

Full Paper

## **Benthic diatoms of Mekong River and its tributaries in northern and north-eastern Thailand and their application to water quality monitoring**

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**Abstract:** Biomonitoring of benthic diatoms was performed to assess the water quality of Mekong River and its tributaries in northern and north-eastern Thailand. Fourteen sampling sites along the river and its tributaries were investigated. Two hundred and fifty-two species in 53 genera of diatoms were recorded. Each sampling site had distinct water chemistry and other physical variables. Cluster analysis identified 11 groups at 80% similarity. The relationship between diatom community composition and water quality variables was determined by statistical techniques. A number of diatom species were found to be useful as indicators of some physico-chemical properties of water.

**Keywords:** benthic diatoms, water quality, biomonitoring, Mekong River

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### **INTRODUCTION**

One of the most important natural resources for human life is water resource. Human use including household, industrial, agricultural and recreational activities affects water quality. There is an urgent need to develop a more sustainable practice for the management and efficient use of water resources as well as the need to protect the ecosystems where these resources are located. Therefore, it is important to monitor the quality of our limited water supplies. Presently, there are several methods to monitor water quality. One of the methods that is successfully used for monitoring aquatic environments around the world is biological assessment of water quality. It is considered an essential part in the assessment of the ecological quality of running waters apart from

the data obtained from other sources such as hydrology, eco-morphology, physico-chemical water analysis and eco-toxicological analysis [1].

In rivers and streams, benthic diatoms, the most common and diverse primary producers [2], are regarded as bioindicators due to their sensitivity and strong response to many physical, chemical and biological changes [3]. Diatoms are successfully used for monitoring aquatic environments around the world, especially in Europe, USA and Japan [4-5].

In Thailand, Mekong River flows through Chiang Rai province in the north. As it continues along its path in Laos, it once again flows back into Loei, Nong Khai, Nakhon Panom, Mukdaharn, Amnaj Charoen and Ubon Ratchadhani provinces in the north-east of Thailand. There are many smaller rivers which are tributaries that may affect the Mekong River. Thus, the water quality in the Mekong River and its tributaries should be monitored continuously.

There have been few studies of diatoms in the Mekong River in the past [6-8]. In this study, the diversity and distribution of benthic diatoms in the Mekong River and its tributaries in northern and north-eastern Thailand was investigated. In addition the relationship between diatoms species and some water physico-chemical properties was studied. The basic ecological data that could be applied to develop sustainable water resources were also obtained. Furthermore, the study should provide more information on diatoms in the South-east Asian region where very few reports on benthic diatoms were documented.

## **MATERIALS AND METHODS**

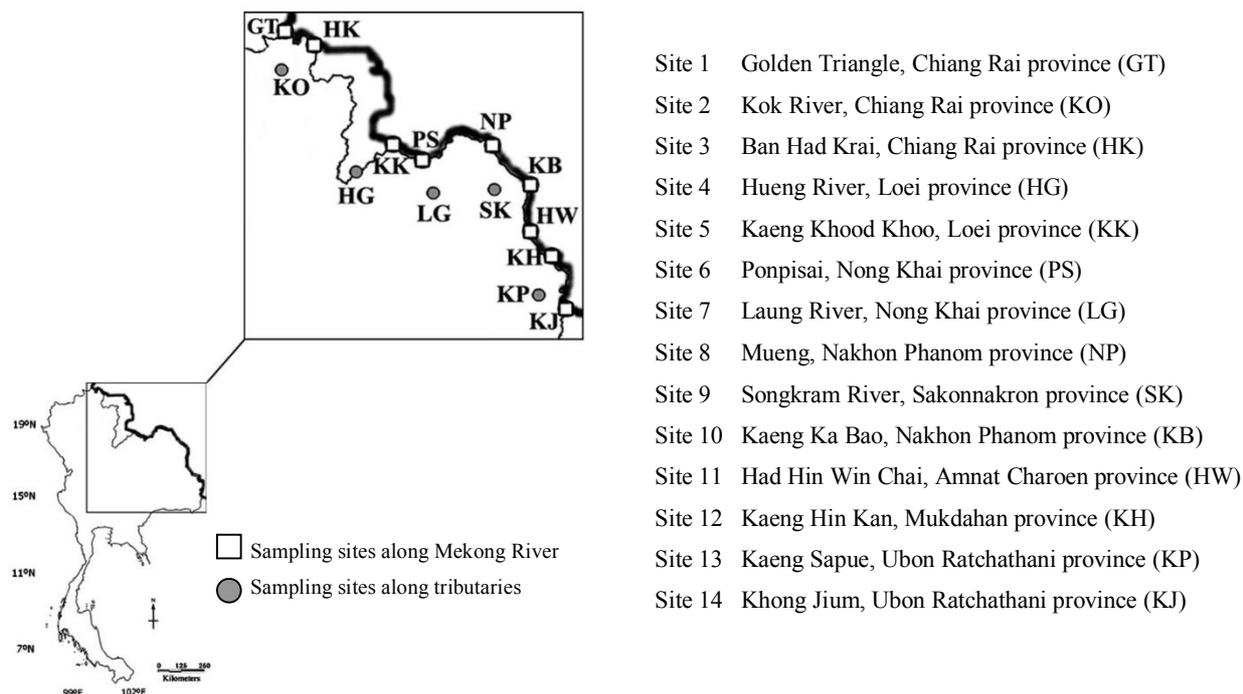
### **Study Area**

Fourteen sampling sites along the Mekong River and its tributaries in northern and north-eastern Thailand were selected based on the distance and environmental impact. Nine sites were located along Mekong River and five sites along its tributaries. The detail of each sampling site is shown in Figure 1. Diatom samples and physico-chemical water quality were determined 3 times per year in each season during July 2005 – April 2007.

### **Benthic Diatom Collection and Identification**

Ten replicates of benthic diatoms were collected at each sampling site. Diatoms were taken from stone surfaces using a toothbrush and a 10-cm<sup>2</sup> plastic sheet. The samples were put in plastic boxes and fixed with Lugol's solution on site. Diatom samples were then taken to the laboratory and cleaned by concentrated acid digestion method [9]. Briefly, each sample was centrifuged at 3,500 rpm for 15 minutes. The diatom cells were placed in an 18-cm core tube, added with concentrated nitric acid, heated in a boiler (70-80°C) for 30-45 minutes, and rinsed 4-5 times with deionised water.

Each cleaned diatom sample was mounted on a microscope slide with Naphrax<sup>®</sup>, a mountant with a high refractive index [9-10]. Up to 300 diatom valves were counted and identified with an Olympus CH30 microscope at ×1000 magnification. Taxonomy and nomenclature was determined according to the relevant references [8, 11-17].



**Figure 1.** Map of Thailand showing the location of 14 sampling sites along Mekong River and its tributaries

### Physico-Chemical Data

Water samples were collected in triplicate at each sampling site. The samples were put in polyethylene bottles and kept in a cool box at 5-7°C. Water chemical and physical properties were determined by established methods [18]; soluble reactive phosphorus (SRP) was determined by ascorbic acid method, nitrate nitrogen ( $\text{NO}_3^-$ -N) by cadmium reduction method, ammonia nitrogen ( $\text{NH}_4^+$ -N) by Nesslerisation method, alkalinity (as mg/L  $\text{CaCO}_3$ ) by phenolphthalein methyl orange indicator method, dissolved oxygen (DO) by azide modification of the Winkler method, and biochemical oxygen demand (BOD) by 5-day incubation and azide modification of the Winkler method. The pH was measured with a pH meter, conductivity with a conductivity meter, turbidity with a turbidity meter, water temperature with a thermometer, and water velocity with a velocity meter (Aquaflow Probe - Model 6900, Ricky Hydrological Company).

### Data Analysis

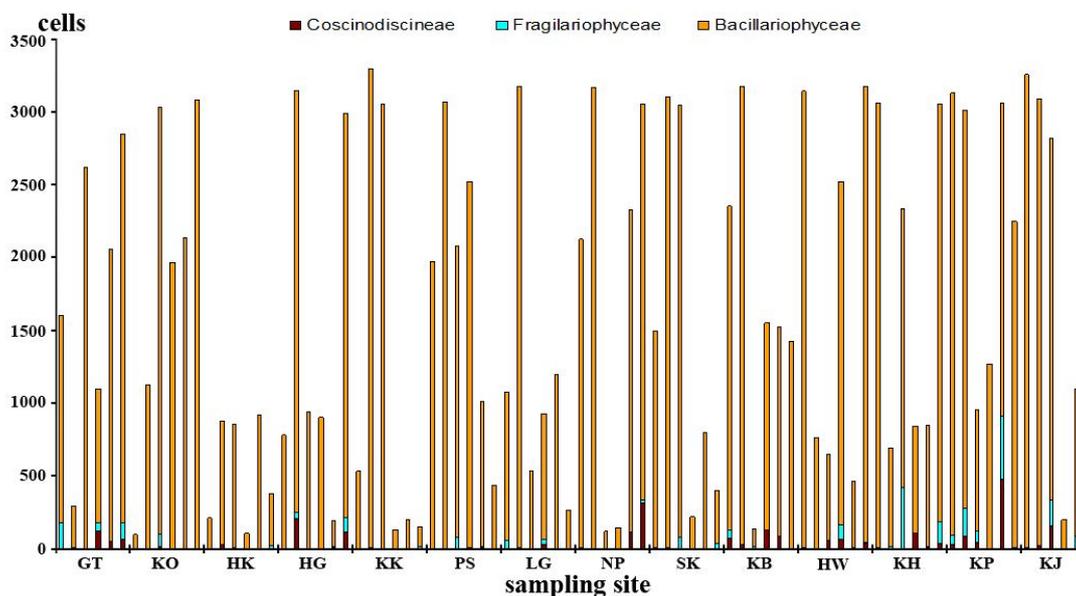
ANOVA single factor was performed on water quality and data sets on benthic diatoms assemblage to determine any significant differences between groups. Pearson's correlation was also calculated for certain variables. Water quality data and diatom species were analysed with canonical correspondence analysis (CCA), a multivariate direct gradient analysis method widely used in ecology, to determine the relationship between physico-chemical water quality and diatom species using multivariate statistical package (MVSP) software. Cluster analysis was performed on the log of transformed water quality data using MVSP software with unweighted pair-group method of arithmetic averages (UPGMA) cluster method to show similarity percentage between samples.

Environmental variables of the clusters were then tested for significance between groups with ANOVA single factor. The number of benthic diatoms in each group was calculated by Minitab program to find significant differences and correlations between groups.

## RESULTS AND DISCUSSION

### Diatom Diversity and Distribution

A total of 135,859 benthic diatom cells were counted. Two hundred and fifty-two species of benthic diatoms were found and classified into 3 classes, 6 subclasses, 14 orders, 27 families and 53 genera. The majority (88.5%) was in Bacillariophyceae class with the remaining 6.0% in Fragilariophyceae class and 5.5% in Coscinodiscineae class. *Nitzschia* was the genus with the highest number of species (30 species) followed by *Navicula* (25 species), *Gomphonema* (16 species), *Eunotia* (14 species), *Luticola* (12 species) and *Pinnularia* (8 species). The number of diatom species recorded was similar to that reported for other river systems of comparable size. Holmes and Whitton [19] listed 230 diatom species collected from Tees River in northern England while Archibald [20] recorded 310 diatom species from Sundays and Great Fish Rivers in South Africa. Similarly, 267 species of diatoms found in La Trobe River and tributaries in Australia was reported [21]. The distribution of the diatoms is shown in Figure 2. The lowest number of diatoms was recorded at HK in Chiang Rai, northern Thailand, during the fourth sampling in July 2006 (rainy season).



**Figure 2.** Number of benthic diatoms in Mekong River and its tributaries between July 2005 –April 2007

Among the 252 species, 29 were common species as shown in Table 1 and Figures 3. *Nitzschia palea* showed the highest percentage (36.0%) followed by *Mayamaea atomus* (35.4%), *Eolimna minima* (25.3%), *Navicula cryptotenelloides* (24.9%), *Cymbella* sp.1 (21.3%) and *Achnantheidium minutissimum* (20.5%).

**Table 1.** Twenty nine common species of benthic diatoms in Mekong River and its tributaries. The percentage of relative abundance is shown in bracket.

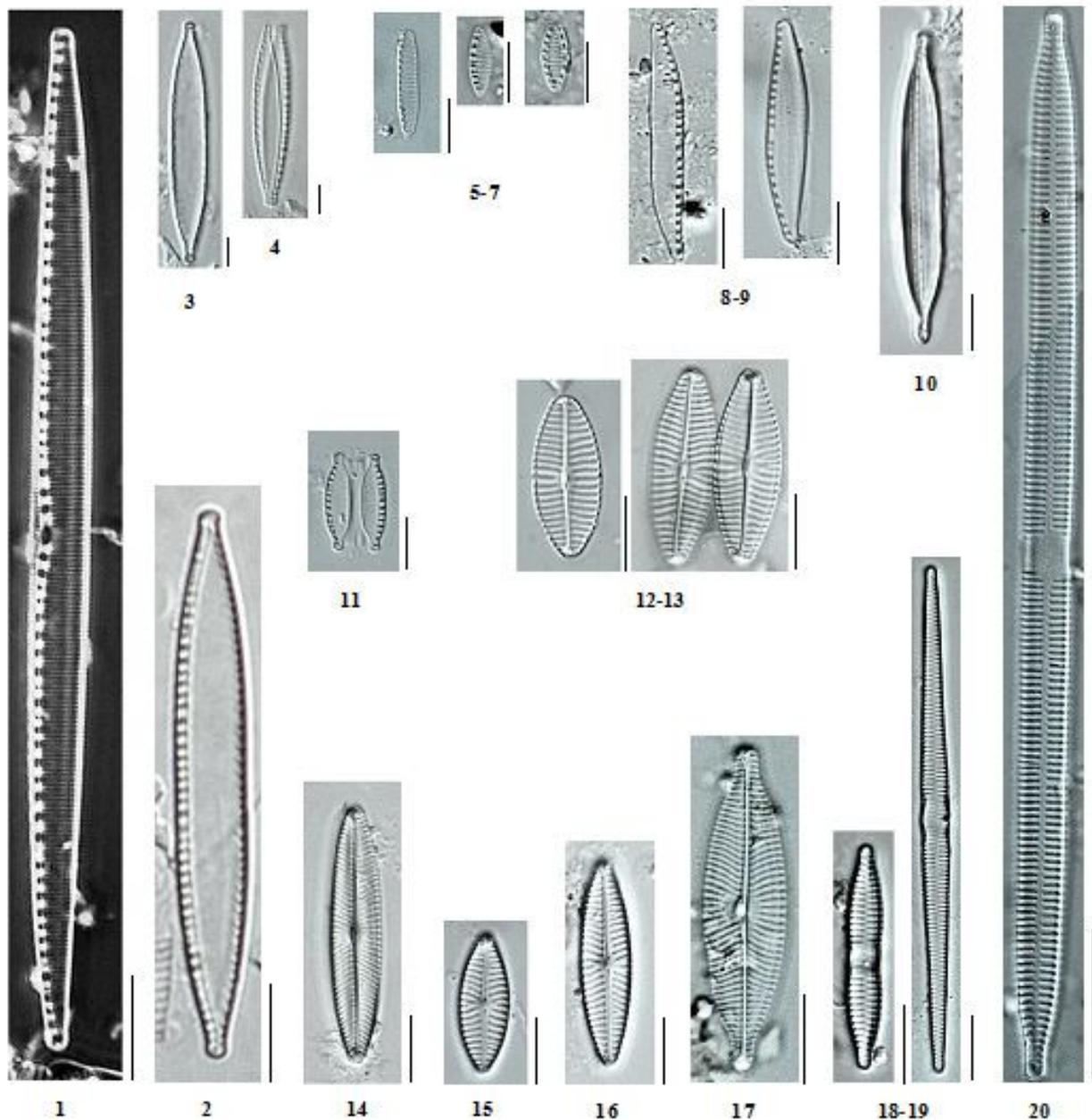
Taxa	
<i>Nitzschia palea</i> (Kützing) Smith (36.0%)	<i>Planothidium frequentissimum</i> (Lange-Bertalot) Round & Bukhtiyarova (11.9%)
<i>Mayamaea atomus</i> (Kützing) Lange-Bertalot (35.4%)	<i>Cymbella sumatrensis</i> Hustedt (11.7%)
<i>Navicula symmetrica</i> Patrick (33.4%)	<i>Nitzschia filiformis</i> (Smith) Hustedt (11.4%)
<i>Eolimna minima</i> (Grunow) Lange-Bertalot (25.3%)	<i>Ulnaria ulna</i> (Nitzsch) Compère (10.8%)
<i>Navicula cryptotenelloides</i> Lange-Bertalot (24.9%)	<i>Eolimna subminuscula</i> (Manguin) Gerd Moser (9.8%)
<i>Gomphonema lagenula</i> Kützing (24.6%)	<i>Fragilaria bidens</i> Heiberg (9.0%)
<i>Cymbella</i> sp.1 (21.3%)	<i>Melosira varians</i> Agardh (9.0%)
<i>Achnantheidium minutissimum</i> (Kützing) Czarnecki (20.5%)	<i>Navicula menisculus</i> Schumann (6.9%)
<i>Navicula cryptotenella</i> Lange-Bertalot (19.9%)	<i>Nitzschia dissipata</i> (Kützing) Grunow (6.6%)
<i>Nitzschia inconspicua</i> Grunow (19.2%)	<i>Geissleria decussis</i> (Østrup) Lange-Bertalot & Metzeltin (5.9%)
<i>Nitzschia supralitorea</i> Lange-Bertalot (17.2%)	<i>Achnantheidium convergens</i> (Kobayasi) Kobayasi (5.9%)
<i>Navicula rostellata</i> Kützing (14.5%)	<i>Frustulia undosa</i> Metzeltin & Lange-Bertalot (4.7%)
<i>Encyonema</i> sp.1 (14.3%)	<i>Sellaphora pupula</i> (Kützing) Mereschkovsky (3.1%)
<i>Luticola goeppertiana</i> (Bleisch) Mann in Round, Crawford & Mann (13.7%)	<i>Nitzschia microcephala</i> Grunow (2.9%)
<i>Nitzschia clausii</i> Hantzsch (13.1%)	

According to Jüttner et al. [22], *M. atomus*, *A. minutissimum* and *N. palea* were common species in streams in agricultural catchments of Kathmandu valley, Nepal. Duong et al. [23] reported the impact of urban pollution in Hanoi area on benthic communities collected from Red, Nhue and Tolich Rivers in Vietnam. They also reported that the diatom assemblage at the Tolich site consisted mainly of *Nitzschia umbonata*, *N. palea* and *Eolimna minima*. Some of these diatoms were reported to have preference for tropical regions without being restricted to these latitudes [23-24]. *Cymbella turgidula* was recorded in many tropical countries such as Sri Lanka [25] and Río Savegre River in the central and southern parts of Costa Rica [26]. *Cymbella tumida* was also reported to be widespread but very often found in the tropics [11]. Patrick and Reimer [27] reported this species from New England. *Diploneis subovalis* was found in Iceland and Finland, but with higher frequency in tropical rivers [11]. *Gomphonema parvulum* var. *lagenula* was regarded as a tropical species [26].

Common species, especially *Cymbella turgidula*, *C. tumida* and *Gomphonema parvulum* var. *lagenula* (currently regarded as a synonym of *Gomphonema lagenula*) were found in many streams and rivers in Thailand [8, 28-38].

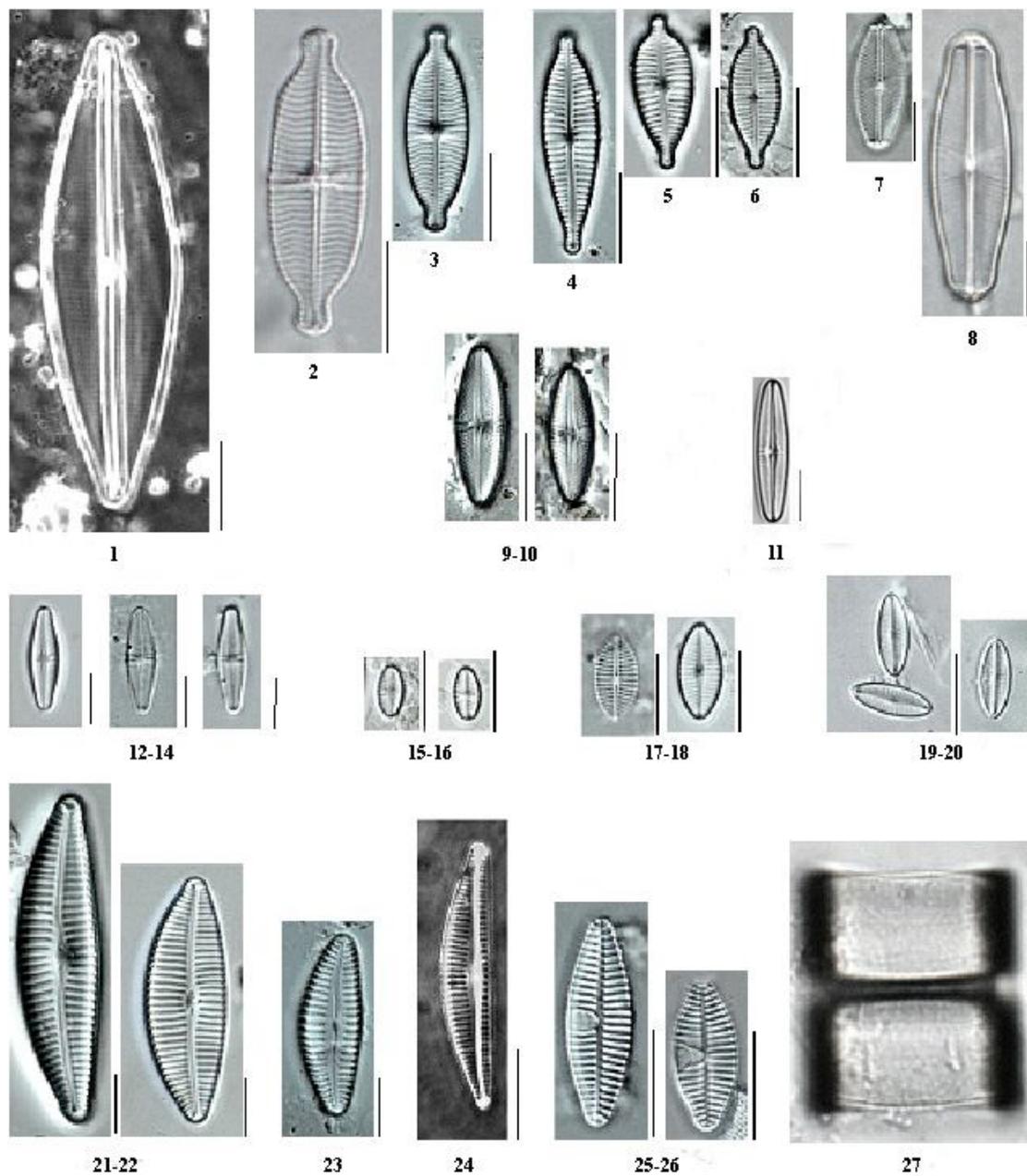
### Water Physico-Chemical Properties

The water physico-chemical properties of Mekong River and its tributaries between July 2005 - April 2007 are shown in Table 2. Broad differences were apparent between sampling sites. The water temperature ranged between 25-32°C, the temperatures at GT, KO and HK in the north being lower than those in the north-eastern areas. The water velocity was highest (8.30 m/s) at KB in the Mekong River. All sampling sites showed neutral pH with the highest (7.67) at GT and the lowest (6.75) at SK. Average alkalinity ranged between 23.3-67.8 mg/L. The highest value of conductivity was recorded at SK in the north-eastern area. The highest DO and BOD values were observed at KO in the north-eastern area, as were the highest NO<sub>3</sub><sup>-</sup>-N (1.57 mg/L) and SRP (0.24 mg/L). The highest NH<sub>4</sub><sup>+</sup>-N (0.53 mg/L) was recorded at KP and the lowest (0.21 mg/L) at GT.



**Figure 3.** Common species of benthic diatoms in Mekong River and its tributaries (scale bar = 10  $\mu$ m)

- (1) *Nitzschia filiformis* (W. Smith) Hustedt, (2) *Nitzschia palea* (Kützing) W. Smith, (3-4) *Nitzschia inconspicua* Grunow, (5-7) *Nitzschia supralitorea* Lange-Bertalot, (8-9) *Nitzschia clausii* Hantzsch, (10) *Nitzschia dissipata* (Kützing) Grunow, (11) *Nitzschia microcephala* Grunow, (12-13) *Navicula menisculus* Schumann, (14) *Navicula symmetrica* R.M. Patrick, (15) *Navicula cryptotenelloides* Lange-Bertalot, (16) *Navicula cryptotenella* Lange-Bertalot, (17) *Navicula rostellata* Kützing, (18-19) *Fragilaria bidens* Heiberg, (20) *Ulnaria ulna* (Nitzsch) P. Compère



**Figure 3 (continued).** Common species of benthic diatoms in Mekong River and its tributaries (scale bar = 10  $\mu\text{m}$ )

- (1) *Frustulia undosa* D. Metzeltin & H. Lange-Bertalot, (2-3) *Geissleria decussis* (Østrup) Lange-Bertalot & Metzeltin, (4-6) *Gomphonema lagenula* Kützing, (7-8) *Sellaphora pupula* (Kützing) Mereschkovsky, (9-10) *Luticola goeppertiana* (Bleisch) D.G.Mann in Round, Crawford & Mann, (11) *Achnantheidium convergens* (H. Kobayasi) H. Kobayasi, (12-14) *Achnantheidium minutissimum* (Kützing) Czarnecki, (15-16) *Eolimna minima* (Grunow) Lange-Bertalot, (17-18) *Eolimna subminuscula* (Manguin) Gerd Moser, (19-20) *Mayamaea atomus* (Kützing) H. Lange-Bertalot, (21-22) *Cymbella sumatrensis* Hustedt, (23) *Cymbella* sp.1, (24) *Encyonema* sp.1, (25-26) *Planothidium frequentissimum* (Lange-Bertalot) Round & L. Bukhtiyarova, (27) *Melosira varians* C. Agardh

The water quality in the Mekong River and its tributaries was classified in the fourth category according to the standards for surface water quality of Thailand certified by the Pollution Control Department [39], and can be used for household consumption after a disinfection process and special water treatment.

**Table 2.** Physicochemical properties of water at 14 sampling sites (average values and min-max values, n=14)

Sampling Site	Temperature (°C)	Velocity (m/s)	pH	Conductivity (µS/cm)	Turbidity (NTU)	Alkalinity (mg/L as CaCO <sub>3</sub> )	DO (mg/L)	BOD (mg/L)	NO <sub>3</sub> <sup>-</sup> -N (mg/L)	NH <sub>4</sub> <sup>+</sup> -N (mg/L)	SRP (mg/L)
GT	25.6 (18.1-30.8)	5.4 (1.8-9.2)	7.7 (7.3-8.0)	218.8 (153.0-312.0)	137.1 (54.0-301.0)	55.70 (9.90-103.00)	8.00 (5.40-10.00)	2.60 (1.80-4.10)	0.78 (0.10-1.90)	0.21 (0.04-0.47)	0.14 (0.06-0.55)
KO	26.0 (20.5-29.2)	5.8 (4.0-7.8)	7.2 (6.9-7.8)	138.5 (78.9-198.2)	199.1 (57.0-305.0)	41.05 (6.90-70.20)	8.20 (5.20-11.00)	3.10 (2.00-5.00)	1.57 (0.80-3.00)	0.37 (0.29-0.46)	0.24 (0.10-1.19)
HK	25.3 (18.5-29.8)	7.8 (3.0-12.3)	7.6 (7.2-8.1)	221.0 (162.0-270.0)	212.6 (48.0-419.0)	60.80 (17.60-97.00)	7.80 (5.20-9.80)	1.50 (0.20-3.10)	1.55 (0.20-3.40)	0.31 (0.13-0.67)	0.15 (0.02-0.67)
HG	30.2 (23.3-35.8)	6.7 (0.5-14.3)	7.6 (7.2-8.1)	180.4 (64.0-389.0)	82.5 (3.0-438.0)	57.80 (19.00-101.00)	7.00 (4.20-8.40)	2.70 (0.40-6.40)	0.88 (0.00-1.60)	0.42 (0.15-0.72)	0.22 (0.10-0.61)
KK	28.9 (23.9-32.8)	3.5 (0.1-5.6)	7.6 (7.0-8.7)	192.8 (49.0-325.0)	205.2 (105.0-453.0)	67.80 (35.00-104.00)	5.90 (4.80-8.60)	2.30 (0.00-5.60)	1.20 (0.20-2.00)	0.28 (0.14-0.43)	0.19 (0.14-0.29)
PS	30.0 (26.0-33.0)	2.74 (0.0-6.2)	7.4 (7.0-7.8)	249.7 (147.0-349.0)	183.4 (96.0-367.0)	65.80 (25.00-107.00)	5.60 (4.40-8.20)	1.20 (0.20-4.40)	1.12 (0.60-1.80)	0.38 (0.16-0.58)	0.19 (0.07-0.26)
LG	31.5 (26.5-34.1)	1.3 (0.0-6.3)	7.2 (6.4-8.1)	292.0 (146.0-401.0)	53.3 (12.0-125.0)	36.00 (8.00-85.00)	4.40 (2.60-5.80)	1.30 (0.10-3.00)	0.79 (0.50-1.10)	0.41 (0.20-0.74)	0.20 (0.07-0.40)
NP	30.6 (25.1-32.9)	1.4 (0.0-4.4)	7.4 (6.7-7.8)	195.7 (91.0-263.0)	127.4 (28.0-266.0)	61.20 (20.50-95.00)	5.70 (4.00-8.20)	1.70 (0.20-4.90)	0.76 (0.00-1.30)	0.36 (0.17-0.55)	0.13 (0.00-0.33)
SK	31.4 (27.0-34.8)	3.7 (0.1-10.4)	6.8 (6.0-7.5)	341.1 (127.0-759.0)	70.1 (10.0-288.0)	23.30 (4.10-45.00)	4.60 (2.20-7.00)	1.60 (0.00-3.60)	0.99 (0.20-1.80)	0.40 (0.18-0.73)	0.09 (0.01-0.20)
KB	30.4 (24.5-32.6)	8.3 (2.0-16.5)	7.5 (6.8-8.0)	193.2 (133.5-255.0)	134.1 (23.0-271.0)	51.40 (17.00-92.00)	6.00 (4.60-8.40)	1.90 (0.30-4.60)	0.68 (0.10-1.90)	0.30 (0.14-0.54)	0.15 (0.04-0.29)
HW	31.0 (27.1-34.8)	6.9 (0.1-14.9)	7.4 (6.8-7.9)	166.3 (66.0-255.0)	136.0 (16.0-303.0)	49.20 (18.50-87.00)	6.10 (4.60-8.60)	1.10 (0.00-4.90)	0.55 (0.10-1.20)	0.31 (0.10-0.60)	0.15 (0.00-0.37)
KH	30.3 (22.4-36.4)	2.7 (0.0-7.1)	7.5 (6.8-7.8)	134.9 (43.0-250.0)	144.1 (22.0-325.0)	52.50 (20.00-90.00)	5.89 (4.00-8.40)	1.40 (0.10-4.80)	0.55 (0.10-1.10)	0.31 (0.16-0.61)	0.17 (0.00-0.70)
KP	32.1 (28.0-36.0)	5.2 (0.1-8.8)	6.9 (6.2-7.9)	175.7 (80.0-265.0)	72.6 (13.0-119.0)	43.90 (10.00-73.20)	4.86 (3.60-7.20)	1.44 (0.00-5.20)	0.65 (0.00-1.90)	0.53 (0.17-0.85)	0.10 (0.02-0.30)
KJ	31.5 (27.0-34.8)	1.7 (0.0-4.7)	7.9 (6.6-8.2)	141.8 (44.0-243.0)	119.9 (14.0-260.0)	59.80 (21.00-85.00)	6.29 (4.60-8.50)	2.36 (0.60-5.10)	0.68 (0.00-1.30)	0.40 (0.11-1.07)	0.14 (0.01-0.34)

### Correlation between Physico-Chemical Variables

There were significant positive and negative correlations between some of the physico-chemical variables of water as shown in Table 3. Significant positive correlation between SRP and NO<sub>3</sub><sup>-</sup>-N was observed (P<0.001): the SRP concentration increased with higher NO<sub>3</sub><sup>-</sup>-N concentration. The pH positively correlated with NO<sub>3</sub><sup>-</sup>-N (P<0.01), NH<sub>4</sub><sup>+</sup>-N (P<0.001) and SRP (P<0.001). It increased with higher NO<sub>3</sub><sup>-</sup>-N, NH<sub>4</sub><sup>+</sup>-N and SRP concentrations. The alkalinity positively correlated with NO<sub>3</sub><sup>-</sup>-N (P<0.01), SRP (P<0.001), pH (P<0.001) and conductivity (P<0.001), but negatively correlated with NH<sub>4</sub><sup>+</sup>-N (P<0.001). Alkalinity increased with higher NO<sub>3</sub><sup>-</sup>-N and SRP concentrations as well as pH and conductivity. On the other hand, it decreased with higher NH<sub>4</sub><sup>+</sup>-N concentration. The BOD positively correlated with NO<sub>3</sub><sup>-</sup>-N (P<0.001), SRP (P<0.001), pH (P<0.001), alkalinity (P<0.001) and DO (P<0.001). However, it showed negative

correlation with  $\text{NH}_4^+\text{-N}$  ( $P < 0.05$ ). The BOD increased with higher  $\text{NO}_3^-\text{-N}$  and SRP concentrations, pH, alkalinity and DO, whereas it decreased with higher  $\text{NH}_4^+\text{-N}$  concentration.

**Table 3.** Pearson's correlation coefficients (r) between water physico-chemical variables. Significant values of r: \* =  $P < 0.05$ ; \*\* =  $P < 0.01$ ; \*\*\* =  $P < 0.001$  (n = 194)

	$\text{NO}_3^-\text{-N}$	$\text{NH}_4^+\text{-N}$	SRP	pH	Conductivity	Alkalinity	DO	BOD	Temperature	Velocity	Turbidity
$\text{NO}_3^-\text{-N}$	1										
$\text{NH}_4^+\text{-N}$	-0.040	1									
SRP	0.360 (***)	-0.032	1								
pH	0.200 (**)	0.446 (***)	0.353 (***)	1							
Conductivity	0.146 (*)	-0.072	0.162 (*)	0.206 (**)	1						
Alkalinity	0.212 (**)	-0.311 (***)	0.313 (***)	0.644 (***)	0.260 (***)	1					
DO	0.069	-0.495 (***)	0.005	0.492 (***)	0.046	0.349 (***)	1				
BOD	0.293 (***)	-0.178 (*)	0.265 (***)	0.382 (***)	0.047	0.310 (***)	0.360 (***)	1			
Temperature	-0.090	0.515 (***)	0.017	-0.337 (***)	-0.053	-0.090	-0.716 (***)	-0.233 (***)	1		
Velocity	0.004	0.041	0.165 (*)	0.057	0.024	0.006	0.149 (*)	0.102	-0.020	1	
Turbidity	0.129	0.177 (*)	-0.032	-0.219 (**)	-0.305 (***)	-0.325 (***)	-0.139 (*)	-0.079	-0.078	0.079	1

Human activities in the Mekong River basin include small-scale livestock keeping, fish farming, subsistence farming and horticultural farming. All these activities are the source of pollution, especially in the tributaries which are frequently disturbed by domestic animals and riparian human communities. Sampling sites such as LG, SK and KP, where the water passes through a city, are directly affected by human activities. On the contrary, at KO where the river runs through a rural area, or at HG where the river runs through mountains, the water is not affected by such activities.

### Relationship between Diatom Species and Physico-Chemical Variables by CCA

Twenty-nine common species of benthic diatoms were subjected to CCA to find the relationship between water physico-chemical properties and diatom species using MVSP statistical program. The results of CCA are shown in Figure 4. It was found that *Achnantheidium minutissimum* (Achmin) positively correlated with conductivity; the amount of this alga increased with higher conductivity. *Navicula menisculus* (Navmen) positively correlated with alkalinity (Alk) but it negatively correlated with  $\text{NH}_4^+\text{-N}$  (NH4). The number of *Navicula menisculus* increased with higher alkalinity but decreased with higher  $\text{NH}_4^+\text{-N}$ . *Nitzschia clausii* (Nitcla), *Luticola goeppertiana* (Lutgeo), *Achnantheidium convergens* (Achcon), *Eolimna minima* (Eolmin) and *Ulnaria ulna* (Ulnuln) positively correlated with SRP and  $\text{NO}_3^-\text{-N}$  but negatively correlated with BOD. They increased with higher SRP and  $\text{NO}_3^-\text{-N}$  but decreased with higher BOD.



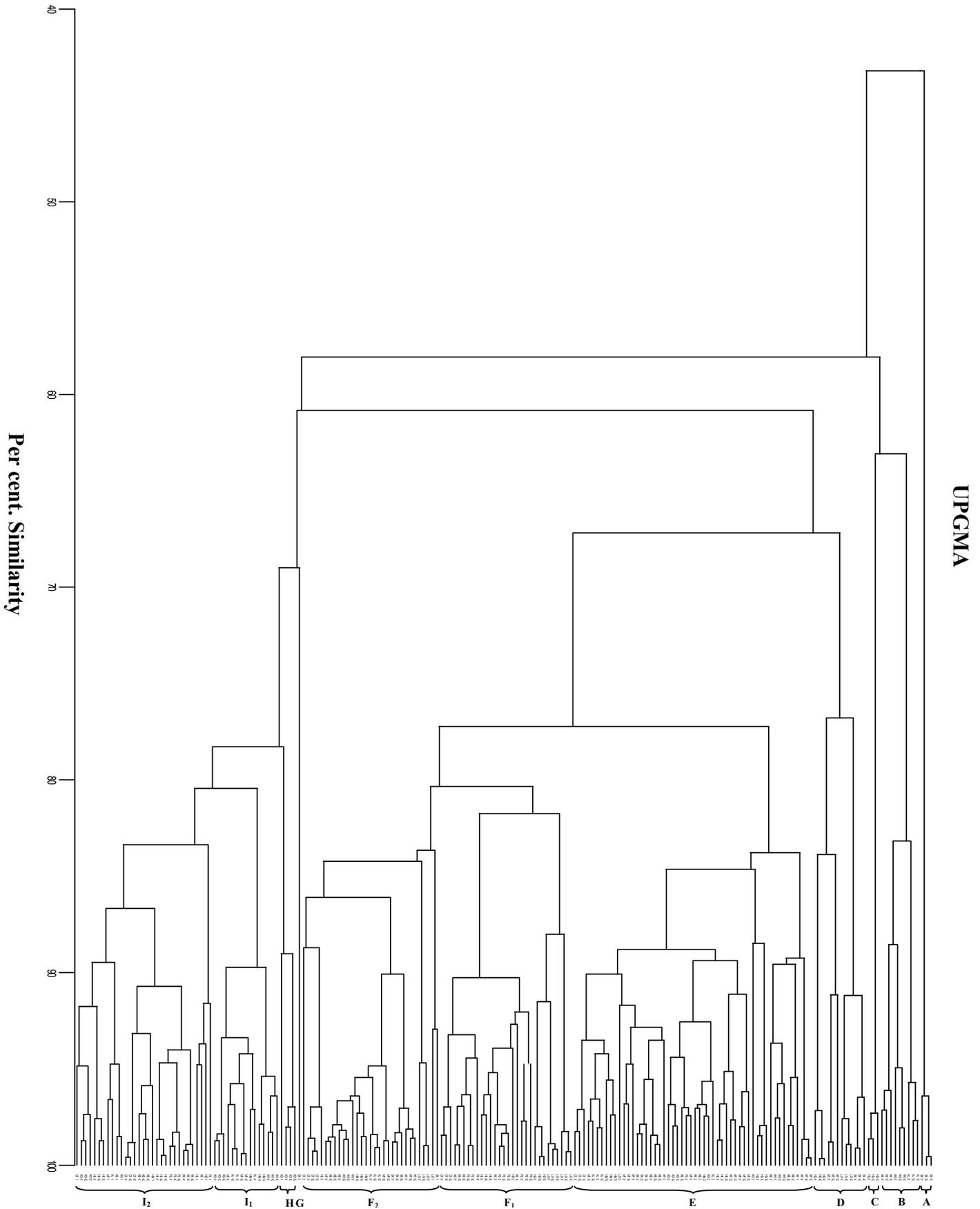
In fast-flowing water, there are diatoms such as *Achnanthes* and *Cocconeis* that can attach on rocks and other hard surfaces [24]. Similarly, in this study, *Cocconeis* spp. were found as dominant species at HG during summer 2007 with high water velocity. In slower flowing water, *Melosira varians* and various species of *Synedra*, *Gomphonema* and *Cymbella* are found on hard substrata [24]. Throughout the sampling period, *Gomphonema* spp. were also observed at LG located about 100 metres downstream from a small dam, where the flow rate of water was extremely low.

### Species of Benthic Diatoms in Relation to Physico-Chemical Properties of Water by Cluster Analysis

Twenty nine common diatom species were arranged in groups of sampling sites detected by cluster analysis of physico-chemical parameters of water quality at 80% similarity. The number of benthic diatoms in each group was calculated by Minitab program to find the significant difference and significant correlation between groups. The relationship between diatom community composition and water quality variables was determined using statistical techniques. Each sampling site had distinct water physico-chemical properties. At 80% similarity, the dendrogram divided sampling sites into eleven distinct clusters of characteristic water quality types: groups A to I<sub>2</sub> (Figure 5 and Table 4). It was found that all sampling sites in groups A (n=3) and B (n=9) and some in group C (n=3) were those during December 2006 (cool dry season). Group E, the biggest group (n=54), was composed of sampling sites during May 2006 (summer) and some sites in two cool dry seasons.

The values of physico-chemical parameters in each group were calculated by Minitab program to find significant differences and correlations between groups A to I<sub>2</sub> as shown in Table 5. It was found that groups A, C, G and H showed a non-significant correlation with NO<sub>3</sub><sup>-</sup>-N concentration. Group F<sub>1</sub> showed higher concentrations of NO<sub>3</sub><sup>-</sup>-N (average of 1.33 mg/L) than groups B, D, E, F<sub>2</sub> and I<sub>1</sub> (P < 0.05). Group D (P < 0.05) was high in NH<sub>4</sub><sup>+</sup>-N concentration (average of 0.59 mg/L). There was a non-significant correlation with NH<sub>4</sub><sup>+</sup>-N concentration in group A (P < 0.05).

Significantly high concentrations of SRP (average of 0.39 mg/L) in group H (P < 0.05) compared to other groups were observed while groups C and G showed a non-significant correlation with the same parameter. The study showed significantly high pH (average of 7.75) in group C (P < 0.05) and significantly low pH (average of 6.59) in group G (P < 0.05). The pH values of all sampling sites in groups A and H were not significantly different within each group. As for conductivity, there were significant differences in all groups (P < 0.05). Group A showed high conductivity values (average of 753.00 µS/cm), whereas low conductivity values (average of 47.78 µS/cm) were observed in group B.



**Figure 5.** Dendrogram of similarities between investigated sites according to physico-chemical parameters of water; 252 cases, 11 variables

**Table 4.** Groups of sampling sites detected by cluster analysis of physico-chemical parameters of water quality at 80% similarity

Group	Sampling site	Description
A	SK5.1, SK5.2, SK5.3	Tributaries in north-eastern Thailand in cool dry season (second year)
B	KK5.1, KK5.2, KK5.3, KH5.1, KH5.2, KH5.3, KJ5.1, KJ5.2, KJ5.3	Mekong River in north-eastern Thailand in cool dry season (second year)
C	HG5.1, HG5.2, HG5.3	Tributaries in north-eastern Thailand in cool dry season (second year)
D	HG4.1, HG4.2, HG4.3, LG4.1, LG4.2, LG4.3, SK4.1, SK4.2, SK4.3, KP5.1, KP5.2, KP5.3	Tributaries in north-eastern Thailand in summer (second year) and cool dry season (second year)
E	GT3.1, GT3.2, GT3.3, KO2, KO3.1, KO3.2, KO3.3, HK3.1, HK3.2, HK3.3, HG3.1, HG3.2, HG3.3, KK2, KK3.2, PS2, LG2, NP2, NP3.1, NP3.2, NP3.3, NP5.1, NP5.2, NP5.3, SK3.1, SK3.2, SK3.3, KB2, KB3.1, KB3.2, KB3.3, KB5.1, KB5.2, KB5.3, HW2, HW5.1, HW5.2, HW5.3, KH2, KH3.1, KH3.2, KH3.3, KP1, KP2, KP3.1, KP3.2, KP3.3, KP4.1, KP4.2, KP4.3, KJ2, KJ3.1, KJ3.2, KJ3.3	Mekong River and its tributaries in summer (first year) and some of two cool dry seasons
F <sub>1</sub>	GT6.1, GT6.2, GT6.3, HK6.1, HK6.2, HK6.3, HG2, HG6.1, HG6.2, HG6.3, KK3.1, KK3.3, K6.1, KK6.2, KK6.3, PS3.1, PS3.2, PS3.3, PS5.1, PS5.2, PS5.3, PS6.1, PS6.2, PS6.3, LG3.1, LG3.2, LG3.3, LG6.1, LG6.2, LG6.3	Mekong River and its tributaries in two summers
F <sub>2</sub>	GT2, GT5.1, GT5.2, GT5.3, HK2, LG1, LG5.1, LG5.2, LG5.3, NP6.1, NP6.2, NP6.3, SK1, SK6.1, SK6.2, SK6.3, KB6.1, KB6.2, KB6.3, HW6.1, HW6.2, HW6.3, KH6.1, KH6.2, KH6.3, KP6.1, KP6.2, KP6.3, KJ6.1, KJ6.2, KJ6.3	Mekong River and its tributaries in summer (second year) and some of cool dry season (second year)
G	SK2	Tributaries in north-eastern Thailand in cool dry season (first year)
H	KO1, KO5.1, KO5.2, KO5.3	Tributaries in northern Thailand in rainy season (first year) and cool dry season (second year)
I <sub>1</sub>	KO4.1, KO4.2, KO4.3, NP4.1, NP4.2, NP4.3, HW4.1, HW4.2, HW4.3, KH4.1, KH4.2, KH4.3, KJ4.1, KJ4.2, KJ4.3	Mekong River and its tributaries in rainy season (second year)
I <sub>2</sub>	GT1, GT4.1, GT4.2, GT4.3, KO6.1, KO6.2, KO6.3, HK1, HK4.1, HK4.2, HK4.3, HK5.1, HK5.2, HK5.3, HG1, KK1, KK4.1, KK4.2, KK4.3, PS1, PS4.1, PS4.2, PS4.3, NP1, KB1, KB4.1, KB4.2, KB4.3, HW1, KH1, KJ1	Mekong River and its tributaries in two rainy seasons and some of cool dry season (second year) and summer (second year)

There were significant differences ( $P < 0.05$ ) in alkalinity in all groups. High values of alkalinity (average of 83.17 mg/L) were observed in group F<sub>1</sub> ( $P < 0.05$ ). The DO values of all sampling sites in groups A and G were not significantly different within each group. High DO values (average of 9.50 mg/L) were observed in group H while low values (average of 4.67 mg/L and 4.71 mg/L) were observed in groups D and I<sub>1</sub> respectively. For BOD, the values were not significantly different in group G while significantly high values (average of 4.47 mg/L) were observed in group C and significantly low values (average of 0.23 mg/L) were in group A.

There were non-significant correlation with water temperature in groups A and G. Group D ( $P < 0.05$ ) and group I<sub>1</sub> ( $P < 0.05$ ) had significantly high water temperatures (average of 33.5°C and 32.8°C respectively). Low water temperatures (average of 22.3°C) were observed in group H ( $P < 0.05$ ). Significant difference in turbidity was observed for all groups ( $P < 0.05$ ). The lowest

turbidity (average of 4.33 NTU) was recorded for group C while the highest (average of 314.16 NTU) was recorded for group I<sub>2</sub>.

**Table 5.** Values of average ( $\bar{X}$ ) and standard error (se) of physico-chemical parameters (P<0.05) and correlation (cor) between groups A-I<sub>2</sub>

Parameter	A	B	C	D	E
<b>NO<sub>3</sub><sup>-</sup>-N (mg/L)</b>	$\bar{X}$ = 0.57 se = 0.19 n = 3 cor ns	$\bar{X}$ = 0.56 se = 0.20 n = 9 cor B<F <sub>1</sub>	$\bar{X}$ = 0.80 se = 0.36 n = 3 cor ns	$\bar{X}$ = 0.47 se = 0.07 n = 12 cor D<F <sub>1</sub> , H, I <sub>2</sub>	$\bar{X}$ = 0.88 se = 0.07 n = 54 cor E<F <sub>1</sub>
<b>NH<sub>4</sub><sup>+</sup>-N (mg/L)</b>	$\bar{X}$ = 0.41 se = 0.03 n = 3 cor ns	$\bar{X}$ = 0.18 se = 0.01 n = 9 cor B<D,I <sub>1</sub> ,I <sub>2</sub>	$\bar{X}$ = 0.22 se = 0.06 n = 3 cor C<D,I <sub>1</sub>	$\bar{X}$ = 0.59 se = 0.04 n = 12 cor D>B,E,F <sub>1</sub> ,F <sub>2</sub> ,H,I <sub>2</sub>	$\bar{X}$ = 0.32 se = 0.02 n = 54 cor E<D,I <sub>1</sub>
<b>SRP (mg/L)</b>	$\bar{X}$ = 0.04 se = 0.03 n = 3 cor A<F <sub>1</sub> ,H	$\bar{X}$ = 0.07 se = 0.03 n = 9 cor B<F <sub>1</sub> ,F <sub>2</sub> ,H	$\bar{X}$ = 0.18 se = 0.04 n = 3 cor ns	$\bar{X}$ = 0.07 se = 0.01 n = 12 cor D<F <sub>1</sub> ,F <sub>2</sub> ,H	$\bar{X}$ = 0.14 se = 0.01 n = 54 cor E<F <sub>1</sub> ,H
<b>pH</b>	$\bar{X}$ = 7.09 se = 0.06 n = 3 cor ns	$\bar{X}$ = 7.56 se = 0.06 n = 9 cor B>D,I <sub>1</sub>	$\bar{X}$ = 7.75 se = 0 n = 3 cor C>D,I <sub>1</sub>	$\bar{X}$ = 6.73 se = 0.13 n = 12 cor D<B,C,E,F <sub>1</sub> ,F <sub>2</sub> ,I <sub>2</sub>	$\bar{X}$ = 7.40 se = 0.07 n = 54 cor E>D,I <sub>1</sub>
<b>Conductivity (μS/cm)</b>	$\bar{X}$ = 753.00 se = 5.03 n = 3 cor A>B,C,D,E,F <sub>1</sub> ,F <sub>2</sub> ,G,H,I <sub>1</sub> ,I <sub>2</sub>	$\bar{X}$ = 47.78 se = 1.33 n = 9 cor B<A,D,E,F <sub>1</sub> ,F <sub>2</sub> ,G,H,I <sub>2</sub>	$\bar{X}$ = 65.17 se = 0.09 n = 3 cor C<A,E,F <sub>1</sub> ,F <sub>2</sub> ,G,H,I <sub>2</sub>	$\bar{X}$ = 110.86 se = 8.77 n = 12 cor B<D<A,E,F <sub>1</sub> ,F <sub>2</sub> ,G,I <sub>2</sub>	$\bar{X}$ = 186.81 se = 3.80 n = 54 cor B,C,D,H,I <sub>1</sub> <E=I <sub>2</sub> <A,F <sub>1</sub> ,F <sub>2</sub> ,G
<b>Alkalinity (mg/L as CaCO<sub>3</sub>)</b>	$\bar{X}$ = 4.25 se = 0.12 n = 3 cor A<B,D,F <sub>1</sub> ,F <sub>2</sub> ,I <sub>2</sub>	$\bar{X}$ = 55.56 se = 6.40 n = 9 cor A,D,I <sub>1</sub> <B<F <sub>1</sub>	$\bar{X}$ = 48.33 se = 0.44 n = 3 cor C<F <sub>1</sub>	$\bar{X}$ = 21.17 se = 5.17 n = 12 cor D<B,E,F <sub>1</sub> ,F <sub>2</sub> ,I <sub>2</sub>	$\bar{X}$ = 55.89 se = 2.78 n = 54 cor A,D,I <sub>1</sub> ,I <sub>2</sub> <E<F <sub>1</sub>
<b>DO (mg/L)</b>	$\bar{X}$ = 6.47 se = 0.07 n = 3 cor ns	$\bar{X}$ = 7.36 se = 0.09 n = 9 cor B>D,I <sub>1</sub> ,I <sub>2</sub>	$\bar{X}$ = 8.13 se = 0.13 n = 3 cor C>D,I <sub>1</sub> ,I <sub>2</sub>	$\bar{X}$ = 4.67 se = 0.41 n = 12 cor D<E,F <sub>1</sub> ,F <sub>2</sub> ,H	$\bar{X}$ = 6.48 se = 0.23 n = 54 cor D,I <sub>1</sub> <E<H
<b>BOD (mg/L)</b>	$\bar{X}$ = 0.23 se = 0.03 n = 3 cor A<C,E,F <sub>1</sub> ,H	$\bar{X}$ = 0.69 se = 0.19 n = 9 cor B<C,E,F <sub>1</sub> ,H	$\bar{X}$ = 4.47 se = 1.30 n = 3 cor C>A,B,D,E,F <sub>1</sub> ,F <sub>2</sub> ,I <sub>1</sub> ,I <sub>2</sub>	$\bar{X}$ = 0.54 se = 0.18 n = 12 cor D<C,E,F <sub>1</sub> ,F <sub>2</sub> ,H,I <sub>2</sub>	$\bar{X}$ = 2.62 se = 0.18 n = 54 cor E>A,B,D,F <sub>2</sub> ,I <sub>1</sub> ,I <sub>2</sub>
<b>Temperature (°C)</b>	$\bar{X}$ = 28.00 se = 0.90 n = 3 cor ns	$\bar{X}$ = 24.71 se = 0.79 n = 9 cor B<D,E,F <sub>1</sub> ,F <sub>2</sub> ,I <sub>1</sub> ,I <sub>2</sub>	$\bar{X}$ = 27.30 se = 0 n = 3 cor C<D,I <sub>1</sub>	$\bar{X}$ = 33.49 se = 0.61 n = 12 cor D>B,C,E,F <sub>1</sub> ,F <sub>2</sub> ,H,I <sub>1</sub> ,I <sub>2</sub>	$\bar{X}$ = 29.96 se = 0.41 n = 54 cor B,H<E<D,I <sub>1</sub>
<b>Turbidity (NTU)</b>	$\bar{X}$ = 41.00 se = 14.05 n = 3 cor A<B,E,F <sub>1</sub> ,G,H,I <sub>1</sub> ,I <sub>2</sub>	$\bar{X}$ = 126.33 se = 10.48 n = 9 cor A,C,D,E,F <sub>1</sub> ,F <sub>2</sub> <B<G,H,I <sub>1</sub> ,I <sub>2</sub>	$\bar{X}$ = 4.33 se = 0.88 n = 3 cor C<B,D,E,F <sub>1</sub> ,G,H,I <sub>1</sub> ,I <sub>2</sub>	$\bar{X}$ = 65.78 se = 4.79 n = 12 cor C,F <sub>2</sub> <D<B,E,F <sub>1</sub> ,G,H,I <sub>1</sub> ,I <sub>2</sub>	$\bar{X}$ = 95.35 se = 3.18 n = 54 cor A,C,D,F <sub>2</sub> <E=F <sub>1</sub> <B,G,H,I <sub>1</sub> ,I <sub>2</sub>

Note: ns = not significant

Table 5. (continued)

Parameter	F <sub>1</sub>	F <sub>2</sub>	G	H	I <sub>1</sub>	I <sub>2</sub>
<b>NO<sub>3</sub><sup>-</sup>-N</b> (mg/L)	$\bar{X} = 1.33$ se = 0.08 n = 30 cor F <sub>1</sub> >B,D,E,F <sub>2</sub> ,I <sub>1</sub>	$\bar{X} = 0.82$ se = 0.08 n = 31 cor F <sub>2</sub> <F <sub>1</sub>	$\bar{X} = 1.80$ se = 0 n = 1 cor ns	$\bar{X} = 1.38$ se = 0.54 n = 4 cor ns	$\bar{X} = 0.68$ se = 0.23 n = 15 cor I <sub>1</sub> <F <sub>1</sub>	$\bar{X} = 1.04$ se = 0.15 n = 31 cor I <sub>2</sub> >D
<b>NH<sub>4</sub><sup>+</sup>-N</b> (mg/L)	$\bar{X} = 0.32$ se = 0.03 n = 30 cor F <sub>1</sub> =F <sub>2</sub> <D,I <sub>1</sub>	$\bar{X} = 0.32$ se = 0.04 n = 31 cor F <sub>2</sub> =F <sub>1</sub> <D,I <sub>2</sub>	$\bar{X} = 0.38$ se = 0 n = 1 cor ns	$\bar{X} = 0.32$ se = 0.01 n = 4 cor H<D	$\bar{X} = 0.49$ se = 0.02 n = 15 cor I <sub>1</sub> >B,C,E,F <sub>1</sub> ,F <sub>2</sub>	$\bar{X} = 0.41$ se = 0.02 n = 31 cor B,E<I <sub>2</sub> <D
<b>SRP</b> (mg/L)	$\bar{X} = 0.23$ se = 0.02 n = 30 cor F <sub>1</sub> >A,B,D,E,I <sub>1</sub>	$\bar{X} = 0.21$ se = 0.03 n = 31 cor B,D,I <sub>1</sub> <F <sub>2</sub> <H	$\bar{X} = 0.07$ se = 0 n = 1 cor ns	$\bar{X} = 0.39$ se = 0.27 n = 4 cor H>A,B,D,E,F <sub>2</sub> ,I <sub>2</sub>	$\bar{X} = 0.09$ se = 0.01 n = 15 cor I <sub>2</sub> <F <sub>1</sub> ,F <sub>2</sub> ,H	$\bar{X} = 0.17$ se = 0.03 n = 31 cor I <sub>2</sub> >H
<b>pH</b>	$\bar{X} = 7.60$ se = 0.06 n = 30 cor F <sub>1</sub> =F <sub>2</sub> >D,E,G,I <sub>1</sub>	$\bar{X} = 7.63$ se = 0.08 n = 31 cor F <sub>2</sub> =F <sub>1</sub> >D,E,G,I <sub>1</sub>	$\bar{X} = 6.59$ se = 0 n = 1 cor G<F <sub>1</sub> ,F <sub>2</sub>	$\bar{X} = 7.16$ se = 0.21 n = 4 cor ns	$\bar{X} = 6.81$ se = 0.03 n = 15 cor I <sub>1</sub> <B,C,E,F <sub>1</sub> ,F <sub>2</sub> ,I <sub>2</sub>	$\bar{X} = 7.36$ se = 0.06 n = 31 cor D,I <sub>1</sub> <F <sub>1</sub> ,F <sub>2</sub>
<b>Conductivity</b> (μS/cm)	$\bar{X} = 316.44$ se = 9.53 n = 30 cor B,C,D,E,F <sub>2</sub> ,H,I <sub>1</sub> ,I <sub>2</sub> <F <sub>1</sub> <A,G	$\bar{X} = 254.71$ se = 3.89 n = 31 cor B,C,D,E,H,I <sub>1</sub> ,I <sub>2</sub> <F <sub>2</sub> <A,F <sub>1</sub> ,G	$\bar{X} = 484.00$ se = 0 n = 1 cor B,C,D,E,F <sub>1</sub> ,F <sub>2</sub> ,H,I <sub>1</sub> ,I <sub>2</sub> <E<A	$\bar{X} = 121.45$ se = 6.21 n = 4 cor B,C,I <sub>1</sub> <H<A,E,F <sub>1</sub> , F <sub>2</sub> ,G,I <sub>2</sub>	$\bar{X} = 78.42$ se = 2.35 n = 15 cor I <sub>1</sub> >A,E,F <sub>1</sub> ,F <sub>2</sub> ,G,H,I <sub>2</sub>	$\bar{X} = 175.96$ se = 6.21 n = 31 cor B,C,D,H,I <sub>1</sub> <I <sub>2</sub> =E <A,F <sub>1</sub> ,F <sub>2</sub> ,G
<b>Alkalinity</b> (mg/L as CaCO <sub>3</sub> )	$\bar{X} = 83.17$ se = 4.05 n = 30 cor F <sub>1</sub> >A,B,C,D,E,F <sub>2</sub> ,G,H,I <sub>1</sub> ,I <sub>2</sub>	$\bar{X} = 62.90$ se = 4.93 n = 31 cor A,D,I <sub>1</sub> ,I <sub>2</sub> <F <sub>2</sub> <F <sub>1</sub>	$\bar{X} = 23.00$ se = 0 n = 1 cor G<F <sub>1</sub>	$\bar{X} = 33.00$ se = 2.08 n = 4 cor H<F <sub>1</sub> ,F <sub>2</sub>	$\bar{X} = 17.95$ se = 1.48 n = 15 cor I <sub>1</sub> <B,E,F <sub>1</sub> ,F <sub>2</sub> ,I <sub>2</sub>	$\bar{X} = 39.41$ se = 3.71 n = 31 cor D,I <sub>1</sub> <I <sub>2</sub> <E,F <sub>1</sub> ,F <sub>2</sub>
<b>DO</b> (mg/L)	$\bar{X} = 6.38$ se = 0.29 n = 30 cor D,I <sub>1</sub> <F <sub>1</sub> <H	$\bar{X} = 6.16$ se = 0.34 n = 31 cor D,I <sub>1</sub> <F <sub>2</sub> <H	$\bar{X} = 7.00$ se = 0 n = 1 cor ns	$\bar{X} = 9.50$ se = 1.43 n = 4 cor H>D,E,F <sub>1</sub> ,F <sub>2</sub> ,I <sub>1</sub> ,I <sub>2</sub>	$\bar{X} = 4.71$ se = 0.19 n = 15 cor I <sub>1</sub> <B,E,F <sub>1</sub> ,F <sub>2</sub> ,H	$\bar{X} = 5.79$ se = 0.27 n = 31 cor I <sub>2</sub> <B,C,H
<b>BOD</b> (mg/L)	$\bar{X} = 2.26$ se = 0.27 n = 30 cor A,B,D,F <sub>2</sub> ,I <sub>1</sub> <F <sub>1</sub> <C	$\bar{X} = 1.25$ se = 0.18 n = 31 cor F <sub>2</sub> <C,H	$\bar{X} = 3.60$ se = 0 n = 1 cor ns	$\bar{X} = 3.05$ se = 0.34 n = 4 cor H>A,B,D,F <sub>2</sub> ,I <sub>1</sub>	$\bar{X} = 0.91$ se = 0.35 n = 15 cor I <sub>1</sub> <C,E,F <sub>1</sub> ,H	$\bar{X} = 1.70$ se = 0.26 n = 31 cor D<I <sub>2</sub> <C,H
<b>Temperature</b> (°C)	$\bar{X} = 30.17$ se = 0.36 n = 30 cor B,H<F <sub>1</sub> <D	$\bar{X} = 29.33$ se = 0.87 n = 31 cor B,H<F <sub>2</sub> <D,I <sub>1</sub>	$\bar{X} = 27.00$ se = 0 n = 1 cor ns	$\bar{X} = 22.33$ se = 1.76 n = 4 cor H<D,E,F <sub>1</sub> ,F <sub>2</sub> ,I <sub>1</sub> ,I <sub>2</sub>	$\bar{X} = 32.83$ se = 0.99 n = 15 cor I <sub>1</sub> >B,C,E,F <sub>2</sub> ,H,I <sub>2</sub>	$\bar{X} = 28.41$ se = 0.76 n = 31 cor B,H<I <sub>2</sub> <D,I <sub>1</sub>
<b>Turbidity</b> (NTU)	$\bar{X} = 101.60$ se = 7.08 n = 30 cor A,C,D,F <sub>2</sub> <F <sub>1</sub> =E <B,G,H,I <sub>1</sub> ,I <sub>2</sub>	$\bar{X} = 28.06$ se = 3.15 n = 31 cor F <sub>2</sub> <B,D,E,F <sub>1</sub> ,G,H,I <sub>1</sub> ,I <sub>2</sub>	$\bar{X} = 288.00$ se = 0 n = 1 cor G>A,B,C,D,E,F <sub>1</sub> ,F <sub>2</sub> ,H	$\bar{X} = 183.00$ se = 9.60 n = 4 cor A,B,C,D,E,F <sub>1</sub> ,F <sub>2</sub> <H <G,I <sub>1</sub> ,I <sub>2</sub>	$\bar{X} = 265.80$ se = 8.64 n = 15 cor A,B,C,D,E,F <sub>1</sub> ,F <sub>2</sub> ,H <I <sub>1</sub> <I <sub>2</sub>	$\bar{X} = 314.16$ se = 10.20 n = 31 cor I <sub>1</sub> >A,B,C,D,E,F <sub>1</sub> ,F <sub>2</sub> , H,I <sub>2</sub>

It was found that from cluster analysis, only 4 from 29 species had a significant correlation with water physico-chemical properties. From Table 5, there was a significant correlation (P<0.05) between *Luticola goeppertiana* in most sampling sites in Group I<sub>2</sub> in wet season and low conductivity. The presence of *L. goeppertiana* thus seemed to indicate low conductivity.

There was also a significant correlation (P<0.05) of *Eolimna minima* in group H (a tributary in northern Thailand) in wet season with high SRP. Therefore, *E. minima* seemed to indicate a high concentration of SRP. In the same manner, *Mayamaea atomus* and *Ulnaria ulna* in Group C (a tributary in north-eastern Thailand) could be indicators of a high BOD.

## CONCLUSIONS

The number of benthic diatom species found (252 species from 53 genera) in Mekong River and its tributaries in north and north-eastern Thailand is similar to those reported for other river systems of comparable size. Determination of the relationship between diatom community composition and water quality variables shows that many species, notably *Achnantheidium minutissimum*, *A. convergens*, *Navicula menisculus*, *Nitzschia clausii*, *Luticola goeppertiana*, *Eolimna minima*, *Ulnaria ulna* and *Mayamaea atomus*, can act as indicators of some of the river-water qualities, viz. conductivity, alkalinity,  $\text{NH}_4^+$ -N,  $\text{NO}_3^-$ -N, soluble reactive phosphorus, and BOD.

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