanobacterial bloom, green algae, and diatoms, respectively. The abundance of the varied types of phytoplankton in the different monitoring sites (S0, S1 and S2) is displayed in Fig. 9. The predominated phytoplankton in S0 and S1 was green algae and diatoms were also more copious in S2, showing an abundance of 59%. Cyanobacteria had the lowest population amongst the phytoplankton and

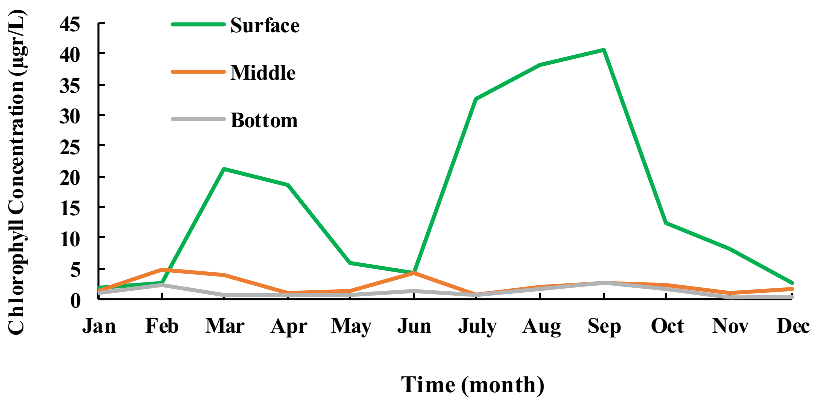

Fig. 7. Seasonal variation of chlorophyll in MLOR in different months of 2019.

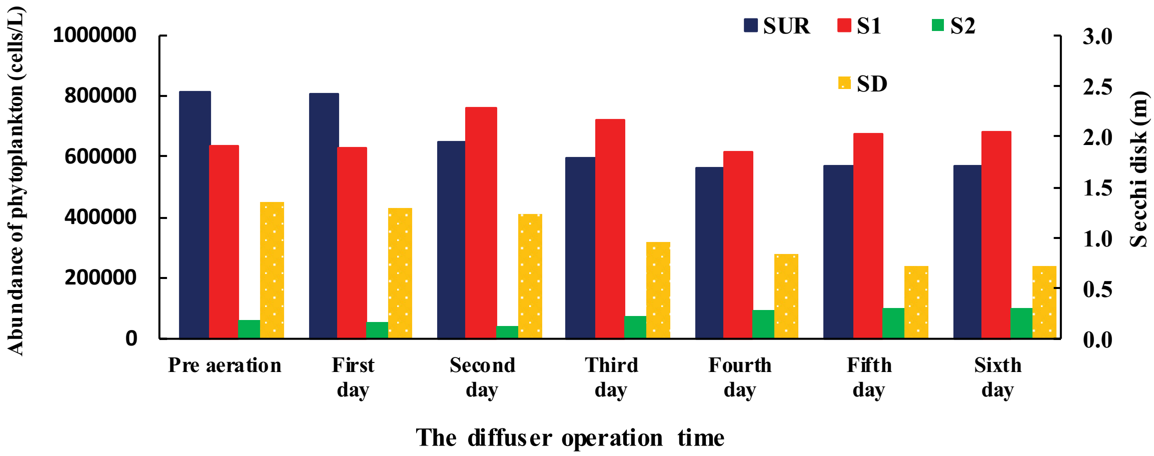

Fig. 8. Vertical distribution of algae at different sampling stations and Secchi disk transparency during the aeration.

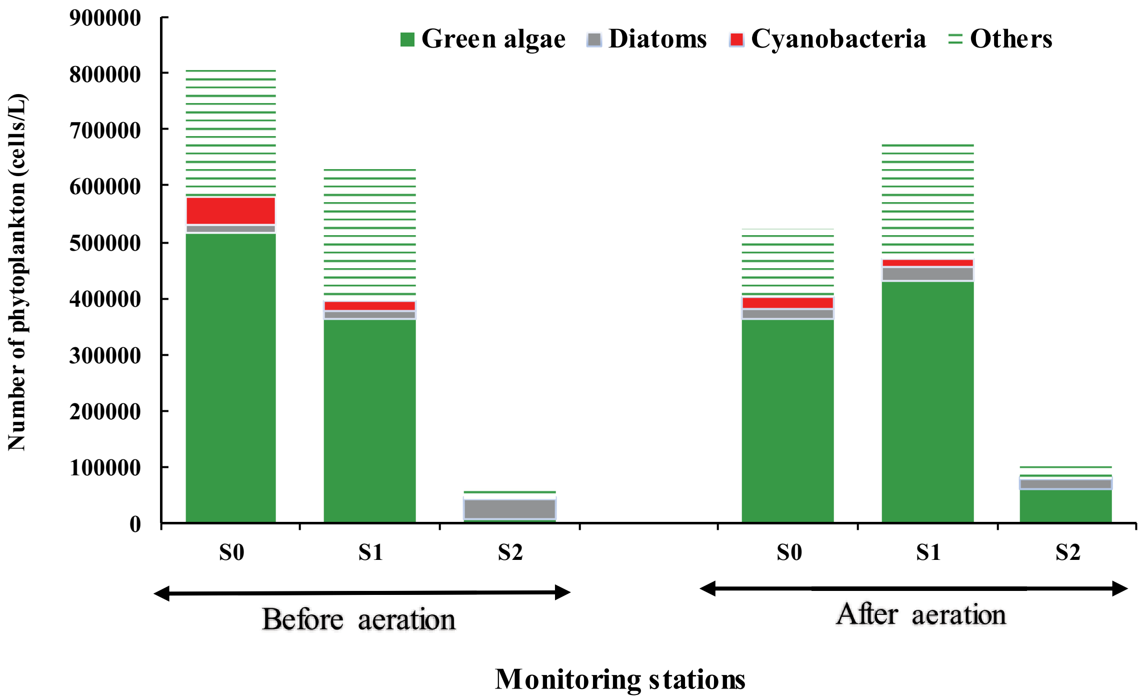

Fig. 9. Phytoplankton community structure and abundance at different depths, before and after the aeration at S0, S1 and S2.

the highest accumulation was observed in the euphotic zone. Then, after the 6th day of aeration, green algae, cyanobacteria and the distribution of diatoms altered in three of the monitoring sites. But the green algae were still the dominant algae in the monitoring column.

The abundance of green algae in the surface layer decreased drastically from 516,132 to 364,406 cells/L (more than 20%), but their distribution in the monitoring column was more homogenous in comparison to the period before aeration (Fig. 9). The number of diatoms increased in the upper layers and the abundance of cyanobacteria in surface layers (S0 and S1) were notably lower than prior to aeration (stratified condition). The structure of the phytoplankton community changes with the artificial aeration performance and is identical with the conditions in the Shibianyu Reservoir [12], Dalbang Lake [15] and Solomon Dam [47].

In a stratified condition, diatoms sink throughout the water column and experience enormous fatalities due to heavy silica frustule. They are adapted to the poor luminosity and are dominant only during the spring turn over [48]. The diffused air system was exploited in MLOR; and the spring turnover was artificially conveyed to the monitoring column; and a good opportunity for further growth and competition with other algae was created for the diatoms. Ma et al. [12] showed that after three weeks of aeration, at the nearest station to the aerator, the diatoms became the dominant algae in the water column and comprised of more than 60% of the phytoplankton population. In another case, in the Dalbang Lake, where, a 12-month operation from the diffused air system could change the dominant phytoplankton from cyanobacteria to diatoms [15].

Dominant species of cyanobacteria in MLOR (Fig. 10) include six species (*Gomphosphaeria* sp., *Anabaena* sp., *Aphanocapsa* sp., *Microcystis* sp., *Gloeocapsa* sp., *Cylindrospermopsis* sp., *Oscillatoria* sp.)

The abundance of cyanobacteria reduced from 51,728 to 22,600 cells/L in the (S0) station and from 20,339 to 11, 884 cells/L in the (S1) station, after 6 d of aeration. Many studies have documented a reduction in the abundance of cyanobacteria as a result of de-stratification [49–51]. A research has shown that, the cyanobacteria which were at a distance of 10m from the aerator, within about one months after aeration, demonstrated a reduction of more than 50% [12]. Kortmann et al. [52], showed that, the abundance of cyanobacteria decreased from 1,700 to 500 cells/mL during artificial (de-stratification) and the diatoms, as well as the green algae became prevalent. The optimum condition for the blooming of cyanobacterial comprises of high-water temperature and nutrient, calm and stable water, including immense solar radiation [52].

Some colonies of cyanobacteria (*Anabaena*, *Microcystis*, *Cylindrospermopsis*) are capable of accelerating photosynthesis and synthesize great amounts of carbohydrates during the period of growth by taking advantage of a buoyancy mechanism. The condition for adjusting this buoyancy mechanism, is that, the water body turbulence is minimal and the euphotic zone is shallow [51]. With due attention to the reserved energy, if the cyanobacteria is under the euphotic zone for a lengthy period of time, reserves are limited and as a result, the initial production will decrease [49,53]. Subsequently, the proportion of time that the cell expends in luminosity is then determined by the Z_{mix}/Z_{eu} ratio. If the mixing depth is enormous, the cells spend shorter periods in the light and their growth will be reduced. Sherman et al. [54], showed that this ratio must be >3 so that de-stratification is effective in curbing

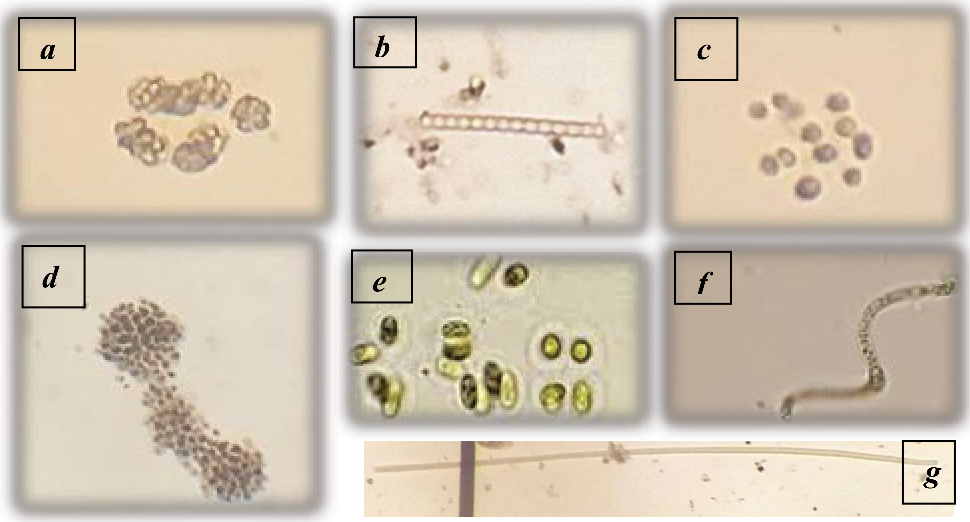

Fig. 10. Cyanobacterial genera in MLOR, (a) *Gomphosphaeria* sp., (b) *Anabaena* sp., (c) *Aphanocapsa* sp., (d) *Microcystis* sp., (e) *Gloeocapsa* sp., (f) *Cylindrospermopsis* sp., and (g) *Oscillatoria* sp.

the cyanobacteria. In this research, since the mixing was strong enough, we can consider (Z_{mix} = Depth of circulation = 18.5 m), and Z_{eu} = Secchi disk × 2.8. Hence, based on the depth of the Secchi disk (=1.63 m) and assuming that the euphotic depth is the depth of 1% surface irradiance, the euphotic zone was equivalent to 4.564 m (Z_{mix}/Z_{eu} = 4.05).

In general, the effect of changes in internal nutrient loading (in relative to the anoxic condition in the hypolimnion), the penetration of light and the turbulence, could determine the abundance of phytoplankton structure in the reservoir [55]. Some studies showed that wherever, algae production, is potentially restricted by light, a reduction in the standing crop of algae was observed with an increase in the mixing depth [56]. The Klapper [57] studies displayed that, a mixing depth of more than 40 m may be required, in order to suppress the total phytoplankton standing crop, by light limitation. Despite the fact that the amount of turbidity is high in MLOR and light penetration is a factor that limits the growth of algae (Fig. 8), in accordance with the Klapper studies, due to the depth of mixing in the MLOR monitoring column (18.5 m), light restriction cannot be considered as an influential parameter, as to the decrease in the number of phytoplankton algae.

4. Conclusion

The application of artificial mixing in the 6 d can obliterate thermal stratification noticeably and reduce the vertical temperature gradient in the sampling column from 7.5°C to 2.12°C. An increment in the content of dissolved oxygen (DO), in the hypolimnion (3.46 mg/L) is due to the weakening of the thermal stratification and the mixing of oxygen-enriched water in the upper layers with that of the deficiently-oxygenated water in the lower layers. In the duration of aeration, a noteworthy correlation between a modification in the concentration of DO and the release of internal nutrients from the sediment was not observed. Content of nutrients in the upper layers (S0–S1), increased rapidly, as the nutrients which had accumulated in the waters below, were conveyed to the upper layers. The concentrations of ammonia nitrogen, total nitrogen, reactive phosphorus and total phosphorus in the hypolimnion (S2) decreased to 0.12, 2.45, 0.05, and 0.17 mg/L, respectively, in comparison to the day, prior to mixing. Therefore, the short-term operation of the diffused air system can change the abundance and structure of phytoplankton in the three studied depths, by mixing the upper and lower water layers, as well as by algae transfer between the surface and deeper layers. In addition to which, the mixing function of the diffused air system can oppose the buoyancy of the cyanobacteria and reduce their abundance in stations (S0 and S1). In conclusion, the results attained during the first 6 d of in MLOR, aeration demonstrated that the variation in the physical, chemical and biological parameters is mainly influenced by the artificial flows produced by the diffuser in the sampling column.

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