Kasetsart J. (Nat. Sci.) 44 : 732 - 743 (2010)

Seasonal Variations of Water Quality in Bangpakong River and Nearby Canals at Banpho District

Teerada Bubphamala[1]*, Lukkhana Benjawan[2] and Warounsak Liamlaem[3]

ABSTRACT

The substantial growth in the population and industries of Banpho district, Chachoengsao recently drove the community to express concern over the health of the Bangpakong River and canals in the vicinity. The water quality of the River and canals in Banpho district was monitored monthly from November 2006 to July 2008, covering the dry season (November-April) and the wet season (May-October). The collected water samples were analyzed for pH, temperature, salinity, conductivity, turbidity, dissolved oxygen (DO) biochemical oxygen demand (BOD), nitrate-N and total and fecal coliform bacteria. The heavy metals in the water samples, Hg, Pb, Cd, Cr^{6+}, and Mn, were determined as well. It was found that the BOD, total and fecal coliform bacteria levels were significantly higher than the standard limits for surface water quality. The levels of Pb, Hg, Cd and Mn were occasionally at higher levels than the standard limits. Among such metals, Pb and Cd were the most critical, since their highest levels were more than 15 times higher than the limits. The severity of the pollution seemed to be higher in the dry season than in the wet. Similarly, high salinity was typically found in the dry season. Furthermore, the highest amounts of the contaminants were generally found in March and April.

Keywords: water quality, Bangpakong River, nearby canals, Banpho district, dry/wet season

INTRODUCTION

The Bangpakong River is one of the five major rivers (Chaopraya, Pasak, Rachaburi, Petchaburi, and Bangpakong) that have been used in Thai Royal ceremonies for decades. It originates at the confluence of the Prachinburi and Nakhonnayok Rivers in Bansang district, Prachinburi province, and empties into the Gulf of Thailand in Bangpakong district, Chachoengsao province (Figure 1(a)). With a length of 122 km, it is considered the main river in eastern Thailand. The people in Prachin Buri, Nakorn Nayok, and Chachoengsao provinces use the water mainly for municipal supplies, irrigation, aquaculture, animal farming and for industry, among other uses.

Unfortunately, the waste or effluent from activities, including domestic waste, agricultural runoff, fish-, shrimp- and pig-farm waste and industrial effluent (from metal plating, smelters and auto parts production) are discharged back into the river without being properly treated. In fact, the situation seemed to get worse when the population and industrial activity expanded recently. The considerable industrial growth, particularly in Banpho district, increased the local

1 Faculty of Science and Technology, Rajabhat Rajanagarindra University, Chachoengsao 24000, Thailand.

2 Research and Development Institute at Kamphang Saen, Kasetsart University, Nakhon Pathom 73140, Thailand.

3 Department of Civil Engineering, Thammasat University, Pathum Thani 12120, Thailand.

* Corresponding author, e-mail: teeramala@hotmail.com

Received date : 08/12/09 Accepted date : 05/03/10

community concern over the health of the River. The water watch in this study was therefore aimed at assessing the quality of the Bangpakong River and the nearby canals in Banpho district (Figure 1(b)).

According to the water resources classification of Thailand, the Bangpakong River was ranked as class 3 for medium clean water, suitable for consumption (after treatment) and/or agricultural use (NEB, 1994). For decades, the water quality in the Bangpakong River has been periodically monitored by various groups.

The Office of Hygiene and Environment 3, Chonburi Branch (2001), for example, reported that the dissolved oxygen (DO) levels in the River were somehow lower than the standard limit, while the biochemical oxygen demand (BOD) and coliform bacteria were beyond the limits at times. Among the heavy metals investigated in the study (Pb, Cd, Cr, Cu, Zn, and Mn), only Mn was detected at 0.1-0.2 mg/L. (Office of Hygiene and Environment 3, 2001). In addition, Wongwiwatanawute (2005) reported that the coliform bacteria levels in the River were frequently beyond the standard limit. The highest numbers of both fecal and total coliform bacteria were 24,000 MPN/100 mL. Of interest, the highest levels of contamination were discovered in April and August 2005 when the bacterial levels were far beyond the limits at all four sampling points of Tah-Kham, Song-Khlong, Bangpakong and Tah-Sa An. The study also found that the DO levels

Figure 1(a) Map of Chachoengsao province in East Thailand (upper right). The Bangpakong River is the main river in the province.

in 2005 were significantly lower than the levels found in 2004 (averages of 3.5 and 5.7 mg/L, respectively).

These results were confirmed by Pollution Control Department (PCD) reports (PCD, 2004-2008). The water quality of the Bangpakong River, based on the DO, BOD, fecal and total coliform bacteria concentrations was annually monitored by the PCD, along with some other major rivers in Thailand. The Bangpakong River was determined to have changed classification from being moderately polluted in 2004 to being in poor condition in 2005. In fact, since then, the status of the river has alternated from year to year between the two classifications (PCD, 2004-2008).

Organic matter in waste is generally non-toxic and biodegradable. But high levels of nutrients, particularly compounds of nitrogen and phosphorus, promote eutrophication or the blooming of aquatic plants and reduce the oxygen concentration in the water.

In contrast, the inorganic substances are mostly toxic and non-biodegradable. They are accumulated in sediments or organisms, which then contribute to other trophic levels of the food

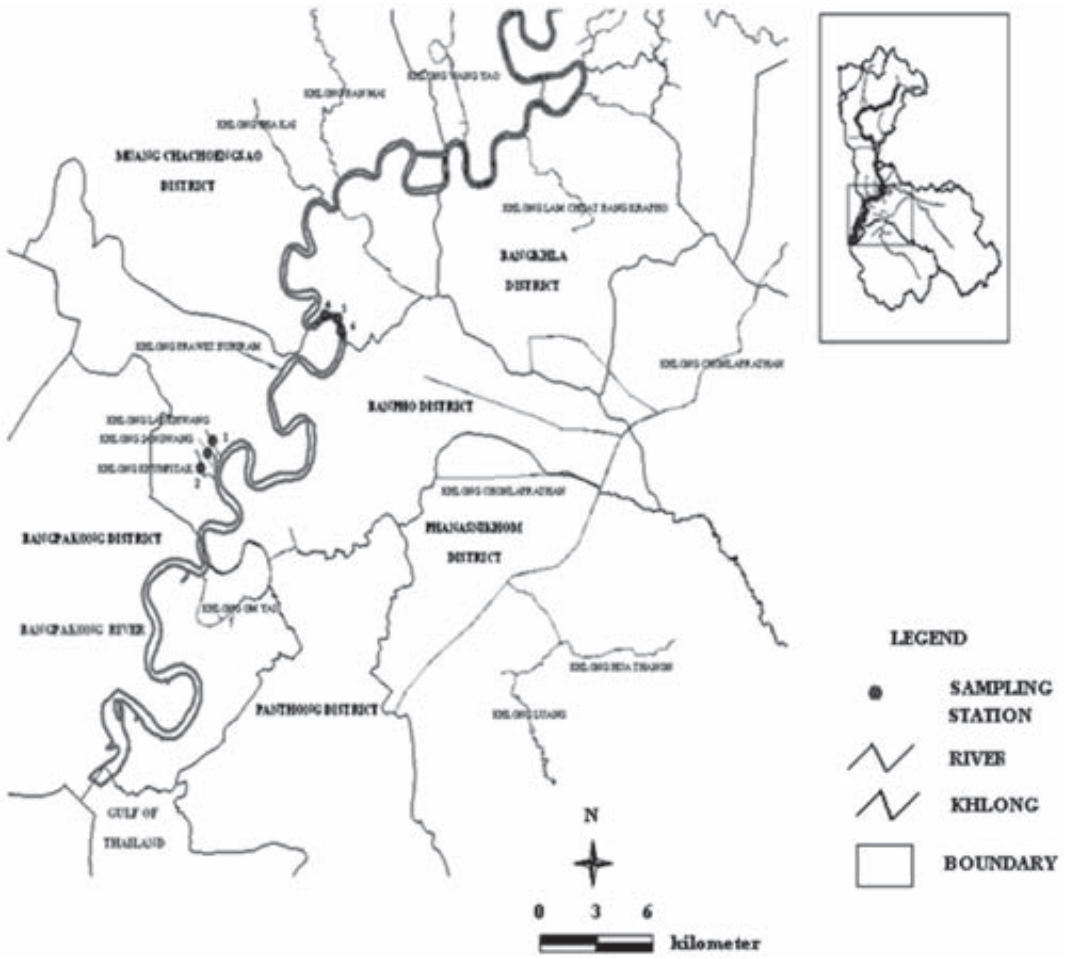

Figure 1(b) Six sampling locations in Banpho district, Chachoengsao, with three on the Bangpakong River and the other three on the Ladkwang, Khumpitak and Janwang canals.

web in the ecosystem. The toxicity depends on the form of the heavy metals, concentrations, animal species, age, duration and frequency of contact, and health status. For example, Cr^{3+} is non toxic to humans, but Cr^{6+} is a human carcinogen. Lead (Pb) can cause neuro and hematological disorders, but it is more likely to harm children (younger than seven years) than the adults.

The River's tributaries or canals seem to have been given less importance, resulting in fewer studies based on them. In fact, most waste water, either from domestic activity, agriculture, or small to medium size industries, was directly loaded into the canals, from where the water then flowed into the River. (Bordalo *et al*., 2001).

Thus, in this study, the water quality of the lower Bangpakong River, including the canals in Banpho district, was monitored and analyzed. In addition, to evaluating the existing situation of the waters, major parameters of water quality were analyzed between the wet (November-April) and dry seasons (May-October) from November, 2006 to July, 2008. Furthermore, appropriate approaches for sustainable water quality management were proposed.

MATERIALS AND METHODS

Sampling area

This study was mainly focused on water quality of the Bangpakong River and its nearby canals in the Banpho district, located about 85 km from the river mouth. Six sampling stations were chosen along the Bangpakong River and the canals in Banpho district, as shown in Figure 1(b). Details of each station are described in Table 1. The sampling period was from November 2006 to July 2008.

Sample collection

The data were analyzed based on monthly sampling of the waters throughout the 21 consecutive months from November 2006 to July 2008. In each month, the sampling was done mostly on the neap tide day, from 10.00 am to 2.00

Table 1 Coordinates of sampling stations.

Stations	Location	Coordinates (UTM)		Remarks
		Easting	Northing	
1	Ladkwang canal	718232	1505718	It is lLocated in Banpho district, at which surrounded by communities and manufacturers.
2	Khunpitak canal	714538	1506033	Located in Banpho district, surrounded by many agricultural communities.
3	Jangwang canal	716752	1501497	Located in Banpho district, surrounded by communities and nearby (metal) manufacturing industries.
4	Bangpakong Station 1 (BP 1)	724324	1505131	Bangpakong River in Banpho district, No. 1 upstream station.
5	Bangpakong Station 2 (BP 2)	724618	1504447	Bangpakong River in Banpho district, No. 2 upstream station.
6	Bangpakong Station 3 (BP 3)	724600	1503660	Bangpakong River in Banpho district, No. 3 upstream station.

pm, when the difference between high and low tide was small.

Analytical procedures

The water samples were collected using grab sampling techniques. They were then analyzed for 13 water quality parameters: pH, temperature, turbidity, electrical conductivity (EC), salinity, DO, BOD, nitrate-nitrogen (NO_3-N), total coliform bacteria and heavy metal concentrations (Hg, Pb, Cd and Mn). All parameters were analyzed based on the Standard Methods for Water and Wastewater Examination (APHA, 2005).

Data analysis

As the Bangpakong River basin is influenced by the wet southwest monsoon (from late May to October) and the dry northeast monsoon (from November to April), direct impacts from the seasonal monsoons on the quality of water in the River (and canals) are certainly unavoidable. Therefore, in this study, the data were grouped and analyzed according to the meteorological wet and dry seasons. In addition, there were two consecutive periods in each season. The dry season consisted of data covering the period from November 2006 to April 2007 and from November 2007 to April 2008 and was categorized as period 1 and 2, respectively, in the dry season (Figures 2 to 7). The wet season data was collected from May 2007 to October 2007 and from May 2008 to July 2008 and was categorized as period 1 and 2, respectively, in the wet season (Figures 2 to 7). All data were analyzed and evaluated using the Microsoft Excel package.

RESULTS AND DISCUSSION

Water quality in the canals: Ladkwang, Khunphitak and Jangwang

Water quality in the canals studied, which were located in Banpho district, had an average surface water temperature in the dry season (DS) ranging from 29.2°C to 29.6°C and in the wet season (WS) ranging from 30.0°C to 30.8°C (Table 2). There was a positive correlation (0.943) between conductivity and salinity, whereas the correlation between turbidity and salinity was negative (-0.852), as was the correlation between

Table 2 Water quality parameters of the canals in the dry and wet seasons.

Parameters	Ladkwang		Khunpitak		Jangwang	
	Dry	Wet	Dry	Wet	Dry	Wet
pH	7.7 ± 0.4	7.5 ± 0.4	7.6 ± 0.7	7.3 ± 0.3	7.6 ± 0.4	7.5 ± 0.3
Temperature (°C)	29.3 ± 2.8	30.0 ± 2.3	29.6 ± 3.1	30.2 ± 2.1	29.2 ± 2.7	30.8 ± 2.4
Turbidity (NTU)	39.4 ± 32.1	66.4 ± 14.5	44.3 ± 30.0	56.6 ± 21.2	40.6 ± 46.7	79.6 ± 47.5
BOD (mg/Ll)	11.0 ± 4.8	5.2 ± 3.6	13.1± 6.8	6.9 ± 5.6	13.4 ± 5.9	5.7 ± 4.8
DO (mg/Ll)	7.4 ± 2.8	5.0 ± 1.7	7.4 ± 5.5	3.6 ± 1.8	5.0 ± 3.4	4.5 ± 2.5
Nitrate (mg/Ll as N)	0.3 ± 0.3	0.3 ± 0.2	0.3 ± 0.3	0.2 ± 0.1	0.4 ± 0.5	0.3 ± 0.3
Salinity (g/Ll)	1.7 ± 1.5	0.5 ± 0.3	1.8 ± 2.5	0.8 ± 0.4	2.4 ± 2.2	0.7 ± 0.4
Conductivity (mS/cm)	3.4 ± 2.4	1.3 ±0.7	4.7 ± 5.6	1.9 ± 0.8	4.4 ± 3.4	1.6 ± 1.0
Total Coliform ($x10^2$ MPN/100 mL)	441.3 ±597.0	1188.8 ± 3005.3	406.2 ± 624.6	22.6 ± 517.8	267.2 ± 347.2	275.2 ± 379.9

Note: All parameters are expressed as average ± standard deviation.

turbidity and conductivity (-0.838). The canal waters showed lower turbidity, but higher BOD in the DS, compared to the WS. Salinity was clearly higher in the DS. The organic matter (BOD) was also lower in the WS in all three canals. This was probably due to the contaminants being more diluted in the rainy season. However, higher turbidity and lower DO in every canal were recorded in the WS than in the DS, which in part could have resulted from the higher turbulence and leaching of soil or sediments either from the canals' banks or beds during the rainy season. The average values of the parameters monitored are shown in Table 2.

Water quality in Bangpakong River at Banpho district

Water quality in the Bangpakong River in Banpho district during the study period (November 2006 to July 2008) had an average surface water temperature ranging from 29.1°C to 29.5°C and from 29.8°C to 30°C in the DS and WS, respectively (Table 3). The pH of the Bangpakong River ranged from 7.2-7.5 throughout the year. There was a positive (0.943) correlation between conductivity and salinity, whereas there was a negative (-0.852) correlation between turbidity and salinity and also between turbidity and conductivity (0.838).

Effects of seasons on salinity

The levels of salinity in the Khunpitak, Ladkwang and Jangwang canals are shown in Figures 2, 3 and 4, respectively. There was obviously higher water salinity in the DS in both the river (connected to the Gulf of Thailand) and its nearby canals (Tables 2 and 3). It was more than likely that the salt intrusion from the Gulf of Thailand regularly occurred in the river and then moved upstream into the nearby canals. The small volumes of water in the DS raised salinity levels even higher than in the WS. Thus, the direct impact of salt intrusion was much greater in the River than in the canals. In other words, the nearby canals suffered from a smaller impact of salt intrusion in the DS than did the River. The results of the monitoring also showed that the salinity in the DS seemed to be higher in 2008 compared to 2007. This was possibly a potential effect of a rise in the sea level as reported in several studies (Bordalo *et*

Table 3 Water quality parameters in the Bangpakong River, Banpho district.

Parameters	BP 1		BP 2		BP 3	
	Dry	Wet	Dry	Wet	Dry	Wet
pH	7.2 ± 0.2	7.5 ± 0.2	7.3± 0.2	7.4 ± 0.4	7.3 ± 0.3	7.5 ± 0.4
Temperature (∝C)	29.1± 1.9	29.8 ± 1.9	29.5 ± 1.6	29.8± 1.9	29.5±1.9	30.0 ± 1.8
Turbidity (NTU)	74.8 ± 144	148.6±100	102.2 ± 238	143.7 ± 111	154.4 ± 332	161.4 ± 120
BOD (mg/L)	3.7 ± 2.0	6.0 ± 5.4	2.7 ± 1.5	4.1 ± 3.6	3.2 ± 1.8	5.0 ± 3.5
DO (mg/L)	5.2 ± 1.3	3.4 ± 1.1	5.7 ± 1.7	4.0 ± 1.1	5.6 ± 1.8	3.5 ± 1.1
Nitrate (mg/L as N)	0.7 ± 0.4	0.4 ± 0.2	0.6 ± 0.4	0.4 ± 0.2	0.6 ± 0.3	0.4 ± 0.2
Salinity (g/L)	16.7 ±12.6	0.3 ± 0.2	17.5±13.2	0.5 ± 0.7	16.9 ± 11.9	0.3 ± 0.2
Conductivity (mS/cm)	28.9 ±18.2	0.8 ± 0.5	29.9±17.9	0.8 ± 0.5	30.4± 18.1	0.8 ± 0.5
Total Coliform ($x10^2$MPN/100mL)	1341.2± 4616.4	54.0±171.2	96.8± 316.0	205.0 ± 355.8	12.7 ± 22.1	254.2 ± 360.4

Note: All parameters are expressed as average ± standard deviation.

al., 1993, Vliet and Zwolsman, 2008, Soontornprasit and Meksumpun, 2008).

Organic matter as BOD is a main parameter for classifying beneficial usage of water resources. The average BOD in the canals was 11.0-13.4 mg/L and 5.2-6.9 mg/L in the DS and WS, respectively (Figures 2a, 3a and 4a), which were all substantially higher than the standard limits (The surface water standard limit for class 3 is ≤2.0 mg/L). The situation seemed to be worse in the DS for all canals.

The average BOD readings at the monitoring stations on the Bangpakong River, Banpho district were 2.7-3.7 mg/L and 4.1-6.0 mg/L in the DS and WS, respectively. The highest levels at all stations of 12.6-19.2 mg/L were recorded in June 2008 (Figures 5, 6 and 7).

Effects of season on heavy metals levels

In this study, the concentrations of mercury (Hg), lead (Pb), cadmium (Cd), chromium VI (Cr^{6+}), and manganese (Mn) were investigated.

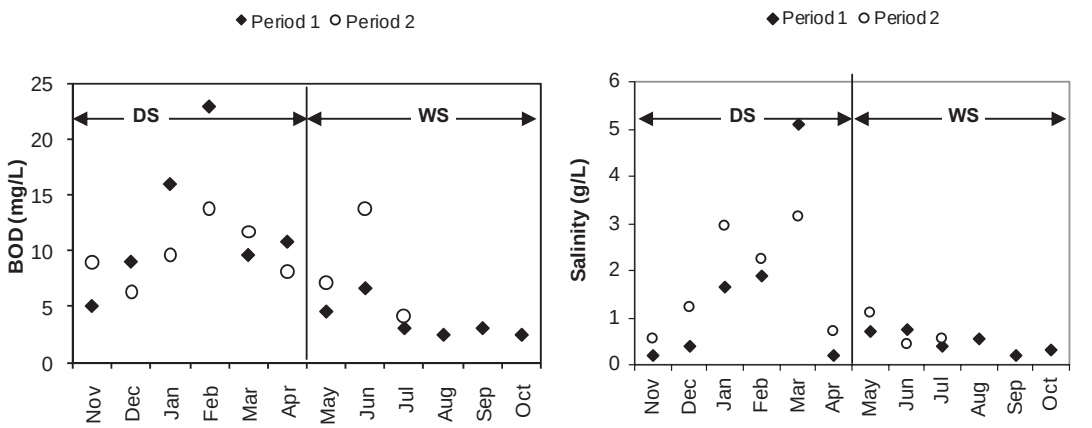

Figure 2 BOD and salinity concentration in the Ladkwang canal during DS and WS.

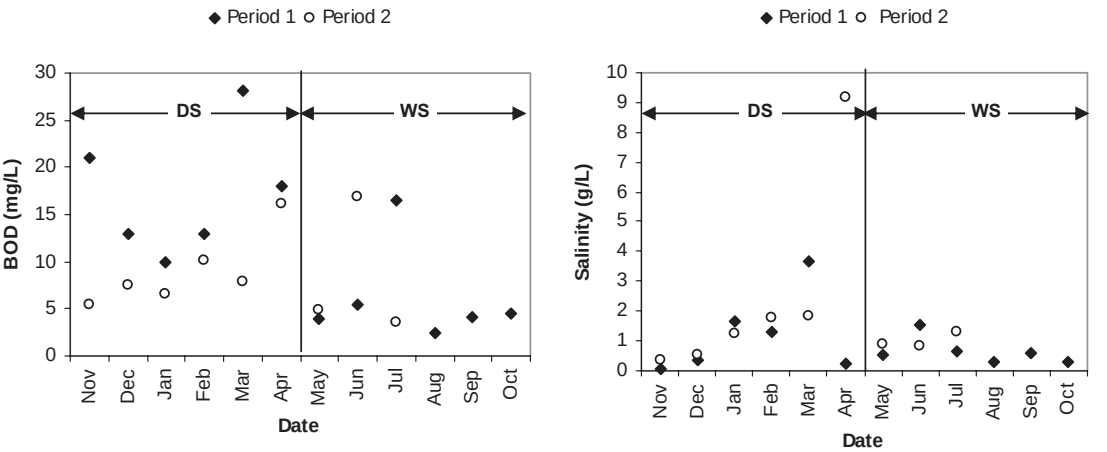

Figure 3 BOD and salinity concentration in the Khunpitak canal during DS and WS.
Note: Period 1 = Nov 06 - Apr 07 (DS1), May 07 - Oct 07 (WS1)
Period 2 = Nov 07 - Apr 07 (DS1), May 08 - July 08 (WS2)

The data obtained from the canals and the River in Banpho district are shown in Tables 3 and 4, respectively. For the canals, in both seasons, the average levels of Cd were about 0.01 mg/L, which were higher than the surface water standard limits for Thailand, which has a standard limit for Cd of less than or equal to 0.005 mg/L (NEB, 1994). In addition, the average Hg concentrations in the Ladkwang and Khunpitak canals in the WS were higher than the standard limits for Thailand, which has a standard limit for Hg of less than or equal to 0.002 mg/L). Though the average concentrations of Mn were within the limits for Thailand (standard limit for Mn is less than or equal to 1 mg/L), it exceeded the limits from time to time during the study period, and the highest concentrations, recorded in May 2008, were 2.30-2.49 mg/L in all canals. Likewise, while the average Pb concentrations were in the acceptable range according to the standard limits (standard limit for Pb in surface water (class 3) is less than or equal to 0.05 mg/L), the highest levels (0.09-

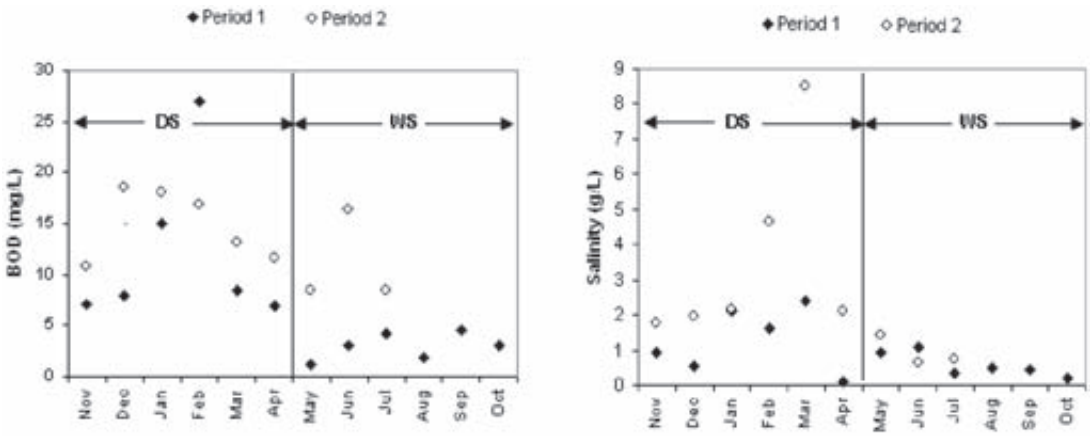

Figure 4 BOD and salinity concentration in the Jangwang canal during DS and WS.
Note: Period 1 = Nov 06 - Apr 07 (DS1), May 07 - Oct 07 (WS1)
Period 2 = Nov 07 – Apr 07 (DS1), May 08 - July 08 (WS2)

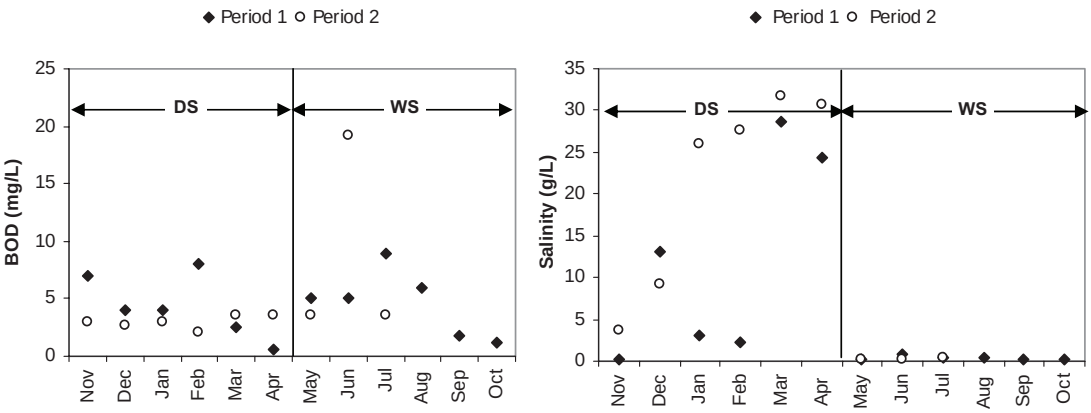

Figure 5 BOD and salinity concentration in BP 1 during DS and WS.
Note: Period 1 = Nov 06 - Apr 07 (DS1), May 07 - Oct 07 (WS1)
Period 2 = Nov 07 – Apr 07 (DS1), May 08 - July 08 (WS2)

0.16 mg/L) were measured in all canals in March 2007, and again in the Khunpitak canal (0.15 mg/L) in April 2008. The Cr (VI) level was below detection limits and much lower than the standard limit throughout the study. As a whole, it was unlikely that the season affected the heavy metal levels in the canals, but rather it was more likely the levels were due to contaminated wastewater loaded into the canals.

With the exception of Cr^{6+}, which was below detectable limits during the study period, the other metals, at times, were detected in the Bangpakong River, Banpho district at levels higher than the standard limits (Table 3). The average Hg concentration in the River was higher in the WS than in the DS. However, Table 3 shows there were two interesting peaks during the study period, with one in September 2007 (0.006-0.007 mg/L), and the other in May 2008 (0.01-0.012 mg/L). On the other hand, the average Pb concentration in the river in the DS was higher than the limits for Thailand. Furthermore, very significant levels of

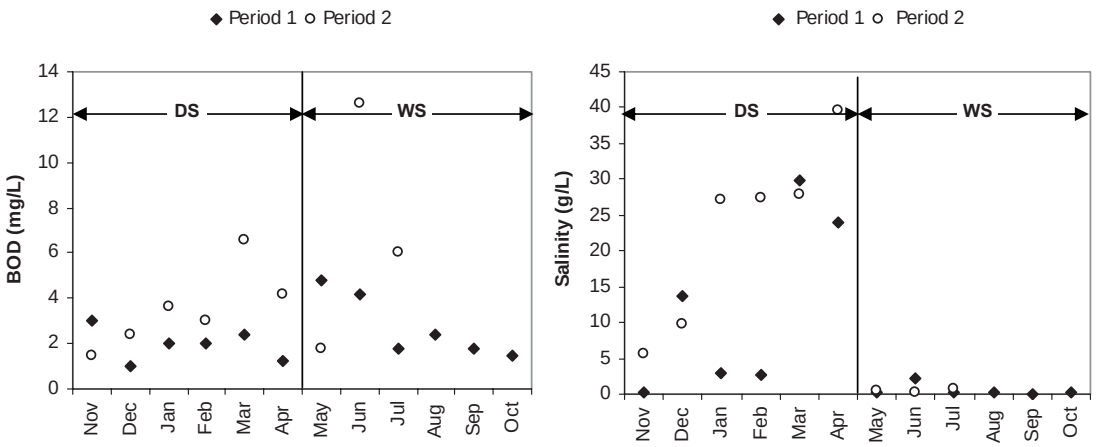

Figure 6 BOD and salinity concentration in BP 2 during DS and WS.

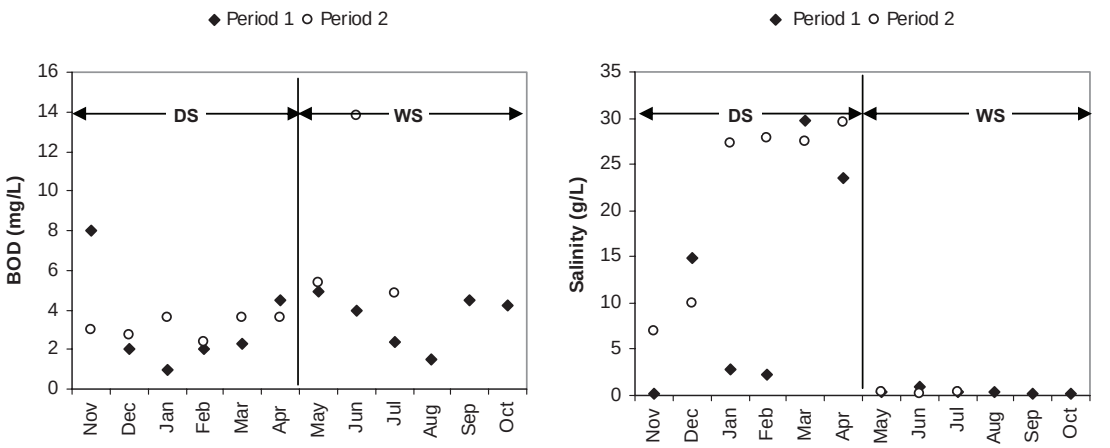

Figure 7 BOD and salinity concentration in BP 3 during DS and WS.

N.B. Period 1 = Nov 06 - Apr 07 (DS1), May 07 - Oct 07 (WS1)
Period 2 = Nov 07 – Apr 07 (DS1), May 08 - July 08 (WS2)

Pb were discovered in the River during March and April. While the range was 0.85-0.87 mg/L in March 2007, it ranged from 0.17-0.19 mg/L in April 2007. In 2008, the highest reading was 0.29 mg/L in April. Similarly, the average Cd level in the river was higher in the DS. The extreme values occurred generally between February and April. For example, in 2007, the highest Cd levels wdΔe 0.075-0.082 mg/L and 0.063-0.064 mg/L in March and April 2007, respectively. In 2008, the peaks were 0.045-0.058 mg/L, 0.047-0.05 mg/L and 0.042 mg/L in February, March and April 2008, respectively.

These significant levels of Pb and Cd were more than 15 times higher than the standard limits for Thailand. The substantial toxicity due to the presence of heavy metals in the water should be a major concern. The heavy metal contamination levels in the waters implied high sink levels in sediments and/or living organisms in the Bangpakong River. These findings perhaps supported Cheevaporn *et al*. (1994) that the sediments in Bangpakong estuary had been contaminated with heavy metals (lead, copper and zinc) during the last 30 y. The higher sink levels in the sediment occurred in the dry season rather than in the wet, partially due to the slower flow rates of water in the dry season. According to Boonphakdee *et al*. (1999), the average flow rates of waters in the Bangpakong River differed greatly between the wet and dry seasons. It was reported that the flow was 512 m^3/sec in the wet season whereas it was only 21 m^3/sec in the dry season. Thus, besides the loading itself, the differences in

Table 4 Presence of heavy metals in the canals studied in Banpho district.

Heavy metals	Ladkwang		Jangwang		Khunpitak	
	Dry	Wet	Dry	Wet	Dry	Wet
Hg (mg/lmg/L)	N.D.	0.005 ± 0.004	N.D.	N.D.	N.D.	0.004 ± 0.005
Pb (mg/lmg/L)	N.D.*	N.D.*	N.D.*	N.D.*	N.D.*	N.D.*
Cd (mg/lmg/L)	0.010 ± 0.007	N.D.**	0.010 ± 0.009	0.013 ± 0.011	0.012 ± 0.008	0.011 ± 0.010
Cr^{6+} (mg/lmg/L)	N.D.***	N.D.***	N.D.***	N.D.***	N.D.***	N.D.***
Mn (mg/lmg/L)	0.645 ± 0.472	0.625 ± 0.802	0.649 ± 0.276	0.909 ± 0.911	0.770 ± 0.593	0.975 ± 0.754

Note: All parameters are expressed as average ± standard deviation.
N.D. = non-detectable level at < 0.0002 mg/L
N.D.* = non-detectable level at < 0.001 mg/L
N.D.** = non-detectable level at < 0.002 mg/L
N.D.*** = non-detectable level at < 0.005 mg/L

Table 5 Heavy metals levels in the Bangpakong River, Banpho district.

Heavy metals	BP St. 1		BP St. 2		BP St. 3	
	Dry	Wet	Dry	Wet	Dry	Wet
Hg (mg/L)	N.D.	0.005 ± 0.004	0.002 ± 0.003	0.002 ± 0.002	N.D.	0.003 ± 0.005
Pb (mg/L)	0.345 ± 0.372	N.D.*	0.454 ± 0.371	N.D.*	N.D.*	N.D.*
Cd (mg/L)	0.040 ± 0.027	0.010 ± 0.007	0.044 ± 0.026	0.011 ±0.006	0.037 ± 0.030	0.018 ± 0.007
Cr VI (mg/L)	N.D.***	N.D.***	N.D.***	N.D.***	N.D.***	N.D.***
Mn (mg/L)	0.204 ± 0.227	0.119 ± 0.039	0.261 ± 0.356	0.114 ± 0.062	0.278 ± 0.437	0.148 ± 0.091

Note: All parameters are expressed as average ± standard deviation.
N.D. = non-detectable level at < 0.0002 mg/L
N.D.* = non-detectable level at < 0.001 mg/L
N.D.*** = non-detectable level at < 0.005 mg/L

water flow rates that caused changes in the pollutant mass flow in the River also play a role.

Similarly, Bordalo *et al*. (2001) mentioned that several heavy metals in the Bangpakong River were attributable to: (i) the wastewater from polluting industries, such as metal plating, electronics, smelting, cable manufacture, batteries and chemical industries, among others, directly loading into the river; (ii) the decrease in water volume and flow in the river, resulting in decreased water dilution; and (iii) the indirect loading of wastewaters from polluted canals (originally either from Bangkok, Prachinburi, or Chachoengsao) to the Bangpakong River.

Therefore, it is noteworthy that there remains further challenging research relating to: the mass flow rate of the pollutants; the transport of and end points for pollutants; and dispersion models of pollutants, among others, either in the waters or sediments of the Bangpakong river and its canals.

CONCLUSIONS

The water quality of the Bangpakong River, Banpho district could be categorized as moderate to deteriorating. Organic matter levels, as measured by BOD and total coliform bacteria, were rather higher than the standard limits for class 3 water resources. The water in the Bangpakong River impacted on salt intrusion, particularly in the dry season andhe salinity concentrations at such times should be watched carefully. Water users for salt-sensitive activities, such as orchid farming, some types of aquaculture and/or agriculture, should be aware of the seasonal fluctuations in the salinity level.

The waters in the Bangpakong River, Banpho district were contaminated for some periods with Pb, Cd, Hg, and Mn. The Hg concentration was higher than the surface water standard from time to time, but the Pb and Cd concentrations were more frequently much higher than the relevant standards. The highest concentrations of Pb and Cd were more than 15 times higher than the limits. The situation with regard to these significant contaminations is serious and should be a concern. In addition, the contamination by heavy metals in the waters implied high sink levels in the sediments and/or organisms in this area. In consideration of this, a closer watch on and monitoring of the sources, transport and the end points of heavy metals are proposed. In addition, additional toxicity assessment of heavy metal contamination should be taken seriously.

ACKNOWLEDGEMENTS

The authors express their appreciation for the generous support of Toyota Public Company Limited, Thailand (Banpho Plant) for financial support, which made this study possible.

LITERATURE CITED

APHA. 2005. **Standard Methods for Water and Wastewater Examination**, 21st Amer. Public Health Association., Washington, D.C.

Boonpakdee, T., P. Sawangwong and T. Fuiwara. 1999. Freshwater discharge of Bangpakong River flowing into the inner Gulf of Thailand. **La Mer.** 37: 101-107.

Bordalo, A.A., W. Nillsumranchit and K. Chalermwat. 2001. Water quality and uses of the Bangpakong River (Eastern Thailand). **Wat. Res.** 35(15): 3635-3642.

Wongwiwatanawute, C. 2005. **Water Quality under the Sea Food Bank Project**. Chachoengsao Coastal Aquaculture, Department of Fisheries, Ministry of Agriculture and Cooperatives. pp. 6-32.

Cheevaporn, V., G.S. Jacinto and M.L. Sandiego-McGlonne. 1994. History of heavy metal contamination in Bangpakong River estuary, Thailand., **J. Sci. Soc. Thai.** 20: 9-12.

NEB. 1994. **Thai Water Quality Standards.** National Environmental Monitoring. pp. 23-26.

Office of Hygiene and Environment 3. 2001. **Report of Environmental Monitoring.** pp. 23-26.

PCD. 2004-2008. **Annual Environmental Report.** Pollution Control Department, Bangkok.

Soontornprasit, K. and C. Meksumpun. 2008. Analysis of aquatic ecosystem response for zone management of Ban Pho Town, Chachoengsao Province, Thailand. **Kasetsart J. (Nat. Sci.)** 42: 513-521.

Vliet van, M.T.H. and J.J.G. Zwolsman. 2008. Impact of summer droughts on the water quality of the Meuse River. **Journal of Hydrology** 353: 1-17.