

THE ASSESSMENT OF WATER QUALITY IN THE UPPER PART OF THE CHI BASIN USING PHYSICOCHEMICAL VARIABLES AND BENTHIC MACROINVERTEBRATES

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Abstract

The purpose of this research was to assess water quality using physicochemical measurements and benthic macroinvertebrates in the upper part of the Chi basin. Ten sampling sites were established along the river course. Physicochemical and biological properties were measured bimonthly. Twelve physicochemical variables of water quality were examined and analyzed. The benthic macroinvertebrates were collected by rectangular dip net kicking samples from February to December 2004. BMWP^{Thai} score, ASPT, and HBI index were used to assess water quality. Relationships between sampling sites and between seasons were analyzed by analysis of variance (ANOVA). Using of water quality standard of Thailand, the results showed that the water quality of the upper part of the Chi basin was in class 2-class 3 of the water quality standard which the condition and beneficial usage of water quality was very clean freshwater resources - medium clean freshwater resources. However, according to statistical analysis, these physicochemical variables were not significantly different. Benthic macroinvertebrates of 8 orders and 25 families were found. The most abundant order was Odonata and the most abundant family was Gomphidae. The water quality assessed by ASPT index agreed with the water quality assessed by physicochemical variables. Whereas, the HBI index was not related to physicochemical variables in most sites.

Keywords: Chi basin, benthic macroinvertebrates, physicochemical variables

Introduction

The Chi river, which is the longest river in Thailand (about 765 km), rises in the central mountain range and runs eastward through the northeastern region of the country. The river passes through 12 provinces; namely, Phetchabun, Chaiyaphum, Nakhon Ratchasima,

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Loei, Nong Bua Lam Phu, Udon Thani, Khon Kaen, Maha Sarakham, Kalasin, Roi Et, and Yasothon to meet another river, the Mun, in Ubon Ratchathani before entering the Mekong river in Ubon Ratchathani. The Chi basin is bordered to the North by the Mekong river basin, to the South by the Mun basin, to the East by the Mekong and the Mun river basins, and to the West by the Pasak basin (Ministry of Natural Resources and Environment, Department of Water Resource, 2006a) (Figure 1). With a capacity of 9300 km³ of water per year, the Chi river serves about 6590000 people for consumption, and for agricultural and industrial activities (Ministry of Natural Resources and Environment, Department of Water Resource, 2006b). Recently, the quality of water in the upper part of Chi basin has been fairly poor. The poor quality was caused by waste water from community, industrial factories and agriculture, which was not treated. Consequently, the amount of BOD, ammonia – nitrogen was high but the amount of dissolved oxygen was low (Environmental Office Region 10, 2005). The problem is spreading out along the watercourse in the watershed. Previously, the water quality of the Chi river has been measured and analyzed. It was found that the most water quality in the upper part of Chi basin was in class 3 representing medium clean freshwater resources (Environmental Office Region 10, 2005).

The water quality at different places along the river should differ in their physicochemical variables that could affect benthic macroinvertebrate diversity and communities. However, the relationships between physicochemical and biological data such as benthic fauna have not been studied. Thus, the objectives of this research are 1) to assess water quality using physicochemical measurements and benthic macroinvertebrates, 2) to examine the relationships between water quality and benthic macroinvertebrates.

Study Sites

The upper part of the Chi basin includes areas of Chaiyaphum, Nakhon Ratchasima,

Phetchabun, Loei, Udon Thani, Nong Bua Lam Phu, and Khon Kaen provinces (Ministry of Natural Resources and Environment, 2003). The water from ten sampling sites with different land use was investigated to find the impact on water quality and benthic macro invertebrates (Figure 1 and Table 1).

Methodology

Physicochemical Parameter Measurement

The physicochemical parameters and procedure measurement are summarized in Table 2. Six replicates of the water samples were collected from each sampling sites by using water sampler at 1 m depth. The water temperature, electrical conductivity, water velocity, dissolved oxygen and pH were measured at the sampling sites. The other parameters were examined in the laboratory. The water samples were collected bimonthly from February to December 2004, and analyzed in the laboratory at Suranaree University of Technology.



Figure 1. The upper part of Chi basin and 10 sampling sites

Table 1. Sampling sites in upper part of the Chi basin

Site	Site name	Location (district/province)	Elevation (Ft.)	Geographic position	Substrate and landuse
1	Ban Tad Ton	Muang/Chaiyaphum	670	102° 00' 02'' E 15° 57' 2'' N	The area is close to Tad Ton National park, which is near a cassava farm, the banks of the Chi River covered by bamboo forest; silt and clay substrate.
2	Ban Huai Hai	Ban Khwao/Chaiyaphum	722	101° 43' 3'' E 15° 51' 36'' N	The higher area is covered by decadent forest and cassava farm; sandy substrate.
3	Ban Non Pluai	Nong Bua Rawe/Chaiyaphum	640	101° 50' 48'' E 15° 46' 06'' N	Both sides of the bank are covered with the bushes, grass land and a cassava farm respectively. Most substrate in the bottom part of the sampling Site 3 is sandy.
4	Ban Non Pho	Ban Khwao/Chaiyaphum	641	101° 52' 41'' E 15° 41' 52'' N	Most area is rice farm, the left side of the bank is covered by the bamboo forest, but the right side of the bank is covered with tree, shrub and grass. The high slope of bank is eroded by water discharge. Most substrate in the bottom part of the sampling Site 4 is sandy with rotten leaves.
5	Ban Khai	Muang/Chaiyaphum	617	102° 00' 55'' E 15° 41' 15'' N	Both sides of the bank is covered by the bamboo forest and rice filed. Most area is covered with muddy soil and rotten leaves.
6	Ban Kaeng Kham	Kaeng Sanam Nang/Nakhon Ratchasima	585	102° 15' 12'' E 15° 51' 13'' N	The right bank is covered with the shrub and grass. The left bank is covered with few trees because of its hard soil. Most soil in the bottom part of the sampling Site 6 is sandy and there is water grass on the left bank.
7	Ban Yang Wai	Khon Sawan/Chaiyaphum	562	102° 19' 09'' E 15° 51' 13'' N	The right bank is covered with a lot of trees and shrubs, but the left bank is covered with bamboo forest and water grass. Most substrate in the bottom part is muddy sand, and the rice filed is next to the bank.
8	Ban Tanang Luan	Chonnabot/ Khon Kaen	532	102° 34' 39'' E 16° 05' 37'' N	Some parts of the right bank is covered with bamboo forest and grass. Whereas, the left bank is covered with trees and herbs. Most substrate in the bottom part is muddy sand, and the rice filed is next to the bank.

Table 1. (continued)

Site	Site name	Location (district/province)	Elevation (Ft.)	Geographic position	Substrate and landuse
9	Ban Non Som boon	Ban Haet/ Khon Kaen	509	102° 46' 44'' E 16° 16' 26'' N	The right bank is covered with shrubs, grass and rice filed. Whereas, some part of the left bank is covered with herbs and there are communities in the area. Most substrate in the bottom part is muddy sand. There is fishing farm around the area.
10	Ban Tha Pra	Muang/Khon Kaen	503	102° 48' 11'' E 16° 21' 04'' N	Both sides of the bank are covered by the shrubs and water grass and there are communities in both sides of the bank. Most area is covered with muddy sand.

Table 2. Physiochemical parameters and measurement

Parameter	Unit	Procedure
Water temperature ¹	°C	Multi-parameter analyzer (Consort C533 version 2.2)
Electrical conductivity ¹	µS/cm	Multi-parameter analyzer (Consort C533 version 2.2)
Turbidity ²	NTU	Turbidimeter (Hack company model 2100 A)
Water velocity ²	m/s	The average times (Noland, 2001)
pH ¹	-	Multi-parameter analyzer (Consort C533 version 2.2)
Alkalinity ²	mg/L as CaCO ₃	Phenolphthalein and methyl orange indicator (APHA, 1998)
Water hardness ²	mg/L as CaCO ₃	EDTA titration method (APHA, 1998)
Nitrate-nitrogen ²	mg/L	Cadmium reduction method (APHA, 1998)
Ammonia-nitrogen ²	mg/L	Nesslerization technique (APHA, 1998)
Phosphate ²	mg/L	Ascorbic acid method (APHA, 1998)
Dissolved oxygen ¹	mg/L	Multi-parameter analyzer Consort C533 version 2.2
Biochemical oxygen demand ²	mg/L	Azide modification method (APHA, 1998)

¹ measured at the sampling sites² examined in the laboratory

Biological Sampling

The study area was an upper part of the Chi River, running through Chiayaphum, Nakhon Ratchasima, and Khon Kaen, where

two dams were built to save water for agricultural purpose and consumption. One was built in Chonabot District, Khon Kaen Province, and

the other was built in Kosumphisai District, Maha sarakham Province. People who live near the Chi River also built reservoirs for water consumption in community. At each site, the sampling zones were delineated for 100 m in length on both sides of the river. Six replicates of sample were collected using a rectangular dip net.

A rectangular dip net of 40 x 60 cm and 595 m of mesh size (Greenberg *et al.*, 1992) was used to collect benthic macroinvertebrates. Sampling began at the downstream end of the reach and proceeded upstream. The sampler disturbed the streambed by dredge a long streambed while holding a collecting net down-current. Benthic sample was collected in the net as the sampler moved upstream. The samples were placed in a collecting box and preserved with 70 ethanol. They were sorted and their family identified following Merritt and Cummins (1996) McCafferty (1998); and Dudgeon (1999).

Biological Matrix

The Hilsenhoff Biotic Index (HBI) was estimated to reflect the nutrient status of the streams by using the tolerance of organisms to pollution. The equation is; (Citizens' Environment water, 2002)

$$HBI = \sum \frac{n_i a_i}{N}$$

where n_i = number of individuals within a taxon

a_i = tolerance value of that taxon

N = total number of organisms in the sample

Tolerance values range from 0 for organisms very intolerant of pollution to 10 for organisms tolerant of pollution.

The Biological Monitoring Working Party Thailand (BMWP^{Thai}) score and the Average Score per Taxon (ASPT^{Thai}) (Mustow, 2002) were calculated for the particular taxa according to their known sensitivity and tolerance to organic pollution.

$$BMWP^{Thai} = \sum a_i$$

where a_i = tolerance value score of that taxon

$$ASPT = \frac{BMWP^{Thai}}{N}$$

where N = the number of taxa used in its calculation

Statistical Analyses

The physicochemical parameters and biological data were analyzed by using the Statistical Program for Social Science (SPSS) version 11.5 to perform the following statistical analyses; Mean and Standard Deviation for water quality; (ANOVA) for the water quality; Principal Component Analysis (PCA) for the relative proportion of benthic macroinvertebrate orders to water quality and physicochemical factors to biological indices.

Results and Discussion

The physicochemical factors, p values and the relationships of physicochemical factors, benthic macroinvertebrates and biological indices were shown in Table 3 and Table 4.

Physicochemical Parameter

Mean of water temperature ranged from $27.3 \pm 0.9^{\circ}\text{C}$ to $30.4 \pm 1.7^{\circ}\text{C}$. The maximum mean of water temperature was $30.4 \pm 1.7^{\circ}\text{C}$ at Site 8, but the minimum was $27.3 \pm 0.9^{\circ}\text{C}$ at Site 1 (Table 3). It was not significantly different between sites ($p < 0.05$). The mean of water temperature was related to families Libellulidae, Naucoridae and Macromiidae accordance with the PCA analysis (Figure 2).

Mean of turbidity ranged from 3.1 ± 1.3 to 39.6 ± 27.2 Nephelometric Turbidity Units (NTU). The highest level was measured at Site 3 while the lowest level was measured at Site 1. However, it was not significantly difference ($p < 0.05$) between sites (Table 3). Site 1 tended to have lower turbidity than

Table 3. Mean of physicochemical factors and biological indices in the upper part of Chi basin from February to December 2004

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	mean	P
Temperature	27.3±0.9	28.6±1.3	28.7±1.1	28.7±1.2	27.6±1.6	28.7±1.7	29.1±1.9	30.4±1.7	28.8±1.6	28.1±1.5	28.6±0.45	0.97
Turbidity	3.1±1.3	28.7±24.3	39.6±27.2	16.3±8.4	17.6±7.2	14.9±9.2	20.1±10.9	30.3±15.9	32.9±22.4	36.1±28.2	24±5.4	0.93
EC	54.7±25.4	259.8±29.9	254.6±34.4	426.8±129.6	605.2±148.8	718.3±155.4	755.9±158.1	596.3±129.5	687.5±129.4	500.6±78.1	486.0±43.9	0.00
Velocity	0.5±0.3	0.6±0.4	0.14±0.0	0.15±0.0	0.48±0.3	0.07±0.0	0.07±0.0	0.4±0.3	0.1±0.1	0.06±0.0	0.27±0.17	0.63
PH	6.7±0.2	7.3±0.1	7.4±0.2	7.4±0.1	7.3±0.1	7.2±0.1	7.4±0.1	7.2±0.1	7.4±0.2	7.5±0.3	7.3±0.1	0.07
Hardness*	78.8±17.1	157.9±14.1	140.4±15.8	149.2±14.9	150.7±22.2	157.9±21.6	135.7±21.6	113.2±14.7	116.7±16.0	99.0±15.6	129.9±6.1	0.03
Alkalinity	25.2±2.3	29.2±3.0	27.0±2.9	28.2±2.8	25.6±3.2	25.4±3.5	25.5±0.8	23.1±2.8	22.9±2.5	23.1±2.4	25.5±0.8	0.82
DO	6.1±0.4	6.2±0.6	5.6±0.5	5.6±0.2	5.6±0.3	5.1±0.3	5.7±0.7	5.1±0.3	5.9±1.2	5.6±0.5	5.7±0.2	0.96
BOD	1.4±0.1	1.8±0.4	1.8±0.3	1.7±0.4	1.5±0.2	2.0±0.3	2.7±0.4	2.2±0.4	2.72±4.9	3.3±0.7	2.6±0.5	0.34
Phosphat	0.01±0.0	0.02±0.2	0.02±0.0	0.01±0.2	0.02±0.0	0.02±0.0	0.2±0.1	0.02±0.3	0.03±0.0	0.02±0.1	0.02±0.1	0.99
Nitrate	0.02±0.1	0.1±0.0	0.2±0.2	0.2±0.0	0.1±0.1	0.1±0.2	0.2±0.3	0.2±0.0	0.2±0.2	0.02±0.0	0.2±0.1	0.82
Ammonia	0.5±0.5	0.1±0.0	0.2±0.1	0.2±0.0	0.2±0.1	0.1±0.0	0.2±0.0	0.2±0.1	0.2±0.1	0.1±0.1	0.2±0.0	0.59
HBI	3.49±1.0	3.578±1.5	4.39±0.9	5.44±2.4	4.71±1.3	5.76±1.4	4.92±1.8	5.59±2.6	5.59±2.6	6.91±1.2	4.83±1.89	0.54
ASPT	5.61±0.3	5.94±2.4	5.70±1.1	5.56±2.3	5.71±0.2	5.41±0.5	5.43±0.4	5.56±2.3	5.68±0.1	5.61±0.1	5.35±1.32	0.83

n = 6 replicates at each site, * *p* < 0.05 significant difference between sites and seasons

Table 4. The number of macroinvertebrates families and interpretation of biological indice values in the upper part of Chi basin (Combined results of 6 collecting trips)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	Total
Hydrometridae	-	-	-	-	-	-	1	-	-	-	1
Nepidae	36	15	19	44	43	49	62	53	57	59	437
Naucoridae	-	-	1	1	-	-	8	2	1	3	16
Notonectidae	-	-	-	-	2	4	8	1	3	2	20
Macromiidae	8	28	3	7	10	-	6	4	-	7	23
Gomphidae	42	109	201	39	62	44	12	55	25	12	601
Chlorocyphidae	6	11	4	13	4	2	3	1	-	8	52
Coenagrionidae	15	24	11	24	35	28	33	13	63	54	300
Libellulidae	3	11	-	-	-	-	23	-	-	-	27
Cordulidae	19	47	4	7	21	-	28	14	17	5	162
Protoneuridae	-	2	-	-	-	2	1	-	-	-	5
Petaluridae	-	2	-	-	7	-	-	-	-	-	9
Aeshnidae	5	-	-	-	-	-	13	1	8	6	33
Lestidae	1	-	-	-	-	-	-	-	-	7	8
Cordulegastidae	1	-	-	-	-	-	-	-	-	-	1
Corallanidae	-	-	3	1	1	7	-	10	-	8	30
Cirolanidae	-	-	-	1	8	-	1	-	-	-	10
Corbiculidae	-	-	-	1	-	2	1	-	-	-	4
Bithyniidae	-	-	-	3	-	1	-	-	1	-	5
Mysidacea	-	-	-	-	2	2	-	-	-	2	6
Heptageniidae	9	5	12	2	4	5	1	-	-	10	48
Leuctridae	-	-	-	-	-	-	-	-	-	1	1
Leptoceridae	6	-	-	-	-	-	-	-	-	-	6
Heptageniidae	-	-	-	2	-	-	-	-	-	-	2
Baetidae	-	-	-	-	-	-	-	4	-	-	4
Total	151	244	258	145	199	146	201	158	175	184	1861
ASPT ^{Thai}	Moderate	Fairly good	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	
HBI	Excellent	Excellent	Very good	Good	Good	Fair	Good	Fair	Fair	Fair poor	

C = Sampling Sites

ASPT^{Thai} Average Score per Taxon Index (Mustow, 2002)

HBI Hilsenhoff Biotic Index (Citizen's Environment water, 2002)

other sites because the banks of the river is sandstorm. Therefore, this site was low suspended solid. Turbidity was related to families Nepidae and Corallanidae accordance with the PCA analysis (Figure 2).

Mean of electrical conductivity (EC) ranged between 54.7 ± 25.4 to 755.9 ± 158.1 $\mu\text{S}/\text{cm}$. The highest mean of electrical conductivity was measured at Site 7, whereas the lowest mean of electrical conductivity was measured at Site 1 (Table 3). The mean of electrical conductivity was significantly different between sites ($p < 0.05$). The highest electrical conductivity was caused by the high rate of soil erosion and that many ions were dissolved in the water. Moreover, the electrical conductivity was affected by the impacts of human activities such as agriculture, the raising of livestock and the discharge of urban wastewaters (Chiangthong, 2005) The mean of electrical

conductivity was not related to any families accordance with the PCA analysis (Figure 2).

Mean of water velocity varied from 0.06 ± 0.0 to 0.60 ± 0.4 m/sec. The fastest water velocity was measured at Site 2 and the slowest water velocity was measured at Sites 10. It was not significantly difference between sites ($p < 0.05$). The slowest velocity at Site 10 is explained by several dams upstream. Water velocity was related to families Gomphidae, Macromiidae, Chlorocyphidae and Protoneturidae accordance with the PCA analysis (Figure 2). Water velocity was a important property of water quality in running water. Therefore, water velocity had affected aquatic insects directly.

Mean of pH ranged between 6.7 ± 0.2 to 7.5 ± 0.3 . The highest value was measured at Site 10 and the lowest value was measured at Site 1 (Table 3). It was not significantly

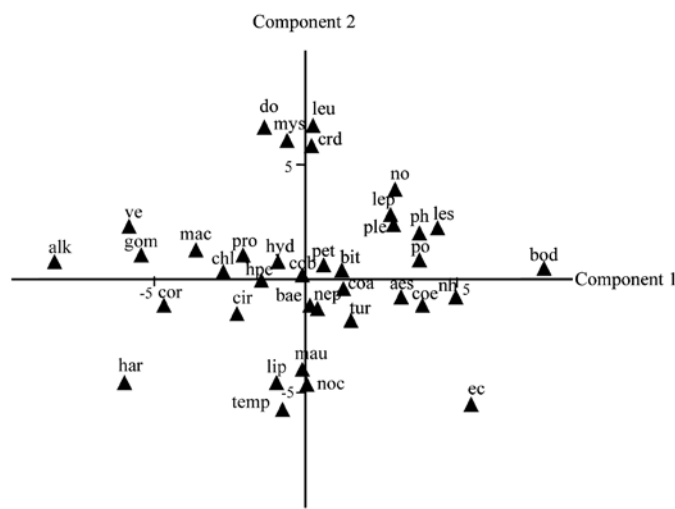


Figure 2. The relationship between physicochemical factors and benthic macroinvertebrate families in the upper part of Chi basin (nh = Ammonia, do = Dissolved Oxygen, alk = Alkalinity, ve = Velocity, no = Nitrate, po = Phosphate, har = Hardness, ec = Electrical Conductivity, tur = Turbidity, bod = Biochemical Oxygen Demand, temp = Temperature, ph = pH, mys = Mysidacea, leu = Leuctridae, crd = Corduliidae, gom = Gomphidae, mac = Macromiidae, chl = Chlorocyphidae, pro = Protoneuridae, hyd = Hydrometridae, hpe = Heptageniidae, cob = Corbiculidae, pet = Petaluridae, bit = Bithyniidae, cor = Corduliidae, cir = Cirolanidae, bae = Baetidae, nep = Nepidae, coa = Corallanidae, aes = Aeshnidae, coe = Coenagrionidae, nau = Naucoridae, lib = Libellulidae, noc = Notonectidae, Ple = Pleuroceridae, Lep = Leptoceridae)

different between sites ($p < 0.05$). The results at Site 1 (Ban Tad Ton) was lower than other sites because Site 1 is the headwater and covered with extensive trees. The trees take up and store, either in their foliage and wood or in the refractory litter that accumulates under them, much of the small stock of action in upland soils. In their doing so, hydrogen ions (H^+) must be released to maintain electrical conductivity (Moss, 1998). Generally pH increased from the headwaters to the lower reaches of river systems and from the bottom to the surface of lakes (Ward, 1992). pH was related to families Lestidae, Pleuroceridae accordance with the PCA analysis (Figure 2).

Mean of hardness ranged from 78.8 ± 17.1 to 157.9 ± 14.1 mg/L as Calcium carbonate ($CaCO_3$). The lowest value was measured at Site 1 and the highest value was measured at Site 7 (Table 3). The results showed a significant difference between sites ($p < 0.05$). The water hardness had impact on species and abundance of aquatic organisms (Pongswat, 2002).

Mean of alkalinity varied from 22.9 ± 2.5 to 29.2 ± 3.0 mg/L as $CaCO_3$. The highest value was measured at Site 2 and the lowest value was measured at Site 9 (Table 3). At Site 1 (Tad Ton), the alkalinity values were lower than other sampling sites because of this sampling site was covered with bamboo forest. Therefore, the water had several weak acids such as humic and fulmic acid. Therefore, the alkalinity was low in this sampling site. Ward (1992) concluded that densities of Diptera and Coleoptera were not significantly correlated with alkalinity.

Mean of dissolved oxygen (DO) varied from 5.1 ± 0.3 to 6.2 ± 0.6 mg/L. The highest level was measured at Site 2 and the lowest level was measured at Site 6 (Table 3). There was no significant difference between sites ($p < 0.05$). In the turbulent, well-mixed waters of upland streams, dissolved oxygen concentrations are usually near saturation levels. As these turbulent reaches gradually give way to more poorly mixed waters downstream (Ward, 1992). Dissolved oxygen was related to families Mysidacea, Leuctridae

and Corduliidae (Figure 2). Accordance with the PCA analysis.

Mean of biochemical oxygen demand (BOD) ranged from 1.4 ± 0.1 to 3.3 ± 0.7 mg/L. The lowest value was measured at Site 2 and the highest value was measured at Site 10 (Table 3). The results showed no significant difference between sites ($p < 0.05$). The BOD increased slightly from Site 1 to Site 10. BOD values at the upstream sites were lower than other sampling sites according to the lower organic substances (Griffiths, 1999).

Mean of phosphate varied from 0.01 ± 0.0 to 0.20 ± 0.1 mg/L. The lowest value was measured at Site 1 and the highest value was measured at Site 7 (Table 3). There was no significant difference between sites ($p < 0.05$). This suggested a low concentration of phosphate in all sampling sites throughout the year (Meybeck, 1982). Additionally, Chapman and Kimstach (1996) reported that in most natural surface waters, phosphorus ranged from $0.005 - 0.020$ mg/L. Phosphate was related to family Aeshnidae (Figure 2). Accordance with the PCA analysis.

Mean of nitrate concentration ranged from 0.1 ± 0.0 to 0.2 ± 0.3 mg/L. The highest value were measured at Site 1, 3, 4, 7, 8, 9, and the lowest value were measured at Site 2, 5, 6 (Table 3). There was no significant difference between sites ($p < 0.05$). The nitrate concentrations of surface water was less than 1 mg/L. When concentration is excess 5 mg/L indicated pollution by human or animal waste or fertilizer runoff (Chapman and Kimstach, 1996). Nitrate was related to family Pleuroceridae and Leptoceridae (Figure 2). Accordance with the PCA analysis.

Mean of ammonia concentration ranged from 0.1 ± 0.00 to 0.5 ± 0.5 mg/L. The highest level was measured at Site 1 and the lowest level were measured at Site 2, 6, 10 (Table 3). The concentration of ammonia was low in all sampling sites throughout the year. It showed no significant difference between sampling sites ($p > 0.05$). Similarly; Chapman and Kimstach (1996) state that natural waters contained small amounts of ammonia

compounds, usually less than 0.1 mg/L. Ammonia was related to family Coenagrionidae (Figure 2). Accordance with the PCA analysis.

Biological Properties

Benthic Macroinvertebrates

One thousand eight hundred and sixty-one individual benthic macroinvertebrates belonging to 8 orders and 25 families were collected from the upper part of the Chi basin. Order Odonata was the most dominant group which included ten families and 1,346 individuals or approximately 71.05% of the total macroinvertebrates. Which regard to the water quality from ten sampling sites assessed by benthic macroinvertebrate, the benthic macroinvertebrates found in this study were the following: Site 1, 10 families of Site 2, 9 families of Site 3, 13 families of Site 4, 11 families of Site 5, 12 families of Site 6, 14 families of Site 7, 11 families of Site 8, 8 families of Site 9, and 14 families of Site 10. The range of family numbers was 8 to 14 families (Table 4). According to the mesh

size, the tiny size (smaller than 500 μm) of benthic macroinvertebrates were not be collected.

HBI

The mean of HBI ranged from 3.49 ± 1.0 to 6.91 ± 1.2 . The highest value was found at Site 10, while the lowest value was found at Site 1 (Table 3). The results showed no significant difference between sites ($P < 0.05$). The HBI revealed water quality from fair to excellent. The water quality at Site 1 and Site 2 were excellent, while that from Sites 8 to 10 can be assigned to fair-fairly-poor. The HBI agreed with the water quality assessed by physicochemical parameters. The HBI was related to pH and biochemical oxygen demand (Figure 3). Accordance with the PCA analysis.

BMWP^{Thai} Score and ASPT

The ASPT varied from 5.41 ± 0.5 to 5.94 ± 2.4 . The highest value was found at Site 3, and the lowest value was found at Site 3 (Table 3). The water quality was assigned to moderate-fairly poor. The results showed no

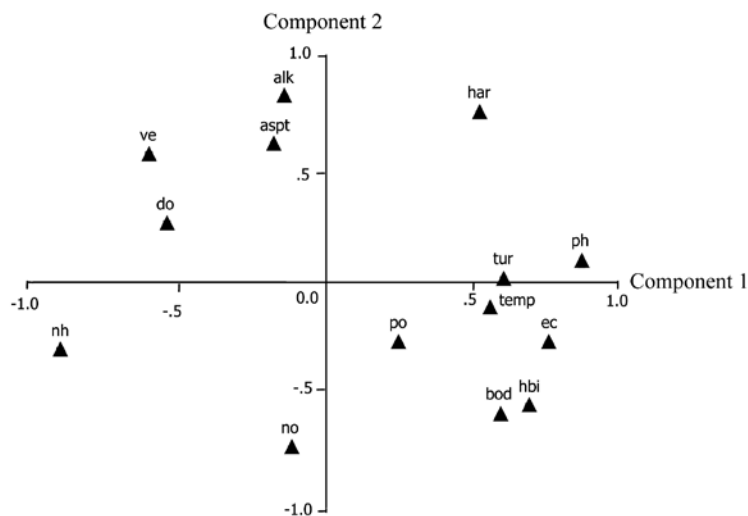


Figure 3. The relationship between physicochemical factors and biological indices in the upper part of Chi basin (ph = pH, temp = Temperature, bod = Biochemical Oxygen Demand, tur = Turbidity, ec = Electrical Conductivity, har = Hardness, alk = Alkalinity, po = Phosphate, no = Nitrate, ve = Velocity, do = Dissolved Oxygen, nh = Ammonia, hbi = Hilsenhoff Biotic Index, aspt = Average Score per Taxon)

significant difference between sites ($p < 0.05$). The ASPT index agreed with the water quality assessed by physicochemicals analyses (Table 4). Similarly, Keawkhao (2007) reported that the BMWP^{Thai} score and ASPT which had been developed in the Ping river could be employed for rapid assessment in the Thachin river because it did not alter the way in which the sites were classified, was easy to use, and was less costly.

Statistical Analysis

The physicochemical factors analyzed by using PCA were assessed to find the relationship between benthic macroinvertebrate families and water quality. The results show that family Mysidacea had relationships with dissolved oxygen, and Libellulidae, Naucoridae had relationships with temperature. Velocity was related to families Gomphidae, Macromiidae, Chlorocyphidae and Protoneuridae. pH was related to families Lestidae, Pleuroceridae (Figure 2). The PCA analysis shows the relationship between physicochemical factors and biological indices. The results reveal that the ASPT index and biotic index were related to dissolved oxygen velocity and alkalinity. Whereas, the HBI was related to biochemical oxygen demand, pH, electrical conductivity and phosphate. According to the PCA plot (Figure. 3) and data in table 4, the two indices were not related to each other. The reason of this unrelated result could be focused on the different origins of both indices which HBI was from North America, while the ASPT was developed for Thai rivers.

Conclusions

This research is a study of water quality in the upper part of the Chi basin from February to December 2004 using physicochemical data and benthic macroinvertebrates. The water samples were collected bimonthly from February to December 2004 and analyzed in the laboratory. Based on this experiment, it could be concluded that using the water quality to compare with the Water Quality Standard of Thailand using dissolved oxygen, pH, nitrate, ammonia and BOD variables, the

upper part of Chi river basin was in class 2 – class 3 of the water quality standard which the condition and beneficial usage of water quality was very clean freshwater resources - medium clean freshwater resources. However, according to statistical analysis, these physicochemical variables were not significantly different. Benthic Macroinvertebrates and biological index could be used in assessment water quality. The water quality assessed by ASPT index agreed with the water quality assessed by physicochemical variables. Whereas, the HBI index was not related to physicochemical variables in most sites, according to the different origin of index.

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