Order Bacillariales (Continued 3)

Family Bacillariaceae

Nitzschia

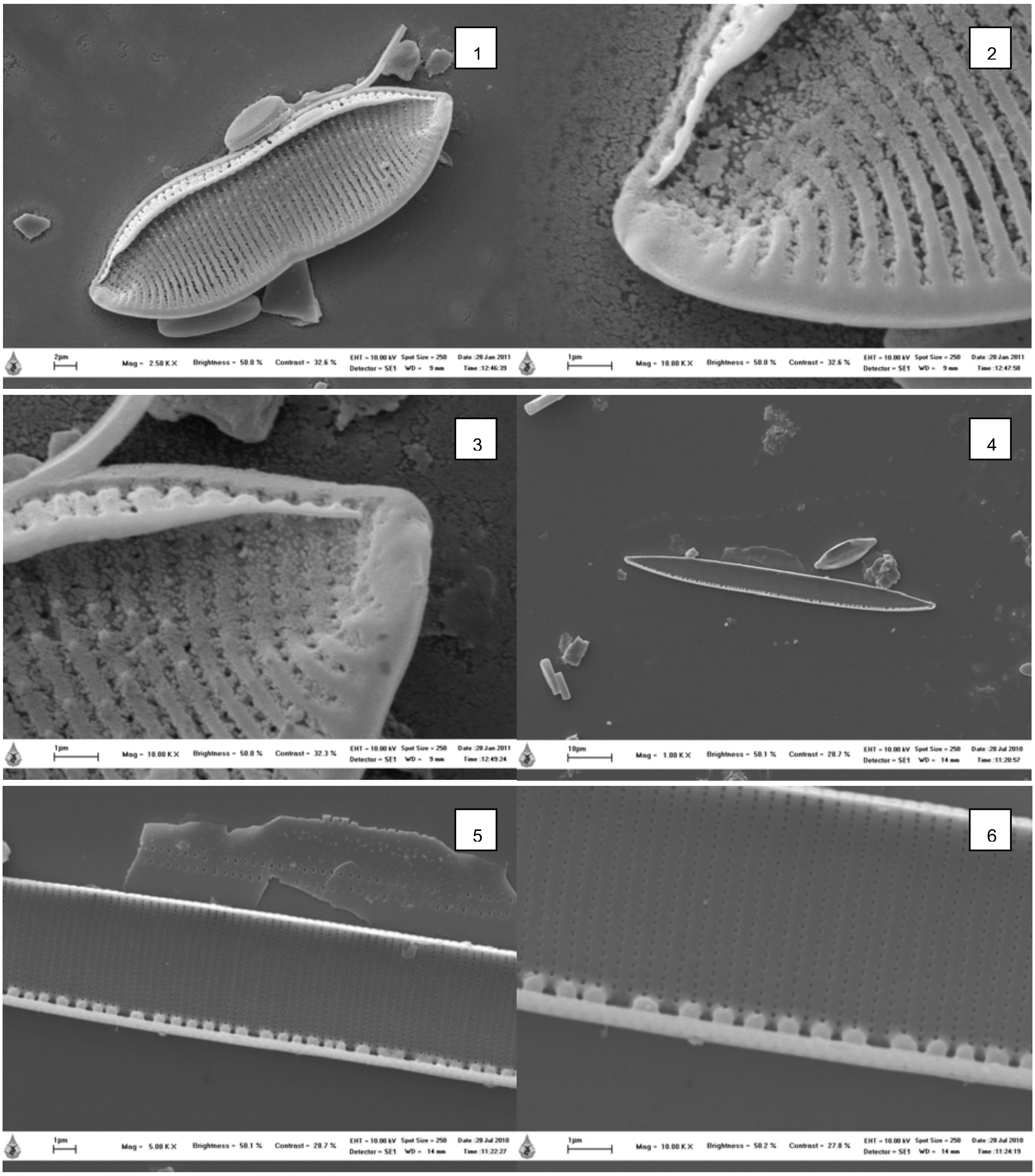

Figure 27. Scanning Electron Micrographs of benthic diatoms in Kok River.

1-3- *Nitzschia coarctata* Grunow in Cleve& Möller, 4-6- *Nitzschia palae* (Kützing) W.Smith

Order Bacillariales (Continued 4)

Family Bacillariaceae

Nitzschia

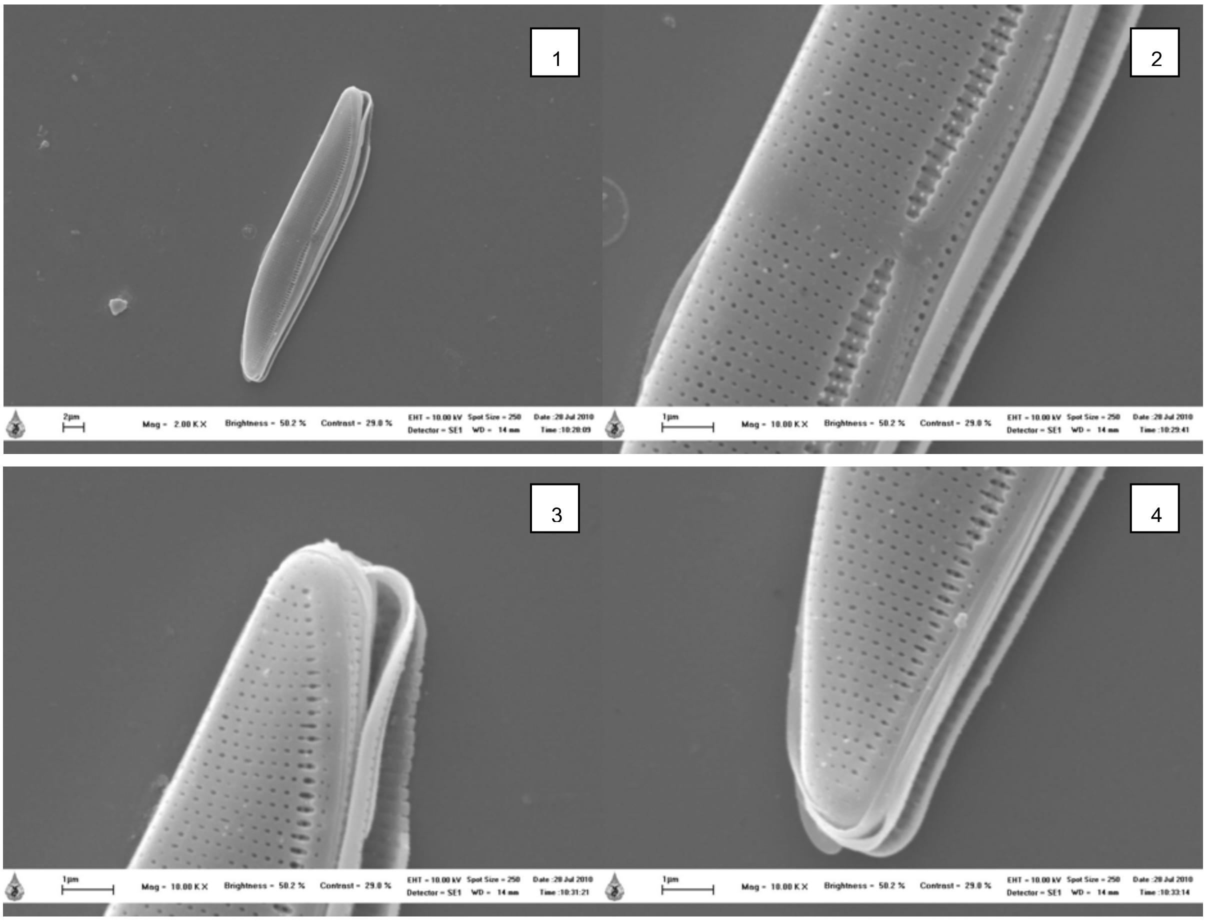

Figure 23. Scanning Electron Micrographs of benthic diatoms in Kok River.

1-4- *Nitzschia* sp.

Order Surirellales

Family Surirellaceae

Surirella

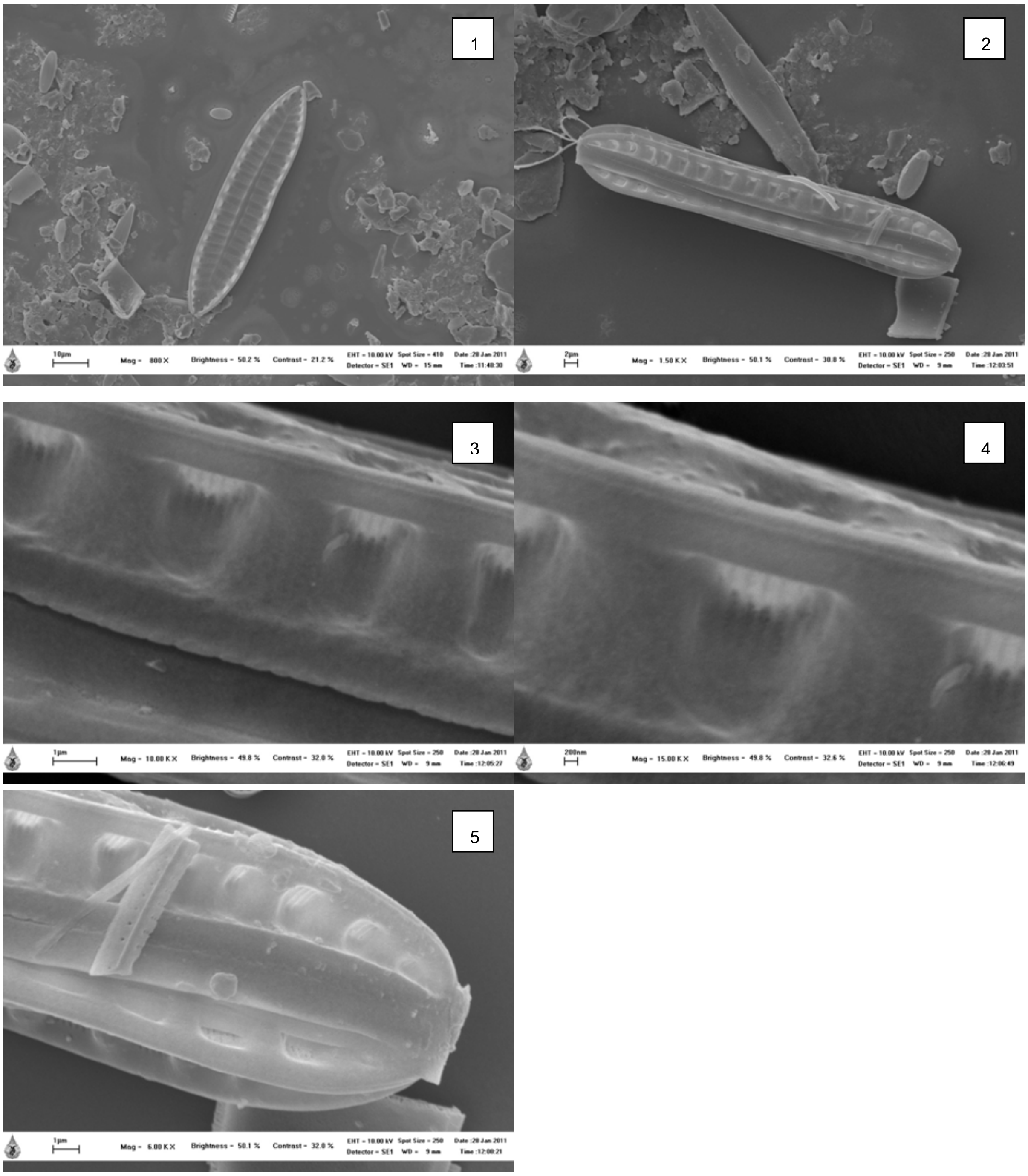

Figure 28. Scanning Electron Micrographs of benthic diatoms in Kok River.

1- *Surirella linearis* W. Smith (valve view), 2-5- *Surirella linearis* W. Smith (girdle view)

Order Surirellales (Continued 2)

Family Surirellaceae

Surirella

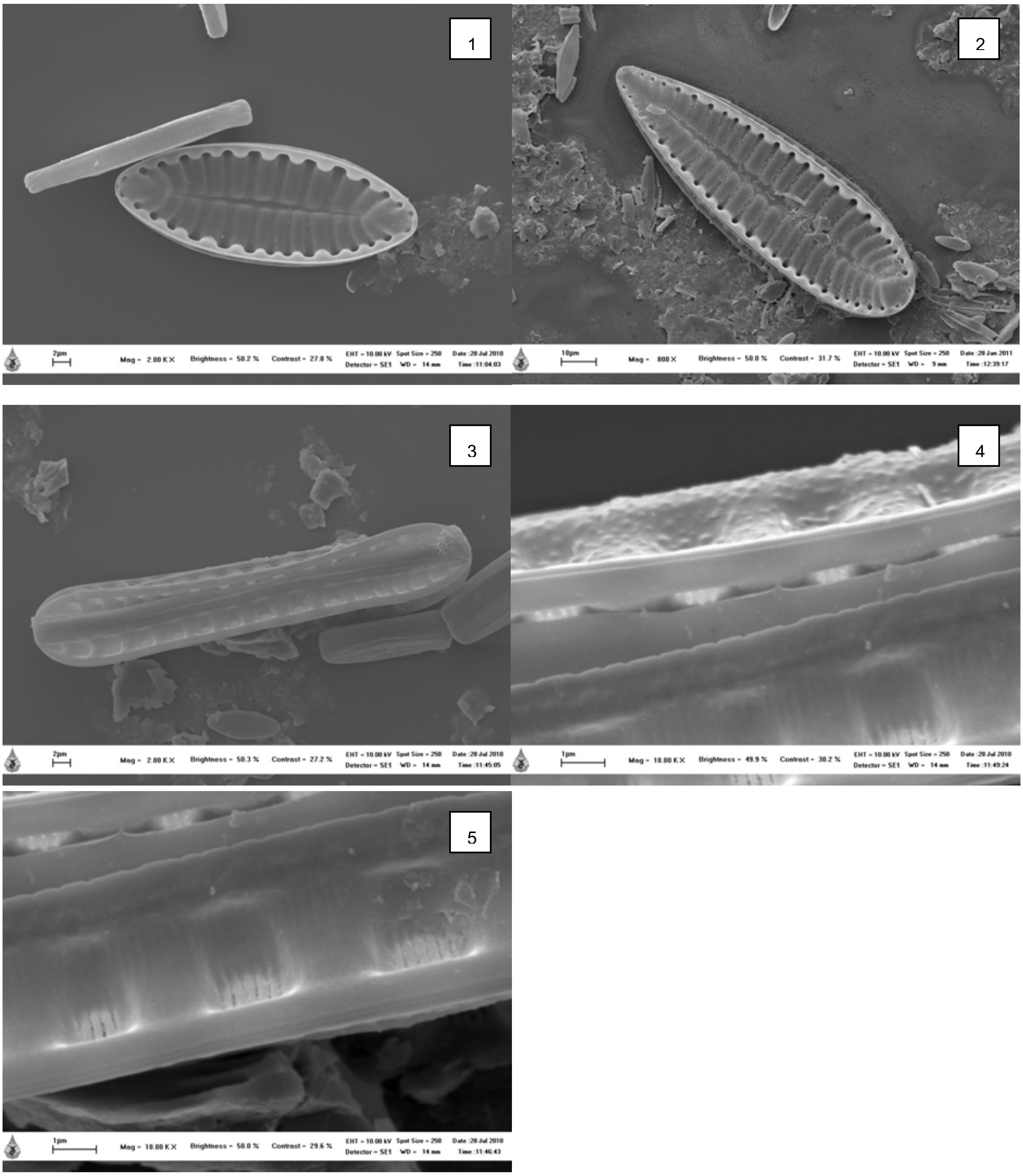

Figure 29. Scanning Electron Micrographs of benthic diatoms in Kok River.

1- *Surirella* sp., 2- *Surirella tenera* Gregory, 3-5- *Surirella linearis* W. Smith (girdle view)

Unknown

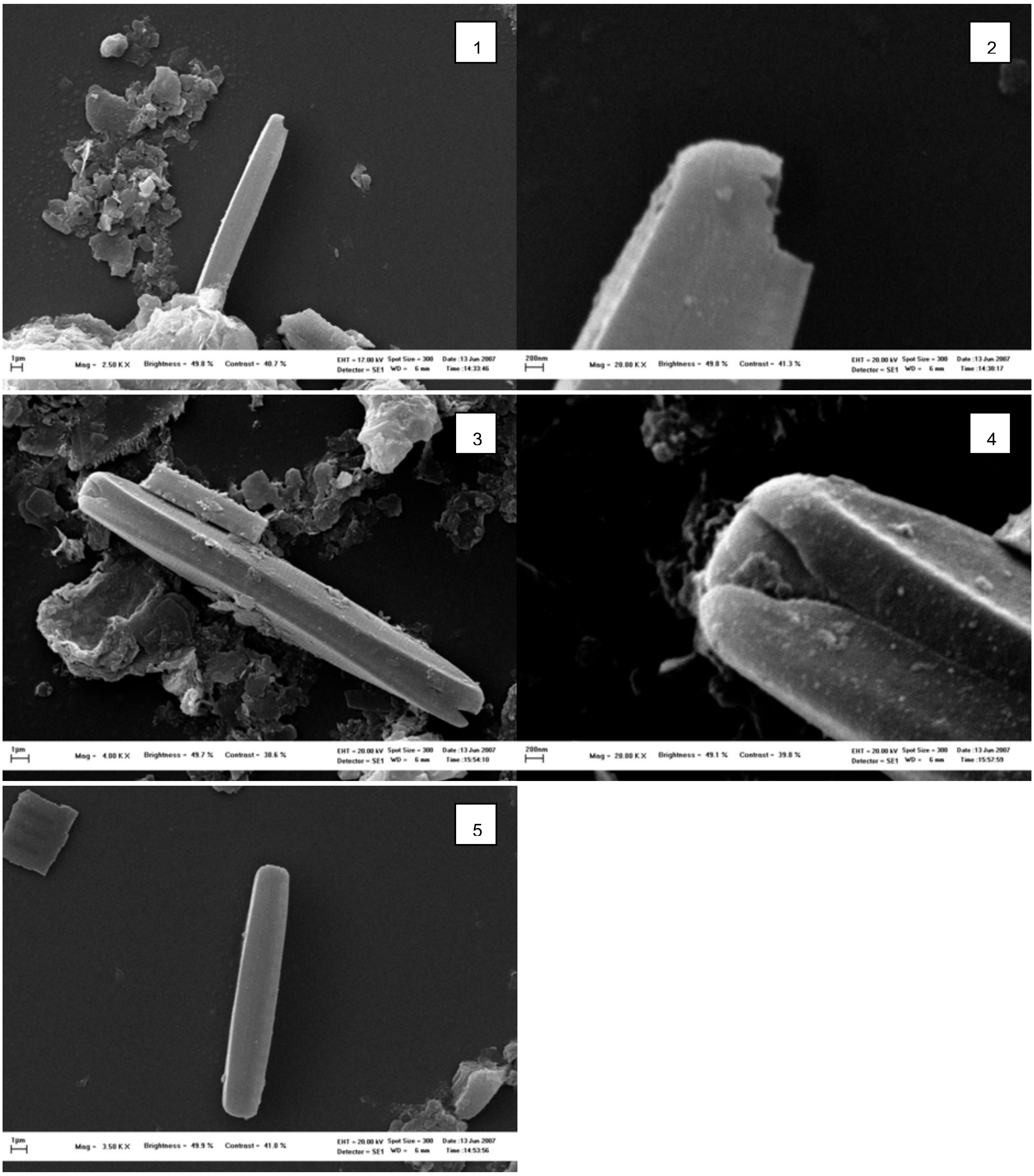

Figure 30. Scanning Electron Micrographs of benthic diatoms in Kok River.

1-2- Unknown1, 3-4- Unknown2, 5- Unknown3

Unknown (Continued 2)

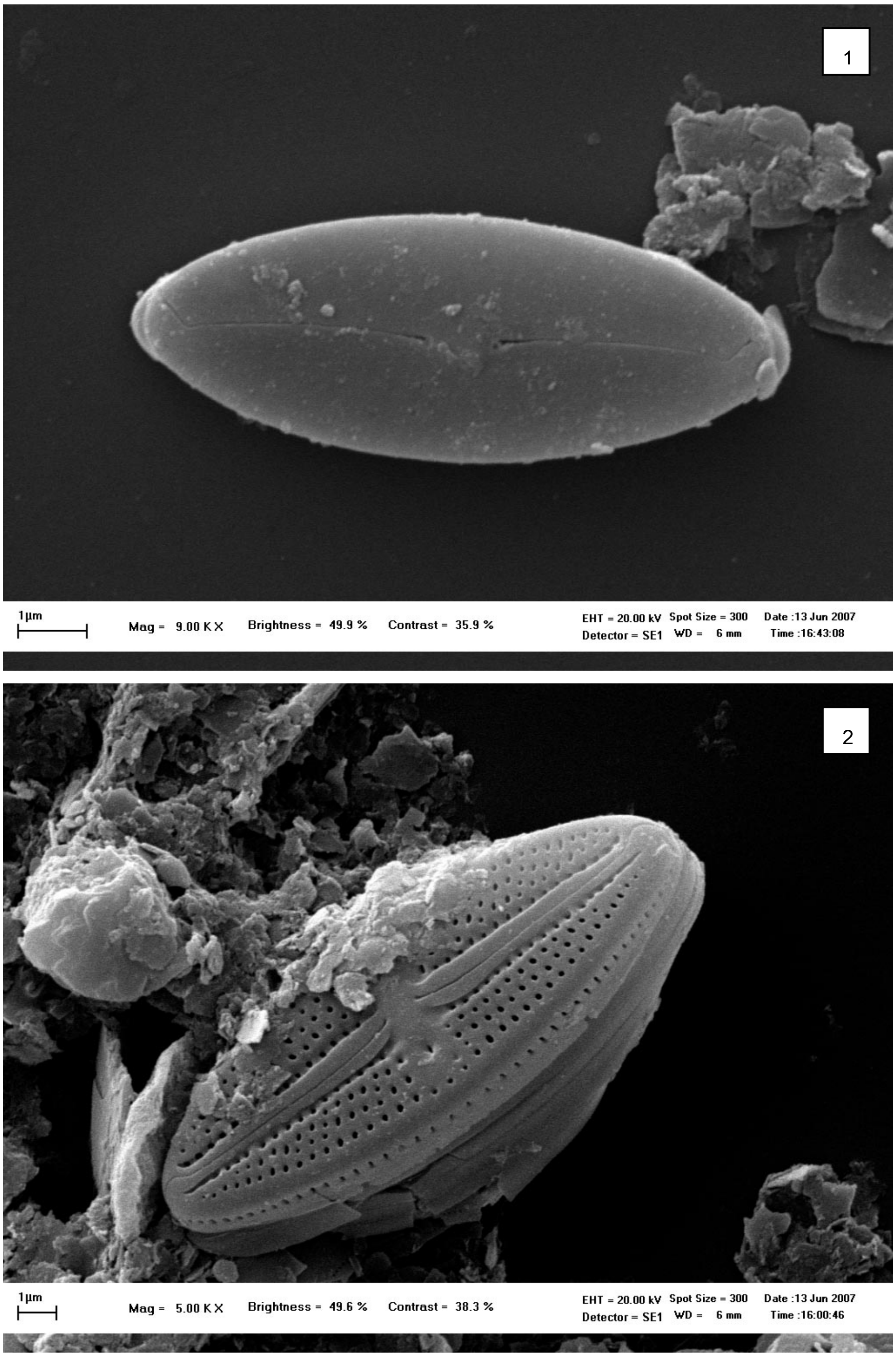

Figure 31. Scanning Electron Micrographs of benthic diatoms in Kok River.

1- Unknown4, 2- Unknown5

Physico-chemical properties of Kok River

The overall results of water qualities in Kok River during the research period were shown in figures of area plots and figures of distribution value in each sampling site (Figures 32 to 53). Raw data of the water quality is given in Table 4. The average data with standard deviation is given in Table 5 and the summarized of the trophic status of Kok River considered from alkalinity, conductivity, nitrate concentration and phosphate concentration in Table 6.

Water qualities in Kok River were classified into oligo-mesotrophic status in most months with the exceptions of months in dry season, which were in mesotrophic status. There were high turbid, concentrations of nitrate and phosphate in some months especially in rainy season.

Alkalinity

The alkalinity of water is its acid-neutralizing capacity. It is the sum of all the titratable bases. Alkalinity is significant in many uses and treatments of natural waters and wastewaters. Because the alkalinity of many surface waters is primarily a function of carbonate, bicarbonate and hydroxide content, it is taken as an indication of the concentration of these constituents. The measured values also may include contributions from borates, phosphates, silicates or other bases if these are present (APHA, AWWA and WEF, 1998).

The area plots of alkalinity are shown in Figure 32. Distribution of values in each sampling sites were shown in Figure 33. Alkalinities in Kok River range between 41.0 and 96.0 mg/l which indicate low impact of effluents. In natural the alkalinity range between 50-100 mg/l and frequently less than 100 mg/l in clean water resources. The averages of alkalinity taken at all sampling sites are non-significantly different.

Alkalinity in excess of alkaline earth metal concentrations is significant in determining the suitability of water for irrigation. Alkalinity measurements are used in the interpretation and control of water and wastewater treatment processes. Raw domestic wastewater has an alkalinity less than, or only slightly greater than that of the water supply. Alkalinity in Kok River is usual for natural resource waters (APHA, AWWA and WEF, 1998).

Table 4. Water qualities of Kok River.

		Alkalinity (mg/l)	Turbidity (FTU)	DO (mg/l)	BOD_5 (mg/l)	Conductivity (µS/cm)	Temperature (°C)	pH	TDS (mg/l)	NO_3^--N (mg/l)	NH_4^+-N (mg/l)	PO_4^{3-}-P (mg/l)	Silica (mg/l)
Site 1	Month1	-	-	5.7	-	115.0	26.6	7.3	108.0	0.1	-	0.7	15.8
	Month2	51	90	9.1	2.7	123.7	20.6	7.5	117.0	3.1	0.4	0.4	18.3
	Month3	72	84	8.1	-	124.1	18.1	7.4	117.0	0.3	0.4	0.2	12.2
	Month4	68	46	9.7	-	122.1	21.5	7.5	114.7	0.3	0.2	0.4	22.3
	Month5	64	111	8.2	-	114.4	24.5	7.0	108.0	4.3	0.5	0.3	18.1
	Month6	80	48	7.3	-	123.3	22.6	7.5	116.7	2.4	0.2	0.2	18.4
	Month7	64	175	11.6	4.3	114.0	25.7	7.8	107.0	5.3	0.7	0.4	20.7
	Month8	51	154	6.7	0.3	108.5	28.5	7.7	102.0	2.4	0.9	0.3	38.9
	Month9	54	115	6.2	-	108.8	29.5	6.7	103.7	1.5	0.4	0.4	22.3
	Month10	49	2091	6.2	-	92.2	26.1	8.6	86.8	ND	1.3	0.2	64.2
	Month11	52	360	7.4	-	87.1	25.3	8.5	25.2	1.1	OV	0.1	13.1
	Month12	52	118	7.3	-	95.9	25.1	7.7	90.4	0.1	0.6	0.3	15.8
Site2	Month1	-	-	7.5	-	116.5	27.4	7.2	110.7	0.8	-	0.5	13.9
	Month2	63	98	8.5	2.1	130.5	22.8	7.3	123.0	3.7	0.5	0.4	17.9
	Month3	81	91	7.7	-	131.4	19.1	7.5	124.0	0.8	0.3	1.9	18.0
	Month4	64	66	8.8	-	126.8	22.4	7.3	116.7	ND	0.3	0.5	20.1
	Month5	76	115	7.8	-	121.6	25.8	6.9	115.0	4.1	0.5	0.5	15.0
	Month6	76	52	8.1	-	127.0	25.7	7.9	120.7	2.9	0.1	0.3	19.4
	Month7	64	192	11.4	3.7	112.8	25.9	7.7	106.0	5.0	0.7	0.4	18.0

	Month8	51	164	6.6	0	113.2	28.3	8.0	106.7	1.7	0.8	0.3	34.8
	Month9	58	112	6.0	-	134.1	31.3	7.0	128.0	1.2	0.5	1.4	19.2
	Month10	46	2014	6.3	-	91.7	27.0	8.5	86.4	ND	2.0	0.1	77.0
	Month11	60	296	7.2	-	91.5	26.2	8.7	86.2	1.0	0.4	0.2	15.3
	Month12	56	159	4.7	-	101.1	25.5	7.5	95.7	0.5	0.3	0.2	15.0
Site3	Month1	-	-	6.8	-	117.9	27.7	7.3	111.3	1.0	-	0.7	14.3
	Month2	47	87	8.1	1.7	126.4	22.4	7.1	116.7	4.9	0.4	0.4	17.0
	Month3	72	82	8.0	0.7	126.7	19.0	7.4	120.0	0.5	0.4	0.2	18.8
	Month4	84	58	9.1	-	122.8	23.0	7.5	116.3	0.4	0.3	0.4	18.2
	Month5	80	121	7.7	-	119.9	26.4	6.8	113.0	3.8	0.4	0.6	15.0
	Month6	84	67	6.4	-	125.4	24.5	7.9	119.0	3.0	0.3	0.3	20.2
	Month7	60	221	8.1	3.1	111.3	25.8	7.8	104.0	5.1	0.7	0.4	19.1
	Month8	53	243	7.0	-	108.4	30.3	7.7	102.3	1.5	0.9	0.4	39.9
	Month9	53	128	6.4	-	111.9	32.0	7.3	104.0	1.9	0.7	0.3	25.7
	Month10	48	1620	9.1	-	91.7	27.7	8.7	86.1	3.3	1.6	0.4	100.7
	Month11	54	308	9.3	-	88.9	26.3	8.3	84.1	OV	0.4	0.3	20.2
	Month12	56	145	7.3	-	97.5	25.6	7.5	91.7	1.6	0.5	0.3	35.3
Site4	Month1	-	-	6.9	-	103.4	27.7	7.3	97.3	2.2	-	0.5	11.6
	Month2	46	101	7.8	1.4	124.1	23.8	7.3	117.0	4.9	1.6	0.4	19.4
	Month3	72	106	7.8	-	125.3	20.0	7.4	118.0	0.6	0.5	0.2	18.0
	Month4	84	130	8.3	-	125.4	23.4	7.5	119.0	ND	0.8	0.4	19.2
	Month5	72	94	7.5	-	121.1	27.4	7.2	115.0	3.5	0.5	0.4	17.0

	Month6	88	159	6.7	-	124.7	27.4	8.0	118.0	4.6	0.7	0.6	17.4
	Month7	68	112	7.2	2.6	119.9	26.3	7.7	113.0	5.5	1.4	0.4	20.8
	Month8	46	158	6.1	0.4	111.6	30.1	7.8	104.3	1.8	0.9	0.3	31.4
	Month9	62	143	5.8	-	118.4	32.2	7.4	111.3	0.7	0.8	0.3	31.9
	Month10	41	1939	5.7	-	120.7	27.7	8.4	113.7	ND	2.7	1.1	OV
	Month11	52	519	6.9	-	84.6	26.3	8.9	79.9	OV	0.9	0.3	19.1
	Month12	50	185	7.3	-	93.6	26.2	7.3	88.0	0.5	0.6	0.3	15.0
Site5	Month1	-	-	6.1	-	99.5	28.4	7.0	93.6	ND	-	0.6	12.8
	Month2	51	108	7.7	1.3	124.9	23.2	7.6	115.3	4.8	1.2	0.4	16.8
	Month3	68	90	7.9	-	130.0	19.6	7.5	123.0	0.4	0.5	0.2	19.4
	Month4	68	126	7.9	-	126.1	23.2	7.6	119.0	ND	0.8	0.4	20.8
	Month5	96	65	6.4	-	126.3	27.6	7.3	119.0	4.3	0.4	0.3	18.1
	Month6	84	68	5.8	-	123.4	27.4	8.0	117.3	3.9	0.4	0.2	15.1
	Month7	72	116	7.3	2.5	117.2	26.3	7.7	110.0	5.0	0.6	0.4	17.9
	Month8	48	194	6.3	1.1	115.1	30.7	7.9	109.3	1.4	1.0	0.3	32.9
	Month9	56	240	6.2	-	107.0	31.5	7.4	100.7	0.2	1.6	0.2	50.6
	Month10	47	399	5.0	-	87.1	28.3	8.3	82.2	1.2	1.2	0.2	36.0
	Month11	52	375	6.6	-	83.8	27.5	8.6	78.8	0.1	0.6	0.3	22.3
	Month12	50	197	6.7	-	92.9	26.4	7.3	87.2	0.1	0.6	0.2	14.8

PS. ND = Non Detected

OV = Over Range

Table 5. Average value of water quality in five sampling sites of Kok River.

(min = minimum value, max = maximum value, Mean = average value, n = number of samples)

	Site 1	Site 2	Site 3	Site 4	Site 5
	Mean ±SD (min-max, n)	**Mean ±SD (min-max, n)**	**Mean ±SD (min-max, n)**	**Mean ±SD (min-max, n)**	**Mean ±SD (min-max, n)**
Alkalinity (mg/l)	59.7±10.5 (49.0-80.0, 36)	63.2±10.9 (46.0-81.3, 36)	62.8±14.4 (46.7-84.0, 36)	61.9±16.1 (41.0-88.0, 36)	62.9±16.2 (47.0-96.0, 36)
Turbidity (FTU)	308±597 (46-2091, 36)	305±571 (52-2014, 36)	280±452 (58-1620, 36)	331±546 (94-1939, 36)	180±117 (65-399, 36)
DO (mg/l)	7.8±1.7 (5.7-11.6, 36)	7.5±1.7 (4.7-11.4, 36)	7.8±1.0 (6.4-9.3, 36)	7.0±0.8 (5.7-8.3, 36)	6.7±0.9 (5.0-7.9, 36)
Conductivity (µS/cm)	110.8±12.8 (87.1-124.1, 36)	116.5±15.0 (91.5-134.1, 36)	112.4±13.4 (88.9-126.7, 36)	114.4±13.6 (84.6-125.4, 36)	111.1±16.6 (83.8-130.0, 36)
Temperature ($^{\circ}C$)	24.5±3.3 (18.1-29.5, 36)	25.6±3.1 (19.1-31.3, 36)	25.9±3.5 (19.0-32.0, 36)	26.5±3.2 (20.0-32.2, 36)	26.7±3.3 (19.6-31.5, 36)
pH	7.6±0.5 (6.7-8.6, 36)	7.6±0.6 (6.9-8.7, 36)	7.6±0.5 (6.8-8.7, 36)	7.7±0.5 (7.2-8.9, 36)	7.7±0.5 (7.0-8.6, 36)
TDS (mg/l)	99.7±25.5 (25.2-117.0, 36)	109.9±14.2 (86.2-128.0, 36)	105.7±12.7 (84.1-120.0, 36)	107.9±12.9 (79.9-119.0, 36)	104.6±15.6 (78.8-123.0, 36)
NO_3^{-}N (mg/l)	1.7±1.8 (0.0-5.3, 12)	1.8±1.7 (0.0-5.0, 12)	3.1±2.7 (0.4-10.0, 12)	2.9±3.0 (0.0-10.0, 12)	1.8±2.1 (0.0-5.0, 12)
NH_4^{+}-N (mg/l)	1.4±2.9 (0.2-10.0, 12)	0.6±0.5 (0.1-2.0, 12)	0.6±0.4 (0.3-1.6, 12)	1.0±0.7 (0.5-2.7, 12)	0.8±0.4 (0.4-1.6, 12)
PO_4^{3-}P (mg/l)	0.30±0.14 (0.14-0.67, 12)	0.54±0.54 (0.12-1.91, 12)	0.38±0.14 (0.20-0.70, 12)	0.41±0.23 (0.22-1.07, 12)	0.31±0.14 (0.15-0.64, 12)
Silica (mg/l)	23.3±14.6 (12.2-64.2, 12)	23.6±17.7 (13.9-77.0, 12)	28.7±24.0 (14.3-100.7, 12)	26.7±23.8 (11.6-100.0, 12)	23.1±11.2 (12.8-50.6, 12)

Table 6. Trophic status of Kok River considered from alkalinity, conductivity, nitrate concentration and phosphate concentration.

Parameters/ Sampling sites	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**Site 5**
Alkalinity (mg/l)	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic	Oligo-mesotrophic
Conductivity (µS/cm)	Mesotrophic	Mesotrophic	Mesotrophic	Mesotrophic	Mesotrophic
NO_3^{-}N (mg/l)	Meso-eutrophic	Meso-eutrophic	Meso-eutrophic	Meso-eutrophic	Meso-eutrophic
PO_4^{3-}P (mg/l)	Meso-eutrophic	Meso-eutrophic	Meso-eutrophic	Meso-eutrophic	Meso-eutrophic
Trophic status	**Oligo-mesotrophic**	**Oligo-mesotrophic**	**Oligo-mesotrophic**	**Oligo-mesotrophic**	**Oligo-mesotrophic**

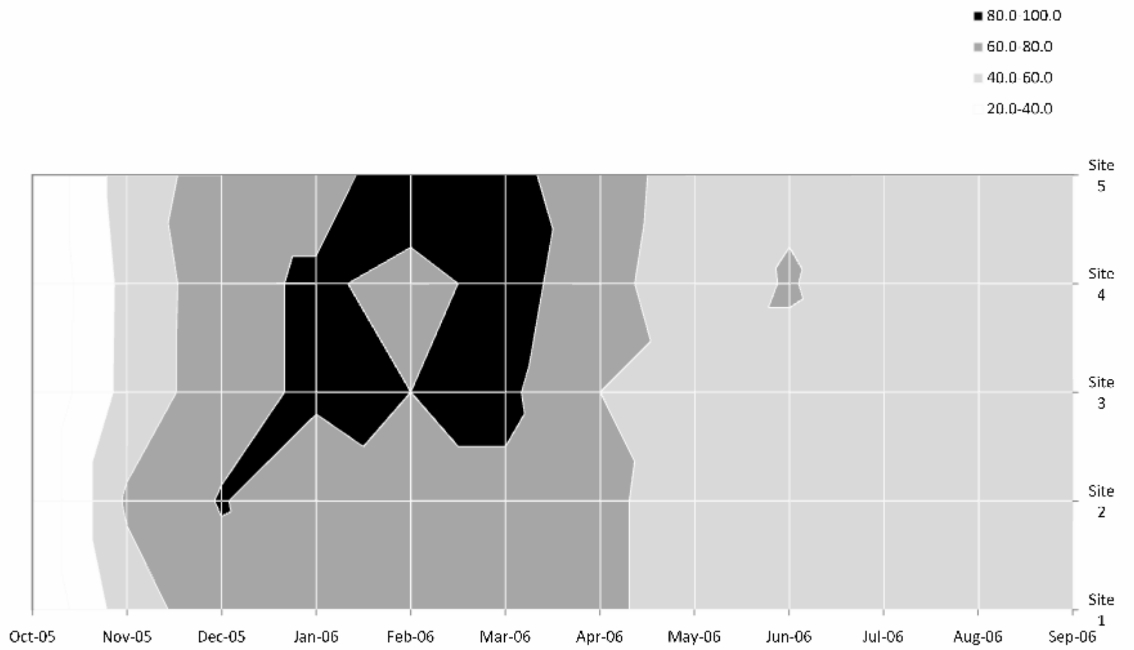

Figure 32. Area plots of alkalinity (mg/l) in Kok River.

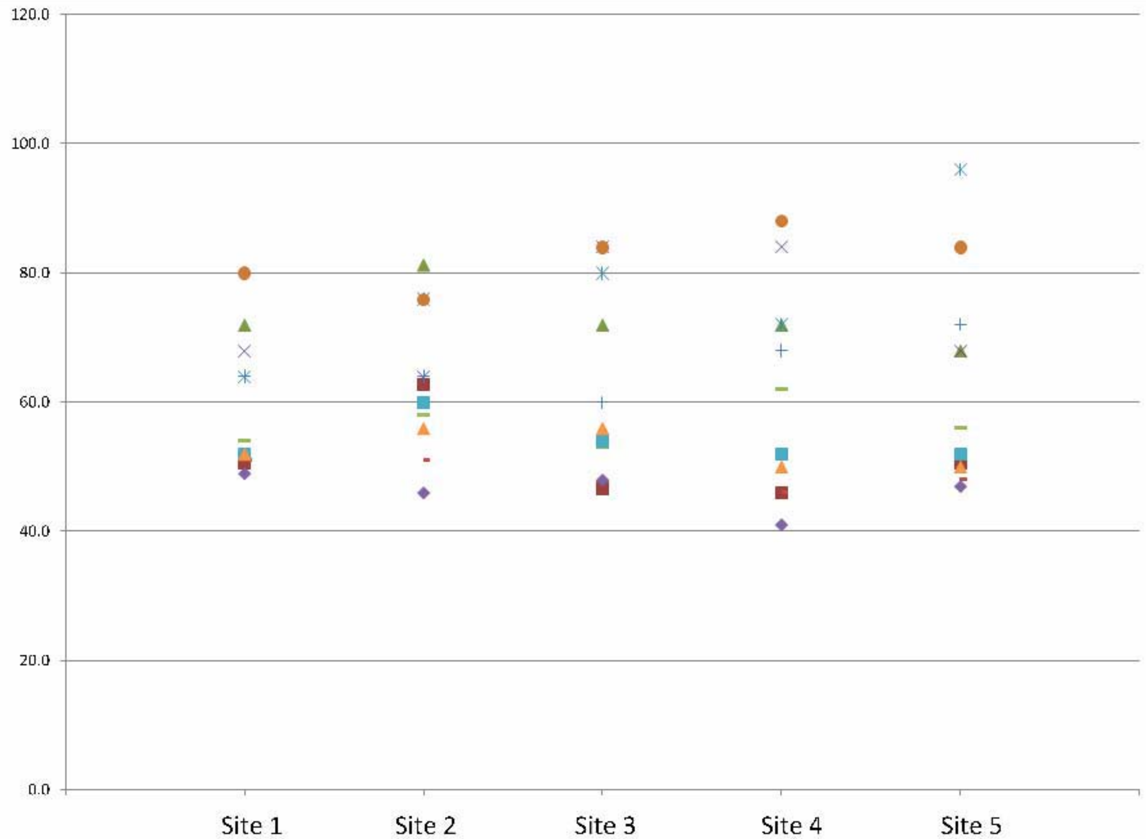

Figure 33. Distribution value of alkalinity (mg/l) in Kok River.

Turbidity

One of the more important density-independent factors affecting diatom growth is turbidity. It may have the effect of clogging up habitats and homogenizing sediments, and thus reducing the diversity of current patterns for various species of diatoms, or it may cut down light penetration. The type of suspended solids may make a great deal of difference in the amount of light which penetrates.

The area plots of turbidity are shown in Figure 34. Distribution values of all sampling sites are shown in Figure 35. Turbidity in Kok River was diverse and range between 46 FAU and 2,191 FAU. There was a report of turbidity less than 10 FAU in some clean and clear head water stream. Kok River was not clear tributary. By average the turbidity of all sampling sites had no significant difference through the sampling period although there is maximum turbidity value in every sampling site on July 2006 (~2,000 FAU) which caused from the rain.

Dissolved Oxygen (DO)

Oxygen is required for respiration, as is a characteristic of most forms of aquatic life. It is produced by the process of photosynthesis. Light and temperature as well as the nutrient levels of the water and other environmental conditions seem to be important in determining the rates of photosynthesis and therefore oxygen production. By average the DO of all sites had no significant difference throughout the sampling period (around 7 mg/l).

DO at Kok River ranges between 4.7 mg/l and 11.6 mg/l which is a standard value for natural streams (which range between 5.0 mg/l and 9.0 mg/l and may be more than 9.0 mg/l in fast flowing streams). Sampling site number 1 and 3 seem to have a high value of average DO (~7.8 mg/l) which also has a high average velocity. The area plots of DO were shown in Figure 36. Distribution values of all sampling sites are shown in Figure 37. By average the DO of all sites had no significant difference throughout the sampling period.

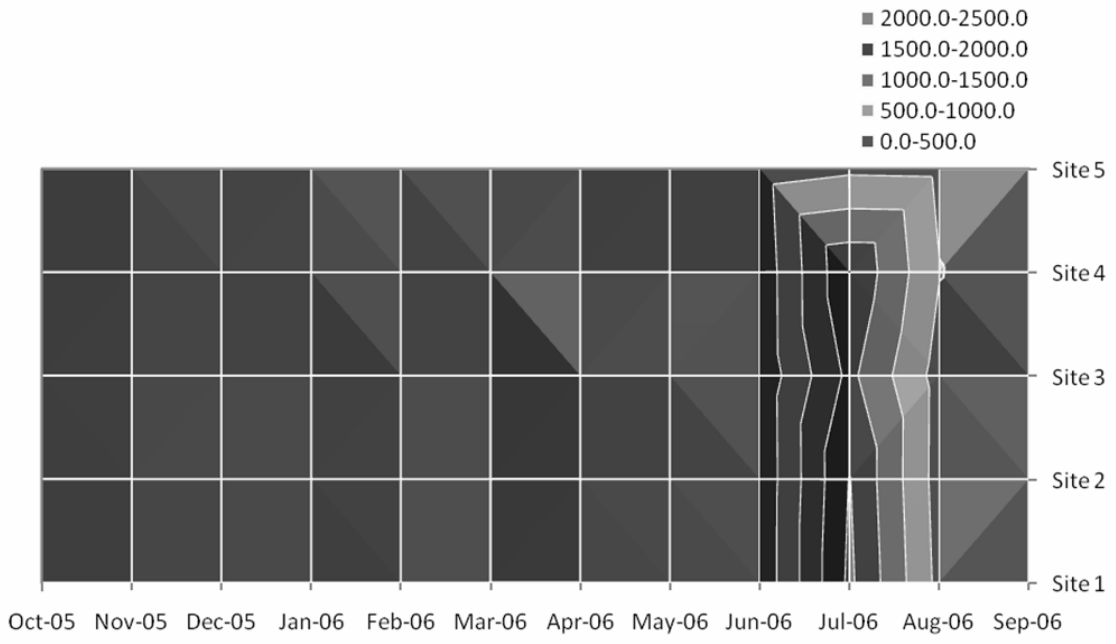

Figure 34. Area plots of turbidity (FAU) in Kok River.

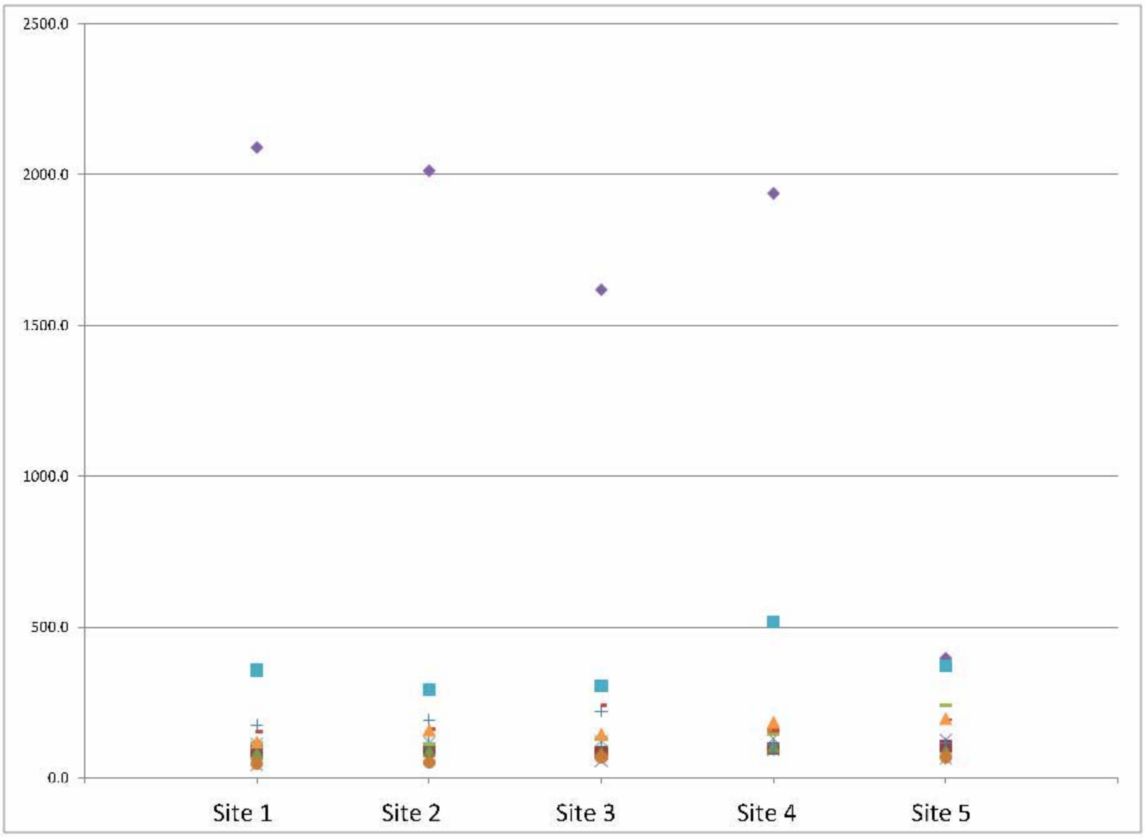

Figure 35. Distribution of turbidity (FAU) in Kok River.

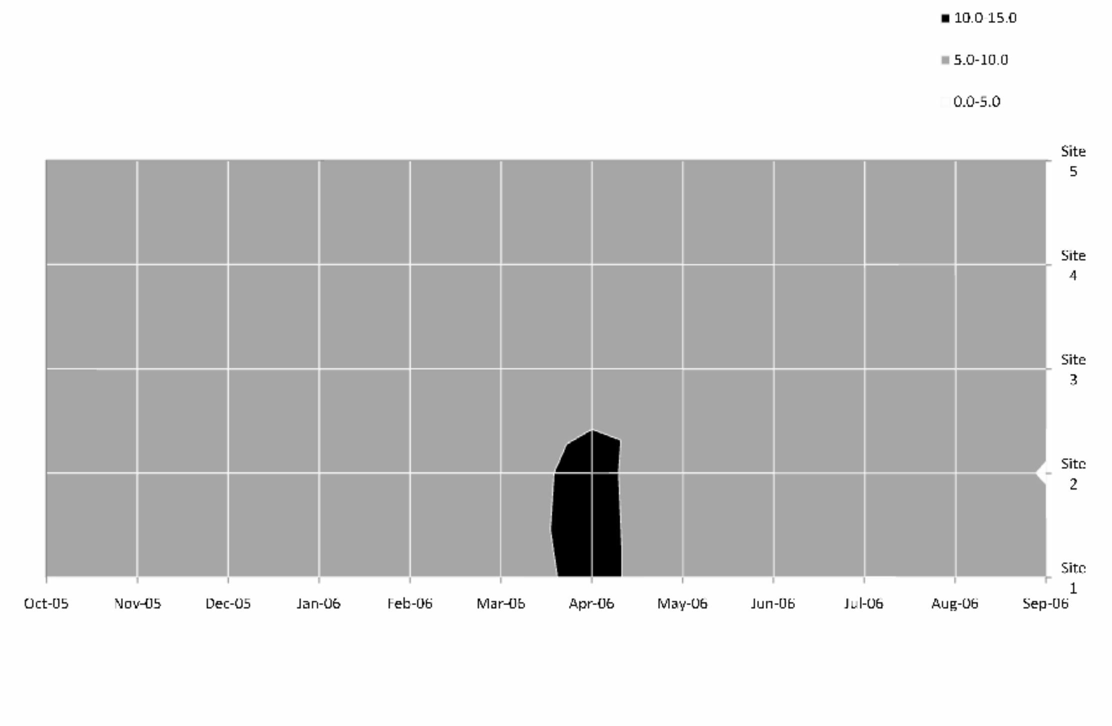

Figure 36. Area plots of DO (mg/l) in Kok River.

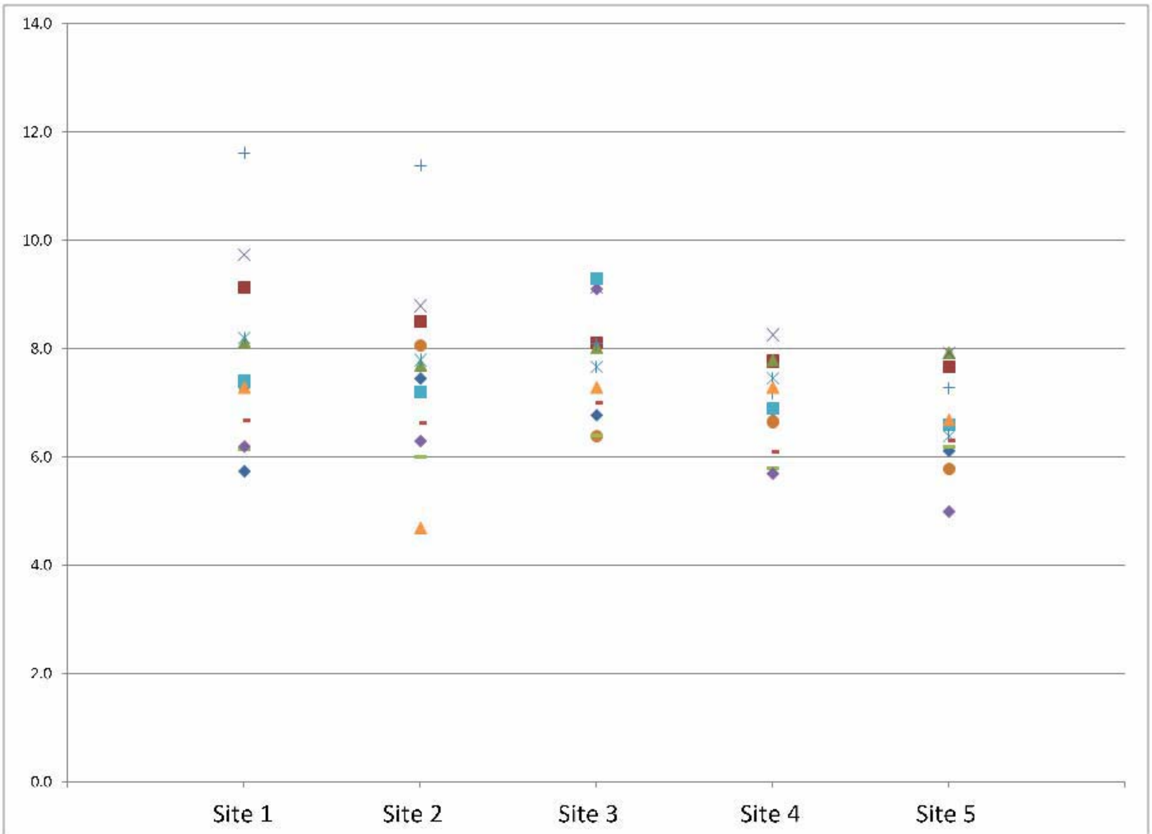

Figure 37. Distribution of DO (mg/l) in Kok River.

Conductivity

Conductivity is the measure of the ability of an aqueous solution to carry an electric current. This ability depends on the presence of ions; on their total concentration, mobility and valence; and on the measurement of temperature. Solutions of most inorganic compounds are relatively good conductors. Conversely, molecules of organic compounds that do not dissociate in aqueous solution conduct a current very poorly, if at all (APHA, AWWA and WEF, 1998).

Conductivity levels at Kok River were ranged between 83.8 μS/cm and 134.1 μS/cm. As seen in the Figures 38 and 39. By average the conductivity of all sampling sites had no significant difference through the sampling period and slightly lower in last 3 months of the study caused from the dilution from the rain.

Conductivity is one of the water quality parameters used to assess the status of the stream. Kelly has suggested that the range for oligo-mesotrophic status range between 50-100 μS/cm and 100-250 μS/cm for mesotrophic status. Conductivity values of some months of the study were determined as oligo-mesotrophic status (July-September 2006). Conductivity values of some months of the study were determined as mesotrophic status (except July-September 2006). (Kelly, 2000).

Water Temperature

Water temperature at the sampling sites ranges between 18.1 ^{o}C and 32.2 ^{o}C. Seasonal changing was presented in Figures 40 and 41. November to January 2005 was shown quite low water temperatures in all sampling sites caused from the cold season in Thailand. In other hand, May and June in 2006 which presented quite high average water temperatures from dry season.

Temperature effects on diatom growth may be both direct and indirect. To many temperate zone species the reduction in temperature seems to be the most profound density-independent environmental effect in the production of biomass. It is well known that certain species have a narrow temperature range and others are able to withstand rather broad temperature ranges.

General diatom diversity seemed to increase as one approached the optimum range of temperature within the range of tolerance for most of the species of a community. When the temperature regime moved away from the optimum either by becoming colder or hotter the diversity was decreased and the biomass was also affected (Patrick, 1977).

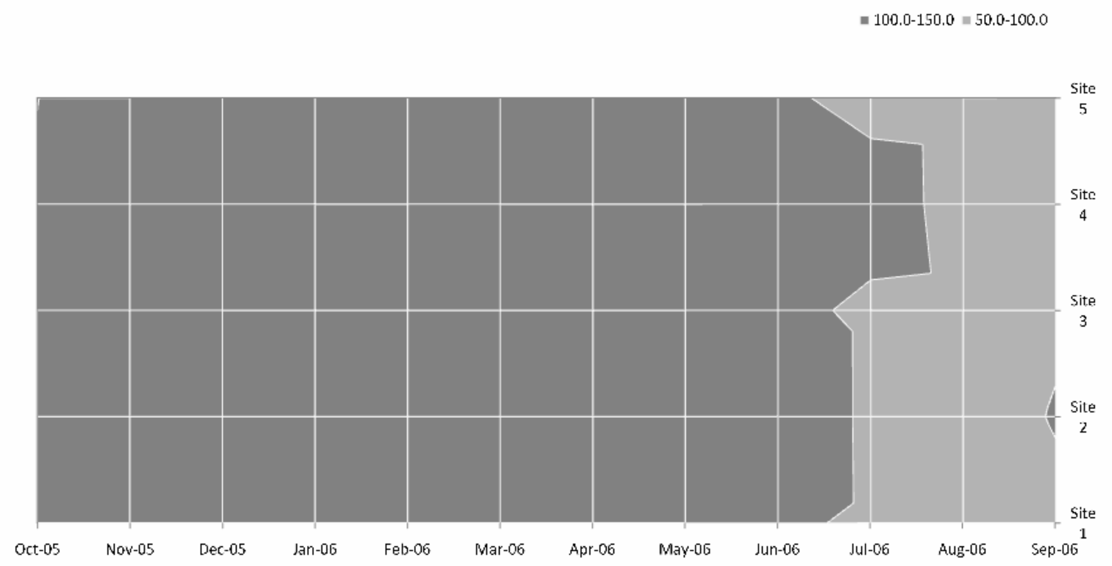

Figure 38. Area plots of Conductivity (µS/cm) in Kok River.

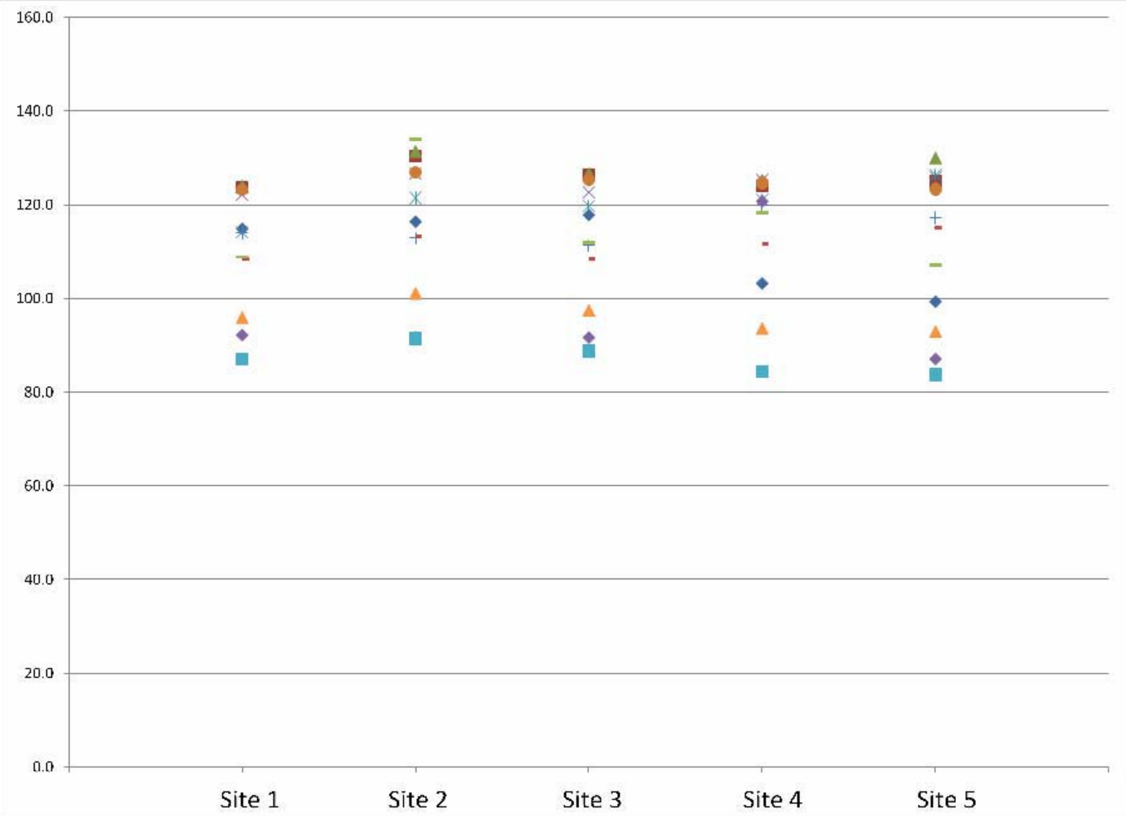

Figure 39. Distribution of Conductivity (µS/cm) in Kok River.

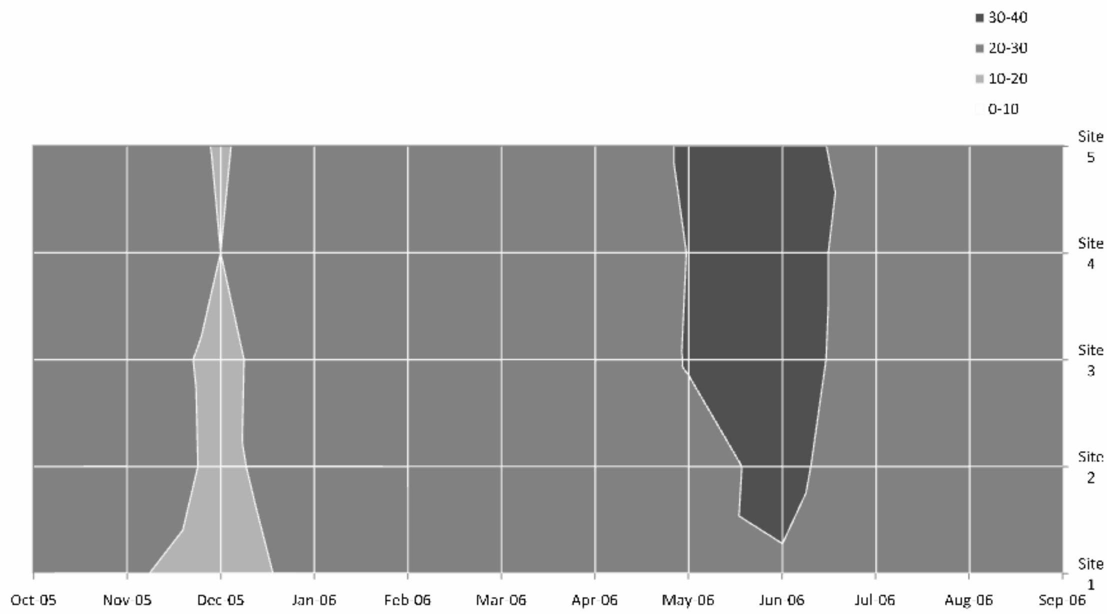

Figure 40. Area plots of water temperature (°C) in Kok River.

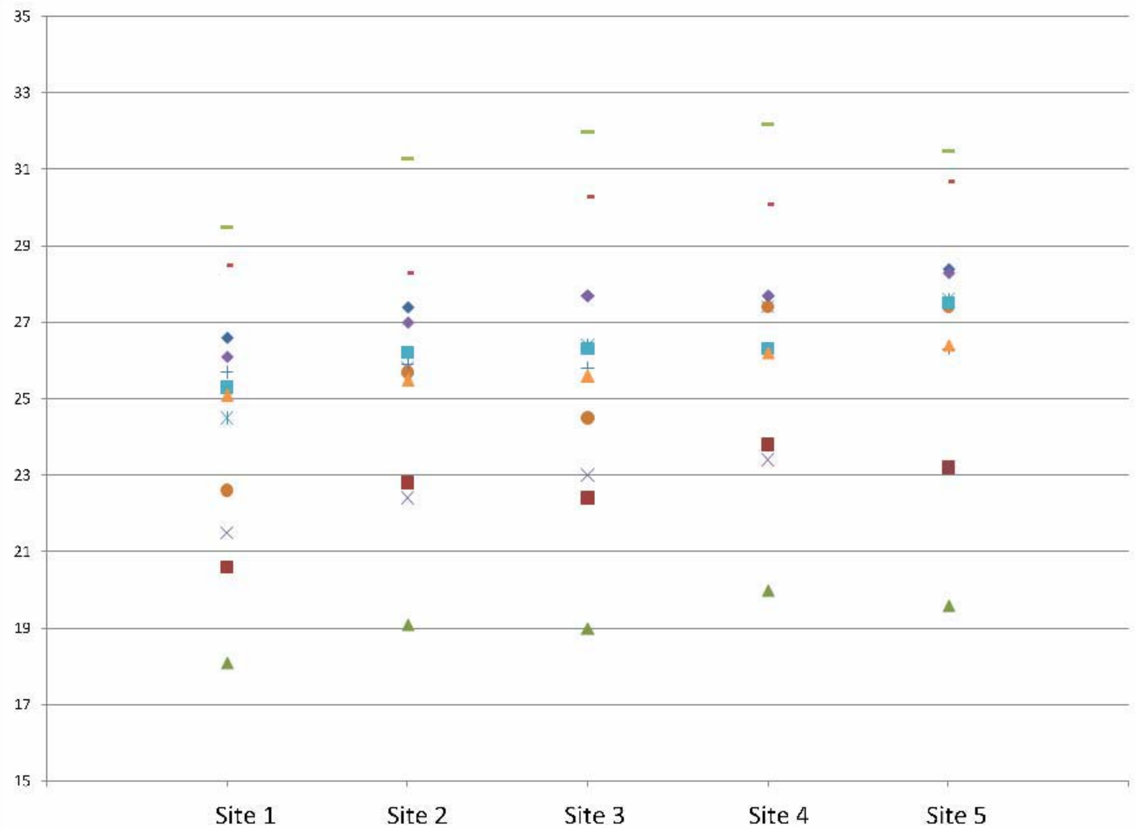

Figure 41. Distribution of water temperature (°C) in Kok River.

pH

In considering the effects of pH or the hydrogen ion concentration on diatom communities, one should think not only of its direct effect upon the organisms but what is even more important is its indirect effect on the solubility of various substances. It is well known that very acid lakes or streams often support smaller numbers of species than circumneutral ones. One of the most important effects of pH is its effect upon the carbonate-bicarbonate buffering system.

Over evolutionary time most species of diatoms have evolved to live within the range of pH in which this system is operative. At pH levels above and below the carbonate-bicarbonate buffering system the numbers of species are relatively few (Patrick, 1977).

The pH at Kok River ranges between 6.7 and 8.9. By average all sampling site present slightly alkaline throughout the sampling period and present high alkaline in July to September 2006. The high concentration of organic waste which contains Nitrate and Ammonium nitrogen causes the high values of pH in this period of time.

The area plots of pH are shown in Figure 42. Distribution values of all sampling sites are shown in Figure 43.

Hustedt (1956 cited by Patrick, 1977) has classified the diatoms as alkalibionte forms, those that prefer pH levels above 7; as alkaliphile forms, those that prefer a pH level around 7; as indifferent forms, those that live in a fairly wide range of pH levels above and below 7; as acidophile forms, those that prefer a pH level below 7; and acidobionte forms those that prefer a pH level of 5 or lower.

Kok River maintains the pH level above 7 which indicate polluted; the alkaliphile species are listed as follows: *Nitzschia palea* Kützing, *Achnanthes lanceolata* (Brébisson) Grunow, *Gomphonema parvulum* Kützing, *Melosira varians* Agardh, *Gyrosigma scalproides* (Rabenhorst) Cleve and *Bacillaria paradoxa* Gmelin.

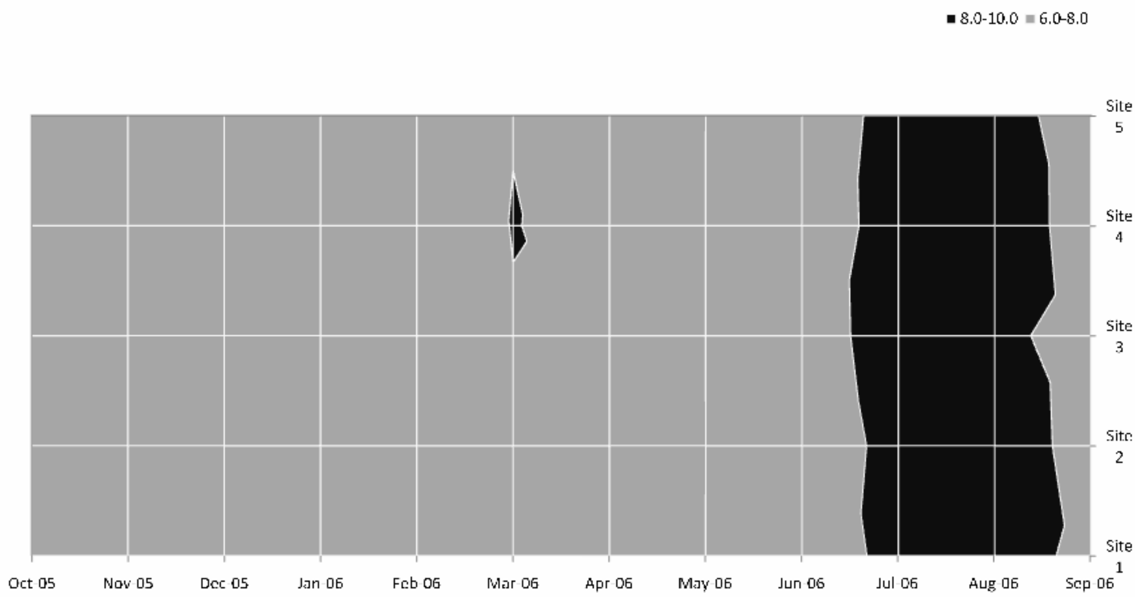

Figure 42. Area plots of pH in Kok River.

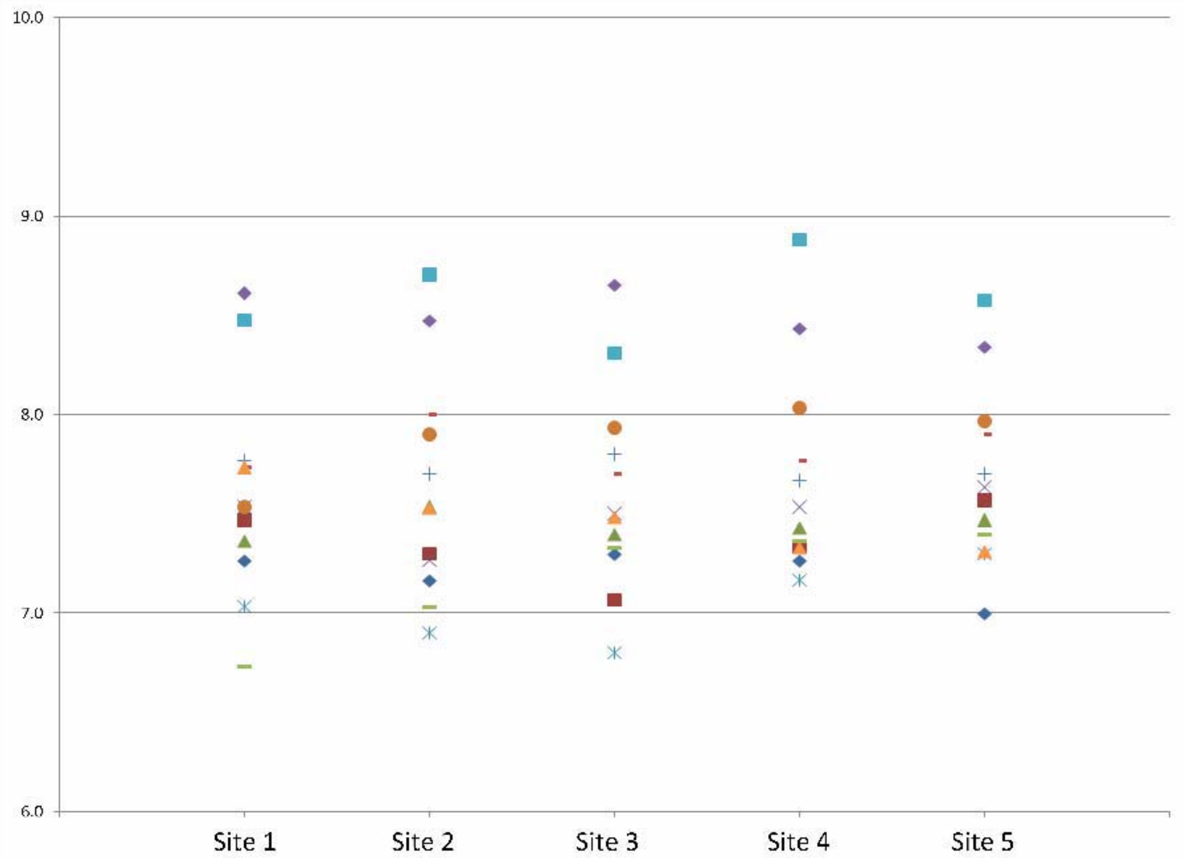

Figure 43. Distribution of pH in Kok River.

Total Dissolved Solid (TDS)

Waters with high dissolved solids generally are of inferior palatability and may induce an unfavorable physiological reaction in the transient consumer. Dissolved solids are the portion of solids that pass through a filter of 2.0 μm (or smaller) nominal pore size under specified conditions (APHA, AWWA and WEF, 1998).

TDS at Kok River have great values which range between 25.2 mg/l and 128.0 mg/l. The results from the TDS measurement are similar to conductivity readings as seen in Figures 44 and 45. Average value in all sampling site were mostly above 100.0 mg/l except in sampling site number 1. By average the TDS of all sampling sites had no significant difference through the sampling period and slightly lower in last 3 months of the study caused from the dilution from the rain.

A limit of 500 mg.l-1 dissolved solids is desirable for drinking waters. Highly mineralized waters also are unsuitable for many industrial applications. Waters high in suspended solids may be esthetically unsatisfactory for such purposes as bathing. A solids analysis is important in the control of the biological and physical wastewater treatment processes and for assessing compliance with regulatory agency wastewater effluent limitations (APHA, AWWA and WEF, 1998).

Nutrients

Ammonia, nitrate, and phosphates which are commonly referred to as nutrient chemicals are utilized by diatoms in varying amounts. Some diatoms typically known as oligotrophic diatoms seem to prefer very low amounts of nitrates or ammonia and phosphates, whereas those that typically live in eutrophic and polysaprobic conditions seem to prefer high amounts of these substances. The preference of various species of diatoms for varying amounts of these chemicals has led to the development of the saprobic system. Phosphorus and nitrogen are the most commonly investigated nutrients, these two nutrients are the most likely to be growth limiting.

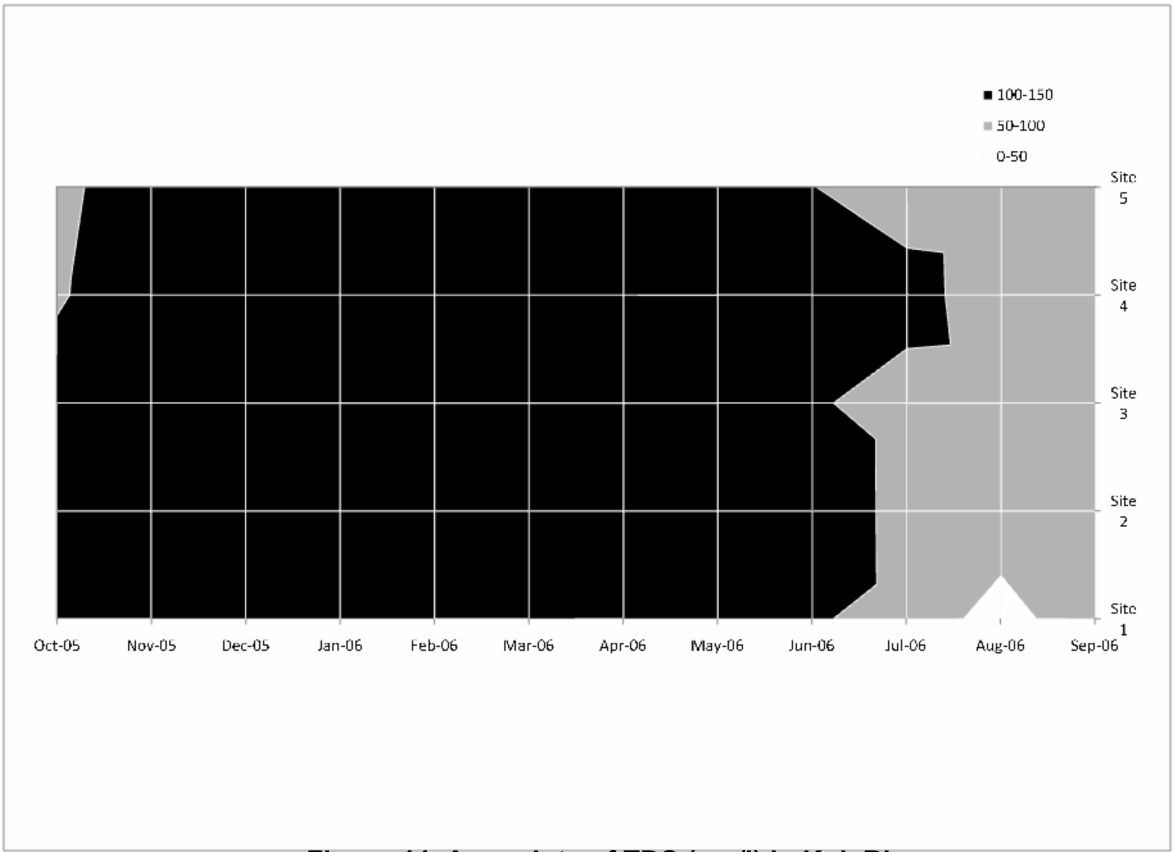

Figure 44. Area plots of TDS (mg/l) in Kok River.

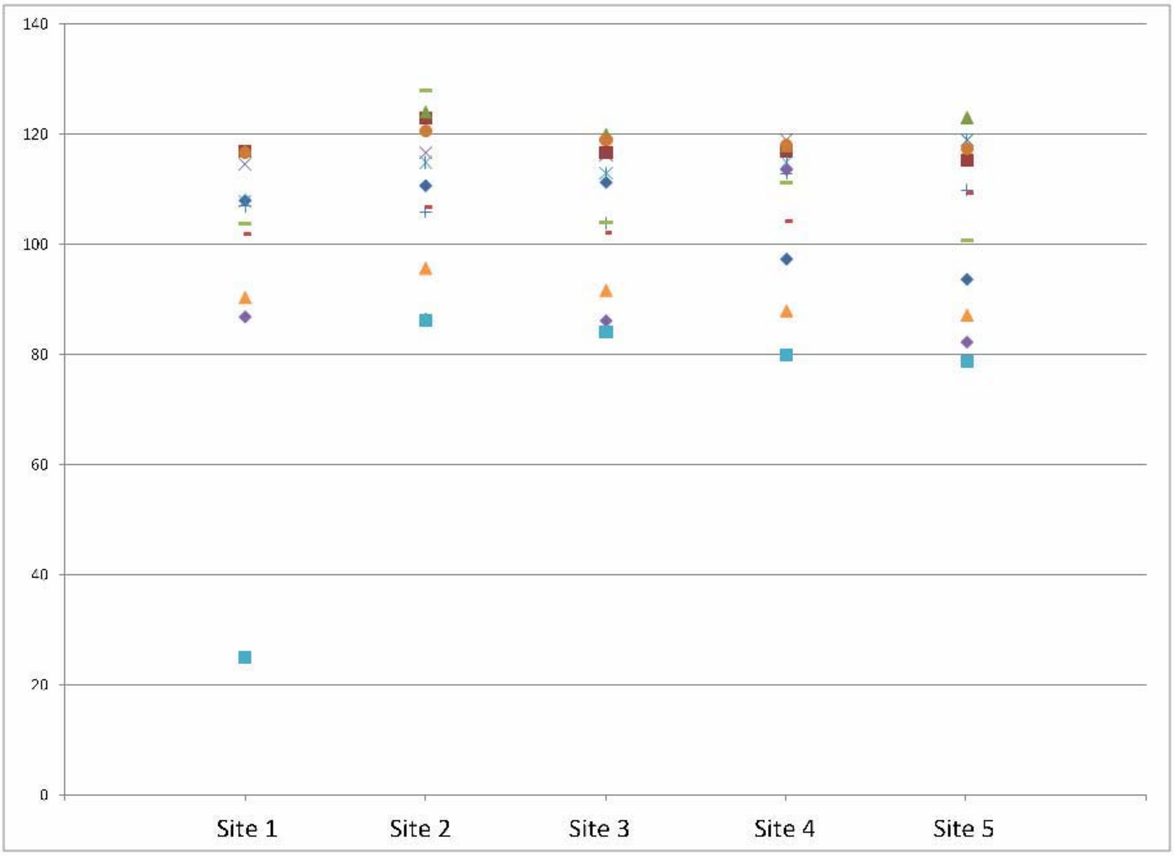

Figure 45. Distribution of TDS (mg/l) in Kok River.

Nitrate Nitrogen

There are many forms of nitrogen in aquatic ecosystems for example organic forms, inorganic forms, soluble and non-soluble forms. Nitrate nitrogen is a soluble and usable form for diatoms utilization. In general, there are low concentrations of nitrate in water resources (not more than 10.0 mg/l and sometimes less than 1.0 mg/l).

The area plots of nitrate nitrogen concentration are shown in Figure 46. Distribution values of all sampling sites are shown in Figure 47.

The nitrate concentration at Kok River has great diversity which ranges between less than 0.1 to more than 10.0 mg/l. In case of rain in August 2006 it was leaching the high amount of nitrate-nitrogen in to the river. There is a maximum concentration of nitrate nitrogen value in these Sites number 3 and 4 in August 2006 (over range in the measurement that indicate more than 10.0 mg/l). Organic waste contains high concentrations of ammonium nitrogen which could be converted to nitrite and subsequently to nitrate nitrogen under aerobic conditions by nitrifying bacteria. Since, however, both ammonium and nitrate nitrogen are important nutrients, problems related to eutrophication can arise as a consequence of organic inputs to water (Abel, 1989).

Ammonium Nitrogen

The major sources of organic pollution are sewage and domestic wastes and agriculture run-off (especially runoff from inadequately stored animal wastes and silage). The fate of the ammonia largely depends on the level of oxygen present. Under aerobic conditions ammonia is converted to nitrite and subsequently to nitrate by nitrifying bacteria (Abel, 1989). Only in sampling site number 1 of Kok River in August 2006 present a high amount of ammonium-nitrogen.

In general, drinking waters, clean surface water, and good quality nitrified wastewater effluent have low concentrations of ammonia (APHA, AWWA and WEF, 1998). The concentration of ammonium nitrogen in all sites had no significant difference throughout the sampling period, mostly less than 2.0 mg/l. The ammonium concentration at Kok River ranges between 0.0 and 10.0 mg/l. The area plots of ammonium nitrogen concentration are shown in Figure 48. Distribution values of all sampling sites are shown in Figure 49.

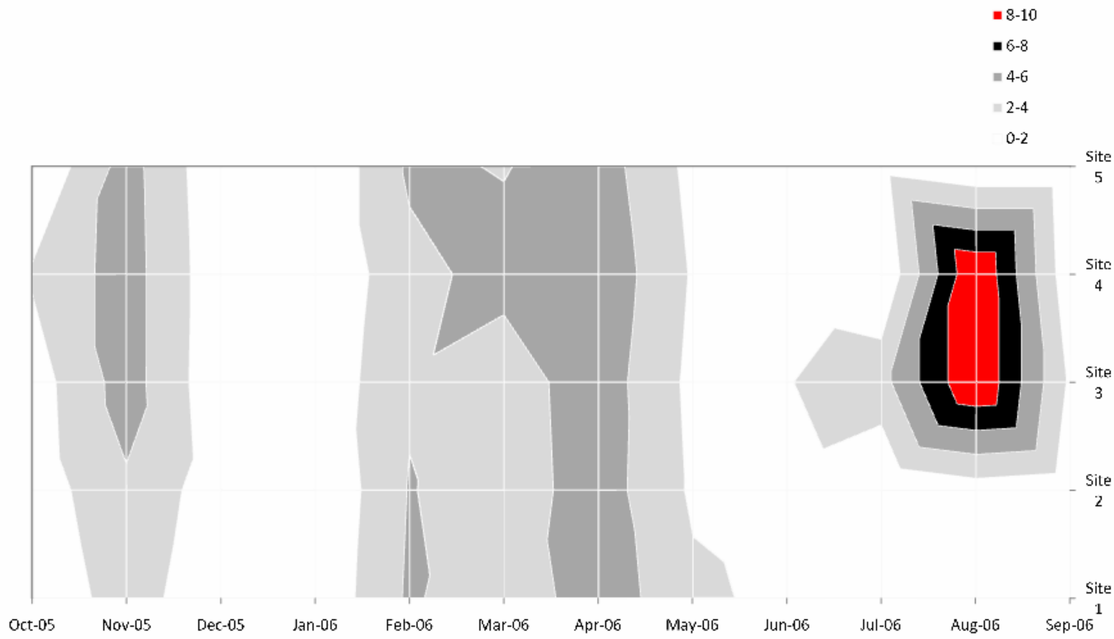

Figure 46. Area plots of Nitrate Nitrogen (mg/l) in Kok River.

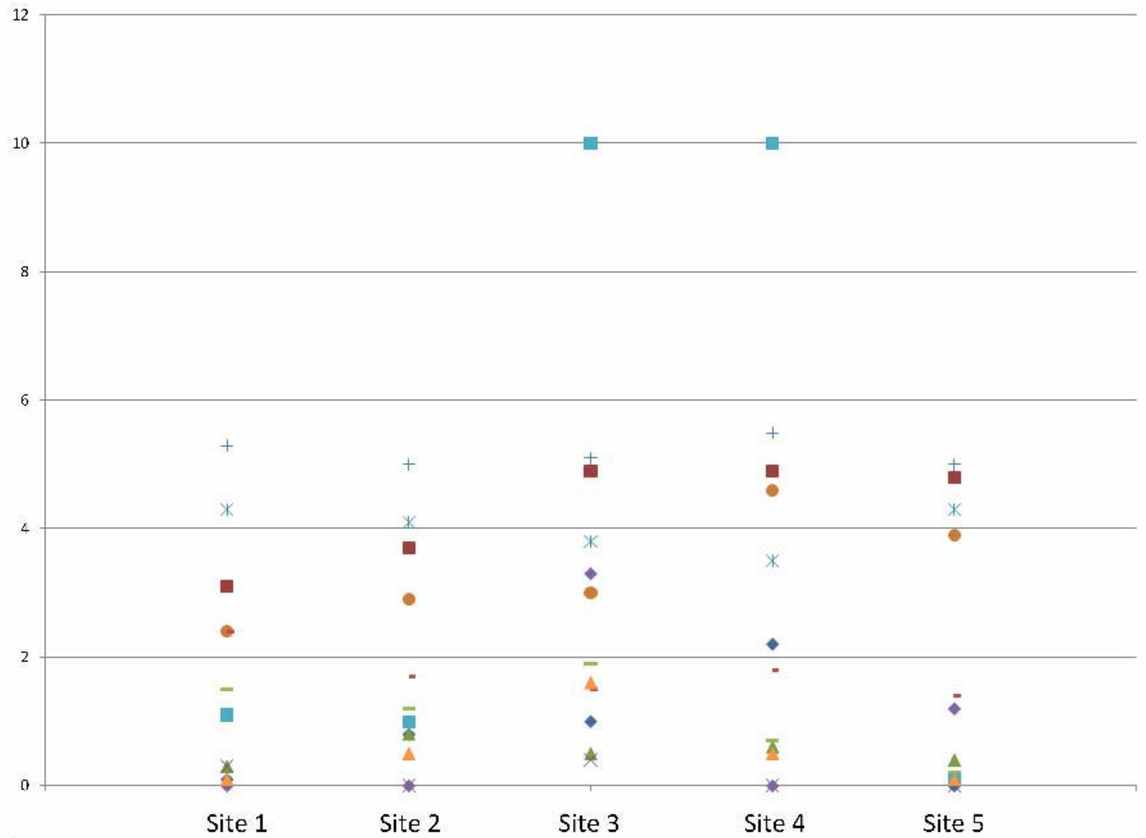

Figure 47. Distribution of Nitrate Nitrogen (mg/l) in Kok River.

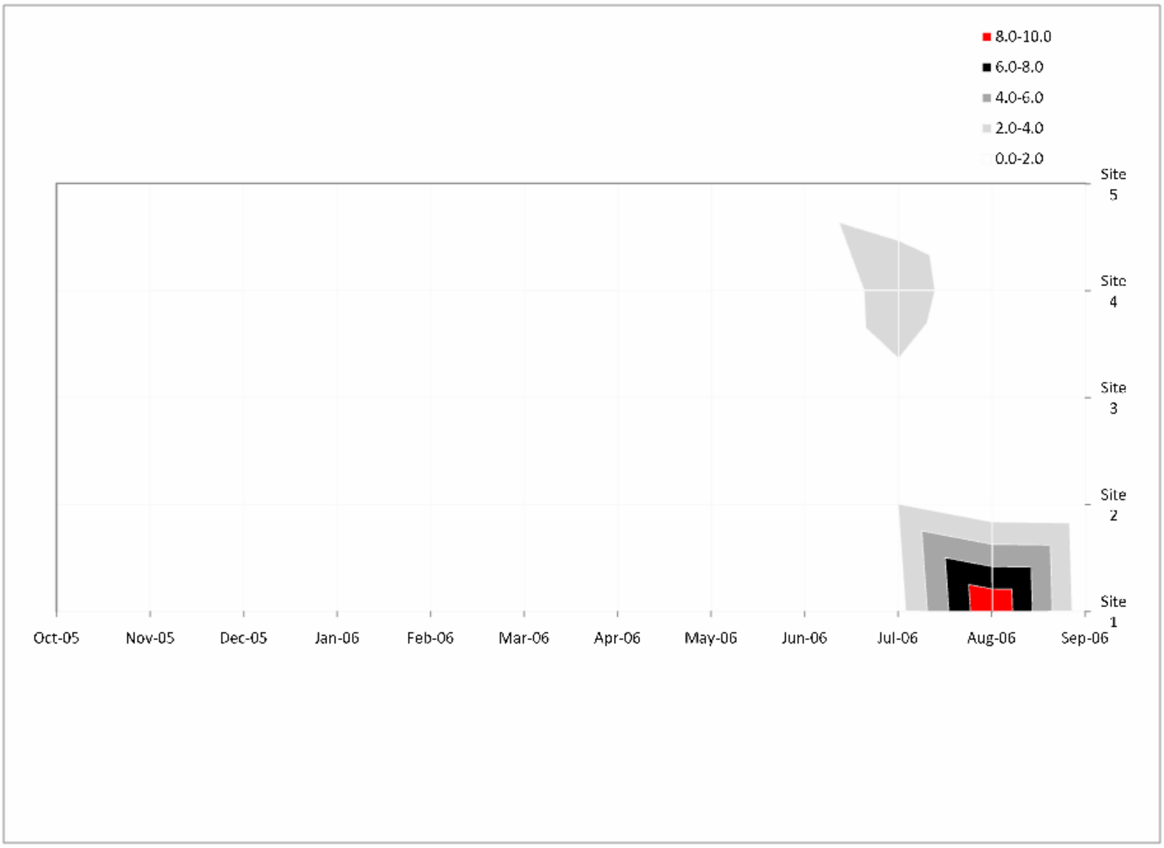

Figure 48. Area plots of Ammonium Nitrogen (mg/l) in Kok River.

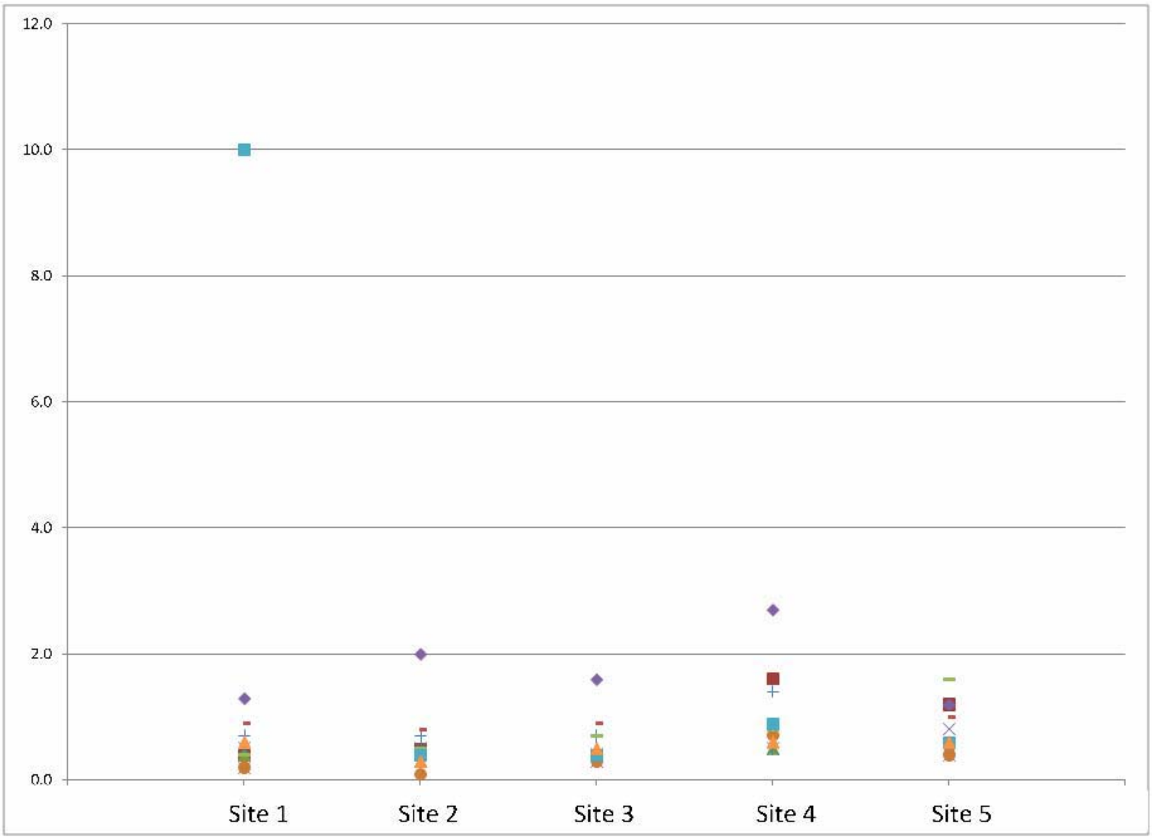

Figure 49. Distribution of Ammonium Nitrogen (mg/l) in Kok River.

Phosphate Phosphorus

Phosphorus occurs in natural waters and in wastewaters almost solely as phosphate. These are classified as orthophosphates, condensed phosphates (pyro-, meta-, and other polyphosphates), and organically bound phosphates. They occur in solution, in particles or detritus, and in bodies of aquatic organisms. Phosphorus is essential for the growth of organisms and can be the nutrient that limits the primary productivity of a body of water (APHA, AWWA and WEF, 1998).

Algal growth in water may be limited by any of several factors, including light and the physical characteristics of the habitat. In many cases, however, the limiting factor is the availability of inorganic nutrients, particularly phosphate (Abel, 1989).

The Soluble Reactive Phosphorus or SRP concentration in Kok River ranges between 0.12 and 100.7 mg/l. The concentration of SRP in all sites had grate diversity especially in sampling site number 2 and 4 in some months.. Large quantities of phosphate compound may be added when the water is used for laundering or other cleaning purposes by villagers. SRP may be applied to agricultural or residential cultivated land as fertilizers which are carried into surface waters with stream runoff.

The area plots of SRP concentration are shown in Figure 50. Distribution values of all sampling sites are shown in Figure 51.

Silica

Silicon is a required element for the formation of cell walls of diatoms. Its uptake as silicic acid or silicates by diatom cells seems to be greatly influenced by sulphydryl groups. In the cell membrane there are enzymes containing sulphydryl groups. It is also known to be important in cell division (Patrick, 1977).

The silica (SiO_2) content of natural water most commonly is in the 1.0 -30.0 mg/l range, although concentrations as high as 100.0 mg/l are not unusual and concentrations exceeding 1,000 mg/l are found in some brackish waters and brines (APHA, AWWA and WPCF, 1998).

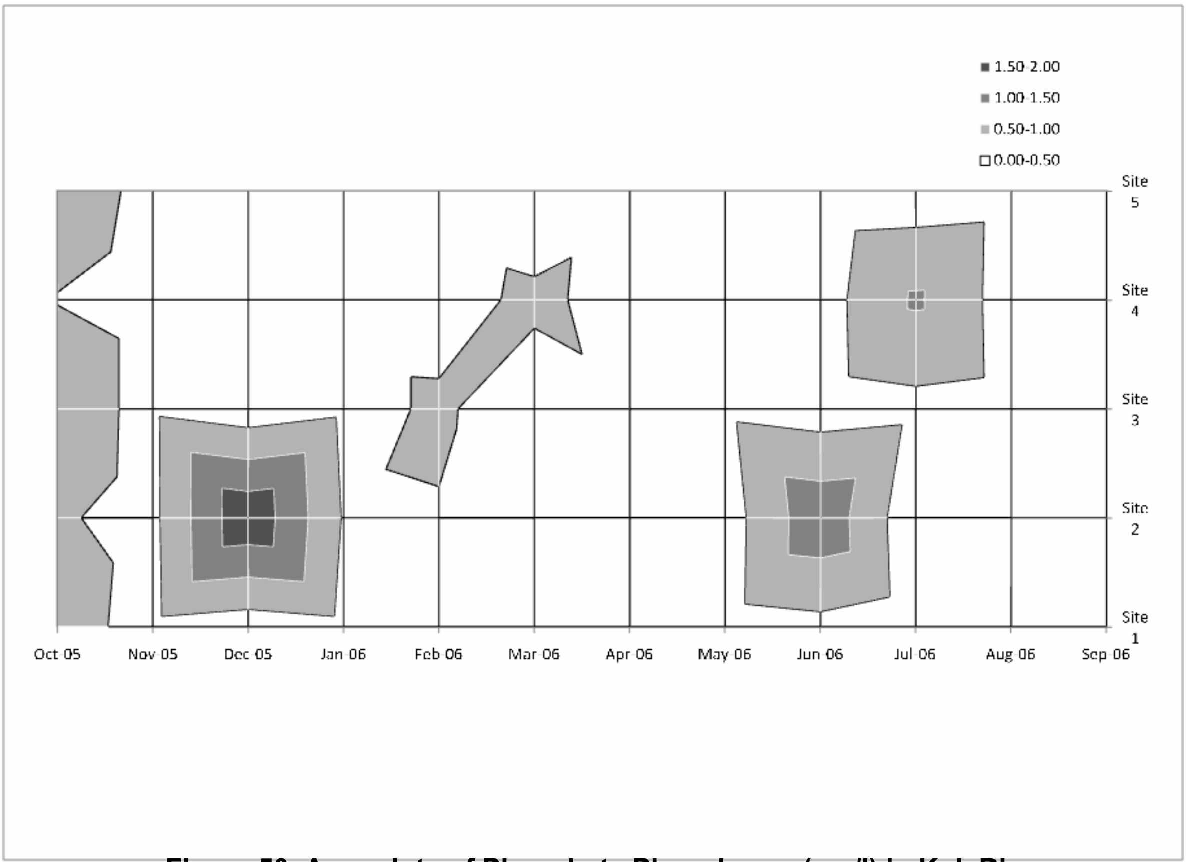

Figure 50. Area plots of Phosphate Phosphorus (mg/l) in Kok River.

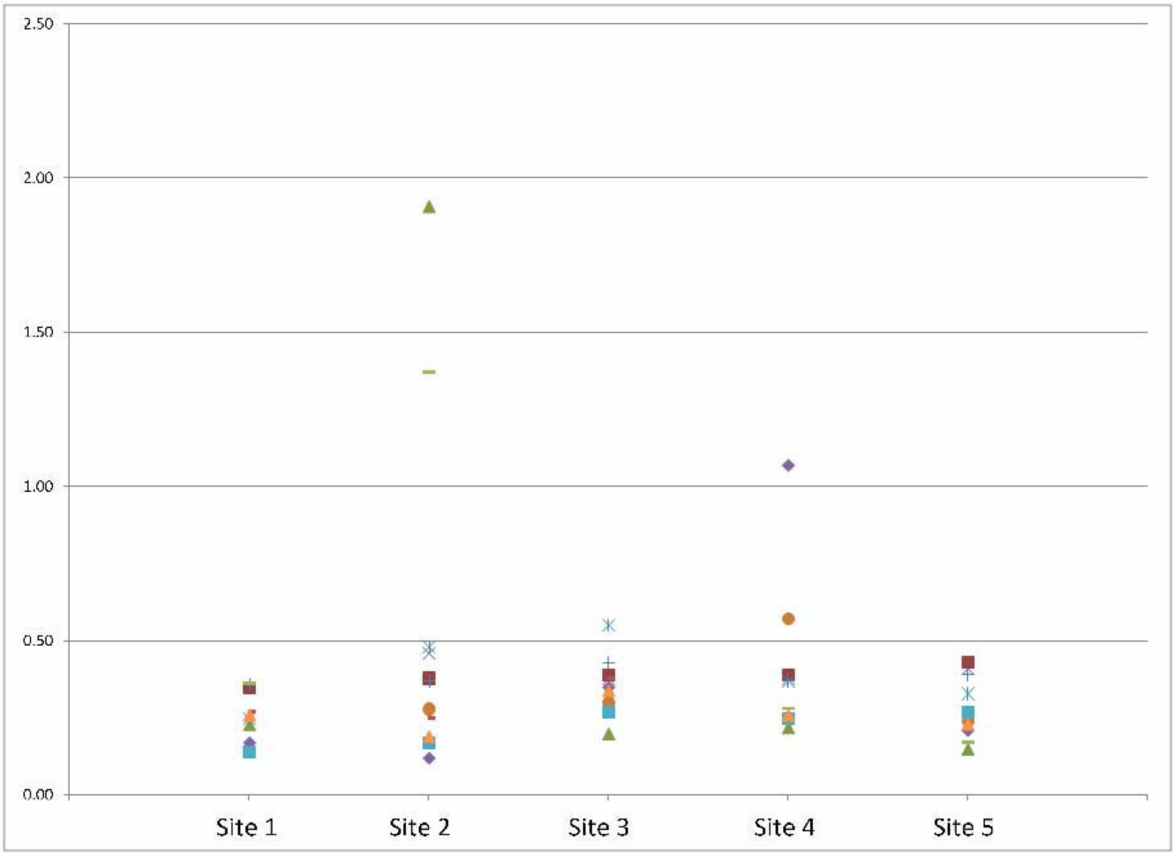

Figure 51. Distribution of Phosphate Phosphorus (mg/l) in Kok River.

The average silica concentration in Kok River was around 20.0 mg/l and had no significant difference throughout the sampling period. But the silica concentration levels in Kok River were over natural conditions in case of rain in July 2006 as shown in Figure 52 and Figure 53.

Werner cited that the silicate concentrations in aquatic habitats are varied with small amounts in temperate regions. From the measurements of Jørgensen, he gave concentrations between 0.03 – 0.45 mg/l in eutrophic Danish lakes during maximum growth periods of diatoms. And I mention Tessenow's work in several lakes in Holstein. He found average concentrations of 0.02 – 12.0 mg/l in the waters leaving the lakes. And after the blooming of diatoms, concentrations of 0.02 – 0.05 mg/l were left behind (Werner, 1977). The larger amounts of silica concentrations in tropical regions occur within this parameter and are not the limiting factor for diatoms growth. The silica concentrations in Kok River are high. Silica concentration levels are well above the values considered to be limiting to diatoms growth.

Biochemical oxygen demand (BOD5)

The BOD determination is an empirical test in which standardized laboratory procedures are used to determine the relative oxygen requirements of waste water, effluents and polluted water. The test has its widest application in measuring waste loading to treatment plants and in evaluating the BOD-removal efficiency of such treatment systems (APHA, AWWA and WEF, 1998).

BOD_5 at the Kok River was recorded only 3 month and ranges between 0.1 mg/l and 4.3 mg/l. The small amounts of BOD5 represent the good water quality. Upon the surface water quality, Classification and objectives reference by the Notification of the Ministry of Science, Technology and Energy, water quality at Site 3 was classified into the water quality class 4 which is fairly clean, fresh surface water resource used for consumption but requires special water treatment processing before use. Other sites were classified into water quality class 2 which is a very clean fresh water resource used for consumption which requires ordinary water treatment processing before use.

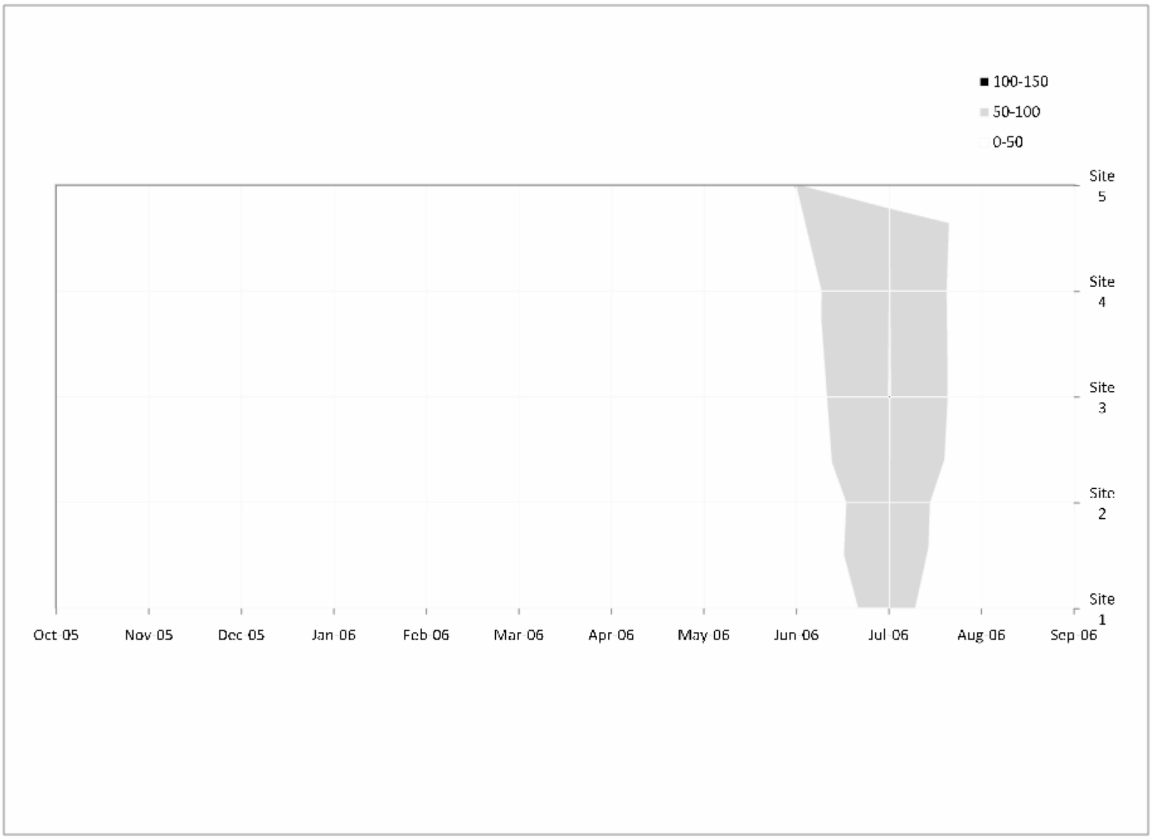

Figure 52. Area plots of Silica (mg/l) in Kok River.

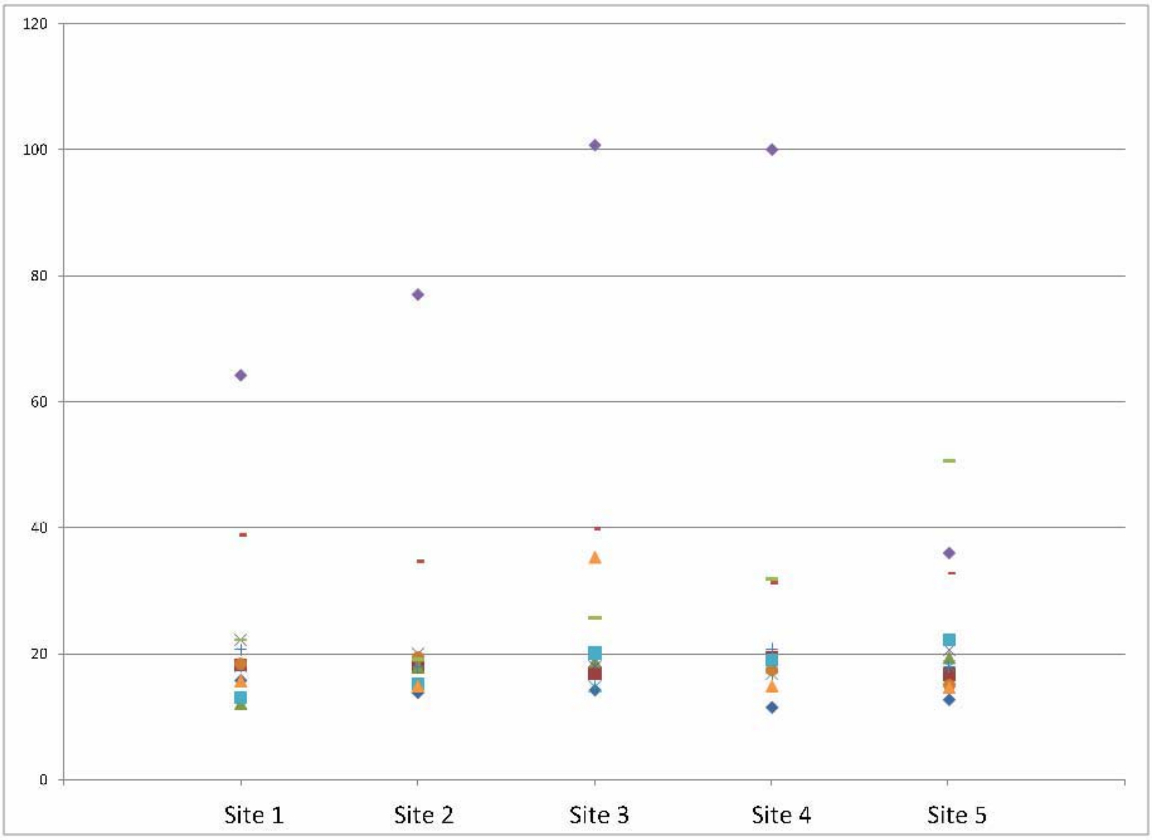

Figure 53. Distribution of Silica (mg/l) in Kok River.

Chapter 5

Conclusion and Recommendations

Trophic status of Kok River

Water qualities in Kok River were classified into mesotrophic status (moderate nutrients) in most months with the exceptions of months in rainy season (July-August 2006), which were in meso-eutrophic status (quite high nutrients) when nitrate nitrogen, ammonium nitrogen and phosphate phosphorus concentration were concerned in the water classification. In case of rain in July 2006 also make high turbid, conductivity and TDS along the river from the leaching.

Water quality of tributaries of Mekong River, which is an international River were monitoring in many countries. The land use areas of the watershed were surveyed to obtain a better understanding of the current status and climate-induced risks concerning surface water quality in this area. The co-project with Dr. Ji-Hyung Park, Department of Forest Environment Protection, Kangwon National University, Republic of Korea in title "Implications of rainfall variability for seasonality and climate-induced risks concerning surface water quality in East Asia" implied the situation of the risk. (Park et al. 2011).

The use of diatoms as a bioindicator

The taxonomic expertise is need for diatomist to confirm the identification and report a checklist of presented species. New recorded species should be confirmed with all published documents. SEM micrographs are necessary to observe small details of the diatoms silica cell wall. Water quality data should be comparing with the distribution of the presented diatoms to extract the indicator species. Statistical program should be applied to the data to extract indicator species accurately.

Diversity of diatoms and new record specie in Kok River

There was only one new record species of *Synedra ulna* (Nitzsch) Ehrenberg in Kok River. The morphology of diatoms will be define and publish in the journal. The report will be added into the list of freshwater diatoms for Thailand checklist. (Pekthong, 2000, 2001 and Suphan, 2010). Indicator species such as *Melosira varians* Agardh, common cosmopolitan living in high nutrients, will be report. A good indicator for polluted water quality such a *Gomphonema parvulum* Kützing and indicator species for oligo-meso status of water quality such a *Neidium ampliatum* (Ehrenberg) Krammer will be list.

The development of Trophic Diatom Index

Diatoms are being used increasingly in a wide range of applications, and the number of diatomists and their publications continues to increase rapidly. An application aspect of algae, especially diatoms group, is that they are important indicators of pollution in aquatic habitats. Diatoms are valuable indicators of environmental conditions in rivers and streams, because they respond directly and sensitively to many physical, chemical, and biological changes in river and stream ecosystems, such as nutrient concentrations. The sensitivity of diatoms to so many habitat conditions can make them highly valuable indicators, particularly if effects of specific factors can be distinguished. Knowing the hierarchical relations among factor effects will help to make diatoms indicators more precise.

Diatoms play a small but important part in the ecosystem and were defined as a valuable natural aquatic resource in ecosystem.

The observation of the changing of the diatom communities from different conditions are significant in determining the indicator species and have been developed into indices that are used for routine water quality monitoring (Kelly, 2000). The use of indices based on benthic communities, especially diatoms has been applied widely (Whitton and Kelly, 1995).

The development of Trophic Diatom Index (TDI) needs more information of species, amount and distribution of benthic diatom which relate to water quality along the period of the study. More data make more precision. The study of relationship between the present species of diatoms and water qualities are required.

There are many Trophic Diatoms Indices (TDI) in developed countries used to monitoring water quality but not for Thailand. There are limitation of the attempt to applied other TDI such as Schiefele and Kohmann (1993), van Dam *et al.*(1997) and Rott *et al.* (1997) etc. in Thailand. The first index for phytoplankton was AARL-PP score by Peerapornpisal et al in 2006. The attempt to develop TDI for Thailand was done in Mae Sa Stream, Chiang Mai in 2002 by Pekthong. But there are small amount of species in Mae Sa Index which is not enough to apply to all water resources in Thailand.

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Output จากโครงการวิจัยที่ได้รับทุนจาก สกว.

1. ผลงานตีพิมพ์ในวารสารวิชาการนานาชาติ

1.1 Publications

- Ji-Hyung Park, Edu Inam, Mohd Harun Abdullah, Dwi Agustiyani, Lei Duan, Thi Thuong Hoang, Kyoung-Woong Kim, Sang Don Kim, My Hoa Nguyen, **Trai Pekthong**, Vibol Sao, Antonius Sarjiya, Sianouvong Savathvong, Suthipong Sthiannopkao, J. Keith Syers and Wanpen Wirojanagud. Implications of rainfall variability for seasonality and climate-induced risks concerning surface water quality in East Asia. Journal of Hydrology. Volume 400, Issues 3-4, 11 April 2011, Pages 323-332.

1.2 Manuscript

- **Pekthong T**, Peerapornpisal Y, Trophic Diatom Index Development for Thailand. *Chiang Mai Journal of Science*. (Manuscript)
- **Pekthong T**, Peerapornpisal Y, New record species, *Synedra ulna*, freshwater diatoms in Kok River, Chiangrai. *Chiang Mai Journal of Science*. (Manuscript)

2. การนำผลงานวิจัยไปใช้ประโยชน์

เชิงวิชาการ: การเรียนการสอนวิชา Algal Biotechnology หลักสูตรวิทยาศาสตรบัณฑิต เทคโนโลยีชีวภาพ B.Sc.Biotechnology มหาวิทยาลัยแม่ฟ้าหลวง

เชิงวิชาการ: ผลงานวิจัยในระดับบัณฑิตศึกษา (ปัญหาพิเศษจำนวน 9 เรื่อง)

เชิงวิชาการ: ผลงานวิจัยในระดับมหาบัณฑิตศึกษา (วิทยานิพนธ์จำนวน 1 เรื่อง)

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- Freshwater Diatoms in Northern Thailand ไดอะตอมน้ำจืดในภาคเหนือ ประเทศไทย (อยู่ในระหว่างการเตรียมต้นฉบับเพื่อจัดพิมพ์)
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Implications of rainfall variability for seasonality and climate-induced risks concerning surface water quality in East Asia

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SUMMARY

Water resources in East Asia are considered particularly vulnerable to climate variability and extremes due to strong hydrologic variability inherent in the monsoon climate and rising water demand resulting from rapid economic growth. To obtain a better understanding of the current status and climate-induced risks concerning surface water quality in East Asia, seasonal and spatial variations in surface water quality were compared among 11 watersheds in eight countries during typical dry and wet periods from 2006 to 2008. While concentrations of dissolved ions tended to be higher during dry periods, concentrations of suspended sediments and dissolved organic matter were significantly higher during wet periods at most sampling locations. Metals with low solubility showed higher total concentrations during wet periods and had strong positive relationships with suspended sediment concentrations. Metals with high partitioning into the dissolved phase exhibited higher concentrations during dry periods at many sites. Seasonal and spatial patterns were distinct along the Lower Mekong River, including much higher monsoonal concentrations of sediment-associated metals and relatively high dry-season concentrations of dissolved As along upper reaches. The results suggest that rainfall variability is crucial in understanding seasonality and climate-induced risks concerning surface water quality in East Asia.

1. Introduction

Despite relatively high annual precipitation, freshwater resources in East Asia, including both Northeast and Southeast Asia, have recurrent problems of shortage and pollution due to strong seasonality in precipitation and rising water demand resulting from the rapid economic growth (Cruz et al., 2007). Seasonality in precipitation and runoff is primarily governed by monsoon rainfall regimes, which have different timing and duration across East Asia (Yihui and Chan, 2005). Recent analyses have suggested that climate change can influence rainfall patterns of Asian monsoon systems (Zhang et al., 2008). Although long-term precipitation trends show large inter-annual and spatial variability across East Asia, the frequency and intensity of extreme events, such as heavy rainfalls during the summer monsoon and droughts during the dry season, have increased in many parts of East Asia (Manton et al., 2001; Jung et al., 2002; Choi et al., 2009).

Increasing rainfall variability and extremes as a consequence of climate change can influence watershed biogeochemical processes and surface water quality through complex interactions between hydrology and biogeochemical processes, including the production, release, and transport of natural materials and anthropogenic pollutants (Murdoch et al., 2000; Delpla et al., 2009). For many parts of this region the majority of annual runoff is concentrated

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during the summer monsoon period. Monsoon rains are thought to play a pivotal role in determining surface water quality through various hydro-biogeochemical processes such as hydrologic flushing of organic matter and rainfall dilution of ions (An and Jones, 2000; Kim et al., 2000; Park et al., 2010). Changing rainfall patterns during the summer monsoon, including changes in rainfall amount and the frequency of extreme rainfall events, can lead to changes in both terrestrial material export and in-stream physicochemical processes, affecting surface water quality (Park et al., 2010). Although there have been many reports on water quality deterioration following extreme events in other parts of the world (Mallin et al., 2002; Baborowski et al., 2004; Presley et al., 2006), water quality has rarely been associated with rainfall variability and extremes in East Asia. However, some recent studies of water quality changes during and following typhoons have illustrated the importance of extreme events in both hydrologic material transport and water quality in mountainous watersheds of East Asia (Zhang et al., 2007; Goldsmith et al., 2008; Tsai et al., 2009).

Watershed topographic features can play an important role in modulating the response of watershed biogeochemical processes to rainfall variability and extremes. Recent studies have emphasized the importance of steep mountainous terrain across Northeast Asia as a key watershed characteristic that can amplify the effects of monsoon rainfalls on watershed processes (Kim et al., 2000; Ogawa et al., 2006; Park et al., 2007). Turbid waters caused by sediments eroded from agricultural lands during extreme rainfall events illustrate the possibility of water quality deterioration as a consequence of the interaction between climate variability and rapid land use change on steep mountainous terrain (Goldsmith et al., 2008; Park et al., 2010). Given the importance of suspended sediments in determining the fate and bioavailability of nutrients and metals (Nagano et al., 2003; Cenci et al., 2006; Quinton and Catt, 2007), surface water siltation in response to extreme rainfall events can pose a serious threat to surface water quality.

The problem of surface water siltation is especially serious in the Lower Mekong River (LMR) Basin, associated with soil erosion from deforested steep hillslopes along Lao and Thai reaches of the Mekong River (Lu and Siew, 2006). For example, in an agricultural watershed in Thailand suspended sediment concentrations of up to 35 g l^{-1} were measured in an extreme rainfall event in June 2004, during which 218 mm fell in 6 h with a maximum intensity of 70 mm h^{-1} (Valentin et al., 2006). Although there is a growing interest in water quality monitoring in Southeast Asia, including river pollution with organic pollutants (Minh et al., 2007; Duong et al., 2010) and groundwater arsenic contamination (Pollizzotto et al., 2008; Winkel et al., 2008), little attention has been paid to climate effects on surface water quality.

Limited information on spatio-temporal variations in surface water quality does not allow an accurate prediction of water quality changes in response to changing patterns of monsoon rainfall regimes in East Asia. The primary objective of this study was to provide baseline information essential for the assessment of climate-induced risks to surface water quality by comparing spatio-temporal variations in surface water quality among 11 representative watersheds across East Asia from China through the LMR basin to Indonesia. A particular focus was placed on the interactions between suspended sediments and metals as an illustrative example of climate risks to surface water quality.

2. Materials and methods

2.1. Study site and sampling

Biannual water sampling was conducted in 11 watersheds in eight East Asian countries during two separate field campaigns (Fig. 1 and Table 1). The first biannual sampling was conducted in 2006 as a pilot study at five watersheds in four countries. A more extensive sampling campaign was conducted at nine watersheds in eight countries from July 2007 through May 2008 as part of a regional collaborative study.

Sampling locations were selected to cover major land use types, including unpolluted headwaters, and streams and rivers receiving agricultural or urban runoff. The Fenhe River (a major tributary of the Yellow River) in China and the Hwangryong and Soyang River in Korea were sampled along a distinct land-use gradient from the forested headwater through the agricultural part to the polluted downstream. In the LMR basin sampling locations were selected along the main-stem Mekong and its major tributary at each site. Because it was difficult to find forested headwaters along the monitored Mekong tributaries, water quality was compared for less polluted upstream versus more polluted downstream reaches. The Kiulu River in the northwestern Malaysian Borneo originates from a steep mountain area and flows through the sparsely populated rural area, with downstream reaches polluted by agricultural runoff and sewage from small towns near Kota Kinabalu. Sampling along the Ciliwung River in Indonesia was also conducted along a relatively distinct gradient of land use, covering headwater and agricultural reaches near Bogor and a polluted downstream reach near Jakarta.

In both campaigns water sampling was repeated during a dry and a wet period at the same 5–15 locations in each monitored watershed (Table 1). Most of the sampling locations in Ubon Ratchatani, Phnom Penh, and Kota Kinabalu were sampled for both sampling campaigns, to compare year-to-year variations in water quality. In Phnom Penh, some of the sampling locations along the Tonle Sap River were changed during the second campaign to encompass both up- and midstream locations.

For the comparison of seasonality in water quality, sampling timing was carefully selected to represent the typical dry or wet period of each country (Table 1). In six countries under the direct influence of the East Asian monsoon climate dry-season sampling was conducted between the mid March and late April, following at least one week without rain, while wet-season sampling was done around the peak of the monsoon. Antecedent precipitation for 1 month before sampling showed clear differences between the dry- and wet-season sampling, although the dry-season precipitation was unusually high in Luang Prabang and Phnom Penh in the 2007–2008 campaign (Table 1). Because Malaysia and Indonesia do not have such a distinct monsoon period as in other countries, a different strategy was used based on local weather conditions. In these countries tropical storms throughout the year, along with recent changes in rainfall regimes, resulted in relatively high 1-month antecedent precipitation before the dry-season sampling (Table 1).

Grab water samples were collected 10–20 cm below the stream surface at the center of flow, using a 1-l Teflon bottle. To avoid contamination from sample handling, newly purchased bottles of the same brand (HDPE bottles, Nalgene) were used after repeated rinsing with ultra-pure water (Milli-Q). During water sampling, in situ water quality parameters were measured, including water temperature, pH, and electrical conductivity. Immediately after water sampling, a portion of sample (50 ml) was filtered on-site using a syringe filter (25 mm Puradisc syringe filter, Whatman; nominal pore size of 0.45 μm) attached to a plastic-only syringe (50-ml PP/PE syringe, Norm-Jet), based on a simplified filtering method developed for trace metal analysis at remote sites (Shiller, 2003). To minimize potential contamination, only newly purchased filters and syringes were used after repeated rinsing with ultra-pure water. The filtered samples, together with unfiltered raw samples, were frozen prior to transport to the laboratory in Korea via express mail services for further chemical analyses.

Fig. 1. Site map showing sampling locations in eight countries. Triangle, round, and square symbols represent the sites sampled for 2006 only, for 2007–2008 only, and for both 2006 and 2007–2008 campaigns, respectively.

2.2. Chemical and statistical analyses

A portion (100–200 ml) of water sample was filtered through a pre-combusted glass fiber filter (GF/F, Whatman; nominal pore size of 0.7 μm). Total suspended solid (TSS) was measured gravimetrically as the difference in filter weight before and after filtering. Filtered samples were immediately analyzed for UV absorbance at 254 nm (UVA_{254}) as a measure of dissolved organic matter (DOM; Deflanddre and Gagné, 2001) using a UV/visible spectrophotometer (UV-1601PC, Shimadzu). An ion chromatograph (DX-320, Dionex) was used for analysis of Cl^-, SO_4^{2-}, NO_3^-, and NH_4^+. Concentrations of dissolved trace metals in syringe-filtered samples were determined by inductively coupled plasma-mass spectrometry (7500ce ICP-MS, Agilent). For the determination of total metal concentrations, unfiltered samples (50 ml) were acid-digested with ultra-pure HNO_3 using an EPA method for acid-recoverable metal analysis (Creed et al., 1994).

For all instrumental analyses, continuous concentration verification using a check standard, along with baseline contamination check with both field and laboratory blanks made of Milli-Q water, was conducted for every batch of 10 samples. As an additional QC measure for trace metal analysis, a standard reference material (SRM 1640, NIST) was analyzed along with check standards. Relative standard deviations from the repeated measurements of check standards were generally within 5% for most measured metals. Baseline contamination checks using blank samples (acidified Milli-Q water) indicated potential contamination by Cu and Zn, while measurements of Cd concentrations were often below the detection limits determined for each analysis. These three metals were excluded from the following data analyses.

To analyze differences in average concentrations of each water quality parameter between dry and wet periods, a paired *t*-test was conducted for each sampling site and sampling campaign. The relationships between TSS and total metal concentrations were analyzed using a general linear model (SPSS, 2003), with data sets pooled for each season of two sampling campaigns. The best-fit regression line was drawn in each of four plots (2 seasons $\times$ 2 years) only when the regression was statistically significant at $P < 0.05$.

3. Results and discussion

3.1. Cross-site comparison of spatial and seasonal variations in surface water quality

Among measured water quality parameters, electrical conductivity, some dissolved anions (Cl^- and SO_4^{2-}), UVA_{254}, and TSS showed relatively clear seasonal differences between dry and wet periods (Table. 2). When all measurements of each water quality parameter were pooled for the comparison of seasonal differences, approximately 80% of the compared values showed decreases in electrical conductivity and concentrations of Cl^- and SO_4^{2-} during the wet period, while the reverse case was found for UVA_{254} and TSS. Clear seasonality was not found for pH, NO_3^-, and NH_4^+.

Electrical conductivity, as a measure of total dissolved ions, was generally lower during wet periods at all sites except Phnom Penh in 2007–2008 and Kota Kinabalu in 2006 (Table 3). Concentrations of Cl^- and SO_4^{2-} were also generally lower during wet periods (Table 2), with significant seasonal differences found at many sites (data not shown). Lower conductivity and ion concentrations during wet periods were likely due to dilution by monsoon rains. The lack of a dilution effect at Kota Kinabalu (2006) and Phnom Penh (2007–2008) might be related to either a small difference in antecedent precipitation between the dry and wet period or unusually high dry-season precipitation, respectively (Table 1). Rainfall-induced decreases in conductivity and ion concentrations have been well established in a number of previous studies (e.g., Brown et al., 1999; An and Jones, 2000; van Vliet and Zwolsman, 2008; Tsai et al., 2009). Negative relationships between ionic concentrations and hydrologic parameters including precipitation, water level and flow have been found in many river systems including the Meuse River (van Vliet and Zwolsman, 2008) and the LMR (Prathumratana et al., 2008).

The dilution effect by monsoon rains was not evident for NO_3^- and NH_4^+, with monsoonal concentration increases found for 62% and 42% of all compared concentrations of NO_3^- and NH_4^+, respectively (Table 2). While decreased dilution of dissolved ions during droughts can pose a risk of water quality deterioration for some pollutants released primarily from point sources, concentrations of nutrients derived from diffuse sources, such as NO_3^-, can increase during the wet period (Schindler, 1997; van Vliet and Zwolsman, 2008). Flushing of inorganic nitrogen from N-enriched upper soils horizons has been suggested as the primary mechanism for increasing N concentrations during storm events (Creed et al., 1996). However, both positive and negative relationships between NO_3^- and NH_4^+ concentrations and discharge have often been observed in watersheds with similar characteristics (Arheimer

Table 1
Summary of sampling sites and climatic conditions (*T*: temperature; ppt: precipitation). Sites are aligned from the highest to lowest latitude.

Site name	Country	Main rivers and tributaries	No. of sampling locations		Sampling time (dry/wet)		Annual average		1-mo antecedent ppt (dry/wet)	
			06	07–08	06	07–08	*T* (°C)	Ppt (mm)	06	07–08
Shanxi	China	Fenhe		9		March 08/July 07	10.4	488		4/116
Chuncheon	Korea	Soyang		9		May 08/August 07	11.5	1491		29/437
Gwangju	Korea	Hwangryong	6		March 06/August 06		14.5	1383	16/333	
Chiang Rai	Thailand	Kok and Mekong	15		March 06/August 06		24.6	1092	2/435	
Luang Prabang	Lao PDR	Khan and Mekong		5		March 08/July 07	25.4	1226		184/192
Vientiane	Lao PDR	Ton and Mekong		9		March 08/July 07	26.4	1661		NA
Ubon Ratchatani	Thailand	Mun and Mekong	14	9	March 06/August 06	March 08/July 07	27.3	1653	1/269	1/324
Phnom Penh	Cambodia	Tonle Sap and Mekong	11	9	March 06/August 06	March 08/July 07	28.2	1636	44/130	106/180
Cantho	Vietnam	Mekong and canals		9		March 08/July 07	27.0	1552		8/46
Kota Kinabalu	Malaysia	Kiulu	14	9	July 06/April 06	November 07/May 08	27.5	3070	72/152	237/430
Bogor	Indonesia	Ciliwung		9		September 07/March 08	25.7	3578		193/319

Table 2
Proportion (%) of monsoonal changes in pH, EC, UVA_{254} and concentrations of Cl^-, SO_4^{2-}, NO_3^-, and NH_4^+ relative to dry periods of both 2006 and 2007/2008 sampling campaigns. The number of compared values is provided in parentheses below each water quality parameter.

Proportion of monsoonal changes	pH	EC	Cl^-	SO_4^{2-}	NO_3^-	NH_4^+	UVA	TSS
	(%)							
Increase	46	20	20	20	62	42	73	77
Decrease	52	79	80	80	38	58	27	23
Number of compared pairs	(121)	(121)	(135)	(135)	(135)	(135)	(135)	(120)

Table 3
Cross-site comparison of seasonality in electrical conductivity (μS cm^{-1}) as a measure of dissolved ions. Bold values indicate significant seasonal differences at $P < 0.05$ at each site for each sampling year. ND stands for 'not determined'.

Site	Electrical conductivity (μS cm^{-1})			
	2006		2007–2008	
	Dry period Mean ± SE (Min–Max, *n*)	Wet period Mean ± SE (Min–Max, *n*)	Dry period Mean ± SE (Min–Max, *n*)	Wet period Mean ± SE (Min–Max, *n*)
Shanxi			**541** ± 34 (448–686, 9)	**344** ± 31 (262–510, 9)
Chuncheon			**103** ± 15 (54–197, 9)	**67** ± 12 (25–143, 9)
Gwangju	243 ± 86 (91–659, 6)	143 ± 33 (76–259, 6)		
Chiang Rai	**180** ± 32 (27–373, 15)	**127** ± 15 (14–209, 15)		
Luang Prabang			ND	268 ± 34 (226–402, 5)
Vientiane			293 ± 46 (136–537, 9)	178 ± 33 (5–259, 9)
Ubon Ratchatani	**241** ± 29 (89–467, 14)	**128** ± 21 (10–261, 14)	**209** ± 18 (105–265, 9)	**153** ± 28 (17–251, 9)
Phnom Penh	152 ± 16 (90–200, 11)	ND	85 ± 16 (12–123, 9)	86 ± 16 (12–128, 9)
Cantho			830 ± 607 (190–5682, 9)	164 ± 6 (142–209, 9)
Kota Kinabalu	74 ± 7 (53–156, 14)	70 ± 3 (51–85, 14)	**63** ± 2 (56–74, 9)	**37** ± 5 (0–49, 9)
Bogor			**22** ± 5 (9–44, 9)	**10** ± 1 (6–14, 9)

et al., 1996), suggesting that mechanisms other than flushing can also prevail, particularly when sources of N in soils are limited or depleted. Given the wide spectrum of land use and physicochemical characteristics of the monitored watersheds, separation of dilution and flushing effect from each other or from other controlling factors would be difficult.

NO_3^- concentrations were relatively low in tropical rivers during both dry and wet periods compared to those observed for the sites in China and Korea, although spatial variability in the latter countries was large, including very low concentrations at a few sampling locations (Fig. 2). At the Southeast Asian sites high water temperatures throughout the year might have led to a rapid transformation of N released from terrestrial sources, dampening either the flushing effect during the monsoon period or the effect of decreased dilution during the dry season. Using water quality data collected worldwide from 75 unpolluted rivers, Meybeck and Helmer (1989) found that without anthropogenic pollution NO_3^- concentrations range from 0.22 to 0.89 mg l^{-1}, with the most common natural concentrations at 0.44 mg l^{-1}. Although many of the monitored streams and rivers across Southeast Asia exhibited the natural level of NO_3^- concentrations, some of the upper LMR sites and many of the sites in Vietnam and Indonesia showed much higher concentrations than the natural range reported by Meybeck and Helmer (1989). Among the polluted sites in China and Korea NO_3^- concentrations tended to be higher in agricultural or urban streams (Fig. 2), reflecting the relatively high levels of surface water nitrogen pollution in both countries, which have been associated with rapid urbanization and agricultural expansion over the recent decades (Bashkin et al., 2002; Park et al., 2010),

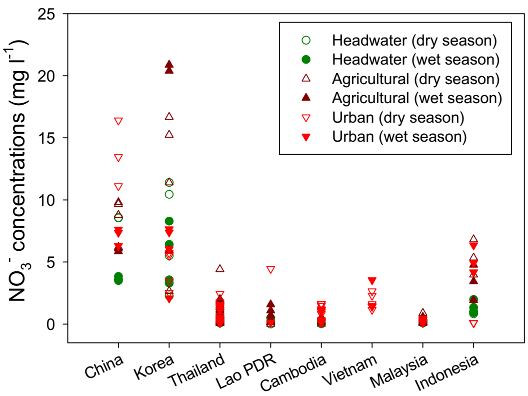

Fig. 2. Seasonal differences in land-use effects on NO_3^- concentrations in streams and rivers excluding the Mekong River during the whole monitoring period (2006–2008).

TSS concentrations were generally higher during wet periods at all sites except Kota Kinabalu in 2006 and Phnom Penh in 2007–2008 (Tables 2 and 4). TSS concentrations showed large year-to-year variations, with much higher concentrations during the 2006 wet period for two Mekong watersheds and during the 2007–2008 wet period for the Malaysian sites. The inter-annual variations in hydrologic conditions might partly explain the lack of seasonality in both TSS and conductivity at the Phnom Penh and Kota Kinabalu sites. TSS concentrations were relatively low in the watersheds with higher forest cover in China, Korea, Malaysia, and Indonesia (Table 4). Unusually high TSS concentrations were observed in Kota Kinabalu during the second wet-season sampling following a large storm event, suggesting that soil erosion can pose a serious problem even in forested areas when heavy rainfall events occur in steep mountainous terrain.

Monsoonal increases in TSS concentrations were more evident at the Thai and Lao watersheds along upper reaches of the LMR (Table 4). This might be related to trans-boundary transport from the upper Mekong River and the high rate of soil erosion from steep slopes along upper LMR reaches. Soil erosion from agricultural lands in Lao PDR and Northeast Thailand has been regarded as a major contributor to very high and increasing TSS concentrations in the Mekong reach upstream of Vientiane (MRC, 2005).

UVA_{254} intensities were generally higher during wet periods at many sites, while this was not the case for Phnom Penh, Cantho, and Bogor (Tables 2 and 5). The well-established 'hydrologic flushing' of DOM from surface soils during storm events (e.g., Hornberger et al., 1994) might have contributed to increases in UVA_{254} intensity during the wet period. At the sites where UVA_{254} intensities increased during the wet period, the monsoonal increases occurred not only in headwater streams but also in big rivers such as the LMR. Dissolved humic substances have many important environmental implications for surface water quality, including complex building with metals (Leenheer et al., 1998; Park, 2009), binding of organic pollutants (Chiou et al., 1986), and formation of disinfection byproducts (Chow et al., 2007). Relatively high intensities of UVA_{254} at some sampling locations in China and upper parts of the LMR basin indicate high potentials of DOM loading during wet periods (Table 5). High UVA_{254} intensities were also found at some of the Indonesian sites and Mekong tributaries in Cambodia and Vietnam, which are influenced by drainage waters from either riparian wetlands or agricultural fields. At these sites increased river flow or inflow from the LMR during the wet period is assumed to dilute drainage waters enriched with DOM derived from local terrestrial sources.

3.2. Spatio-temporal variations and controls of metal concentrations

Measurements of total and dissolved metal concentrations showed element-specific seasonal patterns (Fig. 3). In the case of metals such as Al, Co, Fe, and Pb total concentrations were much higher than dissolved-phase concentrations especially during wet periods, suggesting that these metals primarily exist in the particulate phase. It has been well known that many trace metals have much higher concentrations in suspended sediments than are found in the dissolved phase (Martin and Meybeck, 1979; Horowitz, 1991; Point et al., 2007). Very low proportions of the dissolved phase in total concentrations of these metals are consistent with the known ratios of the dissolved phase partitioning (Al, Fe, Pb: 0.1–1%; Co: 1–5%; Meybeck and Helmer, 1989). The opposite pattern was observed for As, Li, and Sr (Fig. 3), all of which are known to have a relatively high partitioning into the dissolved phase (As: 10–50%; Sr and Li: 50–90%). Since Sr has the highest dissolved phase partitioning among the measured metals, dissolved concentrations comprised the bulk of total Sr concentrations during both periods. Both total and dissolved concentrations of Sr were lower during wet periods at all sites, indicating rainfall-induced dilution of dissolved Sr. This monsoonal decrease was also observed for As, Li, Mn, Ni, and U, but to a different degree depending on sampling sites and metals (Fig. 3).

For those metals that showed large concentration increases during the wet period, positive relationships were found between TSS and total metal concentrations, with stronger relationships during wet periods for both campaigns (Fig. 4). These metals have been shown to have particulate-phase contributions larger than 50%, even when TSS concentrations are as low as 10 mg l^{-1} (Horowitz, 1991). As found in other studies (Nagano et al., 2003; Point et al., 2007), our results also showed that the relative contribution from sediment-associated metals to total metal concentrations increases with increasing TSS concentrations (Fig. 4). During both wet periods TSS concentrations exceeded 100 mg l^{-1} at many sites, and concurrent increases in metal concentrations resulted in much higher particulate-phase concentrations. In contrast, total Sr concentrations exhibited very weak positive relationships with TSS concentrations during dry periods and no relationship during wet periods, suggesting that factors other than suspended sediments might be more important in regulating the concentrations of Sr and other alkali metals. The relationships between TSS and metal concentrations were relatively weak for As and Li (Fig. 4) and those metals that showed mixed seasonal patterns (Mn, Ni, and U; data not shown). Low particulate-phase contributions to total concentrations of these metals might have weakened sediment–metal relationships, resulting in decreased metal concentrations during wet periods.

Current water regulations usually provide water quality criteria only for dissolved metal concentrations. According to criteria such as those recommended by WHO, most of measured dissolved metals were within the range considered ‘safe’ for human health. Only As showed relatively high average concentrations during dry periods at the sites of Chiang Rai and Luang Prabang (4–5 μg l^{-1}

Table 4
Cross-site comparison of seasonality in TSS (mg l^{-1}) as a measure of suspended sediments. Bold values indicate significant seasonal differences at $P < 0.05$ at each site for each sampling year. ND stands for ‘not determined’.

Site	TSS (mg l^{-1})			
	2006		2007–2008	
	Dry period Mean ± SE (Min–Max, *n*)	Wet period Mean ± SE (Min–Max, *n*)	Dry period Mean ± SE (Min–Max, *n*)	Wet period Mean ± SE (Min–Max, *n*)
Shanxi			48 ± 12 (14–114, 9)	55 ± 17 (9–171, 9)
Chuncheon			5 ± 3 (0–26, 9)	ND
Gwangju	17 ± 7 (1–40, 6)	22 ± 6 (5 ~ 50 , 6)		
Chiang Rai	**62 ±** 7 (19–111, 15)	**218 ±** 44 (31–573, 15)		
Luang Prabang			**56 ±** 2 (51–58, 4)	**222 ±** 68 (22–425, 5)
Vientiane			50 ± 10 (17–90, 8)	120 ± 25 (17–217, 9)
Ubon Ratchatani	**20 ±** 4 (1–42, 14)	**113 ±** 13 (54–195, 14)	**29 ±** 5 (10–48, 7)	**71 ±** 9 (46–130, 9)
Phnom Penh	**35 ±** 3 (24–57, 10)	**155 ±** 8 (127–202, 10)	50 ± 12 (17–124, 9)	41 ± 7 (11–86, 9)
Cantho			39 ± 7 (20–83, 8)	51 ± 8 (33–112, 9)
Kota Kinabalu	16 ± 5 (2–68, 14)	17 ± 3 (6–44, 14)	**17 ±** 3 (5–31, 8)	**130 ±** 40 (13–321, 9)
Bogor			49 ± 11 (12–82, 8)	94 ± 36 (7–306, 9)

Table 5
Cross-site comparison of seasonality in UVA_{254} (AU) as a measure of DOM. Bold values indicate significant seasonal differences at $P < 0.05$ at each site for each sampling year. ND stands for ‘not determined’.

Site	Country	UVA254 (AU)			
		2006		2007–2008	
		Dry period Mean ± SE (Min–Max, *n*)	Wet period Mean ± SE (Min–Max, *n*)	Dry period Mean ± SE (Min–Max, *n*)	Wet period Mean ± SE (Min–Max, *n*)
Shanxi	China			**0.06 ±** 0.01 (0.03–0.10, 9)	**0.09 ±** 0.01 (0.04–0.13, 9)
Chuncheon	Korea			**0.02 ±** 0.00 (0.02–0.03, 9)	**0.03 ±** 0.00 (0.03–0.04, 9)
Gwangju	Korea	0.04 ± 0.02 (0.01–0.12, 6)	0.05 ± 0.01 (0.03–0.09, 6)		
Chiang Rai	Thailand	**0.04 ±** 0.01 (0.01–0.14, 15)	**0.07 ±** 0.01 (0.02–0.11, 15)		
Luang Prabang	Lao PDR			0.03 ± 0.00 (0.02 ~ 0.05 , 5)	0.03 ± 0.01 (0.01 ~ 0.05 , 5)
Vientiane	Lao PDR			0.06 ± 0.02 (0.02 ~ 0.16 , 8)	0.10 ± 0.05 (0.03 ~ 0.45 , 9)
Ubon Ratchatani	Thailand	**0.05 ±** 0.01 (0.02–0.08, 14)	**0.09 ±** 0.01 (0.04–0.16, 14)	**0.06 ±** 0.01 (0.02–0.09, 9)	**0.09 ±** 0.01 (0.03–0.14, 9)
Phnom Penh	Cambodia	0.08 ± 0.02 (0.02–0.13, 11)	0.04 ± 0.00 (0.04–0.05, 10)	0.10 ± 0.02 (0.02–0.24, 9)	0.07 ± 0.01 (0.05–0.12, 9)
Cantho	Vietnam			0.05 ± 0.00 (0.05–0.06, 9)	0.05 ± 0.00 (0.04–0.08, 9)
Kota Kinabalu	Malaysia	**0.02 ±** 0.00 (0.01–0.03, 14)	**0.02 ±** 0.00 (0.02–0.04, 14)	**0.03 ±** 0.00 (0.02–0.04, 9)	**0.06 ±** 0.01 (0.04–0.08, 9)
Bogor	Indonesia			**0.06 ±** 0.02 (0.01–0.17, 9)	**0.02 ±** 0.00 (0.01–0.04, 9)

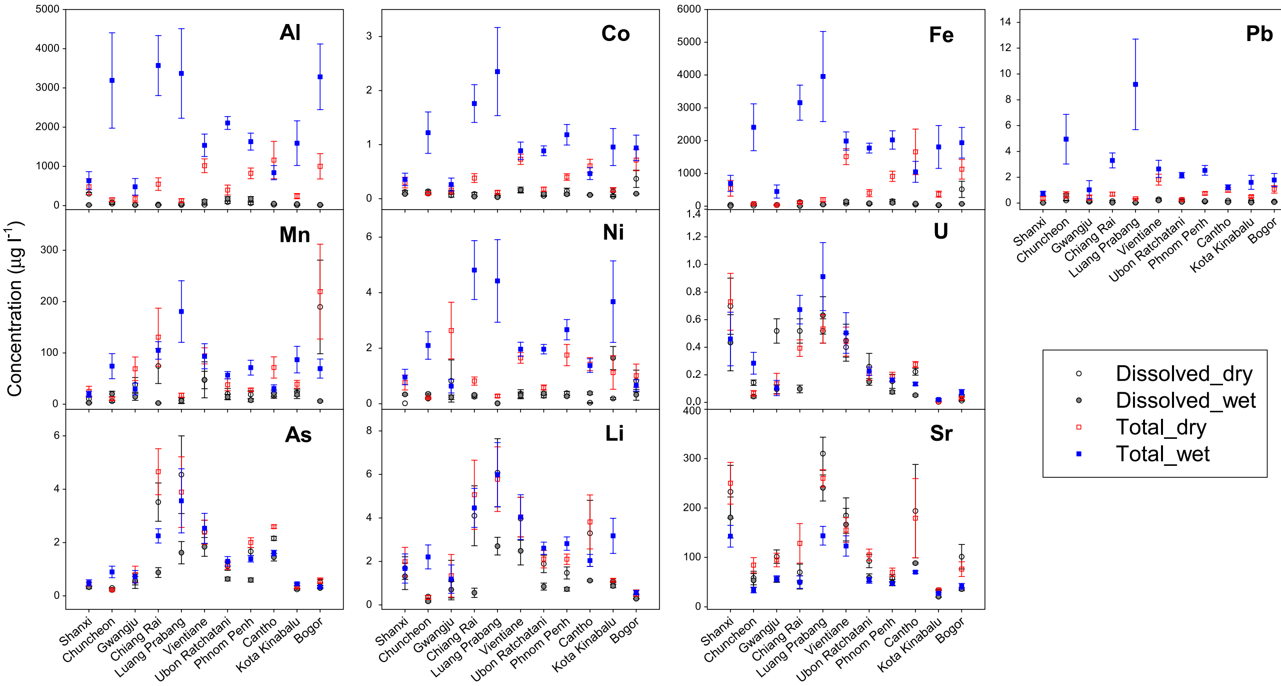

Fig. 3. Seasonal differences in mean concentrations of dissolved and total metals between dry and wet periods at 11 watersheds monitored during 2006 and 2007/2008 sampling campaigns. Error bars indicate ± 1SE.

compared to the WHO safety guideline at 10 μg l^{-1}; Fig. 3). Considering the rainfall-induced dilution of dissolved As, drier weather conditions could elevate water quality risks posed by As.

3.3. Spatio-temporal variations in water quality along the LMR

Seasonal differences in water quality were also observed along the main-stem Mekong River from the most upstream sites in Chiang Rai to the river mouth (Fig. 5). Electrical conductivity and the concentrations of Cl^- and SO_4^{2-} were lower during wet periods for both sampling years and tended to decrease toward the river mouth. At the most downstream site 15 km from the sea, however, extremely high ion concentrations were observed during dry periods, indicating the influence of seawater intrusion. Concentrations of NO_3^-, and NH_4^+ did not show any consistent seasonal patterns, pointing to the contribution of local sources to the contamination of the LMR by nutrients in agricultural and urban runoffs.

In both sampling years TSS concentrations were higher during wet periods and decreased toward the river mouth (Fig. 5). Long-term monitoring data of the Mekong River Commission (MRC) also showed decreasing TSS concentrations towards the river mouth (MRC, 2007). In some of the upstream reaches of the LMR decreasing TSS concentrations and fluxes have been observed since the early 1990s (Lu and Siew, 2006; Kummu and Varis, 2007; MRC, 2007). Sediment transport from the upper Mekong in China has been estimated to account for more than half of the annual Mekong River sediment flux to the South China Sea (Kummu and Varis, 2007). Recent decreases in TSS concentrations and fluxes have been attributed to the construction of the large cascade dams in China, which started in 1992 with the filling of the Manwan Dam (Lu and Siew, 2006; MRC, 2007). TSS concentrations at the sites of Ubon Ratchatani and Phnom Penh also showed large year-to-year variations, particularly during the monsoon period, suggesting an important role of the monsoon hydrology in sediment transport along the LMR (Fig. 5).

UVA_{254} intensity was also higher during the wet period along the LMR except the reaches downstream of Phnom Penh (Fig. 5). UVA_{254} intensities tended to decrease downward along the reaches up to Ubon Ratchatani for both seasons. Because tropical riverine DOM is exposed to strong solar radiation, changes in the amount and characteristics of DOM along large tropical rivers might be associated with photochemical degradation (Spencer et al., 2009). Along the lower reaches from Phnom Penh to the river mouth, the seasonal pattern observed for upstream reaches was either obscured or reversed, presumably due to the release of DOM from local terrestrial sources. In the case of the Mekong Delta, slightly higher UVA_{254} intensities during dry periods suggest a high rate of DOM export in drainage waters through networks of numerous canals, which deliver irrigation water from agricultural fields during the dry season (MRC, 2005).

Metal-specific seasonal patterns were observed for both dissolved and total metal concentrations along the main-stem Mekong sites (examples of As ad Pb shown in Fig. 6). Strong seasonality was found for some of the dissolved metals that comprised the bulk of total metal concentrations and were higher during dry periods, as illustrated by the case of As (Fig. 6). These metals (As, Li, and Sr) showed decreasing concentrations toward the river mouth, suggesting that higher concentrations in upstream reaches might be related to geologic sources along the upper Mekong River. Groundwater As contamination has been associated with riverine transport of As derived from eroded Himalayan sediments (Polizzotto et al., 2008). Although there has recently been considerable research on As contamination in groundwater in the Mekong floodplains in Cambodia (Buschmann et al., 2008; Polizzotto et al., 2008; Winkel et al., 2008), limited information is available about As contamination in surface waters (Martin and Meybeck, 1979; Cenci and Martin, 2004). Our results suggest that As concentrations can reach high levels close to the WHO guideline (10 μg As l^{-1}) along the upper LMR reaches during the dry season.

For the "anthrobiogeochemical metals " referring to the metals associated with human activities (Rauch and Pacyna, 2009), including Al, Cr, Cu, Fe, Ni and Pb, dissolved metals usually comprised a small fraction of total metal concentrations, as illustrate by the example of Pb (Fig. 6). Given the very low dissolved concentrations,

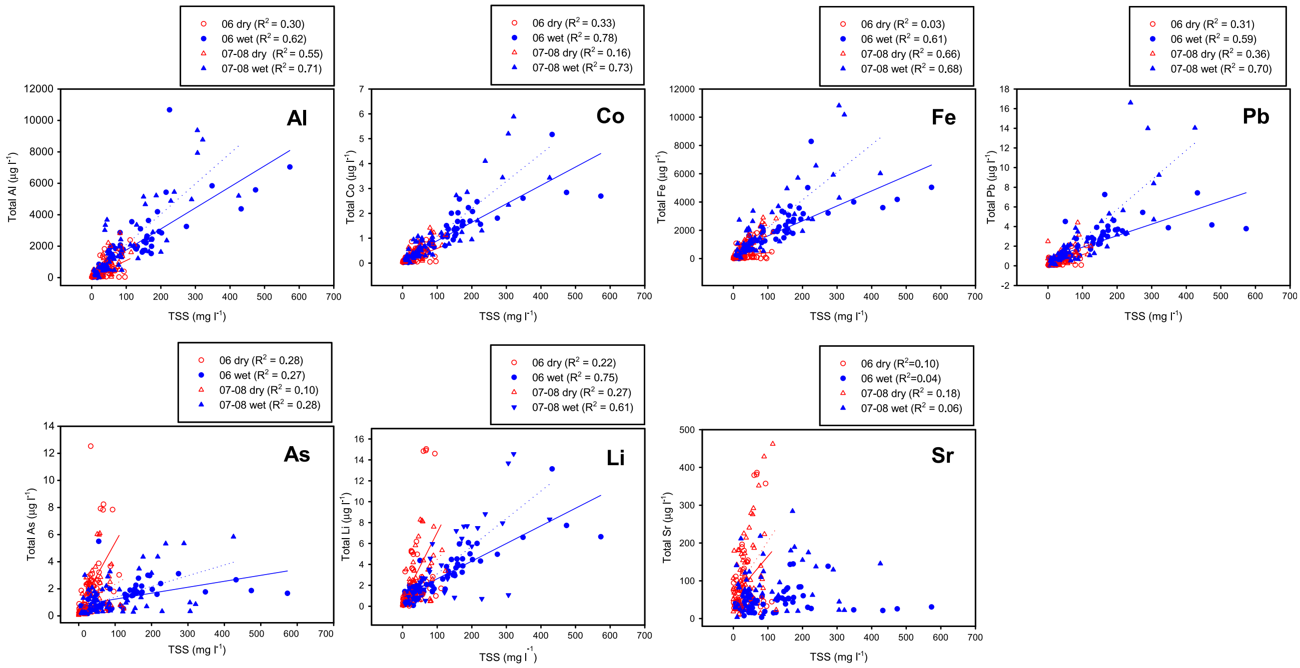

Fig. 4. Relationships between TSS and total metal concentrations during each dry or wet period of 2006 and 2007/2008 sampling campaigns. Significant positive relationships are indicated by best-fit regression lines through each plot.

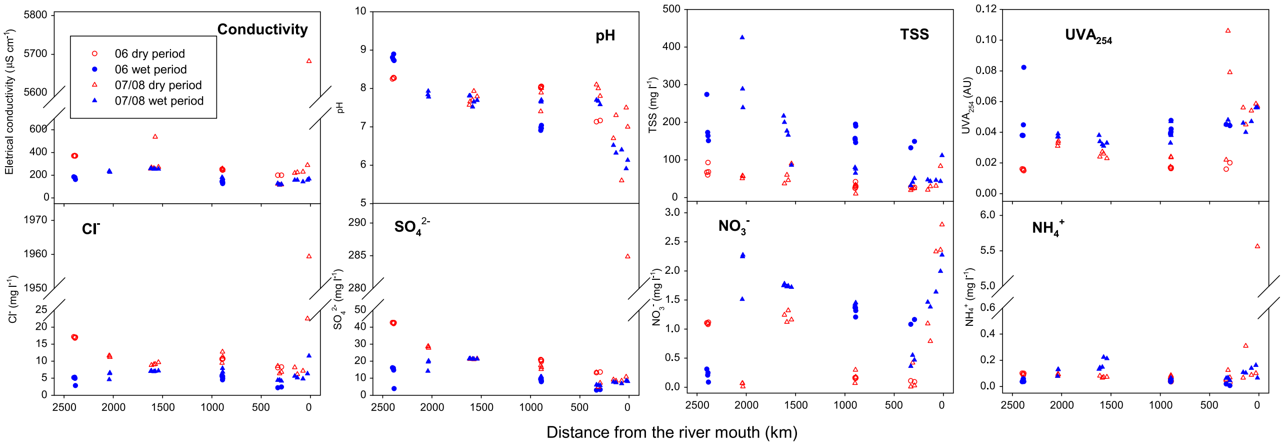

Fig. 5. Spatio-temporal variations in general water quality parameters along the LMR from Chiang Rai to the river mouth in the Mekong Delta.

relatively high total Pb concentrations in the upper reaches, particularly during the monsoon period, can be explained by rainfall-induced increases in sediment-associated metals. During the monsoon period total Pb concentrations exceeded the WHO guideline (10 µg l^{-1}) at some of Lao and Thai sites (Fig. 6). In a water quality survey conducted by MRC, elevated levels of metals were found in river bed sediments along the China-Laos border and near Luang Prabang (MRC, 2007). Although dissolved Pb concentrations tended to be higher along the Mekong Delta sites than the upper reaches, the concentrations were within the range of unpolluted rivers reported by Meybeck and Helmer (1989) and Cenci and Martin (2004).

3.4. Implications of rainfall variability for climate-induced risks to surface water quality

The results suggest that rainfall variability, either seasonal or inter-annual, is crucial in understanding both temporal variations and climate-induced risks concerning surface water quality in East Asia. Some of the measured water quality parameters such as electrical conductivity and dissolved concentrations of Cl$^-$, SO_4^{2-}, As, Li, and Sr showed higher concentrations during dry periods. These components, which usually occur more in the dissolved than in the particulate phase, might be more sensitive to extended droughts during dry periods. van Vliet and Zwolsman (2008) observed increased concentrations of dissolved metals in the Meuse River during the droughts. Drought-induced increases in the concentrations of the metals with higher partitioning to the dissolved phase as well as the chemicals released primarily from point sources were attributed to a decrease in dilution during droughts (van Vliet and Zwolsman, 2008). The riparian countries along the upper LMR have distinct differences in precipitation between the dry and monsoon seasons. Such hazardous metals as As can occur at an unusually high concentration level during extended droughts.

Another distinct pattern of seasonality was observed for suspended sediments. TSS concentrations were higher during wet

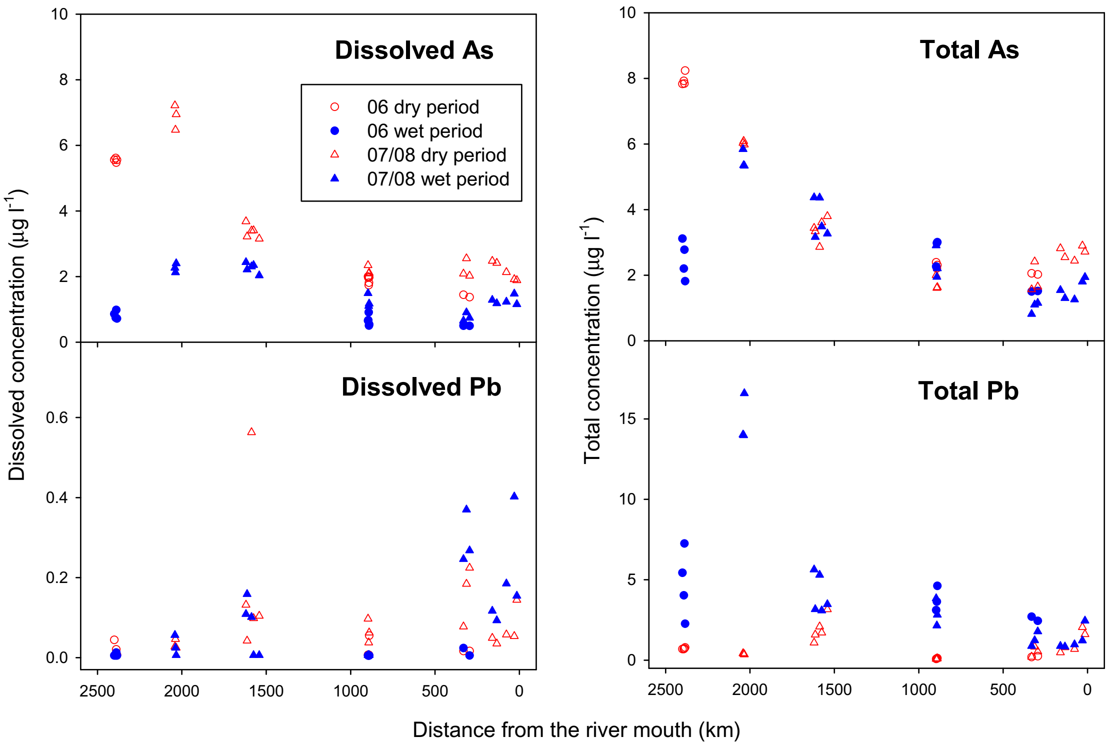

Fig. 6. Spatio-temporal variations in dissolved and total concentrations of As and Pb along the LMR from Chiang Rai to the river mouth in the Mekong Delta.

periods at most of the monitoring sites, particularly along the upper LMR, reflecting both distinct hydrologic differences between the dry and monsoon seasons and large-scale deforestation and agricultural expansion on steep terrain. By comparison, TSS concentrations were relatively low in the watersheds of China, Korea, Malaysia, and Indonesia that have more forest cover than the Mekong sites. In Kota Kinabalu, however, unusually high wet-season TSS concentrations were observed in the second wet-season sampling following a large tropical storm event, suggesting that soil erosion can pose a serious problem even in forested areas when heavy rainfalls occur in steep mountainous terrain.

Some of the measured metals, such as Al, Co, Fe, and Pb, showed much higher concentrations during the wet period and had strong positive relationships with TSS concentrations, reflecting high particulate-phase contributions. Dissolved concentrations of these metals were very low compared to total concentrations. According to current water quality criteria based on dissolved metal concentrations, the observed low dissolved concentrations are considered 'safe' to human health. However, sediment-associated metals can shift partition into the dissolved phase in response to subtle changes in environmental conditions such as pH, Eh, and DO or upon reaction with other soluble agents (Horowitz, 1991). Relatively high total Pb concentrations were observed along the upper LMR reaches near Chiang Rai and Luang Prabang. As reported by MRC (MRC, 2007), potential Pb sources associated with heavy boat traffic and rapid population growth can make the sediment–metal interactions more vulnerable to intense monsoon rainfalls.

Our results also emphasize the importance of site-specific watershed characteristics and rainfall patterns in predicting potential water quality changes in response to concurrent changes in land use and climate. Climate effects on surface water quality can be amplified through complex interactions with land use change (Kaushal et al., 2008; Park et al., 2010). Kaushal et al. (2008) used water quality data from intensive monitoring across an urbanization gradient in Baltimore to show that urban land use change can increase the vulnerability of watershed nitrate export to climate variability and extremes. Land use changes associated with rapid population and economic growth in the LMR basin can worsen soil erosion in steep mountainous terrain during the monsoon period. Suspended sediments can enhance climate-induced risks to surface water quality through their positive relationships with metals having higher particulate-phase contributions. To better understand water quality changes in response to concurrent climate and environmental changes, more research efforts need to be paid to site-specific patterns of watershed responses to climate variability and extreme hydrologic events such as droughts and intense monsoon rainfalls.

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Index B

Abstract

การพัฒนาดัชนีไดอะตอมเพื่อการติดตามตรวจสอบคุณภาพน้ำ ในลำน้ำกก จังหวัดเชียงราย

ตรัย เป๊กทอง[1]และ ยุวดี พีรพรพิศาล[2]

[1] สำนักวิชาวิทยาศาสตร์ มหาวิทยาลัยแม่ฟ้าหลวง 57100 [2] ภาควิชาชีววิทยา คณะวิทยาศาสตร์ มหาวิทยาลัยเชียงใหม่ 50200

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ไดอะตอมพื้นท้องน้ำได้ถูกนำมาใช้เป็นดัชนีความเปลี่ยนแปลงของสิ่งแวดล้อมอย่างกว้างขวางโดยเฉพาะในคุณภาพแหล่งน้ำที่เสีย ดัชนีไดอะตอม (Trophic Diatoms Indices: TDI) ถูกพัฒนาขึ้นมาใช้หลากหลายในประเทศที่พัฒนาแล้วเพื่อติดตามและตรวจสอบคุณภาพน้ำ สำหรับในประเทศไทยยังไม่มีการพัฒนาดัชนีไดอะตอมมีเพียงดัชนีแพลงก์ตอนพืช AARL-PP Score โดยพีรพรพิศาลในปี 2549 ความพยายามพัฒนาดัชนีไดอะตอมเกิดขึ้นในลำน้ำแม่สา เชียงใหม่เมื่อปี 2545 โดยผู้วิจัยเองได้ทำการศึกษาความหลากหลายทางชีวภาพและการเปลี่ยนแปลงส่วนประกอบของไดอะตอมพื้นท้องน้ำในหลาย ๆ แหล่งน้ำเพื่อความแม่นยำ งานวิจัยนี้ทำในลำน้ำกก จังหวัดเชียงรายซึ่งมีต้นกำเนิดในสหพันธรัฐเมียนมาร์ ไหลผ่านเชียงรายจากทิศตะวันตกไปทิศตะวันออกจนไปบรรจบแม่น้ำโขงที่บ้านสบกก อำเภอเชียงแสน มีความยาวทั้งสิ้น 290 กิโลเมตรโดยผ่านจังหวัดเชียงราย 114.5 กิโลเมตร ตรวจคุณภาพน้ำเดือนละครั้งตั้งแต่เดือนตุลาคม 2548-กันยายน 2549 ใช้กล้องถ่ายภาพอิเลคตรอนแบบส่องกราดเพื่อวินิจฉัยถึงระดับชนิด ใช้สถิติแบบความแปรปรวนรวมเพื่อพัฒนาดัชนีเพื่อให้ได้บัญชีรายชื่อไดอะตอมเพื่อเปรียบเทียบกันกับดัชนีแม่สา

งานวิจัยนี้ได้รับทุนสนับสนุนจากสำนักงานกองทุนสนับสนุนการวิจัย (สกว.) ทุน MRG4880164

คำสำคัญ ดัชนีไดอะตอม ไดอะตอม ไดอะตอมพื้นท้องน้ำ ดัชนีชีวภาพ ความหลากหลายทางชีวภาพ คุณภาพน้ำ แม่น้ำกก

The Developing of Trophic Diatom Index for Water Quality Monitoring in Kok River Chiang Rai Province

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Benthic diatoms have been extensively used as indicators of environmental changes such as an eutrophication in stream ecosystem. There are many Trophic Diatoms Indices (TDI) in developed countries used to monitoring water quality but not for Thailand. The first index for phytoplankton was AARL-PP score by Peerapornpisal et al in 2006. The attempt to develop TDI for Thailand was done in Mae Sa Stream, Chiang Mai in 2002 by Pekthong. Benthic diatoms diversity and their changes in composition in several rivers will be investigated to make more precision of the indices for Thailand. This research was done in Kok river which is the main river in Chiang Rai, originates from Myanmar, runs along westside of Chiang Rai through eastside, and meets Mekong River at Bann Sobkok, Chiang San District. Total length of the river is 290 km with 114.5 km runs across Chiang Rai. The water qualities were monitored once a month for one year starting from October 2005 to September 2006. The Scanning Electron Microscope (SEM) was used for the identification into species category. The Multivariate Statistical Package (MVSP) for ecological studies was employed to develop the diatoms index. A list of indicator diatoms species in Mae Kok Index will be compiled with Mae Sa Index.

This work was supported by Thailand Research Funding (TRF) grant MRG4880164

Keywords: Trophic Diatom Index, TDI, diatoms, benthic diatoms, bioindicator, biodiversity, water quality, monitoring, Kok River

Development of Trophic Diatom Index for Water Quality Monitoring in Kok River Chiang Rai Province

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Abstract

Benthic diatoms have been extensively used as indicators of environmental changes such as an eutrophication in stream ecosystem. There are many Trophic Diatoms Indices (TDI) in developed countries used to monitoring water quality but not for Thailand. The first index for phytoplankton was AARL-PP score by Peerapornpisal et al in 2006. The attempt to develop TDI for Thailand was done in Mae Sa Stream, Chiang Mai in 2002 by Pekthong. Benthic diatoms diversity and their changes in composition in several rivers will be investigated to make more precision of the indices for Thailand. This research was done in Kok river which is the main river in Chiang Rai, originates from Myanmar, runs along westside of Chiang Rai through eastside, and meets Mekong River at Bann Sobkok, Chiang San District. Total length of the river is 140 km with 114 km runs across Chiang Rai. There were 5 sampling sites with elevations between 380 – 440 meters. The water qualities were monitored once a month for one year starting from October 2005 to September 2006. Epilithic diatoms were scraped from 5-10 stones. Permanent slides of diatoms were prepared in laboratory. The Scanning Electron Microscope (SEM) was used for the identification into species category. The Multivariate Statistical Package (MVSP) for ecological studies was employed to develop the diatoms index. The two mainly used methods were Principal Correspondence Analysis (PCA) and Canonical Correspondence Analysis (CCA). Water qualities in Kok River were in mesotrophic status in most months with the exceptions of months in dry season, which were in meso-eutrophic status. A list of indicator diatoms species in Mae Kok Index will be compiled with Mae Sa Index developed by Pekthong in 2002, which groups 25 species of diatoms into indicators of (1) oligotrophic status, (2) oligo-mesotrophic status, (3) mesotrophic status, (4) meso-eutrophic status, (5) eutrophic status and (6) hyper-eutrophic status. This will improve efficiency of Trophic Diatom Index for Thailand.

Keywords: Trophic Diatom Index, TDI, diatoms, benthic diatoms, bioindicator, biodiversity, water quality, monitoring, Kok River

Outputs

1. Pekthong T, Peerapornpisal Y, Trophic Diatom Index Development for Thailand. *Chiang Mai Journal of Science*, 2007, 36, page (Manuscript)

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The Developing of Trophic Diatom Index for Water Quality Monitoring in Kok River Chiang Rai Province

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Keywords: Trophic Diatom Index, TDI, diatoms, benthic diatoms, bioindicator, biodiversity, water quality, monitoring, Kok River

Outputs

2. Pekthong T, Peerapornpisal Y, Trophic Diatom Index Development for Thailand. *Chiang Mai Journal of Science*, 2009, 36, page (Manuscript)

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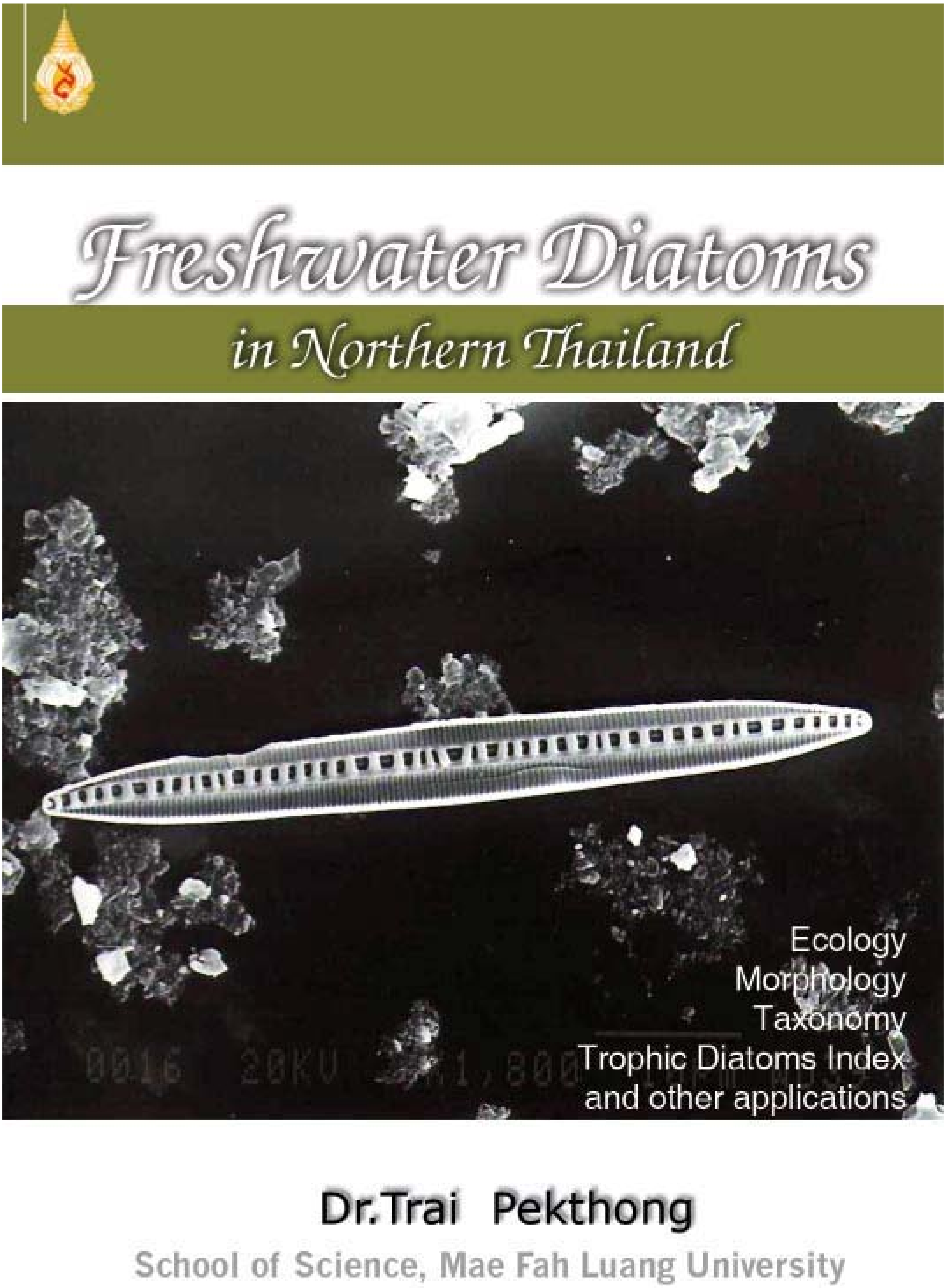
Book



หน้าปกหนังสือ Freshwater Diatoms in Northern Thailand ไดอะตอมน้ำจืดในภาคเหนือ ประเทศไทย (อยู่ในระหว่างการเตรียมต้นฉบับเพื่อจัดพิมพ์)

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ปรัชญา ศรีสง่า สุชาดา วงศ์ภาคำ วาสนา คำกวน **ตรัย เป๊กทอง** จันทรารักษ์ โตวรานนท์ ทัศนีเวศ ยะโสและสุรีย์พร นนทชัยภูมิ. 2554. พฤกษศาสตร์พื้นบ้านของชาวอาข่า หมู่บ้านห้วยหยวกป่าโซ อำเภอแม่ฟ้าหลวงและหมู่บ้านใหม่พัฒนา อำเภอแม่สรวย จังหวัดเชียงราย. วารสารพฤกษศาสตร์ไทย 3. ฉบับที่ 1. หน้า 93-114.

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Pekthong T., Waiyaka P., Peerapornpisal Y. 1999. Diversity of Phytoplankton and Benthic Algae in Mae Sa Stream, Doi Suthep-Pui National Park, Chiang Mai, Thailand. Proc. of the International Conference on Water Resources Management in Intermonatane Basins, Water Research Centre, Faculty of Science, Chiang Mai University, Thailand, 2-6 February 1999. P. 401-434.

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- Member of the National Science and Technology Development Agency (NSTDA)
- Member of the Algal and Plankton Society of Thailand
- Committee of Department of Water Resources, Ministry of Natural Resources and Environment of Thailand

Current Project

- Astaxanthin from microalgae *Haematococus pluvialis* for application in sunscreen product (Mae Fah Luang Fund)
- The Developing of Trophic Diatom Index for Water Quality Monitoring in Kok River Chiangrai Province (Thailand Research Fund: TRF: MRG4880164)
- Cultivation of the Hydrocarbon Rich Alga *Botryococcus braunii* Kützing for the Possibility to Produce Biodiesel
- Restoration of Food Resources and Biodiversity in the Highland Community (Chiang Rai Province) Highland Research and Development Institute (Public Organization) Fund: HRDI

เครื่องราชอิสริยาภรณ์: Companion (Fourth Class) of the Most Exalted Order of the White Elephant **(Last updated: August 2011)**

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2538	วท.บ. จุลชีววิทยา คณะวิทยาศาสตร์ มหาวิทยาลัยเชียงใหม่
2540	วท.ม. ชีววิทยา คณะวิทยาศาสตร์ มหาวิทยาลัยเชียงใหม่
2545	ปร.ด. ชีววิทยา (จุลชีววิทยาสิ่งแวดล้อม) คณะวิทยาศาสตร์ มหาวิทยาลัยเชียงใหม่

ทุนการศึกษา

2539	สำนักงานพัฒนาวิทยาศาสตร์และเทคโนโลยีแห่งชาติ (สวทช)
2541	โครงการพัฒนาองค์ความรู้และศึกษานโยบายการจัดการทรัพยากรชีวภาพในประเทศไทย (โครงการบีอาร์ที) รหัสทุน BRT 541079

ชื่อเรื่องวิทยานิพนธ์:

ความหลากหลายทางชีวภาพของเบนทิคไดอะตอมและการประยุกต์เพื่อติดตามตรวจสอบคุณภาพน้ำในลำน้ำแม่สา อุทยานแห่งชาติดอยสุเทพ-ปุย เชียงใหม่

ความเชี่ยวชาญ:

ชลธีวิทยาน้ำจืด อนุกรมวิธานไดอะตอมน้ำจืด ดัชนีไดอะตอม การบำบัดน้ำเสีย การวิเคราะห์คุณภาพน้ำ การติดตามตรวจสอบสิ่งแวดล้อม การประเมินผลกระทบสิ่งแวดล้อม การเพาะเลี้ยงสาหร่าย

ประสบการณ์การทำงานและฝึกอบรม:

- อาจารย์พิเศษ มหาวิทยาลัยพายัพ พ.ศ.2542-2543
- เข้าร่วมการบรรยายเชิงปฏิบัติการเรื่อง "การใช้ไดอะตอมในการติดตามตรวจสอบสิ่งแวดล้อม" ณ มหาวิทยาลัยอินส์บรูค ประเทศออสเตรีย 3–11 พฤศจิกายน พ.ศ.2540
- เข้าร่วมการประชุมเอเชียแปซิฟิกครั้งที่ 4 เทคโนโลยีชีวภาพสาหร่าย ณ เขตปกครองพิเศษฮ่องกง 3-6 กรกฎาคม พ.ศ.2543
- ฝึกอบรมระยะสั้น ณ พิพิธภัณฑ์แห่งชาติ กรุงลอนดอน ประเทศสหราชอาณาจักร 7–18 พฤษภาคม พ.ศ.2544
- ฝึกอบรมระยะสั้น ณ ภาควิชาวิทยาศาสตร์ชีวภาพ มหาวิทยาลัยเอสเสกซ์ ประเทศสหราชอาณาจักร 21 พฤษภาคม–5 มิถุนายน 2544
- ฝึกอบรมการเป็นวิทยากรโครงการเรียนรู้และสำรวจโลกเพื่อยังประโยชน์แก่สิ่งแวดล้อม (GLOBE) ณ มหาวิทยาลัยไวกาโต ประเทศนิวซีแลนด์ 13–22 มกราคม พ.ศ.2546

ผลงานตีพิมพ์:

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โครงการในปัจจุบัน:

- แอสตาแซนธินจากสาหร่ายสายพันธุ์ *Haematococus pluvialis* เพื่อประยุกต์ใช้ในผลิตภัณฑ์ป้องกันแสงแดด (ทุนจากมหาวิทยาลัยแม่ฟ้าหลวง)
- การพัฒนาดัชนีไดอะตอมเพื่อการติดตามตรวจสอบคุณภาพน้ำในลำน้ำกก จังหวัดเชียงราย (สำนักงานกองทุนสนับสนุนการวิจัย: สกว. รหัสทุน MRG4880164)
- การเพาะเลี้ยงสาหร่าย *Botryococcus braunii* Kützing เพื่อศึกษาความเป็นไปได้ในการนำมาผลิตไบโอดีเซล
- โครงการวิจัยการฟื้นฟูแหล่งอาหารและความหลากหลายทางชีวภาพของชุมชน จ. เชียงราย ทุนจากสถาบันวิจัยและพัฒนาพื้นที่สูง (องค์การมหาชน)

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