Available online www.ijpras.com

International Journal of Pharmaceutical Research & Allied Sciences, 2017, 6(1):89-98

Research Article

ISSN : 2277-3657
CODEN(USA) : IJPRPM

The Use of Biotic Indices for Evaluation of Water Quality in the Streams, Western Thailand

Makaporn Deemool, Taeng On Prommi*

Faculty of Liberal Arts and Science, Kasetsart University, Kamphaeng Saen Campus, Nakhon Pathom, 73140, THAILAND

**Correspondence: faastop@ku.ac.th*

ABSTRACT

The biodiversity of benthic macroinvertebrates was carried out in three seasons (cold-dry season in December 2014; hot-dry season in April 2015 and rainy season 2015) on the Phachi streams in order to determine the water quality of the river and the applicability of both the Biological Monitoring Working Party ($BMWP^{THAI}$) and Average Score Per Taxon ($ASPT^{THAI}$) indices. A total of 14,234 morphotaxa from 72 families were identified: Oligochaeta (1 family), Clitellata (2 families), Gastropoda (5 families), Bivalvia (1 family), Malacostraca (3 families), and Insecta (60 families). The score of $BMWP^{THAI}$ and $ASPT^{THAI}$ in each site (PC1 to PC8) found that the BMWP was 187.33 206.00 140.67 194.33 184.67 and 239.00, respectively. The ASPT was 6.43 6.94 6.11 6.34 6.30 6.21 6.47 and 6.46, respectively. The ASPT in each site was significantly different ($p<0.05$). These scores indicated good water quality. The BMWP was negatively related with nitrate-nitrogen, whereas number of aquatic families was positively related with nitrate-nitrogen. The ASPT was negatively related with water turbidity ($p<0.05$). The water quality of the Phachi streams was found to be unpolluted/slightly polluted according to the physicochemical data and the BMWP and ASPT.
Keywords: *Benthic macroinvertebrate, biotic indices, water quality*

INTRODUCTION

The status of water quality in freshwater environment is reflected in its three components: hydrological, physicochemical, and biological. Therefore, assessment of water quality conditions can be based on the appropriate measurement of these three important components. Although assessing the status of chemical and physical including hydrological variables can be complete with high accuracy values, these values are only specific to the conditions at the time that data and samples were measured [1]. On the other hand, the biological method of using living organisms and their response to their surrounding environment to measure the quality of the environment conditions integrates condition over time. This method of assessing water quality is called biological assessment or biological monitoring and it is designed to be used singly or in combination with chemical monitoring. The use of freshwater organisms allows detection of both the past and current water quality conditions by studying their composition and response to water condition [2].

Many varieties of freshwater organisms are used for biomonitoring include diatom, periphyton, fish, and benthic macroinvertebrates. However, of these groups of organisms, benthic macroinvertebrates were selected because they are common and widely used elsewhere for biomonitoring and assessment of lotic ecosystems. Resh et al. [1] and

Able [3] noted numerous advantages of using macroinvertebrates for biomonitoring, such as they are large in size and therefore relatively easy to see with the naked eye. Importantly, keys are available for identifying the organisms at the family level. Benthic macroinvertebrates possess limited mobility, making them easy to collect and collection can be done with the use of inexpensive equipment. Some macroinvertebrates have a relatively long life cycle but many have a short life cycle with many generations per year. This variety allows temporal and spatial analyses and detection of regular or intermittent perturbations. They are generally present in extremely high densities in streams; therefore, the abundance and diversity of these organisms ensures that at least some will respond to a given environmental change.

The use of benthic macroinvertebrates for aquatic biomonitoring has been developed in many countries. Some of the more established programs include the United Kingdom (Biological Monitoring Working Party, 1978 quoted by [4], America [5], Australia [6], and Africa [7, 8]. However, methods of aquatic biomonitoring using macroinvertebrates have not been fully developed in Thailand. There were many problems for limnological research in Thailand reported by [9]. For example, not enough financial support, lack of experts, and incomplete knowledge of the fauna. Most of the Thai studies have been conducted using methods developed for other zoogeographic regions and are not applicable to Thailand. As an exception, Mustow [10] used macroinvertebrates for biomonitoring in the Ping River, Chiang Mai province; however, the study predominately used method developed in the UK, and the collected specimens were almost all obtained from large rivers such as Mae Ping River, Mae Taneg River, and Mae Klang River. Therefore, the values presented from the study were limited to the large rivers. The 23 study sites from 4 rivers of the Ping Watershed were sampled; the main Ping River, a highly polluted tributary (Kha Canal), a relatively unpolluted tributary (Taeng River) and an upland stream tributary (Klang River). Samples were collect from 1990 to 1993. The $BMWP^{THAI}$ score was therefore modified by removing 15 taxa not present in Thailand and adding 11 taxa which are more suitable to be used in Thailand [10]. It was then applied in several studies to examine the water quality of streams in Thailand [11, 12]. The objective of the present study was to assess water quality of the Phachi streams using biotic indices ($BMWP^{THAI}$, $ASPT^{THAI}$), the Shannon-Wiener Diversity Index, and Simpson's Diversity Index as a tool to evaluate stream health.

MATERIALS AND METHODS

Study area and sampling station

The Phachi streams are located in central western Thailand. It originates in the Tenasserim Hills in Ban Kha district and passes Suan Pheung and Chom Beung districts, Ratchaburi Province. The river tributes to the River Kwai in Mueng Kanchanaburi district, Kanchanaburi Province, Thailand. The area is surrounded by agriculture activities and community settlements. The stream water was primarily to use as a source of portable water supplies to community [12]. Also, it provides a daily source of fish and livelihood to the surrounding community. The eight sampling stations were selected (Figure 1). Details of each sampling site are given in Table 1.

Physicochemical water quality parameters

From the eight stations, physicochemical parameters such as pH, water temperature (WT) dissolved oxygen (DO), total dissolved solids (TDS) and electrical conductivity (EC) were recorded immediately before sampling the benthic macroinvertebrates. Three replicates of selected physicochemical water quality parameters were measured. Water samples from each collecting sites were stored in polyethylene bottles (500 mL). The ammonia-nitrogen (NH_3-N), orthophosphate (PO_4^{3-}), nitrate-nitrogen (NO_3-N), and turbidity (TUB) were determined in accordance with the standard method procedures [13] (APHA, AWWA, WPFC, 1992). Alkalinity (ALK) was measured by titration.

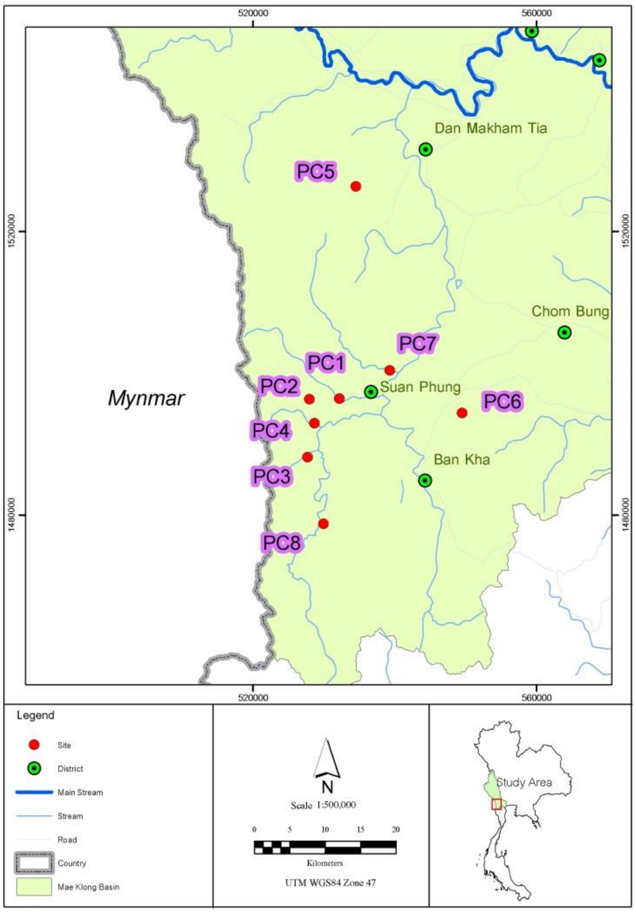

Figure 1. Map showing the sampling sites (PC1 to PC8) at the Phachi streams, central western Thailand.

Table 1. Latitude, longitude of the stations and stream characteristics.

Site	Latitude/ Longitude	Description of stream
PC1	13°32.135´ N, 099°17.842´ E	Cobble, gravel, sand, woody debris. Forest both side.
PC2	13°32.077´ N, 099°15.495´ E	Cobble predominant, gravel and sand. Village and cultivation both side.
PC3	13°27.658´ N, 099°15.348´ E	Boulder, gravel predominant, cobble and sand. Village and cultivation on both side. Concrete on both side. Floating plant are covered around 50% of area.
PC4	13°30.241´ N, 099°15.883´ E	Man made concrete, gravel, woody debris and other stable substrates. Village both side.
PC5	13°48.379´ N, 099°19.152´ E	Cobble predominant, gravel and sand. Many village and cultivation both side.
PC6	13°31.017´ N, 099°27.449´ E	Cobble predominant, gravel and sand. Village both side.
PC7	13°34.275´ N, 099°21.778´ E	Cobble, gravel, sand. Village both side.
PC8	13°22.563´ N, 099°16.585´ E	Cobble predominant, gravel, sand, woody debris. Forest and highland. Village both side.

Benthic macroinvertebrates sampling and identification

Benthic macroinvertebrates were sampled in three seasons (cold-dry season in December 2014; hot-dry season in April 2015 and rainy season 2015) at each of the 8 stations using a standard hand net (30 x 30 size with 500-µm mesh).

The samples were taken from an area of nearly 100 m^2 in order to include all possible microhabitats at each station. In some areas where large stones were present, these were first picked out and washed into the kick net to remove pupae and other attached macroinvertebrates. All of the specimens collected were immediately fixed in 80% ethyl alcohol in the field and brought back to the laboratory. The macroinvertebrates were sorted and identified to the family level using taxonomic keys and were counted under a stereomicroscope [14, 15].

Data analyses

Analysis of variance (ANOVA) was used to test for statistical differences between the means of the physicochemical water quality parameters of the seven sampling sites. Duncan's Multiple Range Test (DMRT) was also used for multiple comparisons of the means of the physicochemical parameters in order to measure similarities of the sampling points. Four biotic indices were used to monitor the impact of disturbances and pollutions on the streams. The indices used in this study were the Biological Monitoring Working Party Score-$BMWP^{THAI}$, Average Score Per Taxon-$ASPT^{THAI}$, Shannon-Wiener Diversity Index, and Simpson's Diversity Index. The BMWP system considers the sensitivity of invertebrates to pollution and families are assigned a score between 1 and 10 accordingly. The BMWP Score is the sum of the values for all families present in the sample. In general, a river with good water quality has a BMWP score of 100 [10]. ASPT was calculated as ASPT = BMWP Score/Number of scoring taxa. A high ASPT was considered indicative of a clean site containing large numbers of high scoring taxa. Pearson's correlation analysis was used to determine the magnitude of the significance and nature of the relationship between parameters.

RESULTS AND DISCUSSION

Physicochemical variables

The results of physical and chemical parameters variables measured at the eight stations are presented in Table 2. The water quality status of the Phachi streams was not significantly different in the eight stations sampled except for total dissolved solids, electrical conductivity, pH and alkalinity. The water temperature varied from 26.30°C (PC5) to 30.07°C (PC7). The highest DO was found at the station PC6 and varied between 6.24 mg L^{-1} and -6.87mg L^{-1}. The lowest TDS value was measured in the station PC4 while the highest value was found in the station PC5 and ranges between 78.24 mg L^{-1} and 167.74 mg L^{-1}. The lowest EC value was measured in the station PC4 while the highest value was found in the station PC5 and ranges between 153.80 µS cm^{-1} and 342.91 µS cm^{-1}. An average of pH values was similar among the sampling points and ranged between 8.08 and 8.77, which can result from the dissolution of calcium and magnesium existing from the mountain region which indicates that water is slightly alkaline in nature [16]. In natural water the pH varies between 5.0 and 9.0. The average of alkalinity ranged between 20.40 mg $L^{-1}$and 34.80 mg L^{-1}. The turbidity of water ranged between 6.33 NTU and 31.78 NTU. The highest ammonia-nitrogen (NH_3-N) was measured in sampling point PC1 as 0.34 mg L^{-1}, the lowest average was measured in sampling point PC7 as 0.11 mg L^{-1}. The average nitrate-nitrogen (NO_3-N) was high in sampling points PC1 as 2.96 mg L^{-1} and low level was measured in sampling point PC6 as 1.00 mg L^{-1}. The highest level of orthophosphate (PO_4^{3-}) was measured in sampling point PC4 as 0.75mg L^{-1} and low level was measured in sampling point PC1 as 0.42 mg L^{-1} (Table 2).

Table 2. Mean values and SD of the physicochemical variable per sites of the stream in three seasons from the Phachi streams, central western Thailand.

Site/parameter	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	*p*-value
WT (°C)	29.83± 5.01^{a}	26.58± 3.65^{a}	27.75± 4.10^{a}	29.27± 3.59^{a}	26.30± 0.49^{a}	28.53± 3.46^{a}	30.07± 2.83^{a}	27.75± 3.97^{a}	0.848
DO (mg L^{-1})	6.84± 0.43^{a}	6.38± 0.36^{a}	6.67± 3.42^{a}	6.68± 2.42^{a}	6.24± 2.07^{a}	6.87± 0.24^{a}	6.29± 3.55^{a}	6.79± 5.38^{a}	0.770
TDS (mg L^{-1})	121.78± 30.22^{abc}	100.24± 26.06^{ab}	90.33± 35.51^{a}	78.24± 16.67^{a}	167.78±16.91^{c}	166.56 ±9.07^{c}	155.11± 10.33^{bc}	166.44 ±12.36^{c}	0.000*
EC (µScm^{-1})	243.78± 57.35^{abc}	200.21± 52.07^{ab}	180.82±71.75^{a}	153.80±30.87^{a}	342.91±19.31^{c}	333.00 ±18.48^{c}	310.89± 21.5^{bc}	334.00 ±26.01^{c}	0.000*
pH	8.43± 0.08^{ab}	8.47±0.29^{ab}	8.08± 0.22^{a}	8.30± 0.09^{ab}	8.77± 0.18^{b}	8.74± 0.18^{b}	8.73± 0.22^{b}	8.72± 0.15^{b}	0.002*
ALK (mg L^{-1})	33.67± 6.03^{b}	33.20± 6.29^{b}	25.40± 5.89a^{b}	20.40± 5.19a	34.80± 1.31^{b}	34.67± 0.83^{b}	33.47± 4.80^{b}	28.87± 1.03^{ab}	0.010*
TUB (NTU)	21.11± 13.36^{a}	17.56± 10.03^{a}	21.00± 10.08^{a}	31.78± 21.07^{a}	16.89± 13.14^{a}	15.78± 14.17^{a}	6.33± 6.09^{a}	7.09± 7.00^{a}	0.342
NH_3-N (mg L^{-1})	0.34± 0.30^{a}	0.13± 0.02^{a}	0.23± 0.10^{a}	0.22± 0.16^{a}	0.17± 0.14^{a}	0.14± 0.02^{a}	0.11± 0.06^{a}	0.12± 0.05^{a}	0.608
PO_4^{3-} (mg L^{-1})	0.42± 0.06^{a}	0.66± 0.42^{a}	0.48± 0.09^{a}	0.75± 0.38^{a}	0.56± 0.25^{a}	0.57± 0.33^{a}	0.56± 0.23^{a}	0.48± 0.30^{a}	0.876
NO_3-N (mg L^{-1})	2.96± 2.17^{a}	1.17± 0.23^{a}	1.48± 0.21^{a}	1.23± 0.23^{a}	1.32± 0.43^{a}	1.00± 0.09^{a}	1.12± 0.28^{a}	1.22± 0.43^{a}	0.158

All the physicochemical parameters at the Phachi streams were within Type II of The Surface Water Standard for Agriculture and Water Quality for Protection of Aquatic Resources in Thailand. Although, water quality in these streams was within standard, some stations were deteriorated by human activities. Human activities such as agricultural activities and discharge of organic pollutants in stream Station PC5 probably led to increase in electrical conductivity, total dissolved solids, pH and alkalinity, which affect the distribution and abundance of benthic macroinvertebrates [17].

Biological results

A total of 14,234 individuals belonging to 70 families were recorded in eight sampling stations. The individuals collected from the stations belonged to Oligochaeta (1 family), Clitellata (2 families), Gastropoda (5 families), Bivalvia (1 family), Malacostraca (2 families), and Insecta (59 families). The order Trichoptera was the dominant and most abundant taxa (26.18%) and there was followed by the Ephemeroptera (24.27%), Hemiptera (16.26%) and Odonata (12.77%). The most common family taxa were Trichoptera (11 families), Odonata (10), Hemiptera (10), Diptera (9) and Ephemeroptera (8) (Table 3). The most individuals were collected at station PC2 (2471), while the fewest individuals were collected at station PC3 (681) (Table 3).

The results of this study revealed that almost stations of the Phachi streams were dominated by Ephemeroptera, Plecoptera and Trichoptera which are considered very sensitive to environmental stress. However, it was also found a tolerant group such as Chironomidae (order Diptera) in the Phachi streams which was the highest density at PC5 station. This station was characterized by the high level of total dissolved solids, which proved Chironomidae to be a good conductor of pollution.

Among the Ephemeroptera recorded in almost all stations of the Phachi streams, the most dominant family was Leptophlebiidae, Heptageniidae and Baetidae. Baetidae are known for tolerance to sedimentation and nutrient enrichment [18]. In the present study, Baetidae were abundant at the station PC5 although this was not a polluted station that confirmed by ASPT score (Table 4). The Hydropsychidae (order Trichoptera) was the most abundant family which believed to be in the mid-range for tolerance of environmental stressors. They are one of the more tolerant in caddisflies group [18]. The water quality of station PC5 such as total dissolved solids, electrical conductivity, pH and alkalinity was slightly poor than other, Hydropsychidae was highly abundant at the station. Hydropsychidae are less impacted by environmental stress than the other caddisflies [19]. For order Plecoptera, only one family Perlidae was recorded from almost station which was highly abundant in PC1 and PC2 stations. The two stations had a good water quality according to biological indices (BMWP and ASPT) and my findings are in accordance with Marson [20] who states that order Plecoptera require very high amount of oxygen and are very sensitive to organic pollution (Table 2).

High abundance of hemipteran families Gerridae was recorded in the station PC3 which this station was constructed in the stream. The Gerridae, normally can be found at lentic areas including limnetic and lotic surfaces. Also, family Coenagrionidae from order Odonata was abundance in this station. Odonata are potentially considerable as indicators of environmental disturbance, especially by logging activities or pollution [21].

According to the Shannon–Wiener diversity index, the index value is between 1 and 3 in moderately polluted streams [20]. The diversity values of the current study showed that there was a varied range of diversity in the field, from 2.33 at the station PC7 to 2.97 at the station PC8. Shannon–Wiener and Simpson diversity indices were calculated for each station to examine whether there was diversity of the macroinvertebrate species. Both indices showed that the lowest diversity was seen at the station PC7 and the highest diversity was found at the station PC8 (Table 3).

Table 3. The Biological Monitoring Working Party Score (BMWP) per sites of the stream from the Phachi streams, central western Thailand in three seasons.

Family	$BMWP^{TH}_{AI}$	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Naididae	1	9							
Glossiphoniidae	3	8		8				2	1
Erpobdellidae	3			1	5	1			
Hydrobiidae	3	2		5	31	3	2	2	18
Thiaridae	3	66	14	51	48	40	45	38	11
Viviparidae	6	3							
Lymnaeidae	3	7		5					
Planorbidae	3	2	1	1	4		8		1
Corbiculidae	3	10	8	13	11	24	13	15	1
Palaemonidae	8	64	16	14	12	25	29	98	74
Parathelphusidae	3	8	5	9	2	5	1	4	
Baetidae	4	157	59	42	48	161	48	144	116
Caenidae	7	5	9	7	5	15	39	6	40
Ephemerellidae	10	23	19		5	43	25	38	21
Ephemeridae	10	24	13	2	9		1	10	40
Heptageniidae	10	89	296	3	53	9	64	154	176
Leptophlebiidae	10	315	270	31	291	89	136	129	152
Neoephemeridae	(4)	2		1		5	1		
Teloganodidae	(10)		15						
Aeshnidae	6								1
Calopterygidae	6	1	7		3	10	2	3	3
Chlorocyphidae	6	7	4	2	14	7	4	8	2
Coenagrionidae	6	31		81	78	26	23	24	92
Corduliidae	6	15	2	3	3			5	5
Euphaeidae	6		62					43	16
Gomphidae	6	72	78	74	51	140	41	105	114
Libellulidae	6	61	36	21	77	71	77	53	107
Platycnemididae	6	1		10	1	2			5

Platystictidae	6	1		6	10		6	1	9
Perlidae	10	115	199	7	3	76	82	21	7
Aphelocheiridae	10	93	45	3		58	91	47	36
Belostomatidae	(5)					13	11	1	32
Gerridae	5	25	60	154	181	124	124	169	87
Hebridae	(5)								1
Helotrephidae	(5)			1		38		38	6
Hydrometridae	5	3			6		1	36	4
Naucoridae	5	92	22	42	40	46	71	9	270
Nepidae	5	6	5	5	5	5	2	1	8
Notonectidae	5							1	5
Mesoveliidae	5	2	1	1	3	31	2	2	11
Micronectidae	5	1				11	3	1	
Veliidae	(5)	3	8	5	11	49	9	6	32
Corydalidae	4						6	5	15
Dytiscidae	5					2		1	9
Elmidae	5	9	12		3	8	13	20	64
Gyrinidae	5		60						3
Hydrophilidae	5	4	1	5	4	14	9		6
Psephenidae	5	13	20	3	6	1	2	27	16
Scirtidae	(5)		5			1			352
Athericidae	(5)								1
Ceratopogonidae	(4)	2				13	4	6	
Chironomidae	2	32	53	1	14	86	49	61	23
Culicidae	5				3				4
Simuliidae	5	46	35	1	16	1	2	47	2
Stratiomyidae	5								1
Tabanidae	5							2	2
Tanyderidae	2						1		
Tipulidae	5	49	46	4	18	27	12	19	20
Crambidae	8		5		4	19	11	22	24
Calamoceratidae	8	31	23			1	3		9
Ecnomidae	3			1		2	3		
Glossosomatidae	10			1					1
Helicopsychidae	8		89						
Hydropsychidae	5	250	560	40	117	826	357	497	137
Lepidostomatidae	10		7						
Leptoceridae	10	1	7		3			3	2
Odontoceridae	10	21	96	17	71	44	17	10	142
Philopotamidae	8	22	144		6	32	14	46	25
Polycentropodidae	10				20	1		2	2
Psychomyiidae	8							17	6
Total number		1803	2417	681	1295	2205	1464	1999	2370
Number of families		46	41	39	41	44	44	48	57
Shannon-Wiener		2.57	2.60	2.39	2.69	2.44	2.51	2.33	2.97
Simpson		0.88	0.90	0.86	0.89	0.84	0.87	0.84	0.93

The Biological Monitoring Working Party (BMWP) score and corresponding Average Score Per Taxa (ASPT) for the Phachi streams were 187.33 (6.43) for the station PC1, 206 (6.94) for the station PC2, 140.67 (6.11) for the station PC3, 194.33 (6.34) for the station PC4, 184.67 (6.30) for the station PC5, 178.00 (6.21) for the station PC6, 185.67 (6.47) for the station PC7, and 239.00 (6.46) for the station PC8 respectively (Table 4). This score is indicative of good, very clean water [22]. The list of benthic macroinvertebrates recorded gave an average BMWP score ranged 140.67 to 239.00, which indicates an unpolluted and un-impacted site with clean water. An average ASPT score ranged 6.11 to 6.94 was obtained which has a category designation of excellent water quality [23]. The scores for the taxa via the ASPT system are more informative than the BMWP score and relates to the average of the tolerance scores of all the aquatic insects' families found in the samples. The water qualities based on the BMWP and ASPT scores for aquatic insects are considered very good mainly due to habitat diversity and lack of pollutants or additional nutrients within the watersheds.

Table 4. Mean of number of families and biotic indices in each sampling site during three seasons.

Sampling site	Number of families	BMWP	ASPT	[1]Category/interpretation
PC1	29.33±11.02[a]	187.33±65.43[a]	6.43±0.20[ab]	Good, very clean water
PC2	29.67±8.50[a]	206.00±58.97[a]	6.94±0.22[b]	Good, very clean water
PC3	23.33±6.81[a]	140.67±30.67[a]	6.11±0.48[a]	Good, clean or not significantly altered
PC4	30.67±1.53[a]	194.33±6.66[a]	6.34±0.20[ab]	Good, very clean water
PC5	29.33±10.02[a]	184.67±62.18[a]	6.30±0.05[ab]	Good, very clean water
PC6	28.67±2.08[a]	178.00±14.42[a]	6.21±0.26[ab]	Good, very clean water
PC7	28.33±11.02[a]	185.67±79.25[a]	6.47±0.36[ab]	Good, very clean water
PC8	37.00±4.36[a]	239.00±27.22[a]	6.46±0.20[ab]	Good, very clean water
p-value	0.681	0.519	0.059*	

[1] adapted from Armitages et al., 1983

Table 5 summarizes the correlations of number of families and biotic indices and physicochemical variables. It was found that the number of families and BMWP have significant correlation with nitrate-nitrogen, while ASPT was significantly correlated with turbidity of water. However, an increase in the results in BMWP and ASPT scores systems shows good ecological quality [20]. Benthic macroinvertebrate species are differentially sensitive to many biotic and abiotic factors in their environment [24]. In many studies diversity indices are also used for assessing water quality but the biotic index and score systems are better for assessing organic pollution and eutrophication [25].

Table 5. Assessment of Pearson correlation between physicochemical parameters, number of families and biotic indices.

Parameter	Number of families	BMWP	ASPT
WT (°C)	-0.143	-0.073	0.234
DO (mg L^{-1})	-0.058	-0.055	0.147
TDS (mg L^{-1})	0.103	0.149	-0.003
EC (µS cm^{-1})	0.090	0.129	-0.020
pH	0.091	0.148	-0.022
Alkalinity (mg L^{-1})	-0.219	-0.198	0.078
Turbidity (NTU)	0.195	0.044	**-0.484***
NH_3-N (mg/ L^{-1})	-0.328	-0.335	0.183
PO_4^{3-} (mg L^{-1})	-0.396	-0.337	0.280
NO_3-N (mg L^{-1})	**0.514***	**-0.462***	-0.032

CONCLUSION

A total of 14,243 benthic macroinvertebrates representing 72 families were recorded in the Phachi streams. The order Trichoptera was the dominant and most abundant taxa (26.18%) and there was followed by the Ephemeroptera (24.27%), Hemiptera (16.26%) and Odonata (12.77%). The most common family taxa were Trichoptera (11 families), Odonata (10), Hemiptera (10), Diptera (9) and Ephemeroptera (8) (Table 3). The most individuals were collected at station PC2 (2471), while the fewest individuals were collected at station PC3 (681). Generally, the water quality of the Phachi streams can be considered as clean based on the diversity and abundance of benthic macroinvertebrates and values of biological indices used in this study. The biological indices (BMWP and ASPT) indicated the water quality of the Phachi streams as rather clean to excellent water quality. The findings of the current study also suggest that biotic indices developed for a particular geographical region introduce deviations between indices into a researcher's evaluation. Thus, the findings strongly indicate that there is still a need for further intensive study and testing of the effectiveness of the BMWP and ASPT indices. These indices may require adaptation for Thailand based on its geomorphological and environmental features.

ACKNOWLEDGEMENTS

Financial support for this study was given through a scholarship and grants of the Faculty of Liberal Arts and Science, Kasetsart University, Kamphaeng Saen Campus and National Research Council of Thailand (NRCT) year 2016 to Miss Makaporn Deemool.

REFERENCES

[1] V.H. Resh, M.J. Myers, M.J. Hannaford, Macroinvertebrates as biotic indicators of environmental quality. In: F.R. Hauer, G.A Lamberti (ed), Stream ecology, Academic Press, California, 1996, 647–667pp.

[2] A.E. Ramm, The community degradation index: a new method for assessing the deterioration of aquatic habitat, *Water Res*, 1987, 22(3), 293–301.

[3] D.P. Abel, Water pollution biology, Ellis Horwood Limited, West Sussex, 1989, 286 pp.

[4] P.D. Armitage, D. Moss, J.T. Wright, M.T. Furse, The performance of the new biological water quality score system based on macroinvertebrates over a wide range of unpolluted running water sites, *Water Res*, 1983, 17, 333–347.

[5] M.T. Barbour, J. Gerritsen, B.D. Snyder, J.B. Stribling, Rapid bioassessment protocols for use in streams and wade able rivers: periphyton, benthic macroinvertebrates and fish. 2nd ed, EPA/841-B-99-002. U.S. EPA, Office of Water, Washington, D.C., 1999, 197 pp.

[6] B. Chessman, Rapid assessment of rivers using macroinvertebrates: a procedure based on habitat-specific sampling, family level identification and a biotic index, *Aust J Ecol*, 1995, 20, 122–129.

[7] C.W.S. Dickens, P.M. Graham, The South African Scoring System (SASS) version 5 rapid bioassessment method for rivers, *Afr J Aquat Sci*, 2002, 27, 1–10.

[8] P. Vos, V. Wepener, D.P. Cyrus, Efficiency of the SASS4 rapid bioassessment protocol in determining river health: a case study on the Mhlathuze River, KwaZulu-Natal, South Africa. *Water SA*, 2002, 28, 13–22.

[9] I.C. Campbell, S. Parnrong, Limnology in Thailand: present status and future needs. Verhandlungen der Internationale Vereinigung fur Theoretische und Angewandte. Limnologie, 2001, 27, 2135–2141.

[10] S.E. Mustow, Biological monitoring of rivers in Thailand: Use and adaptation of the BMWP score, *Hydrobiologia*, 2002, 479, 191–2292.

[11] A. Payakka, T. Prommi, The use o BMW and ASPT biotic score as biological monitoring of streams in northern Thailand, *J Appl Sci Environ Sanit*, 2014, 9(1), 7–16.

[12] W. Maneechan, T. Prommi, Diversity and distribution of aquatic insects in streams of the Mae Klong Watershed, Western Thailand, *Psyche*, 2015, 1–7.

[13] APHA, AWWA, WPCF, Standard method for the examination of water and wastewater, 18th ed. American Public Health Association. Washington DC, 1992.

[14] D. Dudgeon, Tropical Asian streams zoobenthos, Ecology and Conservation,Hong Kong University Press, Hong Kong, 1999.

[15] C.M. Yule, H.S. Yong, Freshwater invertebrates of the Malaysian Region, Academy of Science Malaysia. Kuala Lumpur, 2004.

[16] F. Ishaq, A. Khan, Seasonal limnological variation and macro benthic diversity of river Yamuna at Kalsi Dehradun of Uttarakhand. *Asian Journal of Plant Science and Research*, 2013, 3(2), 133–144.

[17] T. Prommi, A. Payakka, Aquatic insect biodiversity and water quality parameters of streams in northern Thailand. *Sains Malaysiana*, 2015, 44(5), 707–717.

[18] J. Harrington, M. Born, Measuring the health of California streams and rivers- A methods manual for water resource professionals, citizen monitors and natural resources student, Sacramento, California, USA. 2nd ed. Sacramento, California, USA: Sustainable Land Stewardship International Institute, 2000. 199 pp.

[19] A. Skuja, V. Spuņģis, Influence of environmental factors on the distribution of caddisfly (Trichoptera) communities in medium-sized lowland streams in Latvia. *Estonian Journal of Ecology*, 2010, 59(3), 197–215.

[20] C.F. Mason, *Biology of Freshwater Pollution*. 4th ed. London: Prentice Hall, 2002, 387 pp.

[21] S. Harun, S.A. Al-Shami, R. Dambul, M. Mohamed, M.H. Abdullah, Water quality and aquatic insects study at the lower Kinabatangan River catchment, Sabah: In response to weak La Niña event, *Sains Malaysiana*, 2015, 44(4), 545–558.

[22] W. Gabriels, P.L.M. Goethals, N. De Pauw, Implications of taxonomic modifications and alien species on biological water quality assessment as exemplified by the Belgian Biotic Index method, *Hydrobiologia*, 2005. 542, 137–150.

[23] D. Chapman, Water Quality assessments: a guide to the use of biota, sediments and water in environmental monitoring, 2nd ed, UNESCO, London, 1996.

[24] M. Zeybek, H. Kalyoncu, B. Karakaş dan, S. Özgül, The use of BMWP and ASPT indices for evaluation of water quality according to macroinvertebrates in Değirmendere Stream (Isparta, Turkey), *Turk J Zool*, 2014, 38, 603–613.

[25] H. Kalyoncu, M. Zeybek, An application of different biotic and diversity indices for assessing water quality: A case study in the rivers Çukurca and Isparta (Turkey), *Afr J Agric Res*, 2011, 6(1), 19–27.