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Dynamics of Water Quality in the Truc Bach Lake, Hanoi Capital, Vietnam

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Hanoi, the 1,000–year–old capital of Vietnam, has over 100 lakes which play a very important role in creating the landscape, as well as being the habitat for a variety of aquatic animals. However, as closed bodies of water, these lakes are facing a wide range of water quality problems due to their poor rate of exchange with external water sources. Thermal stratification, in particular, which is highly dependent upon meteorological conditions, has a great impact on the quality of their water. To gain insight into this problem, Truc Bach Lake, which is located in the northwest of Hanoi's central region, was chosen as a typical lake that would thus be a favorable place to conduct a case study. In our research, the water quality variables of Truc Bach Lake during its daily cycle were measured on site and were sampled periodically (over four seasons) for laboratory analysis, in order to investigate the vertical dynamics of its water quality during a daily cycle, as well as the seasonal changes that take place in a single year. The results of this study provide much valuable information on the temporal and spatial changes of the lake's water quality over the course of a year. They also provide a foundation for the simulation of the water quality dynamics in the targeted lake, which would provide a useful basis for further research.

Key words: closed water body, thermal stratification, water quality variables, water quality dynamics, water pollution

INTRODUCTION

One of the notable features for foreign visitors to Hanoi, the capital of Vietnam, is its great number of natural lakes (over 100), whose areas range from several hectares to hundreds of hectares. Besides creating a lovely landscape that creates a climate of harmony for Hanoi's citizens, these lakes also provide a habitat for a variety of species of valuable aquatic animals. Unfortunately, due to the city's rapid but unsustainable development, the health of these lakes is rapidly being seriously compromised by a wide range of human activities, such as the discharge of waste and wastewater, among others. Furthermore, as closed bodies of water, lakes also experience many other problems due to their poor exchange with external water resources, such as thermal stratification, entrophication, etc. (Lap and Mori, 2006). As regards thermal stratification, this phenomenon can be found in many closed water bodies. Since it is highly dependent upon meteorological conditions, it is one of the most important factors affecting the health of lakes, and has a great impact upon the ecological environment in reservoirs (Yun *et al.*, 2001). In particular, depending upon the external conditions, the temperature in the top layer of a lake is either raised or lowered by various factors, including solar radiation, air temperature, relative humidity, and wind speed (Chapra, 1997). As a result, a varied distribution of water temperature takes place within the depths of a lake, in a process that is called thermal stratification. Since the water temperature has a significant influence upon all the characteristics of water (e.g., the dissolved oxygen (DO), specific weight, etc.) as well as upon various chemical–biological processes, the dynamics of thermal stratification clearly need to be researched and understood.

In order to conserve Hanoi's natural lakes as well as ensure the quality of their environment for the aquatic animals, it is important to monitor the principal water parameters, as well as gain detailed insight into the dynamic processes that affect water quality in closed bodies of water under various meteorological conditions. From this perspective, Truc Bach Lake was chosen as the site of our case study in order to examine the variations in its water quality in its daily cycle over different seasons. Through this research we have obtained valuable information about this lake, which we share in the body of this paper.

MATERIALS AND METHODS

Study area

Truc Bach Lake is located in the northwest of Hanoi's Old Quarter, immediately adjacent to the eastern shore of the city's largest lake, West Lake, which is a former branch of the Red River, whose west bank is nearby, as shown in Fig. 1.

The lake has an average depth of about 2.0 m. Its maximum length is about 400 m and its maximum width is about 300 m. The total water surface area is approximately 9,000 m^2. In general, the volume of inflow and outflow is zero; that is, there are no changes in the lake's water level.

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Fig. 1. Location of the Truc Bach Lake in Hanoi, Vietnam.

Field observations

Period of observation

Observations on the scale of a day were conducted in the morning (09:00), the afternoon (15:00), and the evening (21:00). Over a cycle of one year, Hanoi has four separate seasons. Normally, spring and autumn are the transit–seasons between summer and winter, which can have a difference in temperature of over 20 Celsius. Therefore, one typical summer day and winter day (April 13th and November 10th, respectively) were chosen as research dates that could clearly represent the impact of meteorological conditions on water quality, especially in terms of thermal stratification. In addition, one typical day in autumn (August 23rd, 2011) also was selected as a transit–season day.

Measurement of water quality parameters

In order to assess the water quality rapidly and correctly, along with the processes of changing quality in the water depths of Truc Bach Lake, several parameters, including water temperature (˚C), hydrogen ion concentration (pH), and dissolved oxygen (DO) (mg/*l*) were selected for direct on–site measurement using the TOA–QC24. In addition, other parameters such as Biochemical Oxygen Demand (BOD_5) (mg/*l*), Ammonia (NH_4^+) (mg/*l*), Nitrate (NO_3^-) and Nitrite (NO_2^-) (mg/*l*) were also measured, as water samples were taken to the laboratory for analysis. To investigate the vertical fluctuation of the lake's water quality, the depth of the lake, which is about 2.0 m, was divided into intervals of 40 cm, and the measurements and water samples were taken at points 0.4 m, 0.8 m, 1.2 m, and 1.6 m below the water surface. All sampling and measurement took place at the center of the lake.

RESULTS AND DISCUSSION

Time–variation of water temperature, DO and pH within horizontal water layers in the lake during a daily cycle

Temperature change

Temperature is a critical water quality parameter, since it directly influences the amount of dissolved oxygen that is available to aquatic organisms. Fig. 2 presents the time–variation of the water temperature in each water layer on two typical days, one in summer (April 13th, 2011) and one in winter (November 10th, 2011). As can clearly be seen in the figure, the water temperature was about 5˚C higher in summer than in winter.

In addition, the water temperature at 15:00 o'clock was the highest, as compared to the temperatures at

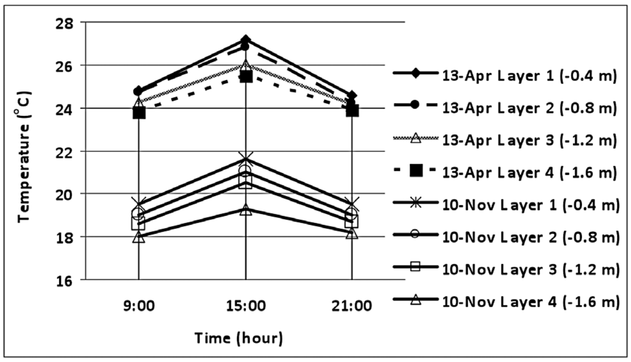

Fig. 2. Time–variation of water temperature within each water layer in the lake on April 13th, 2011 and November 10th, 2011.

09:00 o'clock and 21:00 o'clock. As regards the water layers, it can be seen that in both seasons, the water temperature in the top layer was always higher than it was in the deeper layers, and the change in water temperature in the top layer seems to be more distinct than that in the lower layers. The reason for this is that the top layer is directly contiguous to the atmosphere, and is thus subject to meteorological conditions. Its water temperature therefore changes according to changes in the meteorological conditions. The water temperature in the surface layer, in turn, impacts that in the lower layers by means of convection and diffusion. This impact on the lower layers is inversely proportional to the distance between the surface layer and the lower layers. In other words, the deeper the water layer, the less it is affected by meteorological conditions. The vertical distribution of water temperature in the lake is clarified in Fig. 9, below.

DO change

The term DO is short for dissolved oxygen. It expresses the amount of oxygen dissolved in water, which is normally measured in milligrams per liter (mg/*l*). The oxygen content of natural waters varies with the temperature, salinity, turbulence, the photosynthetic activity of algae and plants, and the atmospheric pressure. An adequate amount of DO is critical to the survival of various aquatic organisms.

Figs. 3 and 4 show the time–variation of DO in each water layer on the selected typical days in summer (April 13, 2011) and winter (November 10, 2011), respectively. As can be seen in these figures, in general, the DO in the upper layer was usually higher than it was in the lower layers. In addition, the changes in DO in the upper layer seem to be proportional to the changes in water temperature. This can be understood by the fact that the presence of aquatic plants in the lake contributes DO to the waters through the process of photosynthesis, which is stimulated by an increase in water temperature. The DO values, however, are relatively low. The maximum value of DO is around 5 mg/*l* (in the top layer at 15:00 o'clock) while it has a minimum value of about 2 mg/*l* (in the bottom layer). These results indicate that the lake water is polluted by organic matter and nutrients, which we will discuss below. According to the "National technical regulations on surface water quality" of Vietnam (QCVN 08: 2008/BTNMT, 2008), with a minimum DO value of about 2 mg/*l*, Truc Bach Lake's water quality meets the standard of class B2, which is suitable only for navigation and other purposes that have low water–quality requirements.

pH change

A pH is a measure of the concentration of hydrogen

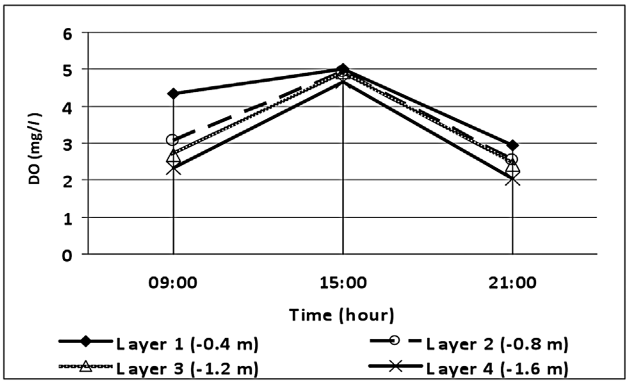

Fig. 3. Time–variation of DO within each water layer in the lake on April 13th, 2011.

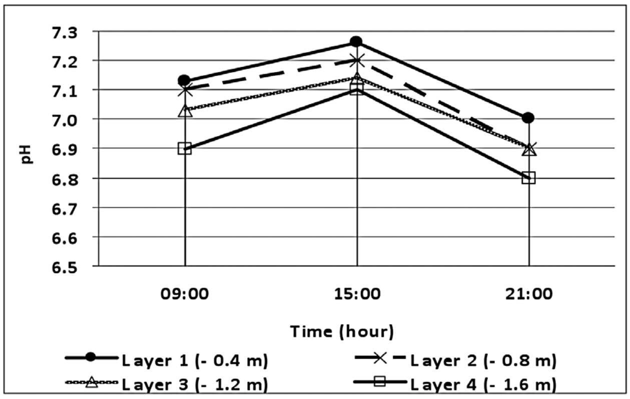

Fig. 5. Time–variation of pH within each water layer in the lake on April 13th, 2011.

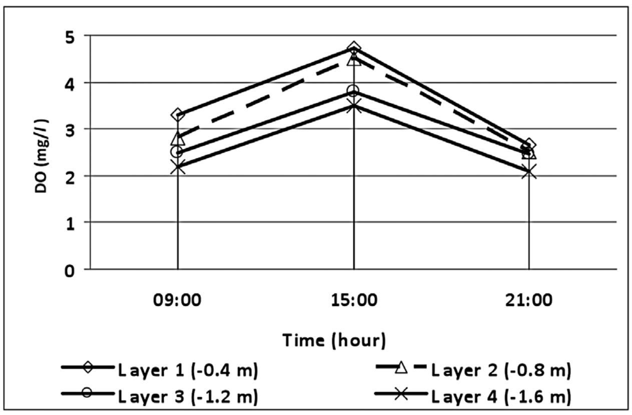

Fig. 4. Time–variation of DO within each water layer in the lake on November 10th, 2011.

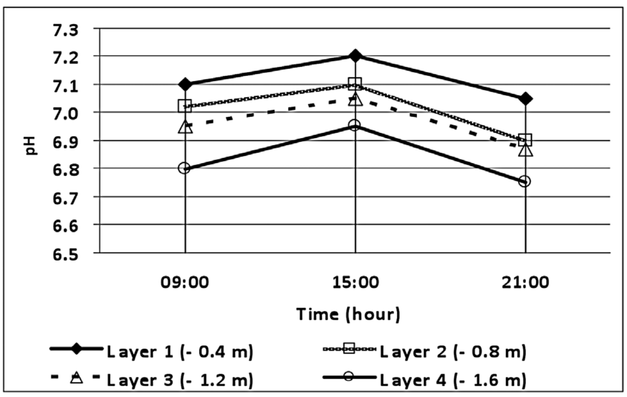

Fig. 6. Time–variation of pH within each water layer in the lake on November 10th, 2011.

ions in a material or fluid. In this case, this measurement indicates the acidity or alkalinity of the water. It is an important variable in the assessment of water quality since it influences many biological and chemical processes within a body of water, as well as all processes associated with water supply and treatment (UNESCO/WHO/UNEP, 1992). Water whose pH ranges from 5 to 9 is capable of supporting aquatic life.

Figs. 5 and 6 indicate the time–variation of the pH in each water layer on the selected study days in summer and winter, respectively. As can be seen in the figures, the maximum pH values were found in the surface layer, while the minimum ones were in the bottom layer. Also, on both days and in all layers, the pH values increased in the morning, peaked at 15:00 o'clock, and then decreased in the evening.

Vertical distribution of water temperature, DO and pH during a daily cycle

Vertical change in water temperature

Fig. 7, which shows the vertical distribution of water temperatures on the study day in summer (April 13, 2011), clearly shows that thermal stratification took place in the lake water at all the times of observation. It took place most distinctly, however, at 15:00. The most significant difference was found between the water temperature in the top layer and the bottom layer. The reason for this is that from around noon to mid–afternoon (from 11:00 to 15:00), both highly intense solar radiation and a high air temperature were present. Therefore, the water was heated during this period, which resulted in the maximum activity and presence of thermal stratification. Due to the fact that the upper layer absorbs most of the solar radiation, the water temperature in the upper layer is highest, while that in the lower layers becomes lower with increasing depth, since the solar radiation is decreasingly absorbed with depth, according to an exponential law. This time period can be called the heating period of the lake. At night, due to the absence of solar radiation and the reduced air temperature, the water radiates heat into the atmosphere, so the water temperature decreases gradually, especially in the upper layers. As a result, the vertical distribution of the water temperature in the lake became almost homogeneous at 21:00. This period can be called the cooling period of the lake.

The presence of a water temperature gradient between the top layer and the bottom layer creates a difference in water density between these layers. As a result, the heavier waters in the lower layers are overlaid by lighter waters in the upper layers. This is why it is more difficult for the waters in the upper layers to mix with the lower layers. How this phenomenon affects the water quality in the lake will be discussed below.

Vertical change in DO

Figs. 8 and 9 show vertical profiles of the DO distribution on April 13, 2011 (a day in summer) and November 10, 2011 (a day in winter), respectively. It can be seen that in general, the DO concentration in the surface

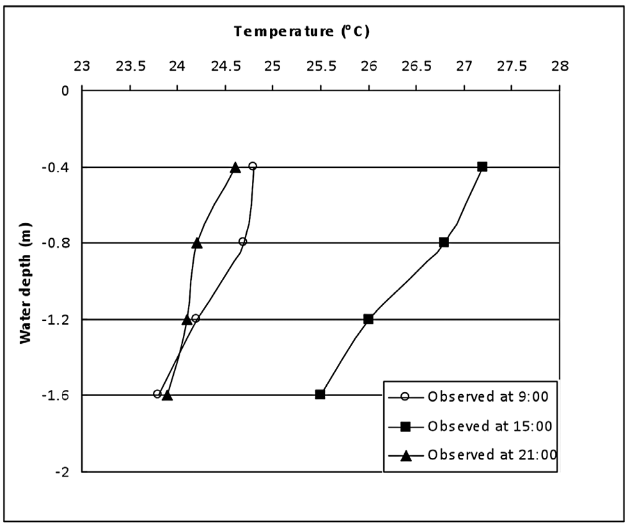

Fig. 7. Vertical distribution of water temperature on April 13th, 2011.

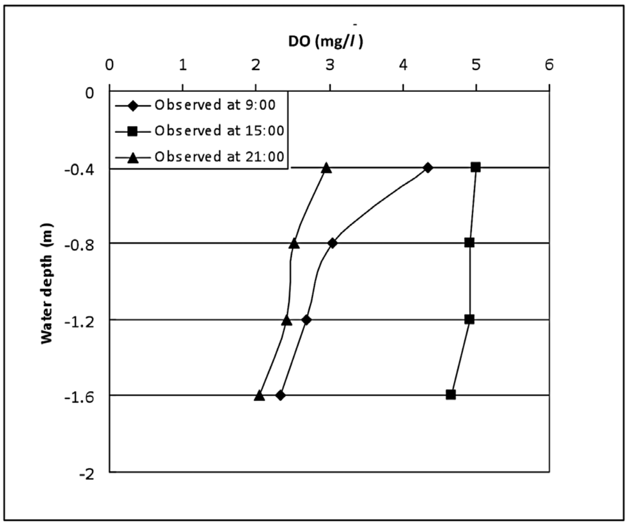

Fig. 8. Vertical distribution of DO on April 13th, 2011.

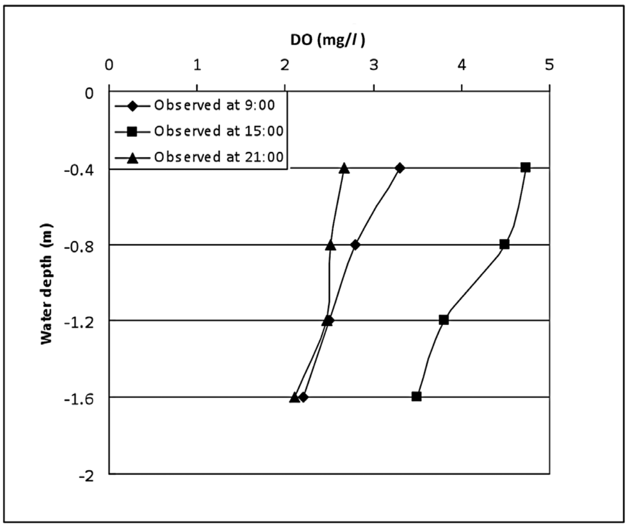

Fig. 9. Vertical distribution of DO on November 10th, 2011.

layer was significantly higher than that in the lower layers, and that the DO in the bottom layer reached its minimum value. This is due to the fact that the upper layers receive more oxygen from the atmosphere by means of reaeration, as well as exposure to more sunlight, which stimulates the photosynthesis process in the upper layers to create additional DO. The lower layers, on the other hand, are physically separated from the atmosphere (which is a source of gases such as oxygen) by the upper layers, and are to a varying extent affected by decomposing sediments in the bottom, which create a demand for oxygen. As a result of these influences, it is common for the lower layers to have a significantly decreased oxygen concentration as compared to the upper layer. In addition, the vertical difference in the DO distribution in the lake is consolidated in part by thermal stratification. Due to the difference in water temperature in the depths of lake water, which was discussed earlier, the water density gradients took place vertically, making it more difficult for the different layers in the lake to mix with one another. As a result, the vertical difference in the DO is remains unchanged. In addition, it can be seen that in both cases (on April 13 and November 10, 2011), the DO values in all the horizontal layers of the lake reached their maximum value at 15:00, when the water temperature was at its maximum. This suggests that the lake is host to a number of aquatic plants that are stimulated by the increase in water temperature to perform photosynthesis, which contributes an additional amount of DO to the water column.

Vertical change in pH

Figs. 10 and 11 show the vertical distribution of pH on April 13 and November 10, 2011, respectively. It can be seen that on both days in two separate seasons (summer and winter, respectively), the pH in all the horizontal layers fluctuated from a maximum value at 15:00 to a minimum value at 21:00 during a daily cycle. Also, the maximum pH value was always found in the surface layer, while the minimum value was always found in the bottom layer. These results might be attributed to the fact that the waters in the bottom layer are in contact with decomposing sediments on the bottom of the lake. Since very little sunlight can reach the bottom layer, a respiration reaction could occur, which would release CO_2. This CO_2, in turn, would combine with water to form carbonic acid as follows:

$$CO_2+H_2O \rightleftharpoons H_2CO_3 \quad (1)$$

The carbonic acid, in turn, would dissociate into ionic form, as shown below:

$$H_2CO_3 \rightleftharpoons HCO_3^-+H^+ \quad (2)$$

$$HCO_3^- \rightleftharpoons CO_3^{2-}+H^+ \quad (3)$$

As a result of the process given in (1) to (3), the amount of hydrogen ions increases, causing the waters in the bottom layer to become more acid or decreasing their pH. This scenario is confirmed by the profiles of DO distribution in Figs. 8 and 9. There, we can see that the DO in the bottom layer always reached its minimum value, a result that is attributed to the fact that more DO in the bottom layer was consumed in the respiration reaction.

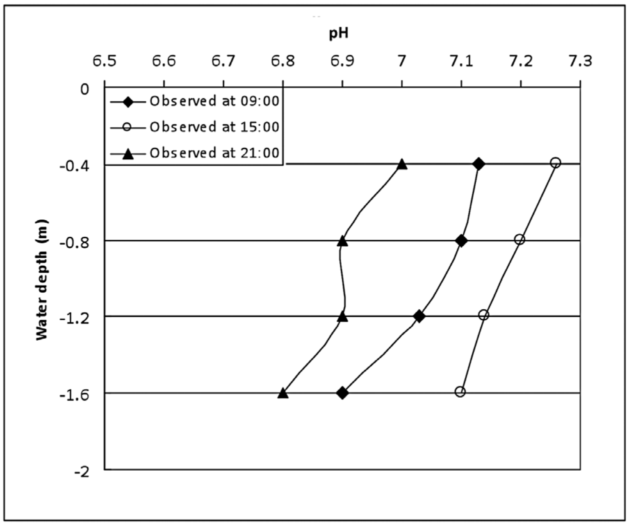

Fig. 10. Vertical distribution of pH on April 13th, 2011.

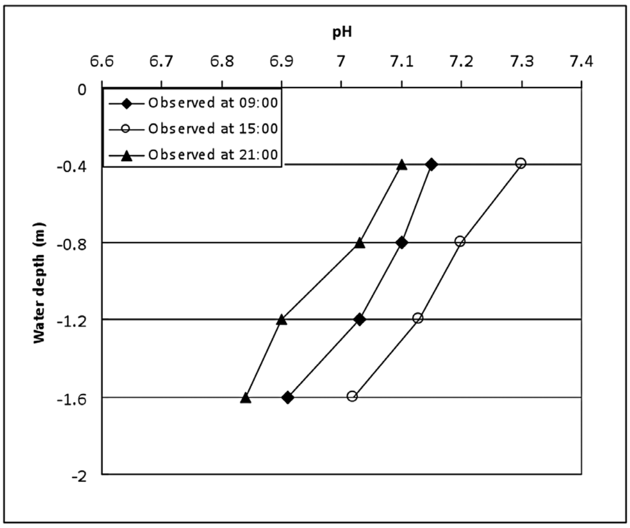

Fig. 11. Vertical distribution of pH on November 10th, 2011.

Seasonal change in DO and BOD_5

Figs. 12 and 13 show the seasonal variation of DO and BOD_5, respectively, in the year 2011. In figures it can be seen that in general, the BOD_5 values are relatively high in the period between the end of spring and the beginning of summer (April 13, 2011) and in winter (November 10, 2011). In these two periods, the BOD_5 fluctuated from a minimum value of about 29 mg/*l* (in the surface layer, on November 10, 2011) to a maximum value of above 38 mg/*l* (in the bottom layer, on April 13, 2011). This maximum value is 2.5 times higher than Vietnam's standard value of water quality class B1 (QCVN 08: 2008/BTNMT, 2008) for irrigation (≤15 mg/*l*). During summer (August 23, 2011) and autumn (October 20, 2011), the BOD_5 in the lake seems to be at a minimum, with a value of around 15 mg/*l* and above. This

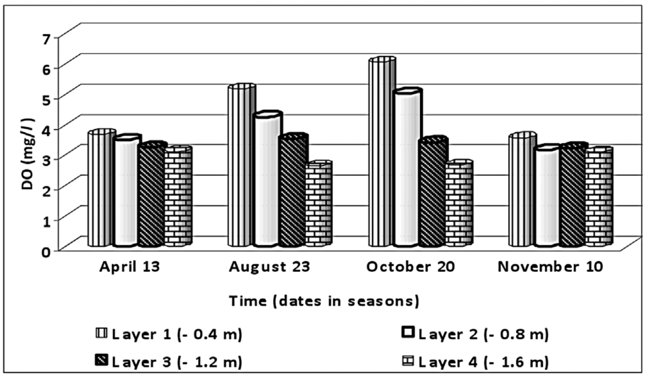

Fig. 12. Seasonal variation of DO in 2011.

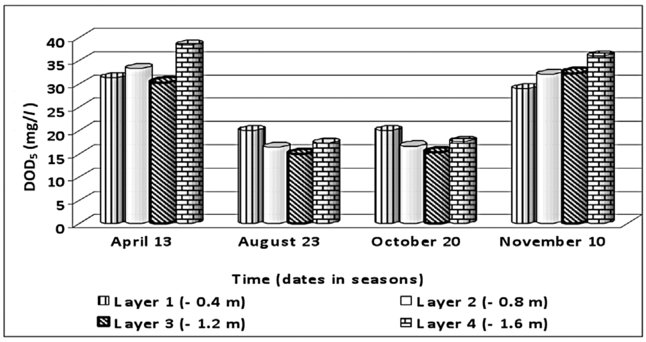

Fig. 13. Seasonal variation of BOD_5 in 2011.

minimum value also does not meet Vietnam's standard value of water quality for irrigation (QCVN 08: 2008/BTNMT, 2008). This seasonal variation of BOD_5 in the lake can be explained by the fact that the period from the end of spring and the beginning of summer (observed on April 13, 2011) and in winter (observed November 10, 2011) are dry periods, during which the lake water column decreased, leading to a high concentration of pollutants, including BOD_5. Summer (observed on August 23, 2011), in contrast, is a rainy season, and the autumn observation date (October 20, 2011) was at the very end of the rainy season. Therefore, the lake water column was increased by rain water. As a result, the concentration of BOD_5 in the lake was diluted, such that it reached its minimum value in this period, as shown in Fig. 13.

Corresponding to this seasonal change in BOD_5, the DO in the lake varied in a manner inversely proportional to the change in BOD_5, a finding that is clearly indicated in Figs. 12 and 13. During the periods in which the BOD_5 level was highest (observed April 13 and November 10, 2011), the DO reached its minimum values (see Fig. 12), with a highest value of around 3.7 mg/l in the surface layer. This value of DO does not meet Vietnam's standard value for water quality class B1 for irrigation (QCVN 08: 2008/BTNMT, 2008), which must be greater than or equal to 4 mg/l. In contrast, in summer and autumn (observed August 23 and October 20, 2011, respectively) the DO reached its maximum values, with a highest value of about 6 mg/l in the surface layer, while the level of BOD_5 reached its minimum values in these periods (see Fig. 13). The inversely proportionality of the changes in DO and BOD_5 is logical, because when there is a lower concentration of BOD_5, a smaller amount of DO is consumed for the purpose of decomposing organic matter (BOD_5), and vice versa.

Variation of dissolved inorganic nitrogen in dry season

In the dry season, the concentration of pollutants may reach its highest value of the year, since this is the season with the largest decrease in the lake's water column. For this reason, we chose to sample waters for the analysis of NH_4^+, NO_3^- and NO_2^- during the dry season, in order to examine the extent of the pollution by these nutrients, which are causative factors in the eutrophication of almost all bodies of water. Fig. 14 shows the variation of these elements on two separate days in the dry season (April 13 and November 10, 2011). As can be seen in the figure, the NH_4^+ value fluctuated around and above 0.5 mg/l, which is the limit of the value for water quality class B1 for irrigation, according to Vietnam's national technical regulation on surface water quality (QCVN 2008/BTNMT, 2008). For NO_3^-, there was a maximum value of above 0.9 mg/l, and a minimum value of around 0.7 mg/l. The range of this value is still within the allowable limits of Vietnam's national technical regulation on surface water quality (QCVN 2008/BTNMT, 2008). As regards Nitrite (NO_2^-), it can be seen that all the analyzed values are above 0.05 mg/l, which only meets the water class B2 standard that is used for navigation (and cannot be used for irrigation), as stated in QCVN 2008/BTNMT (2008).

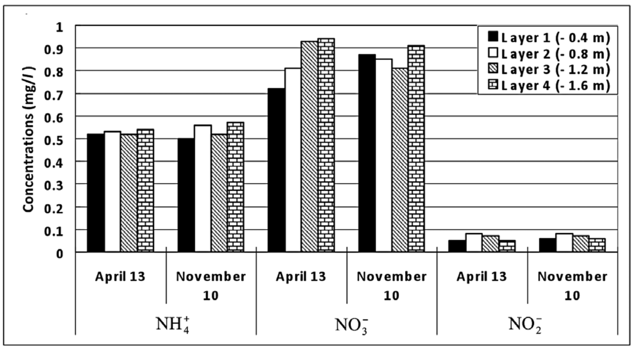

Fig. 14. Variation of NH_4^+, NO_3^- and NO_2^- in the lake during dry season in 2011.

CONCLUSIONS

Based upon the data gathered and analyzed above, our conclusions on the dynamics of water quality in Truc Bach Lake can be summarized as follows:

1. The water temperature in the lake is closely related to the meteorological conditions. In a diurnal cycle, in summer, thermal stratification develops most significantly in the afternoon, and then gradually diminishes during the night, to the point at which the water temperature becomes almost homogeneous.

2. In the lake, the DO is also stratified, since the water temperature is stratified. The DO in the surface layer always reaches its maximum value as compared to that in the lower layers, while in the bottom layer, it usually reaches its minimum value, due to the fact that the surface layer receives additional oxygen due to reaeration with the atmosphere and photosynthesis by aquatic plants. On the bottom layer, on the other hand, it reaches its minimum value due to the influence of decomposing sediments on the bottom, which create a demand for oxygen in order to decompose organic matter on the lake bottom. The difference between the DO in the surface and bottom layers is also caused by thermal stratification, which makes it more difficult for mixing to take place between these two layers of water.
3. The pH in the lake is also stratified, and its minimum value is usually present in the bottom layer of the lake. The reason for this is that the processes of respiration and decomposition of the organic matter in the bottom layer create CO_2, which is further combined with water to form H_2CO_3 in the bottom layer. As a result, the pH in the bottom water layer of a closed body of water is usually smaller than that in the upper layers.
4. The level of BOD_5 in the lake is relatively high, with a maximum value that is 2.5 times greater than the standard value of water quality class B1 (QCVN 2008/BTNMT, 2008) for irrigation. This indicates that the lake has become polluted by organic matter. As a result, the DO in the lake is relatively low, and thus less supportive of the lake's aquatic life, including the fish (dead fish can sometimes be seen in the lake).
5. The research also indicated that the lake is also polluted by nutrients, as shown by an analysis of the NH_4^+, NO_3^- and NO_2^- contents, which are presented above.

The results of this research will supply the input data for a simulation of the lake water quality that will be performed as part of the next steps in our research effort.

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