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Contributed Paper

Toxic Algae as a Component of Phytoplankton in Irrigation Canals (Thailand)

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ABSTRACT

An investigation of the distribution of toxic algae in Khlong Rangsit, Prathumthani Province was conducted from December 2007 to May 2009. Seven divisions and 88 species of phytoplankton were found. Seven species of toxic algae, namely *Anabaena circinalis*, *Cylindrospermopsts phillippinensis*, *C. raciberskii*, *Microcystis aeruginosa*, *Oseillatoria limasa* and *Oscillatoria tenuis*, were found. Futhermore, toxic algae, namely *Microcystis aeruginosa*, was found to be widely distributed at many of the sampling sites and usually formed as scum on the water's surface, of which the highest cell density was recorded as 4864111 cellL^{-1}. The highest biovolume of phytoplankton were *Oseillatoria limasa* and *Oscillatoria tenuis*, respectively. For microcystin analysis, the microcystin RR type was detected in high abundance, but microcystin YR type was not found to be present in any of the samples. The highest values of microcystin RR and microcystin LR type were 0.85 mgmL^{-1} and 0.53 mgmL^{-1}, respectively. Based on the standard for surface water quality of Thailand, the water of Khlong Rangsit was classified in the fourth category and could be used for household consumption after going through disinfection and special water treatment processes.

Keywords: toxic algae, water quality, microcystin toxins, Khlong Rangsit

1. INTRODUCTION

Khlong Rangsit is the principal water passage in the Rangsit area and in the past served as the main artery that sustained the livelihood of the people in the vicinity. It has served as a water source for vegetable growing in the neighborhood as well as a route for transportation and has been used to provide water for household consumption. Due to the increased industrial development in the area, Khlong Rungsit no longer plays as much of an important role in supplying water to the people of the area for the purposes of agriculture. At present, it primarily serves as a drainage canal. Apart from this, the water in Khlong Rangsit has become severely polluted and has experienced frequent episodes of the phenomena known as eutrophication. Eutrophication causes a decrease in the amount of dissolved oxygen in the water body, but it also increases the amount of phytoplankton which has a negative effect on the living organisms in the Khlong, as well as on the surrounding area by diminishing the natural beauty of the environment.

Several species of cyanobacteria are involved in the frequent blooms that occur in eutrophic lakes and are classified as toxin producers. Microcystins are the most commonly found and widespread type of cyanotoxin, being associated with several toxic algae blooms, namely *Microcystis, Nostoc, Anabaena*, *Oscillatoria* and *Planktothrix* [1]. Among them, *Microcystis*is a major contributor to the production of these toxins. Microcystins are cyclic peptides hepatotoxins with over 70 natural structural variants [2]. These toxins have been found to be highly toxic to many animals [3] and can cause acute mortality in animals [4] and illnesses in humans [5].

Phytoplanktons are living organisms with a high potential suitability for be used as a tool to monitor water quality in terms of both the both physical and chemical parameters. Each species of phytoplankton is the best indicator for the quality of the water in which it is found. Since phytoplankton can thrive in different environments, using them to monitor water quality is believed to be very practical because expensive equipment or chemicals are not needed in the process. In addition, the results can be achieved instantly. Phytoplanktons can also serve as an indicator of the condition of the water before the study. Besides, phytoplanktons are sensitive to any decrease in the amount of living organisms that are present in the water, which cannot be chemically detected [6].

The objective of this study was to monitor toxic algae and its *Microcystis* toxins, and to determine the relationship between phytoplankton species and their distribution with regard to the physical, chemical and biological quality of the water in Khlong Rungsit. It is always of significant benefit to know the water quality of the Khlong and the causes of eutrophication. The knowledge learnt can be used in the improvement of the water quality and the quality of the lives of the people living along the Khlong.

2. MATERIALS AND METHODS

2.1 Sampling Sites

Khlong Rangsit, located in Pathumthani Province, is situated to the north of Bangkok and in the central part of Thailand. Khlong Rangsit Prayoonsakis 16 meters wide, 3 meters deep and 56 kilometers long with 16 tributary canals on one side of its entire length, Khlong Rungsit is divided into 14 sections with each section referred to by number, such as Khlong 1 to Khlong 14, respectively, connecting Khlong Rungsit to Khlong Rapeepat which runs parallel.

Water and phytoplankton samples had been collected monthly over an 18-month period from December 2007- May 2009 to determine the water properties. Thirteen stations in Khlong 1 to Khlong 6 were selected for sample collection because this area was perpetually covered with phytoplankton blooms, especially in the urban area of Khlong 5 and 6. The details of the sampling sites are as follows :

Station 1 : Outlet to the Chaophraya River from Khlong Rungsit

Station 2 : Middle of section 1

Station 3 : Middle of section 2

Station 4 : Middle of section 3

Station 5 : Middle of section 4

Station 6 : Middle of section 5

Station 7 : Middle of section 6

Station 8 : Outlet of tributary to canal connecting to Khlong Rungsit

Station 9 : Middle of tributary canal 6

Station 10 : Outlet of tributary canal 6 connecting to Khlong Rapeepat

Station 11 : Outlet of tributary canal 5 connecting to Khlong Rapeepat

Station 12 : Middle of tributary canal 5

Station 13 : Outlet of tributary canal 5 connecting to Khlong Rungsit (Figure 1)

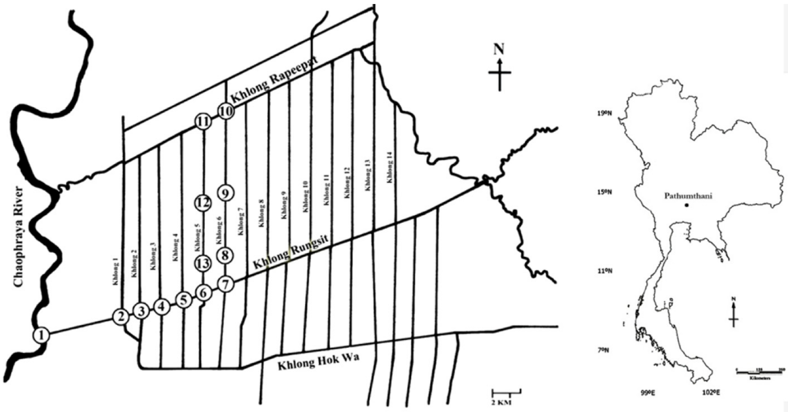

Figure 1. Location of 13 sampling sites in Khlong Rungsit, Pathumthani Province.

2.2 Physical and Chemical Properties of The Water

To study the chemical and physical properties, water samples were collected from the middle of the Khlong at a depth of 1 meter, using a water sampler. The water samples were transferred to a 5 L polyethylene bottle which was later placed in an ice box to reduce the occurrence of any chemical changes.

The study covered the analysis on the following parameters: water conductivity, salinity and the measurement of total dissolved solids (TDS) using a conductivity meter (Hach Company), the pH value and temperature of the samples were recorded with a pH meter and thermometer, turbidity was measured with a turbidity meter, alkalinity was determined through the indicator method, dissolved oxygen (DO) was analyzed using the method of Azide modification of the Winkler analysis of biochemical oxygen demand (BOD) by a 5-day incubation process and by Azide modification of the Winkler method, total organic nitrogen was recorded through the use of a digestion mixture (H_2SO_4 - $CuSO_4$ mixture) and titration method, total nitrite nitrogen was determined by the method of Colorimetric (NED), soluble reactive phosphorus was recorded by the ascorbic acid method, whereas total phosphorus was recorded by the nitric acid - sulfuric acid digestion and ascorbic acid methods, total ammonia nitrogen was determined through the distillation and titration method, nitrate nitrogen was determined by the cadmium reduction method and total iron investigation was done using the Eaton et al. [7] method.

2.3 Phytoplankton Investigation

Phytoplankton samples were collected at a depth of 1 meter at specified sampling sites for identification using a plankton-net (mesh size 10 μm) to scoop up the sample. The identification process was carried out following the relevant steps stated in related texts (i.e. Prescott [8], Whitford and Schumacher [9], Huber-Pestalozzi [10, 11], John et al. [12] and Komárek and Anägnostidis [13]. Other publications that were produced from studies in tropical countries were also used.

2.4 Phytoplankton Biovolumeanalysis

Water samples were collected at specified sampling locations by a water sampler and were preserved with 1-2 ml of Lugol's solution for 100 ml of water sample.

The analysis of the biovolume of phytoplankton was done according to the method of Utermöhl [14] and Rott [15]. For the calculation of the total biovolume, a programme called "Phyto", that was prepared by Dr. Evelin Pipp, Innsbruck University was employed.

2.5 Toxic Algae and Microcystin Analysis

The quantitative analysis of *Microcystis aeruginosa* was done using a sonicator to isolate each cell and a haemacytometer was used to count the number of cells.

For Microcystin analysis [16], the bloom or scum material was stored at -20 °C. Dried material was resuspended in 1 ml 70% (v/v) methanol (HPLC grade; Rathburn, Walkerburn, U.K.), sonicated and allowed to stand for 1 hour. The suspension was centrifuged and the supernatant was dried. The residue was re-suspended in 150 μl 70% methanol and 25 μl analysed microcystin content by high performance liquid chromatography (HPLC). The amounts of microcystin -LR, YR and RR were calculated based on the standard of each toxin.

2.6 Bacterial Analysis

Water samples were collected from all 13 locations at a depth of 30 cm from the water surface. Only the coliform bacteria that was found to be present in the sample was investigated by the MPN method [7].

2.7 Sampling and Analysis for Sediment Investigation

To study the chemical properties of the sediment samples, the sample was collected from the middle of the Khlong at the sediment level by a grab sampler. Then the sample was transferred to a 1L polyethylene bottle, which was later placed in an icebox to reduce any chemical changes by the method of Eaton et al. [7].

The study covered the analysis on the following parameters : total phosphorus by the method of perchloric acid and nitric acid digestion and ascorbic acid methods, phosphate by the ascorbic acid method, total nitrogen by the method of Macro-Kjedahl, ammonium nitrogen by the method of distillation and tritration, nitrate nitrogen by the method of distillation and tritration, available potassium using a spectrophotometer FerroVerR and total iron by the method of Eaton et al. [7].

2.8 Data Analysis

The correlation between the physico-chemical and biological quality of the water and the biovulome of phytoplankton was studied using the SPSS programme, as well as the two-tailed and Multivariates Statistical Package (MVSP) programme version 3.1.

3. Results and Discussion

3.1 The Study of Toxic Algae

Seven species of toxic algae, namely *Anabaena circinalis*, *Cylindrospermopsis phillippinensis*, *C. raciberskii*, *Microcystis aeruginosa*, *Oseillatoria limasa* and *Oscillatoria tenuis*, were found. *Microcystis aeruginosa* was the dominant species and grew in abundance at all stations and in all seasons. Figure 2 shows that the quantity of *Microcystis aeruginosa* increased substantially in April, May and June 2008 while the quantity became very low from July to October 2008. Intestinally, in November 2008, at station 12, the quantity of this species increased to 4864111 cellL^{-1} which was the highest recorded number, while the number found at station 9 was 4805555 cellL^{-1}which did not exceed 15,000 cellmL^{-1} as had been set by the Australian Water Quality Centre. At stations 9 and 12, this species of toxic algae was found to grow quickly and abundantly almost all year round. However, water blooms of toxic algae, especially *Microcystis* spp., have been reported in many countries such as Tunisia [17], Portugal [18], Morocco [19], Brazil [20, 21], Greece [22], The Netherlands [23], Korea [24], the People's Republic Of China [25] and India [26]. In Thailand, Senpracha et al. [27] reported that *Microcystis aeruginosa* was the dominant species in the channel named Jeeneo, Sri Sakhett, Thailand and a 0.059% yield (2.93 $\times 10^{-4}$ g in 0.50 g of sample) of microcystin LR was found. In Khon Kaen Province, four reservoirs (Bueng Kaen Nakhon, Bueng Tung Sang, Bueng Nong Khot and Bueng See Than) were investigated about toxic cyanobacterial communities. *Cylindrospermopsis* sp., *Microcystis* sp., *Oscillatoria* sp. and *Psedanabaena* sp. were found as dominant species[28].

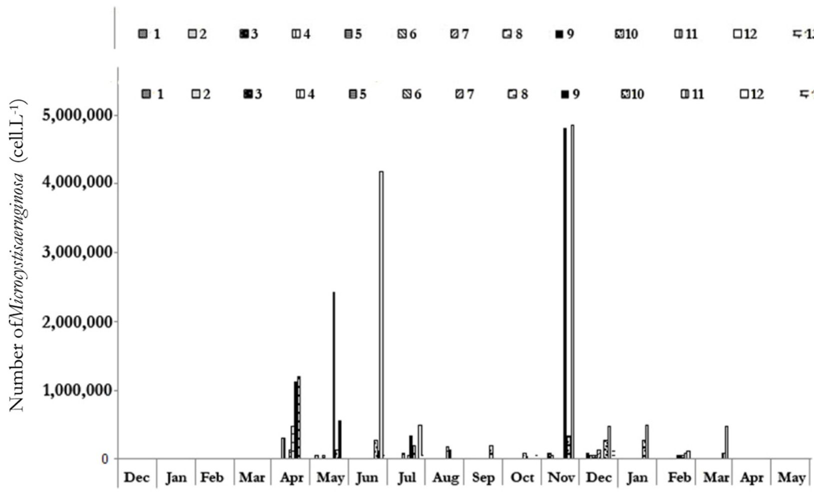

Figure 2. Number of *Microcystis aeruginosa* at each station in Khlong Rangsit, Pathumthani Province from December 2007 to May 2009.

The microcystins were determined using HPLC. The dominant toxic components were found to bemicrocystin-RR and microcystin-LR, respectively. The results showed that microcystin-RR was found atall sampling sites over the period of July to September 2008. The maximum microcystin-RR concentration was reported at 0.85 mgmL^{-1}and was recorded at station 6 on April 2008 and the microcystin-LR concentration was reported at 0.53 mgmL^{-1} and was recorded at station 10 on February 2008 and did not exceedthe measurement of1 μgL^{-1}that was established by the World Health Organization (WHO) [29]. This was consistent with the findings of Sangolkar et al. [26] who reported that 732 μgg^{-1} of microcystin-RR was the dominant toxic algae that was produced from *Microcystis*in a Central Indian water bloom. On the other hand, microcystin-LR was found at all sampling sites in February 2008, while no microcystins were found in May 2008 and January 2009. However, microcystin-YR was not found to be present in this study (Figure 3).

In fact, Sivonen and Jones [1] reported the microcystins could be produced by *Microcystis*spp., *Anabaena* spp., *Nostoc* spp., *Oscillatoria*spp. and *Planktothrix* spp., which was the same as the results found in this study where *Microcystis*spp., *Anabaena* spp., and *Oscillatoria*spp. Were found to be dominant in many stations. Furthermore, microcystin-RR have been reported to be less toxic when compared to microcystin-LR [27].

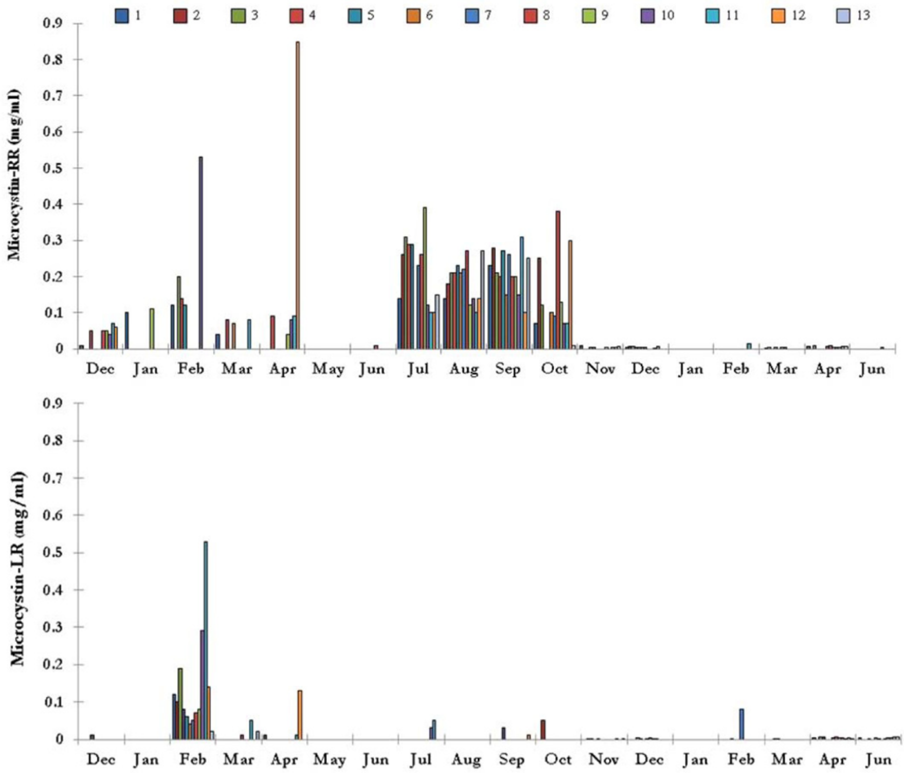

Figure 3. The amount of microcystin-RR and microcystin-LR found at each station in Khlong Rangsit, Pathumthani Province from December 2007 to May 2009.

3.2 Phytoplankton Investigation

In the study, 7 divisions and 88 species of phytoplankton were found (Table 1). Among them, Division Chlorophyta was the most abundant with 35 species representing 39.77% of the total species number. The rest of the divisions were lower in number, namely Division Bacillariophyta and Division Euglenophyta with 17 species representing 19.32 % of the total, while Division Cyanophyta with 14 species represented 15.19% of the total species population. The other 2 Divisions reported the presence of Chrysophyta and Pyrrhophyta with 2 species which represented 2.27%, and the Division with the least amount of species reported Crytophyta with 1 species representing 1.14% of the total species population (Figure 4).

The largest and the smallest biovolume of phytoplankton found that Cyanophyta was the largest with 2,898 $mm^3.m^{-3}$, which was 38.81% of the total biovolume. The smaller reported amounts in the biovolume were Euglenophyta with 1,970 $mm^3.m^{-3}$ representing 26.39% of the total species biovolume, Chlorophyta, 1552 mm^3m^{-3} representing 20.78%, Pyrhophyta, 625 $mm^3 m^{-3}$ representing 8.37%, while Bacillariophyta was found to be at 401 mm^3m^{-3} which represented 5.37% of the total and Chrysophyta, 21 mm^3m^{-3} representing 0.28% of the total species biovolume. The smallest reported amount in biovolume was Cryptophyta with 0.1 mm^3m^{-3} which represented 0% of the total (Figure 6).

The investigation on biovolume flactuation was only carried out among Cyanophyta, which was the Division with the largest recorded biovolume. The results indicated that Cyanophyta was abundant from January 2008 on and was the highest in volume in May and August of the same year. After that, the biovolume of Cyanophyta decreased continuously (Figure 5). In figure 6, *Oscillatoria tenuis* (C. Agardh) Gomont and *Oscillatoria limosa* (C. Agardh) Gomont were shown to be the majority species of Cyanophyta during these periods with high amounts of nutrient loads. Furthermore, *Oscillatoria tenuis* (C.Agardh) Gomont were found in high amounts and in wide distribution in sampling sites 11, 12 and 13 in August 2008 with a high amount of nitrate nitrogen in the water (Figure 9). At sampling sites 2-7 between January-April 2008, it was found that the amounts of ammonia nitrogen and orthophosphate were high during these periods and a high density of *Oscillatoria limosa* (C. Agardh) Gomont was also revealed.

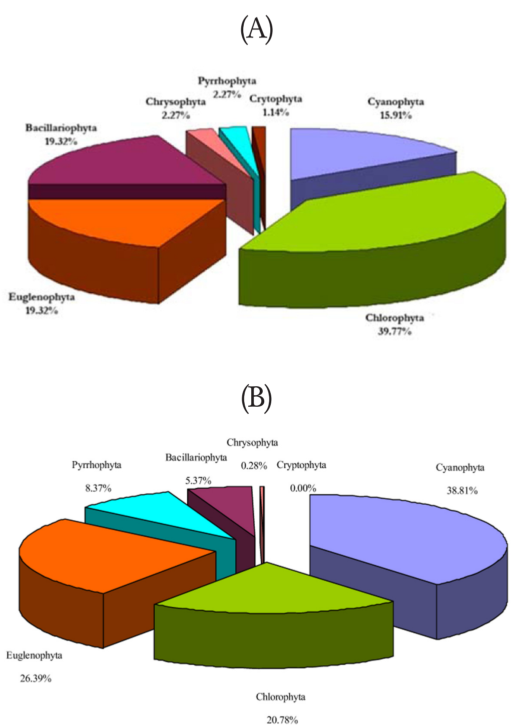

Figure 4. The percentage of number (A) and biovolume (B) of phytoplankton in each divisionin Khlong Rangsit, Pathumthani Province from December 2007 to May 2009.

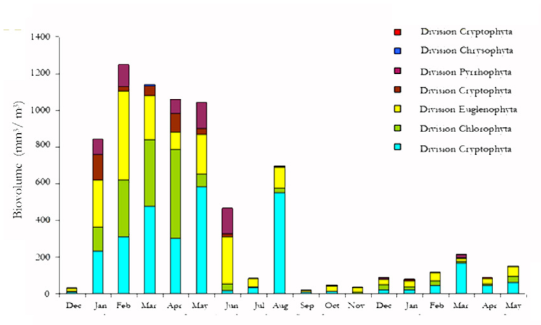

Figure 5. Biovolume of phytoplankton in each division in Khlong Rangsit, Pathumthani Province from December 2007 to May 2009.

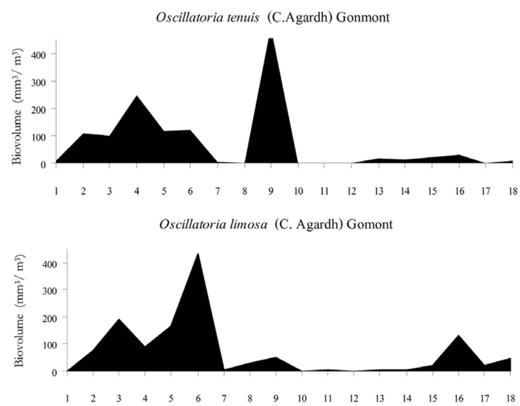

Figure 6. Biovolume of *Oscillatoria* spp. in Khlong Rangsit, Pathumthani Province from December 2007 to May 2009.

During the study of the water quality at all 13 stations, the biovolume of phytoplankton was investigated in order to find the dominant species of phytoplankton, through principle component analysis using Multi-Variate Statistical Package Version 3.1 (Figure 7). At stations 1-7, the dominant species found were *Oscillatoria tenuis* (C. Agardh) Gomont (oscten), *Oscillatoria limosa* (C. Agardh) Gomont (osclim), *Pandorina morum* (O.F.M□llue) Bory (Panmor), *Peridinium* sp. (persp1) and *Strombomanas caudata* (Ehrenberg) Stein (strcau). At stations 8-10 located in the 6th tributary area, *Oscillatoria limosa* (C.Agardh) Gomont (osclim), *Phacus ranula* Pochmann (Ehrenberg) Dujardin (pharan), *Strombomanas* *gibberosa* (Playfair) Deflandre (strgib), *Aulacoseira granulate* (Ehernberg) Ralfs (aulgra) and *Peridinium* sp. (persp1) were found. At stations 11-13 located in the 5th tributary area, *Oscillatoria tenuis* (C. Agardh) Gomont (oscten), *Eudorina elegans*Ehrenberg (eudele), *Phacus ranula* Pochmann (Ehrenberg) Dujardin (pharan), *Strombomanas gibberosa* (Playfair) Deflandre (strgib) and *Aulacoseira granulata* (Ehernberg) Ralfs (aulgra) were found. The results showed that *Oscillatoria* spp. were the dominant species that were recorded in many stations. The toxic *Oscillatoria* spp. is a common species in eutrophic reservoirs [17], and Lindholm *et al*. [30] reported that the *Oscillatoria* spp strain did not usually form scum on the water surface, but they may occur in high concentrations deeper in the water column. This is consistent with the findings of this study that found the scum of *Microcystis aeruginosa* usually formed during the investigated period. According to El Herry [17], it was reported that *Microcystis* spp. and *Oscillatoria tenuis* were the dominant species in the Lebna Dam, Tunisia from January to December 2005.

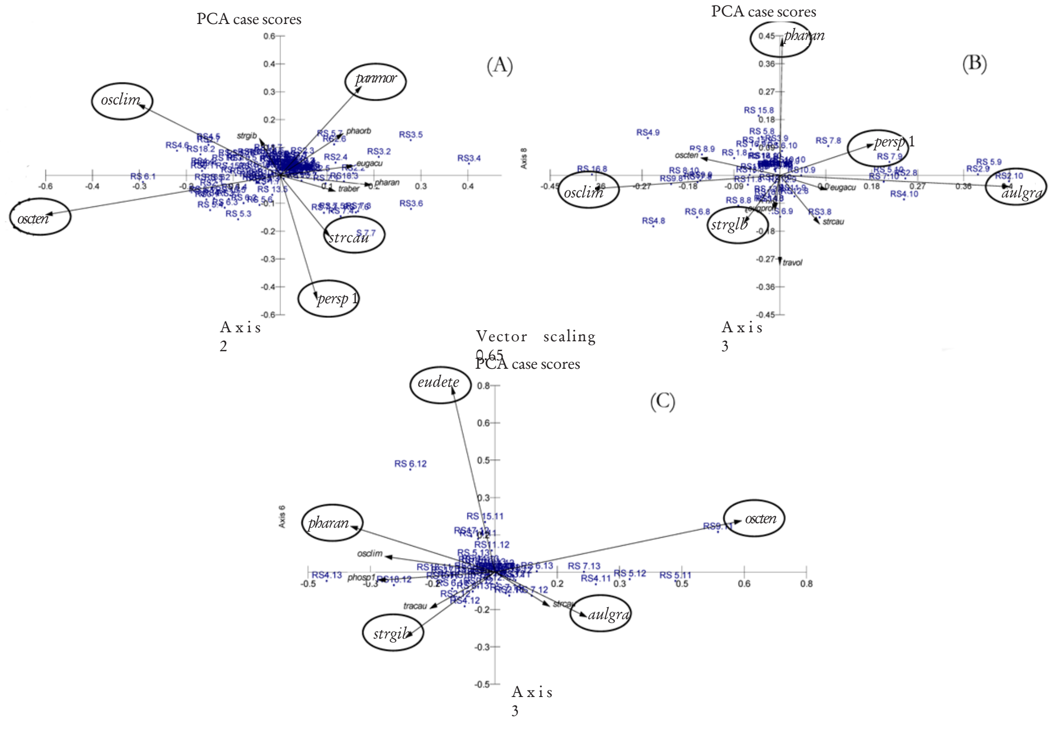

Figure 7. Principal component analysis (PCA) presenting the dominant species of phytoplanktons in Klong Rangsit, Pathumthani Province from December 2007 to May 2009 Station1-7 (A), Station8-10 (B), Station11-13 (C).

Analysis of the diversity and the evenness index of the phytoplankton found in this study was conducted using Shannon's method, the results showed that the diversity index was between 0.000-2.440. In January 2008 at station 3, the diversity index was found to be the highest and a total of 17 glues (species) of phytoplankton were found.

The value of evenness was between 0.000 and 1.000. The highest value of evenness was found in July 2008 at station 7, in August 2008 at station 6, in September 2008 at station 6, in October 2008 at station 12, in November 2008 at station 3, at station 4, at station 6, at station 9 and at station 13, while in December 2008 the highest value of evenness was recorded at station 10, at station 12 and at station 4. In 2009, the highest value of evenness was recorded in January at station 6 and at station 13 and in April at station 9.

Table 1. Total phytoplankton amount found at each station in Khlong Rangsit, Pathumthani Province from December 2007 to May 2009.

TAXA	
Division Cyanophyta	*Staurodesmus* sp.
Anabaena circinalis Rabenhorst	*Tetraedron minimum* (A. Braun) Hansgirg
Aphanizomenon sp.	*Tetrahedron trigonum* var. *gracile* (Reinsch) De Toni
Arthrospira platensis (Nordstedt) Gomont	
Arthrospira subsalsa (Oersted) Crow - Unchecked	*Treubaria triappendiculata* C. Bernard
Chroococus sp.	*Volvox* sp
Cylindrospermopsis philippinensis (Taylor) Komárek	**Division Euglenophyta**
Cylindrospermopsis raciborskii (Woloszynska) Seenayya&SubbaRaju	*Euglena acus* (O.F.Müller) Ehrenberg
Merismopedia punctata Meyen	*Euglena charkoviensis* Swirenko
Microcystis aeruginosa (Kützing) Kützing	*Euglena proxima* P.A.Dangeard
Oscillatoria limosa C.Agardh ex Gomont	*Phacus angulatus* Pochmann
Oscillatoria tenuis (C. Agardh) ex Gomont	*Phacu shelikoides* Pochmann
Planktolyngbya limnetica (Lemmermann) J.Komárková-Legnerová & G.Cronberg	*Phacus longicauda* (Ehrenberg) Dujardin
	Phacus monilatus var. *suecicus* Lemmermann
Phormidium sp.	*Phacus orbicularis* K.Hübner
Synechocystis sp.	*Phacus ranula* Pochmann
Division Chlorophyta	*Strombomonas caudata* (Ehrenberg) Stein
Actinastrum gracillimum G.M. Smith Ehrenberg	*Strombomonas fluviatitis* (Lemmermann) Deflandre
Ankistrodesmus falcatus (Corda) Ralfs	
Botryococcus braunii Kützing	*Strombomanas gibberosa* (Playfair) Deflandre
Chlorella sp.	
Closmarium sp.	*Trachelomonas caudata* (Ehrenberg)Stein
Closteriopsis acicularis (Chodat) J.H.Belcher& Swale	*Trachelomonas bernardinensis* Vischer
Closterium acerosum Ehrenberg ex Ralfs	*Trachelomonas hispida* (Perty) F. Stein
Closterium sp.	*Trachelomonas oblonga*Lemmermann
Coelastrum microporum Nägeli	*Trachelomonas volvocina* (Ehrenberg)
Coelastrum pseudomicroporum Korshikov	
Crucigeniella crucifera(Wolle) Komárek	**Division Bacillariophyta**
Dictyosphaerium tetrachotonum Printz	*Acanthoceros zachaiasii* (Brunnthaler)
Eudorina elegans Ehrenberg	*Aulacoseira granulate* (Ehrenberg)

Table 1. Continued.

TAXA	
Golenkinia sp.	Simonsen
Korshikoviella limnetica (Lemmermann) P.C.Silva	*Cyclotella* sp.
Monoraphidium arcuatum (Korshikov) Hindák	*Cymbella tumidula* Grunow
Monoraphidium tortile (West &G.S.West) Komárková-Legnerová	*Encyconema* sp.
Micractiniumpucillium Fresenius	*Eunotia* sp.
Oocystis sp.	*Fragilaria ulna* var. *acus* (Kützing) Lange-Bertalot
Pandorina morum (O.F.Müller) Bory de Saint-Vincent	
Pediastrum duplex var. *duplex* Meyen	*Dictyosphaerium pulchellum* H.C.Wood
Pediastrum simplex var. *echinulatum* Wittrock	*Fragilaria* sp.
Pediastrum simplex Meyen	*Gomphonema gracile* Ehrenberg
Scenedesmus acuminatus (Lagerheim) Chodat	*Gyrosigma* sp.
Scenedesmus armatus (R.Chodat) R.Chodat	*Navicula* sp.
Scenedesmus quadricauda (Turpin) Brébisson	*Nitzschia* sp
Scenedesmus opoliensis P.G.Richter	
Scenedesmus serratus (Corda) Bohlin	
Staurastrum brachioprominens Børgesen	

3.3 Physical Variables in Water Samples

Figure 8 shows the physical variables of water samples taken from Khlong Rangsit, Pathumthani Province from December 2007 to May 2009. The overall conductivity was found to be between 167.20 and 690mscm^{-1} with an average of 374.63 mscm^{-1}. At station 2, the water collected in January 2008 showed the highest conductivity at 690 mscm^{-1} and at station 8, the water was found to have been polluted when the value of conductivity was above 300 mscm^{-1}[31]. The water collected in May 2009 showed the lowest conductivity level at 167.20 mscm^{-1}. The secchi depth of the 13 stations was between 0.05-0.91 m with an average of 0.4 m. The water level at station 3 measured in November 2008 was found to be the highest at 0.9 m and the water level at station 13 measured in May 2008 was the lowest at 0.05 m. In this study, the secchi depth of the water at station 1 to station 8 were found to be higher than the other stations. The depth of the water studied was between 0.36 m to 6.40 m with an average depth of 2.50 m. The depth of station 1 measured in October 2008 was the deepest at 6.40 m and the shallowest was 0.36 m recorded at station 10. The turbidity of all 13 stations was between 1.60 and 346 NTU with an average of 43.36 NTU. The water at station 10 measured in December 2008 was 346 NTU and was the highest, while the water at station 11 measured in April 2009 was 1.6 NTU and was the lowest. The turbidity of the water at station 1- station 8 was lower than the water at the other stations. The total dissolved solids ranged from 25.8 to 345 mgL^{-1} with 183.23 mgL^{-1} and were measured in January 2008 at station 2. The lowest level of total dissolved solids of 25.8 mgL^{-1} was measured in February 2009 at station 13.

3.4 Chemical Variables in Water Samples

The results of the study showed that the pH of the water was in the range from 6.02 to 8.16 with an average of 7.07, which did not exceed the standards of surface water [32]. The highest pH of 8.16 was measured in April 2008 at station 8, while the lowest pH of 6.02 was measured in July 2008 at station 2. The pH level of the water at each station was very much the same, which signaled a balanced state of the pH level. The alkalinity value was between 231.18 to 64.05 mgL^{-1} with an average of 106.76 mgL^{-1}. The highest value occurred in April 2008 at station 8, and it was found that the value exceeded the amount of alkalinity in natural water, and varied between 10-200 mgL^{-1} [33], and the lowest value was found in June 2008 at station 13. The value of the dissolved oxygen was between 0.70 to 9.92 mgL^{-1} with a mean value of 3.77 mgL^{-1}. The highest value was found in April 2008 at station 8 and the lowest value was found in July 2008 at station 13, which was lower than 2 mgL^{-1} of the standards of the surface water quality [32]. The BOD ranged from 1.20 to 32 mgL^{-1} with a mean value of 5.05 mgL^{-1}. The highest value occurred in April 2008 at station 8, while the lowest value was recorded in January 2008 at station 12. The results showed that the highest value of BOD was higher than 4.0 mgL^{-1}, the standard of surface water quality [32] (Figure 9). The orthophosphate value ranged between 0.001 to 1.222 mgL^{-1} with a mean value of 0.115 mgL^{-1}. The highest value was found in April 2008 at station 8 and was 1.222 mgL^{-1} while the lowest value of 0.001 mgL^{-1} was recorded in March 2009 at station 12 (Figure 9).

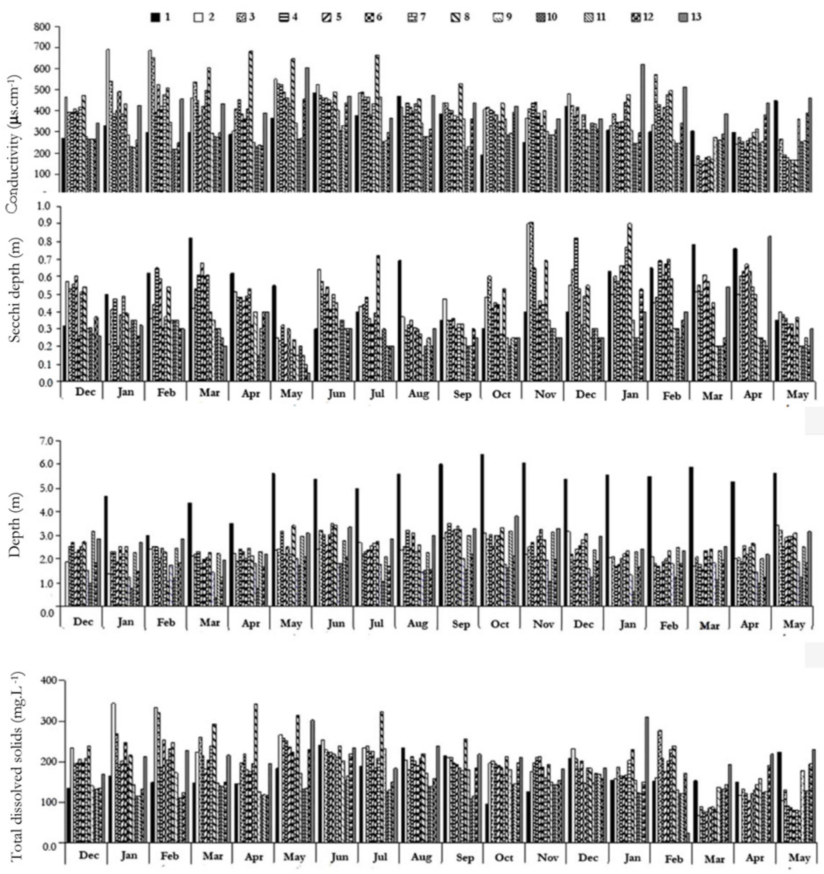

Figure 8. Physical variables of water samples taken from Khlong Rangsit, Pathumthani Province from December 2007 to May 2009.

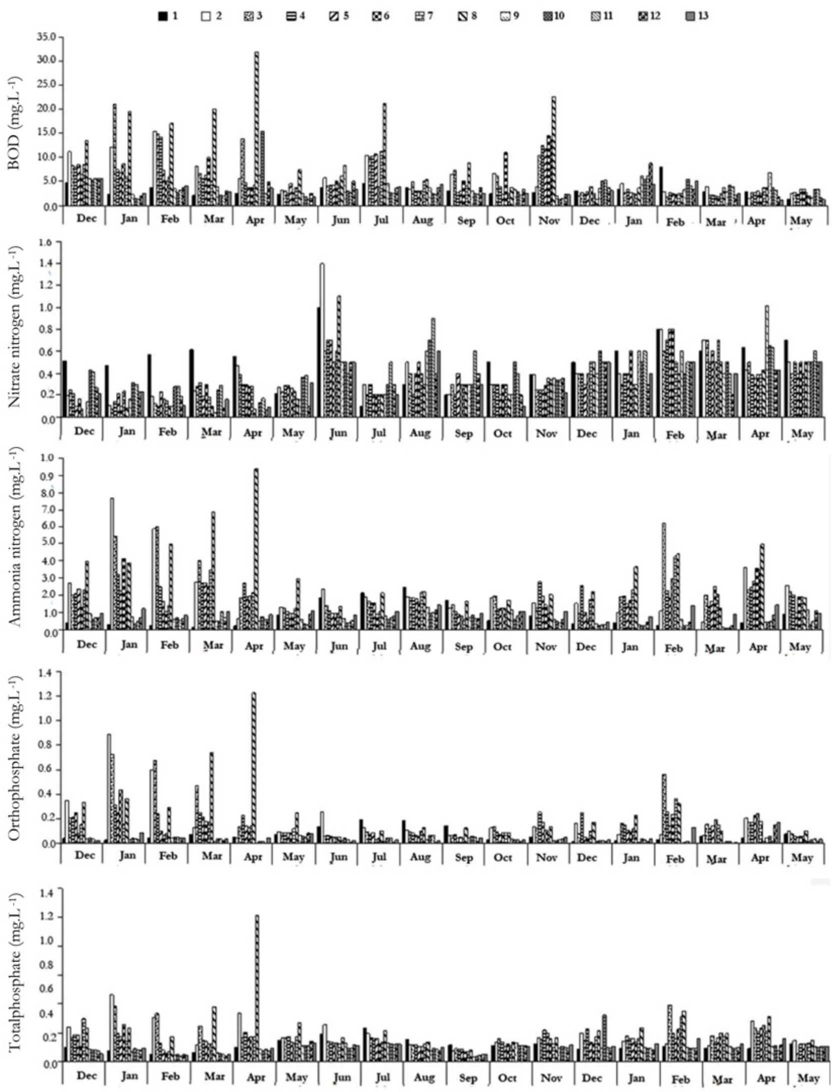

Figure 9. Chemical variables of water samples taken from Khlong Rangsit, Pathumthani Province from December 2007 to May 2009.

The amount of total phosphorus was between 0.082 to 2.533 mgL^{-1}. The average total phosphorus was 0.352 mgL^{-1}. The highest level of total phosphorus occurred in April 2009 at station 8 and the lowest level occurred in September 2009 at station 9. In conclusion, in summer, the value of total phosphorus was at its highest and in the rainy season, at its lowest (Figure 9).

The amount of ammonia - nitrogen varied from 0.020 to 9.4 mgL^{-1} with an average value of 1.530 mgL^{-1} in April 2008, in the summer. The highest value of ammonia - nitrogen was found at station 8 and was higher than the value determined in the standard surface water quality of Thailand. The rest of the year, the level of ammonia - nitrogen found at all stations was lower than the prescribed level of the standard surface water quality of Thailand [32] (Figure 9). The amount of nitrate-nitrogen at the surface ranged from 0 to 1.4 mgL^{-1} with an average value of 0.373 mgL^{-1}. The highest value of nitrate- nitrogen was found in June 2008 at station 2, while the lowest value was found in December 2007 at station 8. The level of nitrate- nitrogen found at all stations did not exceed the value of the prescribed standard surface water quality of Thailand [32] (Figure 9). The quantity of organic nitrogen ranged from 0.056 to 12.826 mgL^{-1} with a average level of 2.663 mgL^{-1}. The highest value was found in April 2008 at station 4, while the lowest value was found in October 2008 at station 12 from April to July 2008. The lowest value occurred from August to October 2008 at all stations. The salinity remained relatively the same-between 0.10 to 0.30 ppt throughout the study period. Total iron exiting in the surface water was from 0.12 to 2.17 mgL^{-1} with a mean value of 0.75 mgL^{-1}. The highest value of total iron was found in December 2008 at station 10 and the lowest value was found in February 2009 at station 8.

3.5 Biological Properties of Water Quality

Total coliform bacteria was found to be in the range of 3.6 to 1100 MPN/100 mL^{-1} (Figure 10). The lowest value was found in November 2008 at station 1, and in December 2008 and May 2009 at station 2. The highest value was found in August 2008 at stations 8 and 9, while at station 7, it occurred in February 2009 and the same phenomena was found in April 2009 at stations 4 and 5. Throughout this study, the value of total coliform bacteria found did not exceed the determined value of 5,000 MPN/100 mL^{-1} of the standard surface water quality of Thailand [32].

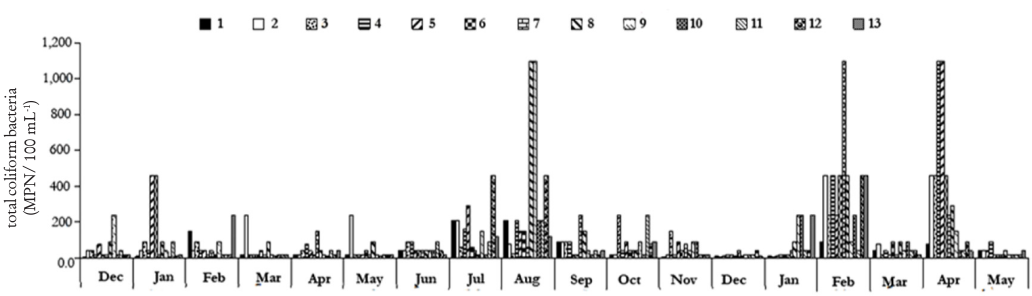

Figure 10. Total coliform bacteria in Khlong Rangsit, Pathumthani Province from December 2007 to May 2009.

The study of the water quality in Khlong Rungsit, Pathumthani Province was carried out from December 2007 to May 2009 following the standard surface water quality set by the National Environmental Board [32]. The study covered the biological, physical and chemical factors of the water. Based on the total coliform bacteria, biochemical oxygen demand and dissolved oxygen found to be present in the water, the quality of the water was then classified as being in category 4 which was suitable for consumption after the compulsory normal sterilization process and water quality improvement stages.

3.6 Phytoplankton as Water Quality Indicator

Multi-variate Statistical Package (MVSP) version 3.1 with an emphasis on correspondence analysis was used in this study to find the species of phytoplankton to be used as a water quality indicator (Figure 11). At stations 1-7, *Microcystis aeruginosa* Kützing (Micaer) could be used to monitor nitrate nitrogen quantity; the amount of this algae increased with higher nitrate nitrogen content. This result was consistent with the findings of Moisandera et al. [34] who investigated the nutrient limitations of *Microcystis aeruginosa* in the northern California Klamath River Reservoirs. The results showed that the total phytoplankton biomass increased with additions of nitrate nitrogen and ammonia nitrogen before and during the *Microcystis* blooms, and this study also suggested that the availability of nitrogen during the summer is a key growth-limiting factor for the initiation and maintenance of toxic *Microcystis* blooms in these reservoirs. At stations 8-10, *Aulacoseira granalata* (Ehremberg) Ralfs (Aulgra) could be used to indicate pH and dissolved oxygen values. The amount of *Aulacoseira granalata* increased with higher pH and dissolved oxygen values. According to the report of Bere and Tundisi [35], *Aulacoseira granulate* could be used to characterize relatively less polluted water quality and was dominant in the upstream branches of the Monjolinho River in Brazil, which had a lower value of conductivity and total dissolved solids than the down stream areas. At stations 11-13, *Oscillatoria tenuis* (C. Agardh) Gomont (Osten) were used as indicators for soluble reactive phosphorous and dissolved oxygen. According to El Herry *et al* [17] who investigated the seasonal occurrence and toxicity of *Microcystis* spp. and *Oscillatoria tenuis* in the Lebna Dam, Tunisia between January to December 2005, they reported that *Microcystis* spp. and *Oscillatoria tenuis* were the dominant species existing among the environmental conditions which consisted of high temperatures and high nutrient levels, especially high amounts of phosphorus.

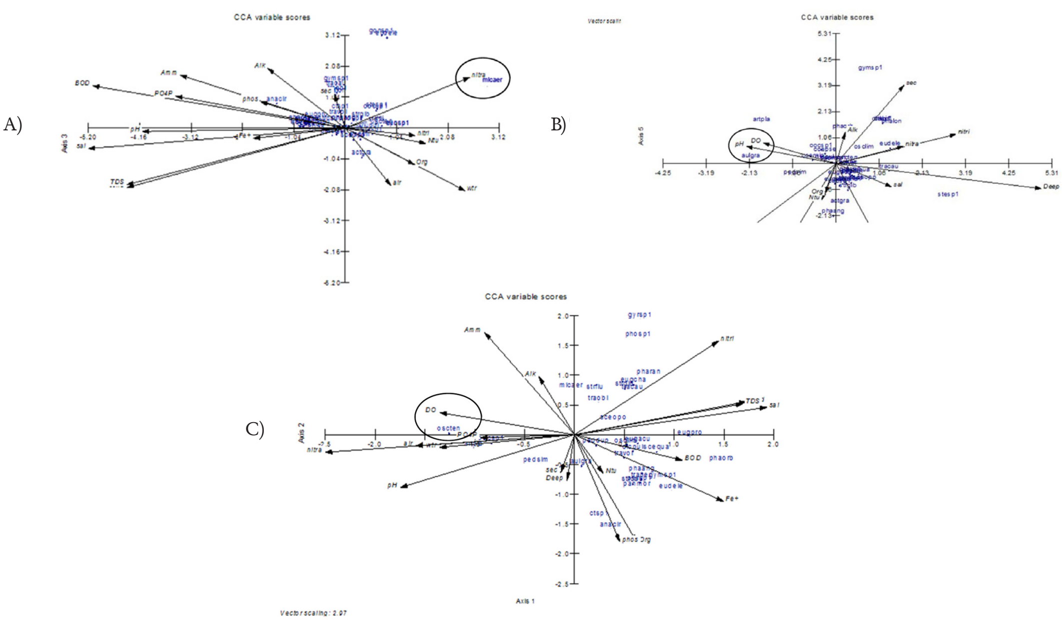

Figure 11. Canonical Correspondence Analysis (CCA) presenting the relationship between water quality and the species of phytoplankton (% of relative abundance > 1); Station 1-7 (A), Station 8-10 (B), Station 11-13 (C).

3.7 Investigation of Sediment in Khlong Rangsit

Figure 12 shows the chemical parameters of the sediment in Khlong Rangsit, Pathumthani Province from December 2007 to May 2009. The amount of nitrate-nitrogen in the sediment ranged from 2.803 to 70.003 $mgkg^{-1}$. The highest value was found in December 2007 at station 12 and the lowest value was found in April 2008 at station 6.

The ammonia-nitrogen value ranged from 25.210 to 296.801 $mgkg^{-1}$. The highest value was found in December 2007 at station 7 and the lowest value was found in August 2008 at station 11. The amount of TKN ranged from 1,100 to 7,137.358 $mgkg^{-1}$. The highest value was found in December 2007 at station 2 and the lowest value was found in August 2008 at station 11. The value of phosphate ranged from between 2.72 to 197.00 $mgkg^{-1}$. The highest value was found in April 2008 at station 13 and the lowest value was found in August 2008 at station 10. The total phosphate value ranged from 396 to 2,590 $mgkg^{-1}$. The highest value was found in April 2008 at station 5 and the lowest value was found in April 2008 at station 10. The amount of total iron was found to range from 81.54 to 172.66 $mgkg^{-1}$. The highest value was found in August 2008 at station 12 and the lowest value was found in December 2008 at station 1. The potassium value at the sediment ranged from between0.19to 0.50 $mgkg^{-1}$. The highest value was found in April 2008 at station 3 and the lowest value was found in December 2007 at station 1.

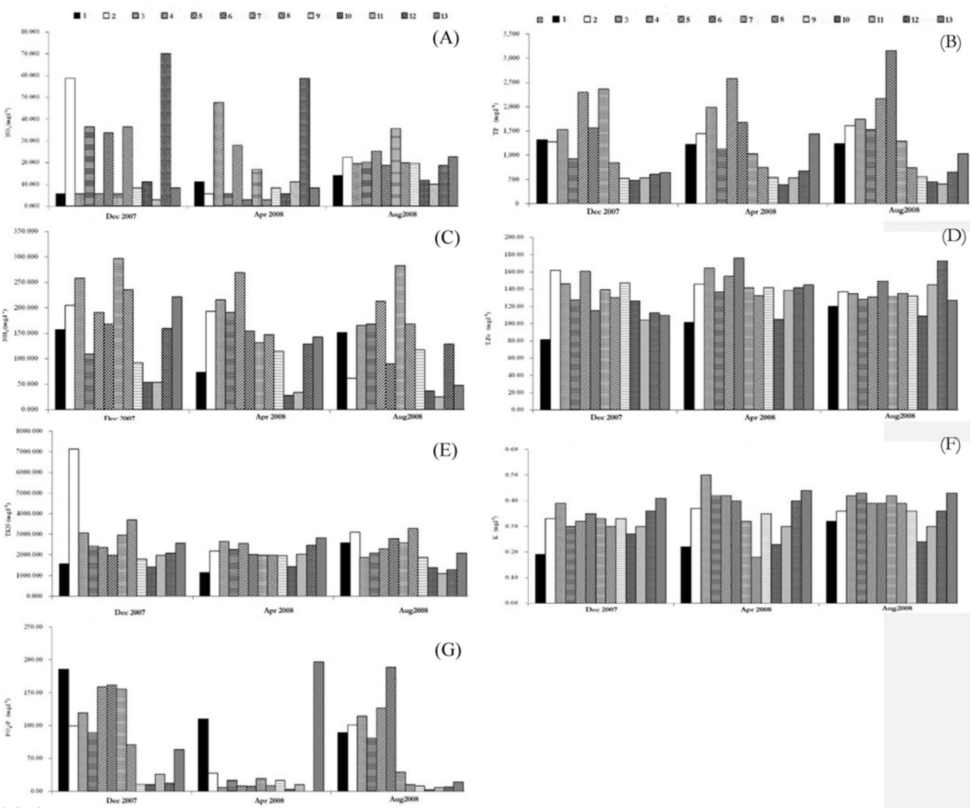

Figure 12. The chemical parameters of the sediment in Khlong Rangsit,Pathumthani Province from December 2007 to May 2009: (A)nitrate-nitrogen, (B) total phosphate, (C) ammonia-nitrogen, (D) total iron, (E) TKN, (F) potassium and (G) phosphate.

4. Conclusion

The scum of the cyanobacterium *Microcystis aeruginosa* was found in many eutrophic lakes. On the other hand, *Oscillatoria* spp. strains do not usually form scum on the surface of the water as they require lower light intensities for growth, but they may grow in high concentrations deeper in the water column [30]. This phenomenon also occurs in these water resources in which the algal blooming of *Microcystis aeruginosa* often occurs along with a high biovolume of the *Oscillatoria* spp. strains.

Recently, microcystins have been classified as being "possibly carcinogenic to humans" in group 2B by the International Agency for Research on Cancer (IARC) [36]. According to the results regarding the water quality, the amount of ammonia - nitrogen and orthophosphates were high in many sampling sites and all seasons, which demonstrated that many nutrients had entered into this irrigation canal. According to Rantala et al. [37] reported the total nitrogen and total phosphorus concentrations were related to the microcystin-producing genera and microcystin concentration levels.

This is not only an ecological problem but when water bodies are used for consumption this can also seriously affect humans as a significant health risk. We recommend that the water quality in these irrigation canals be monitored and the water should be put through a disinfection process and special water treatment processes before being used by the people surrounding these areas.

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