(4) NATURAL AND ANTHROPOGENIC FACTORS AFFECTING SEASONAL VARIATION OF WATER QUALITY IN DAU TIENG RESERVOIR, VIETNAM

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This paper reports the water quality monitoring results of Dau Tieng (DT) Reservoir, which is located in the upstream of Sai Gon River and supplies both irrigation and municipal waters to Ho Chi Minh City and the surrounding areas. DT Reservoir was characterized by seasonal stratifications. In late dry season, i.e. from March to May, anoxic condition was observed at some monitoring stations and chlorophyll *a* concentration increased. The water quality parameters such as pH, EC, turbidity, DO, temperature, COD, NO_2-N, NO_3-N, TN, TP, and PO_4-P were significantly different in the dry and rainy seasons (t-test, $p<0.01$). During the rainy season, episodic acidification was also observed and the variation ranges were much higher due to the increase of eroded materials in runoffs entering the reservoir after heavy rainfall. The human activities have deteriorated reservoir water quality. Nutrients from the runoffs associated agricultural activities contributed 73% TN and 30% TP flowing into the reservoir. Fish cage culture and livestock raise in the reservoir added about 15% and 4% of TN, and 36% and 12% of TP, respectively. Regulating fish cage culture and livestock raise will significantly reduce the TP inputs, a limiting factor to algal growth in DT Reservoir in the dry seasons.

Key Words *: acidification, chlorophyll a, eutrophication, fish-cage aquaculture, nutrient loads.*

1. INTRODUCTION

Water quality deterioration in reservoirs in tropical countries has become a great environmental concern due to its impact on water uses and ecosystems. Extensive monitoring results of those reservoirs have not yet been reported due to the lack of human and financial resources in many developing countries. Water quality classification for standing water was developed based on the three gradients: tropic status, acidification and toxic contaminations[1)]. Eutrophication by external nutrient inputs is a widespread problem of fresh and coastal marine waters all over the world[2,3)]. Thermal stratification is the process that controls buoyancy of aquatic organisms and distribution of dissolved materials and nutrients[4)]. The availability of nutrients, coupled with higher temperatures, a stable water column, an absence of river flow, weak winds, thermal stratification, DO depletion and the warm, dry period in a year, provide conditions favourable for cyanobacterial growth[5)]. High water temperatures and lengthy periods of hypolimnetic anoxia of reservoirs provide a favourable environment for anoxic phototrophic bacteria[6)]. Nitrate fertilizers from surrounding farmland[7)], pH, turbidity, orthophosphate, BOD_5[8)] are all relevant to the increase of eutrophication in lakes and reservoirs.

Dau Tieng (DT) Reservoir is the largest structure for water supply and irrigation purposes in Vietnam. It supplies water for irrigation of about 90 000 ha in Tay Ninh Province, Long An Province and Ho Chi Minh City (HCMC) and supplies $10m^3/s$ to domestic water demand. Due to seasonal variation of rainfall, increasing water demands, and water quality deterioration caused by both natural and anthropogenic processes, operation and management of DT Reservoir has become more difficult to satisfy all the needs. Intensive fish cage culture, livestock raise, sand exploitation and the agricultural activities in upstream catchments[9)] cause water quality deterioration. The lack of science-based understanding of the water quality characteristics makes a better management of the reservoir more difficult and uncertain.

The objective of this study was to elucidate the current status of water quality in DT Reservoir based on the monthly water quality monitoring and to estimate the factors that contribute to water quality variation. Results obtained in this study may help the reservoir managers and decision makers to come up with a better management policy of Reservoir.

2. MATERIALS AND METHODS

(1) Site description

DT Reservoir is located on the upper of Saigon River between 11°20'N to 11°35'N and 106°10'E to 106°30'E. The catchment area is 2,700 km^2, of which 17% lies in Cambodia. Its storage capacity is 1.58 billion m^3 at the normal operation water level of 24.4 m. The mean and maximum depths are 5.81 m and 25.1, respectively. The hydraulic residence time is 0.8 year. The shoreline development index is 0.48.

The altitude of DT catchment is 5200 m. Topography slope direction is from Northeast to Southwest and the average slope is less than 15°. Its watershed has 4 soil types including haplic acrisols, rhodic ferrasol, ferralic acrisols and humic acrisols. Haplic acrisols are dominant covering 67.3% of the area. This soil type has a thin cultivatable layer suitable for crop and industrial perennial plants such as cashew and rubber. Rhodic soil occupies 17.8 % and is mainly located in the high land, i.e. 100 – 150 m above the mean sea level. Ferralic acrisols and humic acrisol occupy 14.4 % and 0.5 % of the total catchment area, respectively. The land use of DT watershed in 2001 is shown in Table 1.

Table 1 Land use distribution in DT Reservoir watershed.

Land use types	Area* (ha)
Annual crop	44,416.35
Perennial plant	77,557.14
Surface water	29,567.92
Forest	62,229.34
Specific use land	7,506.84
Uncultivated land	2,870.22

Sources: DTIEC, 2005[10],* total area excluded the area belonging to Cambodia which is mainly forest.

DT Reservoir has 3 main inflows denoted as In$_1$, In$_2$ and In$_3$ (**Fig. 1**), which contribute 19%, 2% and 78% of the total inflow, respectively. The average inflow in period of 1985-2005 was 62.24 m^3/s, while the average outflow was 54.8 m^3/s, which flowed out through three sluices at DT7 (41% of volume released), DT6 (30%), DT9 (7%) and 1 spillway near DT7 (22%).

Fish cage culture in DT Reservoir started in 2003. In 2004, the highest yield was achieved with 9,664 tons of fish harvested from 1,208 fish cages[11]. However, fish cage culture was banned in June, 2005 because of water pollution. Hence, natural fish stocking in DT Reservoir started with 28 tons of baby fish in December, 2005 and is planned to be continued with 8 tons of baby fish annually. In addition, there are other sources of nutrient load to the reservoir, which include an annual sand exploitation of 180,000 m^3, illegal encroachment of fish ponds (9 ha), livestock raise (961 cattle, 351 cows, 65 goats, 50 pigs, 20,000 mature ducks and 6,700 young ducks) in the semi-submerged areas. The reservoir also receives about 20 m^3/day primary treated wastewater from one tapioca and two rubber processing plants.

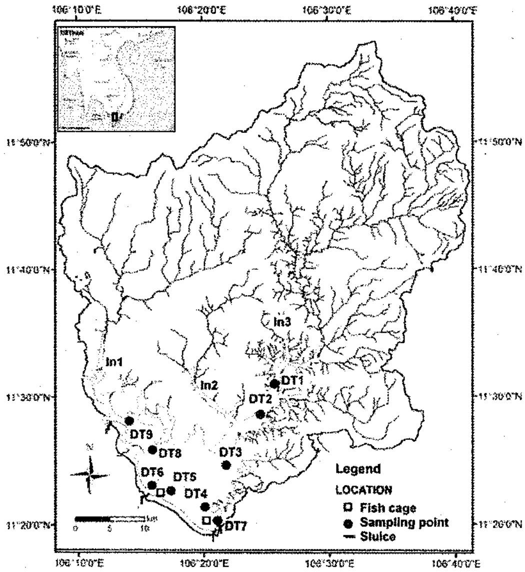

Fig.1 Dau Tieng Reservoir watershed and sampling sites.

In the DT reservoir, there are about 156 algal species belonging to Chlorophyta, Cyanophyta, Bacillariophyta, Pyrrophyta, Euglenophyta, and Chrysophyta. The green algae are dominant with *Closterium, Cosmarium, Micrasterias, Pediastrum, Staurastrum* and *Scenedesmus*. Phytoplankton is more diverse in downstream DT reservoir and higher density in dry season[12].

(2) Sampling and analysis methods

Water samples were collected monthly from March 2005 to March 2006 at nine locations (denoted as DT1 to DT9 in Fig. 1). At each location water was sampled at 3 depths of 0.5, 3 and 8 m. Water samples at DT1, DT3 and DT9 represent 3 main inflows: In$_3$, In$_2$ and In$_1$; DT2 and DT8 are in the middle of two inflow streams. DT3, DT4, and DT5 are in the central reservoir; and DT6 and DT7 are at the two main outlets, where two fish cage villages located nearby.

Sampling locations and water depth were monitored by GPSmap 178C Sounder. The water parameters such as water temperature (°C), water depth, Total Dissolved Solids (TDS), dissolved oxygen (DO), conductivity (EC) and turbidity were measured at the reservoir by using the Horiba W-23XD probe. Total phosphorous (TP), orthophosphate (PO_4-P), total nitrogen (TN), ammonia (NH_4-N), nitrite (NO_2-N), nitrate (NO_3-N), BOD_5, COD, Secchi Disk Depth (SDD) and chlorophyll a (Chl. a) were analyzed in the laboratory following the Standard Methods[13,14].

Additionally, probe measurements were also taken at 1 m intervals from surface to bottom of the water column at 9 locations in June, September and December 2005 and March 2006. Wastewater was sampled twice a year.

(3) Secondary data

The secondary data of rainfall and its characteristics in this study were obtained from the hydrology and weather gauge stations[15]; and flow and water level data were reported by Dau Tieng Irrigation and Exploitation Company (DTIEC)[10].

a) Weather parameters

DT watershed lies in tropical monsoon climate with annual precipitation of 1,840 mm, mostly between May and November; the average temperature is 27°C, average humidity 77% and the average annual evaporation 990 mm. **Fig. 2** shows daily rainfall in 2005 at DT gauge station; the total precipitation of 1,491 mm on 96 rainy days. The maximum monthly rainfall was 362 mm in July and the maximum daily rainfall was 65 mm on 2nd July.

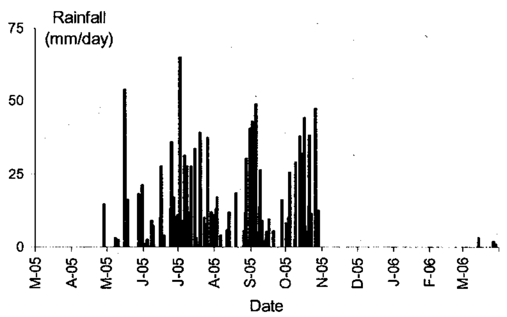

Fig.2 Daily rainfall at Dau Tieng Reservoir.

Because the Dau Tieng gauge station did not measure rainfall water quality, we used the rain water quality data of Tay Ninh gauge station as substitutes, which is about 10 km away from DT reservoir to the West. pH values of rainfall were recorded for each rainfall event more than 1 mm. NH_4-N, NO_3-N, Cl^-, SO_4^{2-} and HCO_3^- were measured in the laboratory.

b) Water level changes

Figure 3 shows the inflow, outflow and water storage of DT Reservoir from March 2005 to March 2006. Due to less precipitation occurring in 2004 and 2005 than usual years, the average annual inflow in 2005 was only 70% of the normal annual inflow. This has led to a reduced outflow from Reservoir, with only 47% of the normal outflow, causing a serious water shortage in the downstream of Sai Gon River in the dry season of 2005.

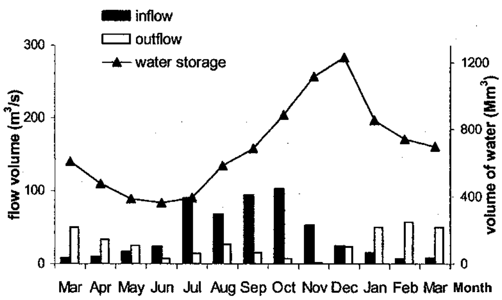

Fig. 3 Monthly inflows, outflows and water storages in DT Reservoir (March 2005 to March 2006).

3. RESULTS AND DISCUSSION

(1) Overall condition of water quality in DT Reservoir

Table 2 shows the average concentrations of the monitoring parameters in dry and rainy seasons, as well as the average; in total 328 water samples were taken, of which 128 samples were taken in the dry season. Comparing between the seasons pH, EC, turbidity, DO, temperature, COD, NO_2-N, NO_3-N, TN, TP, and PO_4-P were significantly different (t-test, $p<0.01$). During the rainy season, the variation ranges were much higher due to the increase of eroded materials in runoffs entering the reservoir.

At different water depths, pH, EC, DO, temperature and NH_4-N changed significantly (ANOVA, $p<0.001$) due to stratification and depletion of dissolved oxygen in water. Higher concentrations of NH_4-N and PO_4-P, and higher EC were found in hypolimnion, which could be caused by intensive decomposition of organic compounds and phosphorous-binding compounds in sediment.

(2) Stratification

Tropical lakes have small vertical changes in temperature but can generate a stable stratification[16]. Wind mixing and ventilation to the depths can effect anoxic conditions of the hypolimnion in lakes[17]. We also found small vertical changes in temperature, DO, pH and conductivities at all 9 monitoring locations in DT Reservoir. **Fig. 4** shows the isopleths of temperature, DO, pH and conductivity at the deepest monitoring point, DT7, while the similar trends were also found at other monitoring locations. Temperature stratification was observed clearly from January to May, then reduced gradually until September and did not stratify again until January (**Fig. 4a**). The stratification was quite stable in April and May with a temperature difference of about 2-3°C, resulting from impact of the higher temperature of surface water in dry season and less rainfall. Rain storms starting in May until November created strong waves in the reservoir which could accelerate mixing and disintegrate stratification. Temperature stratification started to form again in January when dry season started. The depth of mixing layer varied depending on season and water depth. At the deep locations when clear stratification took place in March, the epilimnic layer was 3 m while the hypolimnion was below 10 m of water column. When thermal stratification was completely developed, the depth of main thermocline coincided with the depth of the outlet[19], i.e., 13 m above sea level.

DO stratification was also observed during the dry season between January to May in the shallow depth (less than 6m), whereas the mixing layer was certainly deeper, ca. 12m, during the rainy season (**Fig. 4b**). In March, at all the sampling locations deeper than 9 m, i.e. DT3, DT4 and DT5, DO dropped drastically to zero below 8 m, while at the shallower locations water body was anoxic below 6 m. In the past, anoxia often brought about fish mass-kill in the reservoir. **Fig. 4b** shows high oxygen conditions in the euphotic zone (>8 mg/L) and anoxic conditions in the hypolimnion in March. DO less than 1.5 mg/l was found at 4 m in water depth, which was just below the fish cages. Sudden upward movement of such an anoxic plume might have killed the fish in the cages. In the hypolimnion layer, i.e. below 10 m of water depth, the DO varied from about 6.5 mg/L in December to 0 mg/L in March (**Fig. 4b**). Thus, DO depletion rate in hypolimnion layer of DT Reservoir was 2.2 mg/L per month from December to March which is lower than the rate of 3-7 mg/L per month reported for the other tropical reservoirs[6].

Water in DT reservoir is acidic because of acidic precipitation and inflow of acidic waters. The epilimnion was only slightly acidic (pH 6.5-7.0), but the hypolimnion was more acidic (5.1-6.5) (**Fig. 4c**). The exceptionally high pH (8.7 and 8.0) due to algal photosynthesis[16] was observed at locations DT7 and DT5 in December and March, which coincided with the peak concentrations of chlorophyll *a*. The low pH and anaerobic condition near the bottom, created favourable conditions for additional release of nutrients, especially phosphorous, from the mud[6,16], leading to high EC in this layer (**Fig. 4d**). Elevated levels of EC were more obvious during the dry season when the bottom water was more anaerobic due to stratification of the water column. The high EC coincided with the higher concentrations of NH_4-N, PO_4-P and TP in the water samples analysed in the laboratory.

(3) Episodic acidification

Surface water acidification is a relatively recently-identified phenomenon affecting standing water[1]. During dry season pH in the reservoir was mostly higher than 6, which became below 6 in the rainy season due to inflow of acidic rain water (**Fig. 4c**). pH of the runoff dropped during rainy season to between 5.24 and 6.14. Monthly average pH of rainfall in June and September were 6.12 and 6.20, respectively. Acidic rain (pH between 3.9 to 6.7) have been reported in HCMC and South of Vietnam, including Tay Ninh Province[20]. Tay Ninh Province also has the highest concentrations of SO_4^{2-} and NO_3-N in rain water amongst other provinces[21]. The annual average concentration of NO_3-N and SO_4^{2-} in Tay Ninh rain water was 0.22 mg/L and 1.8 mg/L, respectively, between 1998 and 2005. The rainfall in 2005 contained 0.23 mg/L of NO_3-N, 2.48 mg/L of Cl^-, 5.11 mg/L of HCO_3^- and 1.87 mg/L of SO_4^{2-}[14].

Table 2 Average concentrations of main water quality parameters in DT Reservoir.

	pH	EC mS/m	DO mg/L	Temp. °C	COD mg/L	NH_4-N mg/L	NO_2-N mg/L	NO_3-N mg/L	TN mg/L	TP mg/L	Chl. *a* μg/L	SDD cm
Rainy season (N = 200)												
- Mean	5.88	3.45	6.69	29.39	3.96	0.07	0.006	0.27	2.10	0.10	6.60	118.33
- SD*	0.48	0.88	1.58	0.96	1.21	0.07	0.004	0.21	1.57	0.07	4.43	44.42
Dry season (N = 128)												
- Mean	6.34	3.85	7.43	27.91	4.57	0.08	0.001	0.08	0.87	0.02	6.48	191.67
- SD*	0.58	0.88	3.27	1.74	1.73	0.08	0.002	0.07	0.87	0.02	3.95	51.34
Average	6.06	3.61	6.98	28.81	4.20	0.07	0.004	0.20	1.63	0.07	6.55	160.24

Note: * SD : Standard Deviation

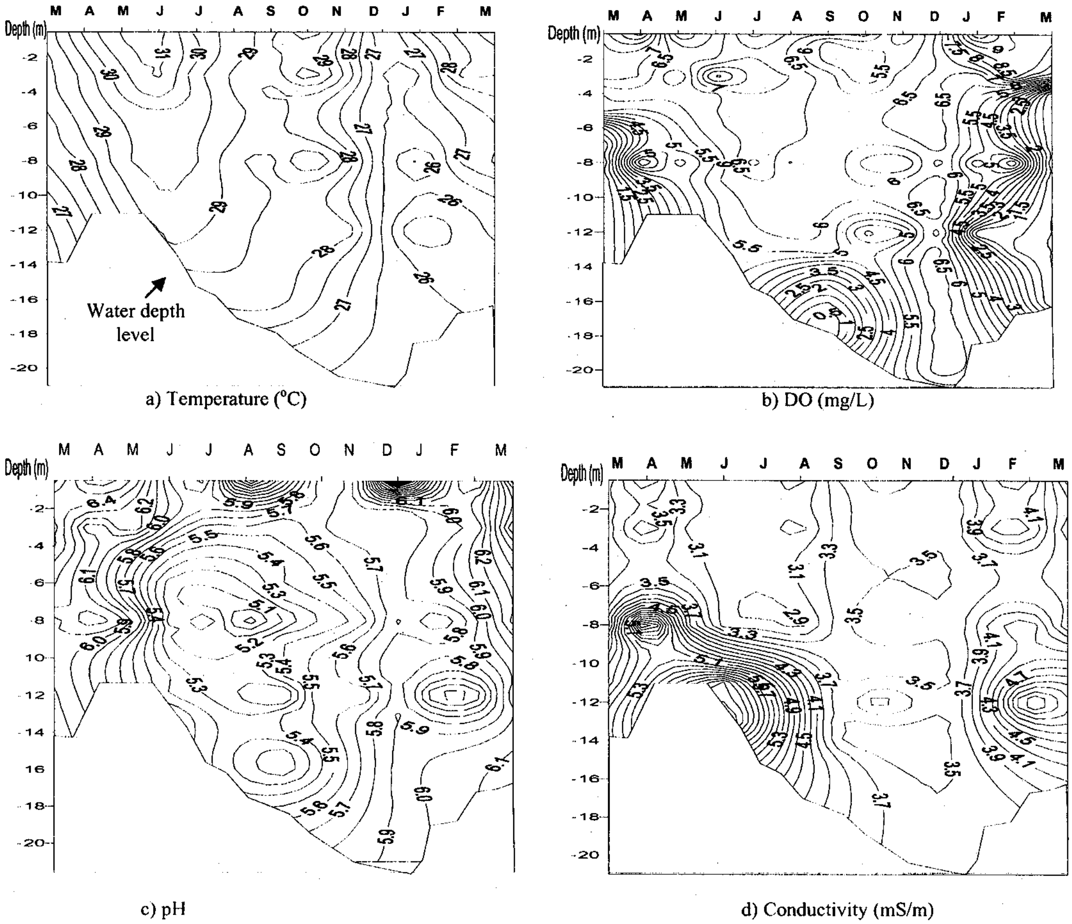

Fig. 4 Isopleths of temperature, DO, pH and conductivity at location DT7 (March 2005 to March 2006).

Although the cause of acidic rain has so far not extensively elucidated in the study area, both dry and wet deposition could affect water quality of the reservoir by adding acidic materials and/or diluting the buffering capacity in the reservoir[22]. Recently the pH of rainfall has been reported to be acidic especially at the beginning of rainy season, which caused adverse impacts on shrimp ponds[21] and damaged construction materials[20] in South of Vietnam. Fish farmers also reported that the initial stage of rainfalls caused fish-death in DT Reservoir during our study.

Nitrogen leaching from watersheds increases in organic acid and nitrate concentrations contributes to episodic acidification[23]. The ammonia uptake (leaving an equivalent amount of proton) and nitrification (leaving twice as much of protons) acidify water in a reservoir. In addition, the alkalinity as the buffering capacity against acid inputs was found to be low in DT Reservoir. Thus, a sudden increase of nutrient inputs, especially NH_4-N, in the reservoir in rainy season (**Fig. 5**) brought about episodic acidification of the reservoir.

(4) Nutrient inputs

Figure 5 shows the comparison of NH_4-N, NO_3-N and TP concentrations in two inflows (DT1 and DT9), in the central of the reservoir (DT4) and in the outflow (DT7). We found that DT1 had the highest inflow and was the dominant inputs to the reservoir, followed by DT9. NO_3-N inputs to the reservoir came mainly along with runoff from watershed during rainy season, normally lasting from May to November. **Fig. 5a** showed a rapid increase of nitrate input during the rainy season at all locations. Agricultural activities and soil erosion in the upstream catchment were responsible for the high nutrient and suspended solid inputs from the eastern inflow represented by DT1.

In contrast, the supply rate of NH_4-N from watersheds are generally low[23] except such point-sources as domestic wastewater and fish aquaculture.

The NH_4-N input also increased slightly in the inflows in rainy season. NH_4-N in reservoir water, however, also increased occasionally in dry season (**Fig. 5b**). This indicated the importance of internal ammonium loads, such as aquaculture and livestock raise especially in dry season. The concentrations of NH_4-N in water nearby the fish cage areas were significantly higher than those away from the fish cages[10] and even higher than concentrations in the catchment inflows. NH_4-N was found higher in the deeper water. The maximum concentrations of NH_4-N was found to be 0.5 mg/L near the fish cage area at 8 m depth in May. This result indicated intensive organic decomposition from the mud under anoxic condition during periods of stratification, which was caused by excess feeding by the fish cages.

TP concentration was also increased during rainy season due to increases of both flow rates and TP concentrations in inflows to the reservoir (**Fig. 5c**). However, similar to ammonia nitrogen, internal load of TP was also important, as indicated by the higher concentrations of TP in reservoir water (DT4) in May compared with those of the inflows. TP was found higher in deeper water, and highest, at 0.334 mg/L, at 8 m depth in May. This, again, implied that decomposition of organic matter and additional nutrient-release from the bottom were taking place in this time period.

Nutrient concentrations except ammonium in DT reservoir decreased in December because of dilution effect when its water storage capacity was maximum. Slight increases of those concentrations in dry season were probably brought about by decreased water volume in the reservoir combined with nutrient input from the on-site human activities including fish aquaculture and livestock raise.

The main nutrient loading sources into DT Reservoir are shown in **Table 3**. The external loads were estimated by multiplying monthly discharges from point sources, population distribution data and the unit aerial loads for different land use types[24,25,26,27]. Internal loads were calculated based on combination of our survey data, emission rates[24] and export coefficient[25,28,29] for different activities in reservoirs from the relevant studies. Nutrients from the runoffs contributed 73% TN and 30% TP to the reservoir nutrients budget. Fish cage culture and livestock raising activities contributed about 14.6% and 3.7% of the total nitrogen load, especially for boi-available nitrogen, into DT Reservoir, respectively.

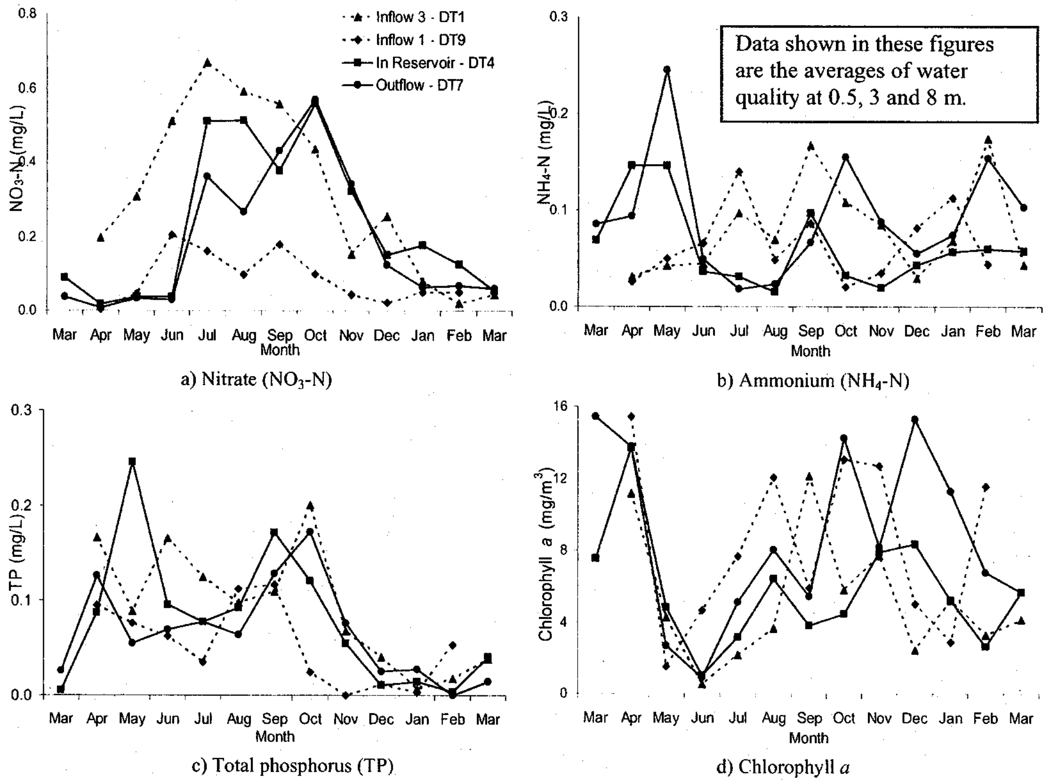

Fig. 5 Monthly variations of nitrate, ammonium, total phosphorus and chlorophyll *a* (March 2005 to March 2006).

Table 3 Source of nutrient loadings to DT Reservoir.

Nutrient budgets	TN (ton)	TP (ton)	TN (%)	TP (%)
External loads				
Agriculture	3,459	137	73.1	30.3
Point sources	2.6	0.3	0.06	0.07
Urban, domestic	118	24	2.5	5.3
Air deposition	85	6	1.8	1.3
Internal loads				
Fish cage culture[10]	689	161	14.6	35.8
Livestock raise[24]	177	52	3.7	11.6
Submerged areas[24]	198	70	4.2	15.6

(5) Chlorophyll *a*

Chlorophyll *a* (Chl. *a*) concentrations for all locations were higher in the end of dry season, i.e. April (**Fig. 5d**). Phytoplankton was present at a higher density in dry season in DT Reservoir[11]. The average concentration of Chl. *a* for all the sampling points was also at the maximum in April, as ca. 12 μg/L. The high concentration of Chl. *a* coinciding with high pH and DO indicated an active photosynthesis. This led to high potential for maximum Chl. *a* which occurred in April. At this time, water temperature and sun light intensity increased; stratification of temperature, DO and EC developed completely and there was less mixing in the DT Reservoir as compared with the other time periods of the year. These create a favourable condition for algal growth. Amongst the surveyed locations, the area of the Western branch near DT8 was an ideal place for algal growth, due to its shallow water, slow water flow-rate and high nutrient concentration.

The second peak of the average Chl. *a*, about 9 μg/L, occurred in December. However, the high concentrations of Chl. *a* were found only at DT6 and DT7, where fish cages were located, but not at other locations. This local algal-growth acceleration was derived from the internal nutrient enrichment from human activities such as fish cage culture and livestock raising nearby those locations.

There are several ways to evaluate the trophic status of the reservoir and the most widely used method is the guidelines of OECD[30]. The tropics-state classification of OECD is based on concentration of TP and Chl. *a* and Secchi Disk Depth (SDD). According to the OECD rank, 35μg/L of TP, 8 μg/L of Chl. *a* and 150 cm of SDD are the lower limits of eutrophic status. The TP of DT Reservoir varied from 4 to 334 μg/L, of which 57% of the samples had TP exceeding the lower limit of eutrophy. The Chl. *a* varied between 0.23 and 15.4 μg/L with 27% samples greater than 8 μg/L. SDD was in a range of 40270 cm with 40% of samples lower than 150 cm. Thus, DT Reservoir was at the early stage of eutrophy and the nutrient input should be controlled to prevent further eutrophication and algal bloom.

The limiting nutrient for algal growth was phosphorous due to the high TN:TP ratio[30], which ranged between 3 and 243, with about 60% of samples greater than 15. High TN:TP ratios may have resulted from excretion of cattle and fish, a nutrient sources characterized by a high ratios of N to P[31], and seasonal nitrate runoff[32].

We found that the aerial TP and TN loads were 1.67g TP/m^2 and 17.5 g TN/m^2 per year, which are 8 times and 6 times higher than the critical loading levels of TP and TN recommended by Wollenweider[33] for reservoirs that have more than 10 m in the mean water depth. In order to maintain DT Reservoir below the upper limit of mesotrophic status, aerial TP loadings should be reduced by 45%, i.e. 0.8 g TP/m^2 per year. The TP loadings could be cut off by reducing anthropogenic sources such as aquaculture and livestock in and around the reservoir, by controlling agricultural activities and erosion rate in upstream catchment.

4. CONCLUSION

DT reservoir was characterized by seasonal stratification; the thermal, DO, and EC stratifications between March and May coincided with high concentration of chlorophyll *a*. It experienced anoxic condition in March and episodic acidification in rainy season. Regarding eutrophic status, DT Reservoir can be classified as being in a mesotrophic-eutrophic boundary condition. The increase of flow rate and nutrient content in runoff changed the water quality significantly in rainy season. The internal nutrient loads from fish cage culture, livestock raise and agricultural activities in submerged areas have contributed additional nutrient inputs to the water body. Especially a significant amount of TP, which was found to be the limiting nutrient for algal growth in DT Reservoir, was found to come form those activities. Therefore, the ban on fish cage culture in DT Reservoir since May 2005 would curtail a significant input of nutrients into the reservoir, but it should also be mentioned that other sources and activities should also be regulated in order to maintain a good state of water quality and ecosystems in DT Reservoir.

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