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Contributed Paper

Water Quality and Trophic Status in Main Rivers of Thailand

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ABSTRACT

The water quality and trophic status monitoring in the main rivers of Thailand during all three seasons in March 2008, August 2008 and January 2009 were investigated. Water samples were collected from 6 regions in Thailand which differed in geological and useful characteristics. In northern Thailand, the Ping River was selected; in the central region, the Tha Chin River; in the northeast region, the Chi River; in the eastern region, the Chanthaburi River; in the western region, the Kwai River and in the southern region, the Tapee River. Samples were taken from the upper, middle and lower parts of each river. At each site, some physical and chemical parameters were studied and the water quality was classified based on its trophic status. It was found that the water quality at most of the sampling sites were not clearly different and could be classified as clean-moderate water quality (oligotrophic-mesotrophic status). However, the water quality at some sampling sites were different, especially, upstream of the Ping and Tapee Rivers which could be classified as clean (oligotrophic status) and downstream of the Tha Chin River showed moderate to polluted water quality (mesotrophic-eutrophic status).

Keywords: moderate water quality, mesotrophic status, rivers, Thailand.

1. INTRODUCTION

At present, the water quality is important world wide. Thailand is a developing country with an increasing population. Some industrial and agricultural activities affect the water quality e.g. waste discharge into the water consisting of organic, inorganic nitrogen and phosphorus compounds which could change water properties. Classification of water quality and trophic status are routine in America and Europe. The water quality survey is conducted by using some organic and inorganic compounds such as criteria of Lorraine and Vollenweider [1] which uses total phosphorus, total nitrogen, secchi depth and chlorophyll a to classify the trophic satatus and separate into 4 classes: oligotrophic, mesotrophic, eutrophic and hypereutrophic. Wetzel [2] used chemical oxygen demand (COD), total phosphorus, total nitrogen and total dissolved solid to classify the trophic status and separate into 8 classes: ultraoligotrophic oligotrophic, oligomesotrophic,

mesotrophic, mesoeutrophic, eutrophic, hypereutrophic and dystrophic. In Asia, especially in Thailand, a few methods to classify the trophic status had been proposed. The first method was modified by Peerapornpisal et al. [3] and selected such parameters as DO, BOD, conductivity and nutrients (NO_3^-, NH_4^+ and PO_4^{3-}) and separated into 7 classes: ultraoligotrophic oligotrophic, oligotrophic-mesotrophic, mesotrophic, mesotrophic-eutrophic, eutrophic and hypereutrophic.

In Thailand, most water quality surveys were done by the Pollution Control Department, Ministry of Natural Resources and Environment and some physical and chemical properties were used to assess the water quality [4]. However, most recent trophic status studies were done in the northern region [5-7]. This research present the first report of water quality and trophic status by using physical and chemical properties of water in some of the main rivers of Thailand covering 6 regions. The Ping River in northern Thailand; the Tha Chin River in central region; the Chi River in northeast region; the Chanthaburi River in eastern region; the Kwai River in western region and the Tapee River in southern region. The results of the water quality and trophic status in some main rivers will be shown in the database of Thailand water quality by trophic status.

2. MATERIALS AND METHODS

The study areas are located in 6 regions of Thailand. In northern Thailand, Ping River (5 sites) was selected; in central region, Tha Chin River (5 sites); in northeastern region, Chi River (5 sites); in western region, Kwai River (5 sites); in eastern region, Chanthaburi River(4 sites) and in southern region, Tapee River (4 sites) (Table 1 and Figure 1). The waters were sampled from upstream to downstream during summer, rainy and cool dry seasons during March 2008 - January 2009.

Some physical and chemical properties of water were determined at the sampling sites. The temperature, pH, conductivity, total dissolved solid and salinity were measured using the multimeter (electrode kit of WTW Company). Measurement of some chemical properties of water was done by the method of Eaton et al. [8]. Dissolved oxygen (DO) and BOD_5 were measured using the azide modification method. Alkalinity was measured by phenolpthalein methyl orange indicator method. Concentrations of nutrients, i.e. ammonia-nitrogen, nitrate-nitrogen and soluble reactive phosphorus (SRP) were determined in the laboratory by nesslerization, cadmium reduction and ascorbic acid methods, respectively.

The trophic status of water was evaluated from the main parameters (conductivity, DO, BOD_5, ammonia-nitrogen, nitrate-nitrogen and soluble reactive phosphorus) by the Applied Algal Research Laboratory Physical and Chemical score (AARL PC score) (Tables 2, 3) according to Lorraine and Vollenweider [1], Wetzel [2], Peerapornpisal et al. [3] and Pollution Control Department [9]. The calculation of trophic status from AARL PC score is shown in Table 4.

The relationship of water properties and sampling sites were analyzed using Principal Component Analysis (PCA) and Cluster Analysis (CA) in Multivariate Statistical Package version 3.1 (MVSP).

3. RESULTS AND DISCUSSION

3.1 Water Quality and Trophic Status

Some physical and chemical properties of water in each of the sampling sites are shown in Table 5. The water quality of the Ping River at the upstream area (MP1) in terms of BOD_5, TDS, conductivity, alkalinity and nutrients (ammonia-nitrogen, nitrate-nitrogen and soluble reactive phosphorus) were found to be at low level. MP2 showed high

Table 1. Sampling sites and their topography.

Name of sites	Locations District and Province	Latitudes and Longitudes	Altitudes (m)
MP1	Chiang Dao, Chiang Mai	19°45″359′N 98°53″720′E	841
MP2	Mueang, Chiang Mai	19°44″270′N 98°58″916′E	350
MP3	Ban Tak, Tak	17°02″186′N 99°04″015′E	325
MP4	Khlong Khlung, Kamphaeng Phet	16°16″012′N 99°41″449′E	58
MP5	Mueang, Nakhon Sawan	15°42″697′N 100°08″685′E	42
TC1	Wat Sing, Chainat	15°12″748′N 100°04″200′E	18
TC2	Sam Chuk, Suphan Buri	14°44″454′N 100°06″086′E	9
TC3	Bang Pla Ma, Suphan Buri	14°24″103′N 100°09″392′E	8
TC4	Samphran, Nakhon Pathom	13°44″613′N 100°15″568′E	3
TC5	Krathum Baen, Samut Sakhon	13°39″985′N 100°16″074′E	1
CH1	Nong Bua Daeng, Chaiyaphum	16°03″543′N 101°40″004′E	218
CH2	Chonnabot, Khon Kaen	16°05″790′N 102°34″302′E	163
CH3	Kosum Pisai, Mahasarakham	16°15″055′N 103°04″409′E	139
CH4	Mahachaichana, Yasothon	15°31″444′N 104°15″003′E	133
CH5	Khueang Nai, Ubon Ratchathani	15°18″653′N 104°26″184′E	124
KW1	Srisawat, Kanchanaburi	14°23″167′N 99°08″631′E	102
KW2	Srisawat, Kanchanaburi	14°18″041′N 99°12″724′E	66
KW3	Mueang, Kanchanaburi	14°13″804′N 99°14″399′E	19
KW4	Mueang, Kanchanaburi	14°05″992′N 99°24″858′E	18
KW5	Mueang, Kanchanaburi	14°02″495′N 99°30″224′E	5
TP1	Phipoon, Nakhon Si Thammarat	08°32″454′N 99°40″973′E	206
TP2	Phrasaeng, Surat Thani	08°34″261′N 99°15″271′E	77
TP3	Khian Sa, Surat Thani	08°51″957′N 99°11″853′E	33
TP4	Phun Phin, Surat Thani	09°06″035′N 99°13″829′E	1
CB1	Khao Khitchakut, Chantaburi	12°49″854′N 102°04″644′E	78
CB2	Khao Khitchakut, Chantaburi	12°47″656′N 102°06″747′E	60
CB3	Mueang Chantaburi	12°38″165′N 102°08″265′E	19
CB4	Mueang, Chantaburi	12°37″493′N 102°07″380′E	18

* MP= Ping River, TC= Tha Chin River, CH= Chi River, KW=Kwai River, TP=Tapee River, CB=Chanthaburi River

ammonia-nitrogen and SRP and most sampling sites at the downstream showed no difference in water properties. All samples from the Tha Chin River at TC1, 2 and 3 showed high level of DO and low level of BOD_5, TDS, conductivity, alkalinity, SRP, ammonia-nitrogen and nitrate-nitrogen compared to those at. TC4 and 5. CH1, 2 and 3 of Chi River showed high level of salinity, conductivity and TDS especially at CH2 in summer season showed highest level of salinity, conductivity and TDS. At Tapee River, high level of DO and low level of TDS, conductivity and alkalinity were found in samples from TP1. Most of the sampling sites downstream in the Tapee River showed

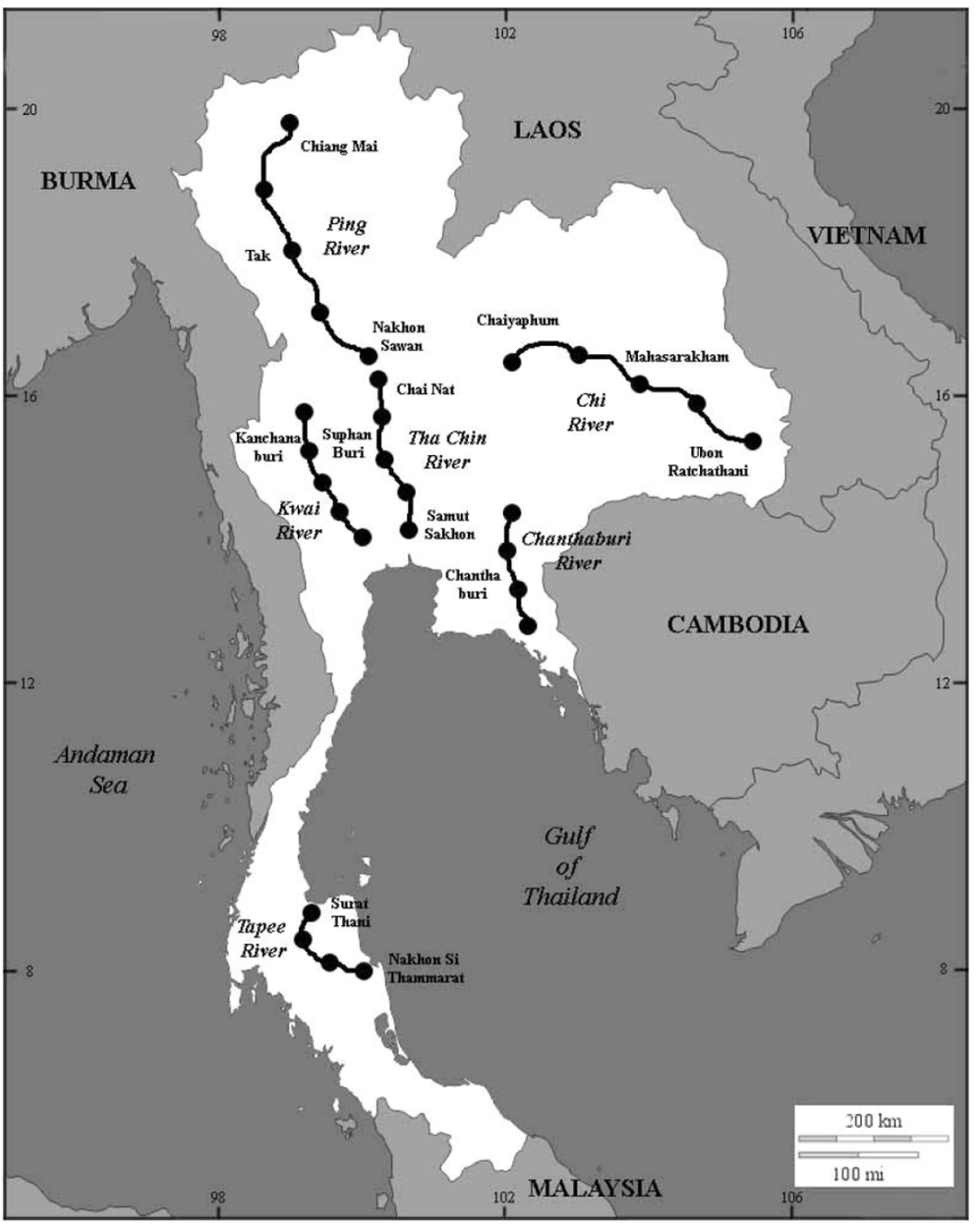


Figure 1. Map of Thailand showed Ping, Tha Chin, Chi, Kwai, Tapee and Chanthaburi Rivers and sampling sites.

high levels of TDS, conductivity and alkalinity. At the Kwai and Chanthaburi Rivers no differences in the water quality at each site were found. The Kwai River showed low levels of turbidity, SRP, ammonia- nitrogen and nitrate- nitrogen. The Chanthaburi River showed low levels of turbidity, TDS and conductivity and high level of DO.

The trophic status and AARL PC score of water at each sampling site were shown in

Table 2. Applied Algal Research Laboratory Physical and Chemical score (AARL PC score) for DO, BOD_5, conductivity, nitrate-nitrogen, ammonia-nitrogen and soluble reactive phosphorus.

DO ($mg.l^{-1}$)	score	BOD_5 ($mg.l^{-1}$)	score	conductivity ($\mu S.cm^{-1}$)	score
>8	0.1	<0.25	0.1	<10	0.1
7-8	0.2	0.25-0.5	0.2	10-20	0.2
6-7	0.3	0.5-1	0.3	20-40	0.3
5-6	0.4	1-2	0.4	40-70	0.4
4-5	0.5	2-4	0.5	70-100	0.5
3-4	0.6	4-10	0.6	100-150	0.6
2-3	0.7	10-20	0.7	150-230	0.7
1-2	0.8	20-40	0.8	230-400	0.8
0.5-1	0.9	40-80	0.9	400-550	0.9
<0.5	1.0	>80	1.0	>550	1.0

NO_3-N ($mg.l^{-1}$)	score	NH_3-N ($mg.l^{-1}$)	score	SRP ($mg.l^{-1}$)	score
<0.05	0.1	<0.1	0.1	<0.05	0.1
0.05-0.1	0.2	0.1-0.2	0.2	0.05-0.2	0.2
0.1-0.3	0.3	0.2-0.4	0.3	0.2-0.4	0.3
0.3-0.8	0.4	0.4-0.8	0.4	0.4-0.8	0.4
0.8-1.5	0.5	0.8-1.5	0.5	0.8-1.5	0.5
1.5-3.0	0.6	1.5-3.0	0.6	1.5-3.0	0.6
3.0-10.0	0.7	3.0-5.0	0.7	3.0-5.0	0.7
10.0-20.0	0.8	5.0-10.0	0.8	5.0-10.0	0.8
20.0-40.0	0.9	10.0-20.0	0.9	10.0-20.0	0.9
> 40.0	1.0	>20.0	1.0	>20.0	1.0

Table 3. Seven classes of trophic status based on AARL PC score.

Score	Trophic status	Water quality
< 0.8	ultraoligotrophic	very clean
0.9-1.6	oligotrophic	clean
1.7-2.4	oligotrophic-mesotrophic	clean-moderate
2.5-3.2	mesotrophic	moderate
3.3-4.0	mesotrophic-eutrophic	moderate-polluted
4.1-4.8	eutrophic	polluted
> 4.8	hypereutrophic	very polluted

Table 4. Trophic status calculated from AARL PC score of MP1 in summer.

Parameters	Levels	AARL PC score*
DO ($mg.l^{-1}$)	7.8	0.2
BOD_5 ($mg.l^{-1}$)	1.4	0.4
conductivity ($\mu S.cm_{--}^{-1}$)	53.2	0.4
NO_3-N ($mg.l^{-1}$)	0.3	0.3
NH_3-N ($mg.l^{-1}$)	0.31	0.3
SRP ($mg.l^{-1}$)	0.01	0.1
Total score		1.7 **
Trophic status		oligotrophic-mesotrophic status**

* from Table 2, ** from Table 3

Table 6. Most of the sampling sites showed different trophic status in each season due to different activities along the rivers. Ping and Chi Rivers were cleaner at the upstream area because these areas were surrounded by deciduous forest so there was not much contamination of the water bodies and the downstream was more contaminated by the community and agricultural activities. Whilst, Chanthaburi and Tapee Rivers were located in the western and southern regions with longer period of rainy season and short length of the rivers, therefore the change in water quality were not much in each season. The water at most sampling sites in the Ping River were classified in the oligotrophic-mesotrophic status, except at MP1, during the rainy season which was oligotrophic and at MP2, in all seasons, was mesotrophic. The Tha Chin River was classified as mesotrophic, except at TC4 and 5 which were mesotrophic-eutrotrophic. Tapee River was classified as oligotrophic-mesotrophic, except at TP1, in all seasons was oligotrophic. Most of the sampling sites in the Chi, Kwai and Chanthaburi Rivers were classified in the oligotrophic-mesotrophic status, except those at KW2 and 3 of the Kwai River were mesotrophic and CB2 of Chanthaburi River in cool dry season was oligotrophic status.

3.2 Statistical Analysis

In Asia and Europe, the PCA and CA were primary methods for description of correlation between sampling sites and physico-chemical parameters [10-12]. The PCA showed positive and negative correlation. The positive correlations were conductivity, total dissolved solid, salinity and alkalinity (axis 1; 0.433, 0.431, 0.438, 0.341, axis2; 0.141, 0.170, 0.092, 0.114), air and water temperatures (axis 1; 0.032, 0.133, axis2; 0.160, 0.166), ammonia-nitrogen and soluble reactive phosphorus (axis 1; 0.241, 0.204, axis2; -0.496, -0.501). The negative correlations were DO and BOD_5 (axis 1; -0.323, 0.253, axis2; 0.184, -0.157). Besides, nitrate-nitrogen (axis 1; -0.097, axis2; -0.365) showed negative correlation with conductivity, total dissolved solid, salinity and alkalinity (Figure 2). The CA of water properties in the main rivers of Thailand showed 6 groups with 75% similarity. Groups 1 were all samples from MP1 at Ping River and all samples in Chanthaburi River. Group 2 were all samples from TP1 in Tapee River and CH1 of Chi River in rainy season was in Group 3. Most of the sampling sites were included in Group 4 and downstream of Tha Chin River were in Group 5. Only CH2 of Chi River in summer season was in Group 6 (Figure 3).

Table 5. Minimum and maximum values of some physical and chemical parameters of water in Ping, Tha Chin, Chi, Kwai, Tapee and Chanthaburi Rivers. (n=3 in each sites).

Sampling sites	Air temp.(°C)	Water temp.(°C)	pH	Alkali. ($mg.l^{-1}$ as $CaCO_3$)	Turbidity NTU	Salinity (%)	TDS ($mg.l^{-1}$)	Coduc. ($\mu S.cm^{-1}$)	DO ($mg.l^{-1}$)	BOD_5 ($mg.l^{-1}$)	NO_3-N ($mg.l^{-1}$)	NH_3-N ($mg.l^{-1}$)	SRP ($mg.l^{-1}$)
MP1	21-30	18-23	6.92-7.51	31-37	14-36.3	0	21.3-32	45.7-53.7	7.6-8	0.3-1.3	0.27-0.8	0.05-0.37	0.01-0.12
MP2	21-33	23-27	6.78-7.51	84-120	38-268.7	0.1	79.7-109	169.9-250	5.1-6.9	1.7-3.3	0.47-0.5	0.55-0.86	0.12-0.67
MP3	24-35.5	23-32	7.23-7.53	78.7-104	8-120.7	0.1	91-122.7	202-213.3	5.2-8.3	1.1-4.1	0.2-0.4	0.09-0.75	0.1-0.22
MP4	26-37	25.5-32	7.52-7.81	68.7-84.7	30.3-106	0-0.1	83-112.3	177-187.7	7.3-7.9	1.7-3.1	0.23-0.87	0.1-0.56	0.09-0.15
MP5	30.5-31.5	27-31.5	6.32-7.83	77.3-89.3	72-120.3	0.1	87.3-122.7	186.3-196.7	7.4-8.3	2.9-5.3	0.23-1.07	0.15-0.47	0.13-0.26
TC1	27.5-29	27-29	6.83-7.67	69.7-82	44.3-168.7	0.1	77-108	163.8-190	5.6-6.5	1.8-3.7	0.17-1.00	0.19-0.74	0.15-0.19
TC2	18-30	23-30	7.07-7.35	49.7-92	34.3-107.3	0.1	79.7-131	169.6-220	3.7-5.4	2.1-5	0.2-0.33	0.2-0.83	0.17-0.53
TC3	21-34	24-32	7.04-7.30	46.7-109.7	26.7-73	0.1-0.2	89.3-186.3	192.3-314	2.8-5	3-4.7	0.13-0.73	0.34-0.7	0.12-0.59
TC4	27-32.5	25.5-32	7.1-7.21	71.7-109.3	10.3-27.3	0.2	167.3-224	351.3-398.7	1.3-2	4-5.8	0.3-0.77	0.45-0.61	0.26-0.57
TC5	28-31	26-30.5	6.7-7.25	74.7-143.3	2-19	0.2-0.3	175.7-281	373.3-474	0.77-1.7	5.3-7.5	0.27-0.57	0.69-1.27	0.57-0.92
CH1	25.5-27	21.5-29.5	7.07-7.47	20.7-157.7	6.7-146.7	0-0.2	42.3-244.7	89.7-410	4.5-7.5	0.3-5	0.03-0.73	0.14-0.45	0.01-0.07
CH2	18-32	22-32	7.17-7.72	26.7-82.7	15.3-119.7	0.2-0.5	139.3-558	322.3-992	6-6.3	0.7-2.7	0.1-0.17	0.2-0.44	0.01-0.26
CH3	25-35	25-33	6.84-7.27	28.7-76	61-105.7	0.1-0.2	129.3-163.7	242-348	4.9-9.7	1.3-3	0.23-0.43	0.36-0.48	0.03-0.16
CH4	28-37	24-33	7.03-7.37	25.3-43	55.7-170.3	0.1	94.7-110.7	177-234	5-6.5	1.7-3.1	0.27-0.4	0.41-0.62	0.04-0.17
CH5	25.5-30	25-30	6.66-7.3	26.3-43.7	52-166.3	0.1	101.7-117.7	183.3-252.7	4.7-6	1.2-3.6	0.1-0.77	0.43-0.57	0.08-0.14
KW1	22-34	25-28	7.11-7.77	55.3-146	0-6.33	0.1	111-149	246.7-251.3	3.5-5.8	2-5	0.1-0.27	0.07-0.18	0.03-0.1
KW2	22-33	24-29	7.27-7.61	55.3-140.3	0-7.33	0.1	116.3-153.7	246-265.7	2.4-4	2.6-4.6	0.13-0.33	0.15-0.23	0.04-0.14
KW3	24-33.5	25-29	7.12-7.68	57.3-146.7	0-9.33	0.1	116.3-155	245.7-261.7	2.2-5	2.1-5.8	0.1-0.33	0.1-0.12	0.01-0.13
KW4	30-34	27.5-32	7.48-7.91	46.7-143	0-10.7	0.1	115.7-156.7	245.3-268.3	3.9-8.2	1.2-3.9	0.1-0.33	0.02-0.09	0.04-0.09
KW5	30-33	26.5-32	7.64-7.67	55.7-136	0-11.3	0.1	111.7-157	239-265.3	5.8-7	1.5-3.9	0.2-0.5	0.12-0.14	0.04-0.13
TP1	27-33	24-29	6.12-7.02	7.3-13.7	0-7.7	0	6.7-8.3	13-20.4	6.9-8.5	0.5-4.5	0.2-0.33	0.02-0.1	0.01-0.07
TP2	28-32	27.5-32	7.41-7.85	74-113	9.3-81.3	0.1	76.3-159.7	160.1-269.7	6.3-8.3	2-4.9	0.17-0.33	0.13-0.22	0.08-0.12
TP3	29-34	28-32	7.49-7.66	59-96	13.3-51.3	0.1	73.3-153	155.5-259	6.5-8.5	1.5-3.5	0.1-0.3	0.16-0.18	0.02-0.08
TP4	27-33	26-32	6.92-7.39	52-69.7	19.7-27.3	0.1	61.7-106.3	131.7-174.7	4.8-7.7	1.7-5.5	0.3-0.43	0.15-0.25	0.02-0.12
CB1	29-35	28-32	6.6-6.77	8.3-34.3	0-51.3	0	16-42.3	37.9-68.7	6.6-7.9	1.1-3.5	0.1-0.67	0.1-0.22	0.04-0.37
CB2	29.5-30	27.5-31	5.88-6.42	7.3-22	1.7-24.3	0	18-32.4	38.2-53.1	5.2-7.6	1.4-3.1	0.23-0.9	0.15-0.16	0.03-0.22
CB3	26-30	25-32	5.85-6.68	7.7-24.3	1-39.7	0	17.7-31.3	39.2-52.3	5.3-7.7	1.2-2.9	0.27-0.57	0.19-0.2	0.08-0.34
CB4	24-30	23-32	6.04-7.11	9.7-26.3	0-45.3	0	16.3-33.5	37.5-55.7	4.6-7.5	1.1-3.1	0.27-0.67	0.1-0.2	0.02-0.5

Table 6. Water quality by trophic status in each sampling site and season of 6 main rivers of Thailand.

Name of sites	AARL-PC score			Trophic status		
	summer	rainy	cool dry	summer	rainy	cool dry
MP1	1.7	1.2	1.7	oligo-meso	oligo	oligo-meso
MP2	2.5	2.7	2.9	meso	meso	meso
MP3	2.2	2.3	2.5	oligo-meso	oligo-meso	meso
MP4	1.7	2.2	2.5	oligo-meso	oligo-meso	meso
MP5	2.3	2.6	2.4	oligo-meso	meso	oligo-meso
TC1	2.2	2.6	2.7	oligo-meso	meso	meso
TC2	2.4	3.0	3.0	oligo-meso	meso	meso
TC3	3.0	3.0	3.0	meso	meso	meso
TC4	3.3	3.2	3.6	meso-eutro	meso	meso-eutro
TC5	3.8	3.4	3.7	meso-eutro	meso-eutro	meso-eutro
CH1	2.5	1.9	2.1	meso	oligo-meso	oligo-meso
CH2	2.4	2.2	2.7	oligo-meso	oligo-meso	meso
CH3	2.6	2.5	2.1	meso	meso	oligo-meso
CH4	2.2	2.5	2.6	oligo-meso	meso	meso
CH5	2.4	2.4	2.7	oligo-meso	oligo-meso	meso
KW1	2.3	2.4	2.4	oligo-meso	oligo-meso	oligo-meso
KW2	2.8	2.5	2.8	meso	meso	meso
KW3	2.8	2.5	2.5	meso	meso	meso
KW4	2.5	1.9	2.3	meso	oligo-meso	oligo-meso
KW5	2.3	2.4	2.4	oligo-meso	oligo-meso	oligo-meso
TP1	1.1	1.6	1.5	oligo	oligo	oligo
TP2	2.4	2.2	2.1	oligo-meso	oligo-meso	oligo-meso
TP3	2.2	2.1	2.0	oligo-meso	oligo-meso	oligo-meso
TP4	2.4	2.3	2.2	oligo-meso	oligo-meso	oligo-meso
CB1	1.7	1.7	2.1	oligo-meso	oligo-meso	oligo-meso
CB2	2.1	1.6	2.4	oligo-meso	oligo	oligo-meso
CB3	2.0	2.0	2.3	oligo-meso	oligo-meso	oligo-meso
CB4	2.0	1.7	2.4	oligo-meso	oligo-meso	oligo-meso

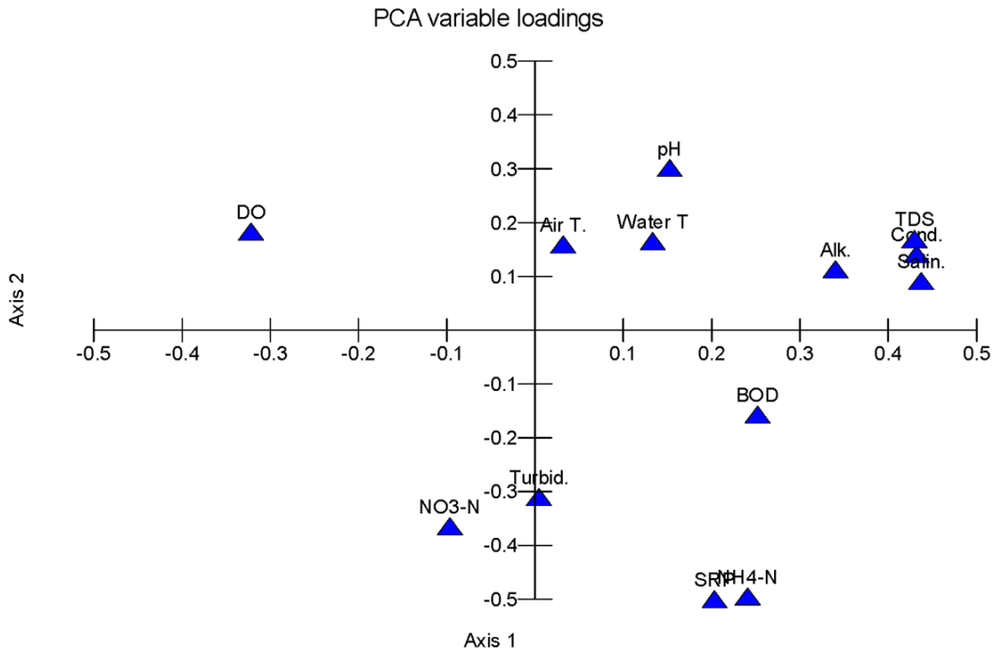


Figure 2. The principal component analysis (PCA) indicating correlation of water properties in 6 main rivers of Thailand.

In this study, 80% similarity of CA in the Ping, Tha Chin, Chi and Tapee Rivers were selected on the basis of physical and chemical factors. The Ping River showed 3 groups; all samples of MP1 were in Group 1 because this site was located at the upstream area with low levels of BOD_5, TDS, conductivity, alkalinity and nutrients (ammonia-nitrogen, nitrate-nitrogen and soluble reactive phosphorus). The water quality was clean to moderate and classified in the oligo-mesotrophic status based on AARL PC score, especially in the rainy season which was similar to that reported by Kunpradid and Peerapornpisal [13]. Most of the sampling sites were in Group 2. Only MP2 in rainy seasons was in Group 3 because it was affected by Mae Kha Canal i.e. waste water from this canal mixed with water bodies and showed high ammonia-nitrogen, SRP and low level of DO. The water quality was moderate and classified in the mesotrophic status (Tables 5 and 6; Figures 4 and 5).

At Tha Chin River, all samples of TC1, 2 and 3 were in Group 1 which showed high level of DO and low levels of BOD_5, TDS, conductivity, alkalinity, SRP, ammonia-nitrogen and nitrate-nitrogen. The water quality was moderate and classified in the mesotrophic status. Group 2 included TC4 and 5 which were downstream of Tha Chin River. The water was moderate to polluted quality and classified in the meso-eutrophic status which was similar to the report by Simachaya [14] and Petipong [15] (Tables 5 and 6; Figures 4 and 5).

There were 5 groups at Chi River. CH1 and 2 of summer and cool dry seasons were within group 1 with high levels of salinity, conductivity and TDS. All samples of CH3, 4 and 5 were in Group 2 with high levels of SRP, ammonia-nitrogen and nitrate-nitrogen.

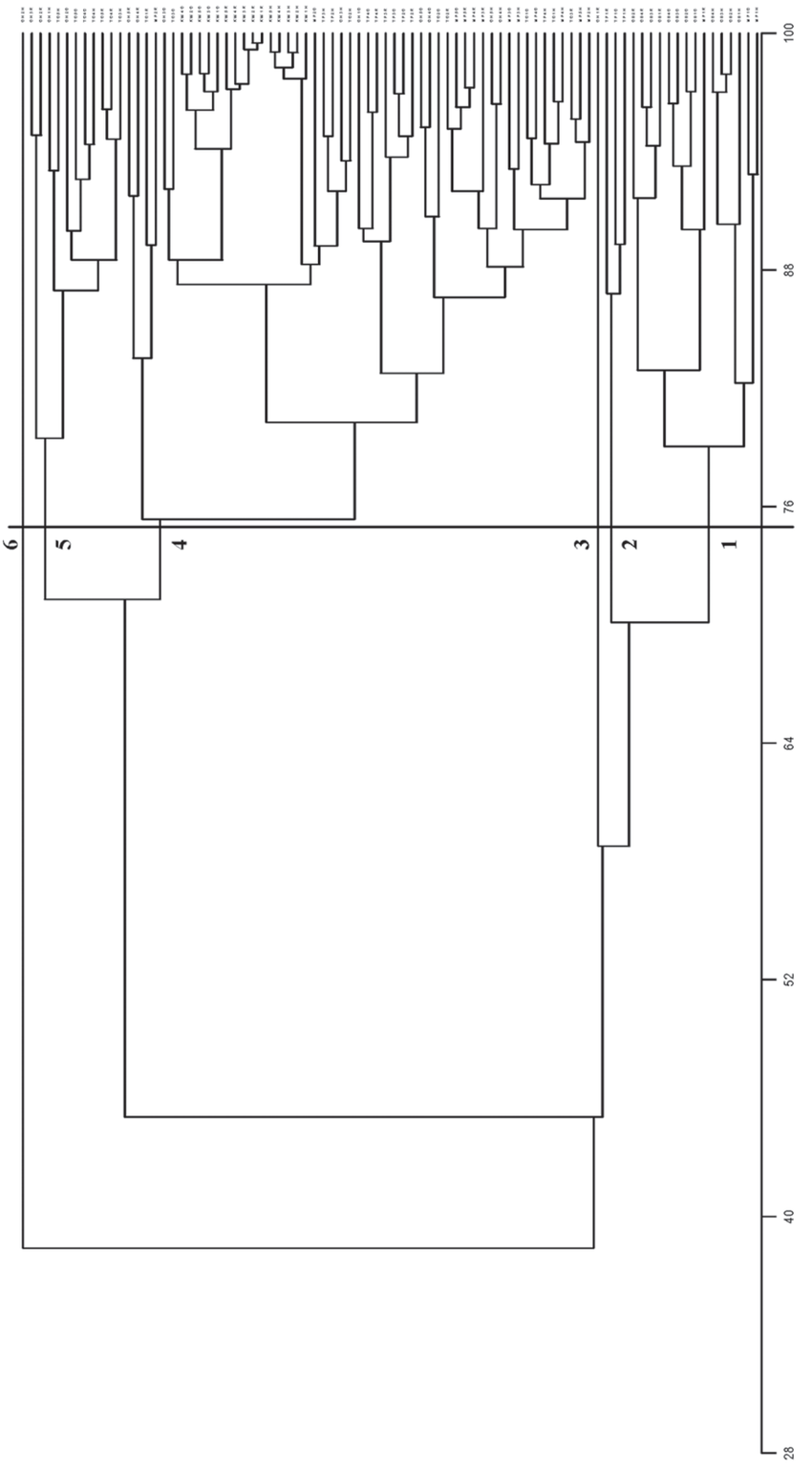


Figure 3. Cluster analysis of water properties in the main rivers of Thailand showing 6 groups with 75% similarity.

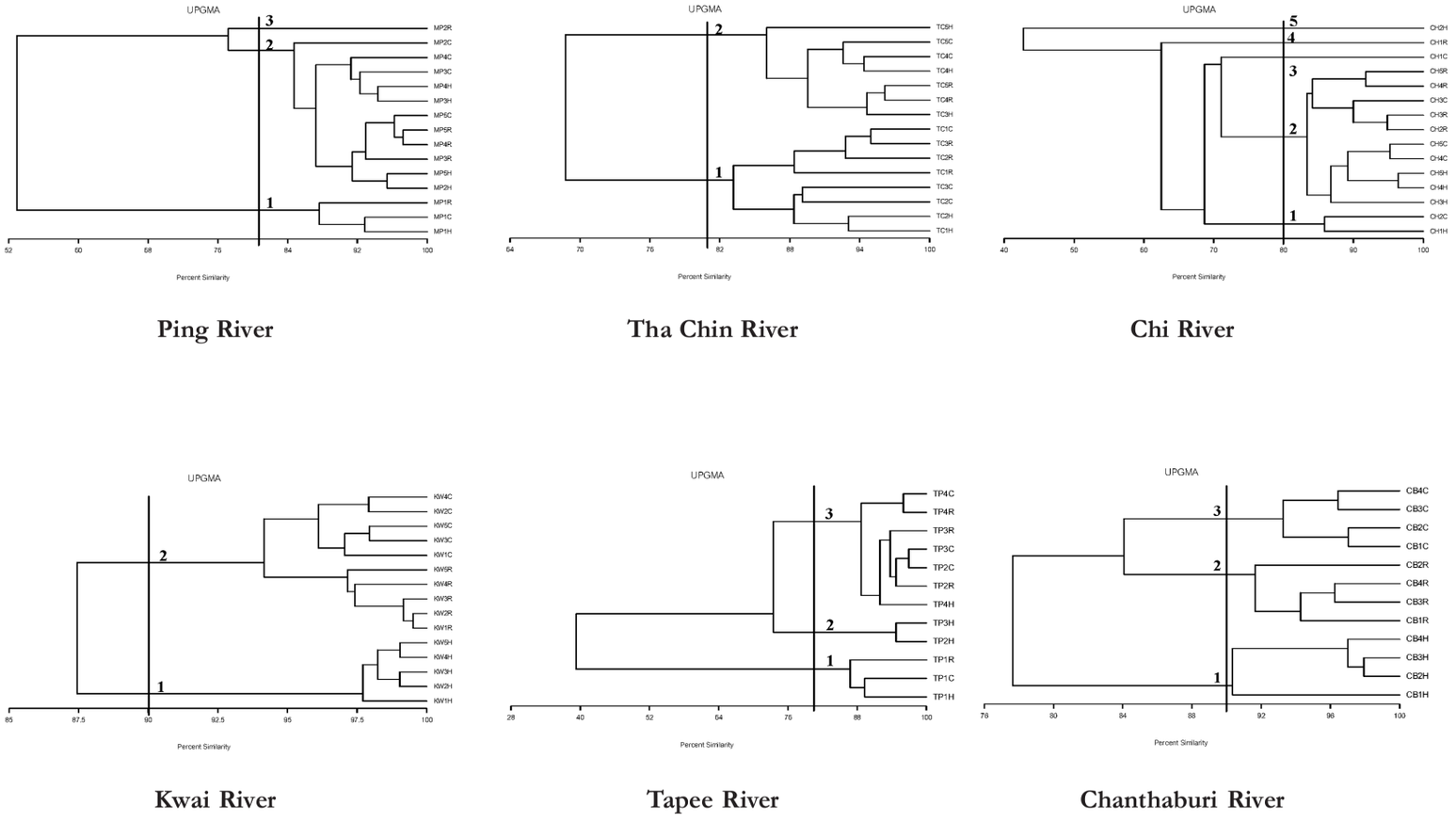
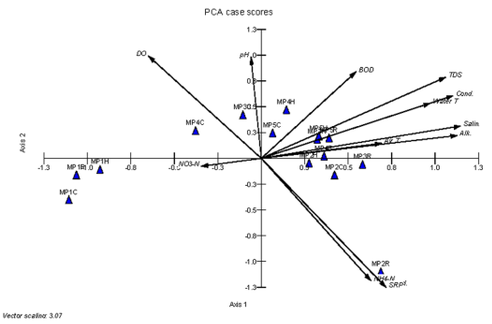
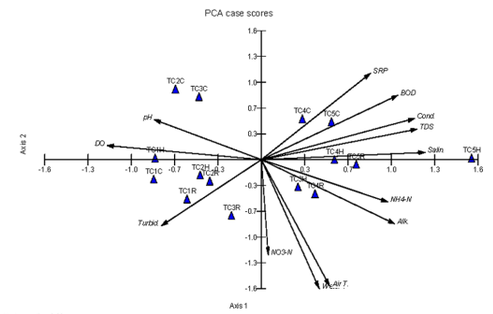


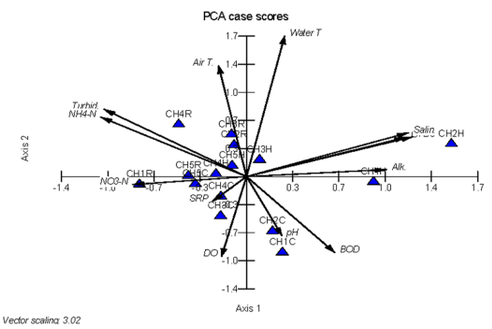
Figure 4. Cluster analysis of water properties of sampling sites in 6 main rivers of Thailand.



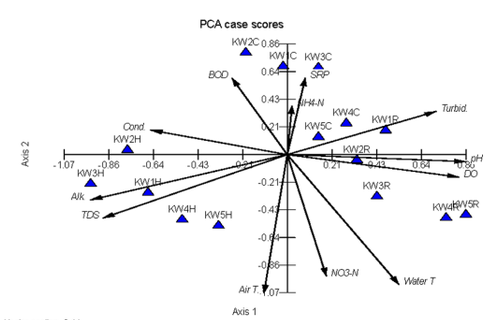
Ping River



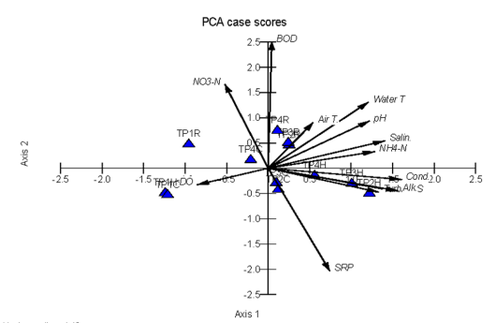
Tha Chin River



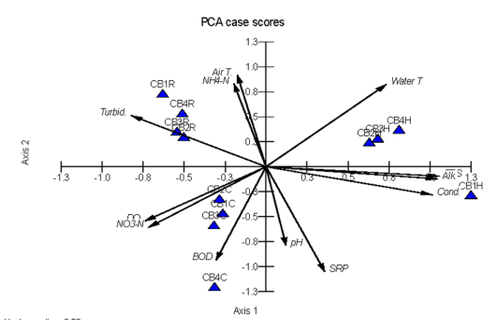
Chi River



Kwai River



Tapee River



Chanthaburi River

Figure 5. The principal component analysis (PCA) of water properties showing correlation between physico-chemical parameters and sampling sites in 6 main rivers of Thailand.

Only CH1 of cool dry season was in Group 3 with high levels of BOD_5 and pH. Group 4 was only CH1 of rainy season with a high level of nitrate-nitrogen and low level of BOD_5, salinity, conductivity and TDS. Group 5 was only CH2 of summer season which showed highest level of salinity, conductivity and TDS with values 0.5±0.00%, 992±2.65 µs/cm and 558±0.00 mg/L. This was due to the dissolution of saline soil into water body [16, 17]. The water quality of Groups 2, 3 and 4 were clean to moderate and classified in the oligo-mesotrophic status whereas Groups 1 and 5 were moderate and classified in the mesotrophic status (Tables 5 and 6; Figures 4 and 5).

The Tapee River showed 3 groups. Group 1 was all samples of TP1 because it was located in a National Park with high levels of DO and low levels of TDS, conductivity and alkalinity which was similar to the report by Petipong [15]. The water quality was clean and classified in the oligotrophic status. Group 2 had all samples of TP2 and 3 in summer season with high level of TDS, conductivity and alkalinity. Group 3 had most of the sampling sites and the water quality was clean to moderate and classified in the oligo-mesotrophic status which was similar to the report by Petipong [15] and Chuaygud et al. [18]. (Tables 5 and 6; Figures 4 and 5).

The 90% similarity of CA was selected for the Kwai and Chanthaburi Rivers. There were 2 groups for the Kwai River, Group 1 was all samples in summer season with high levels of TDS, conductivity, alkalinity and low levels of turbidity which was similar to the report by Tyler [19]. Group 2 was all samples in rainy and cool dry season. In addition, at Chanthaburi River, there were 3 groups by seasons. Group 1 was all samples in summer season with high level of water temperature and low level of DO and nitrate-nitrogen. All samples in rainy season were in Group 2 with high level of turbidity and low levels of TDS, conductivity, alkalinity. Group 3 was all samples in cool dry season with high levels of DO, BOD_5 and nitrate- nitrogen. The water quality of Kwai and Chanthaburi Rivers was clean to moderate and classified in the oligo-mesotrophic status which was similar to the report by Petipong [15] and Bordalo et al. [20]. (Tables 5 and 6; Figures 4 and 5).

4. CONCLUSIONS

The water quality of some of the main rivers of Thailand from March 2008 - January 2009 showed mostly clean to moderate and classified in the oligotrophic-mesotrophic status, except in the upstream of the Ping and Tapee Rivers which were clean and classified in the oligotrophic status. Besides, the downstream of the Tha Chin River showed moderate to polluted water quality and classified in the mesotrophic-eutrophic status.

In this investigation, beneficial usages of each river were recommended by standard surface water quality of Thailand [21]. The Ping, Chi, Kwai, Chanthaburi and Tapee Rivers could be used for agriculture, industry and communication. Tha Chin River could be used for industry and communication. The water has to undergo an ordinary treatment process before use for consumption. However, the water from Tha Chin River requires special treatment.

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