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# Analysis of Aquatic Ecosystem Response for Zone Management of Ban Pho Town, Chachoengsao Province, Thailand

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## ABSTRACT

This research was carried out in the Ban Pho Town ship, Chachoengsao Province in the eastern part of Thailand, an important area for aquaculture. The objectives of the study were to assess the aquatic status and its potential carrying capacity for pollution and to understand the ecosystem response to human and natural impacts leading to a proposal for an appropriate zone management approach for sustainable utilization of the area. Information on community-based utilization patterns was obtained through surveys using questionnaires. Field conditions were monitored by 2-monthly surveys from August 2004 to August 2005. The survey areas covered 12 stations in the middle zone of the Bangpakong River, 12 stations at adjacent canal mouths that received pollution loads from a nearby community and 29 stations at pollution point sources. Results indicated that Bangpakong River was eutrophic all year round. High nutrient loads from Ban Pho community continuously flow into the aquatic environment. The highest concentration of $NH_4^+$ nutrients came from crocodile farms (5,408 mg/m$^3$), whereas maximum total loads ($299\times10^9$ mg) during the year were from domestic sources. Total nutrient loads varied temporally and were different among zones. Almost all nutrient levels were high during high-loading periods while the remediation potential was generally low. Land remediation potential with respect to $NH_4^+$ and $PO_4^{3-}$ was inexcess of 30 times more efficient in areas with comparatively high flow rates and more mangrove vegetation. In terms of river-water remediation potential, the efficiency of $NH_4^+$ elimination was less during the dry period. It was observed that the Na Lang, Nong Bua and Yai Loy canals were affected by some human and environmental impacts. These areas needed more attention with regard to monitoring and management. In addition, focus should also be given to the areas around the Pra Wet canal because of their low remediation potential during the dry period. Results of multivariate analysis on the ecosystem responses indicated that functions of $NH_4^+$ and total suspended solids in the aquatic system significantly influenced chlorophyll *a* changes. Based on the overall results, area zonation of the Ban Pho Town was being proposed and problems were being prioritized. Moreover, the application of integrated models suggested the need for better water quality control and/or management.


**Key words:** remediation potential, ecosystem response, water quality, zone management, Bangpakong River

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## INTRODUCTION

The Bangpakong River and its tributaries are very important areas in the lives of the people and for the environment in the eastern part of Thailand. There is a high abundance of aquatic resources, including a very biodiverse ecosystem. The river provides a source of water crucial not only for irrigation, but also for aquaculture, animal farming, municipal supply/wastewater dilution and heavy and light industries, supporting the whole Chachoengsao Province (Pollution Control Department, 1998; Bordalo *et al*., 2001).

According to the Department of Marine and Coastal Resources (2005), water quality in many part of the river and in the lower estuary of Ban Pho Town has deteriorated. Thailand's Pollution Control Department (1997, 1998), Junchompoo (2006) and Pongpadung (2006) have indicated that water quality was below the standards for several water quality parameters. The major cause of dereriorating water quality was reported to be untreated wastewater discharge from urban communities, industrial activities, agriculture aquaculture, and animal husbandry, leading to the continuous flow of toxic wastes into the river.

Such water pollution problems due to agriculture, industrialization and rapid urban growth are common to many Thai riverine and estuarine areas. This situation directly impacts not only on local economic development, but also causes serious threats to public health. Nowadays almost all estuarine ecosystems are subject to environmental deterioration resulting from excess nutrient loads from diverse natural processes and anthropogenic activities. Bangpakong River, similarly, receives pollutants from land use activities (Boonphakdee *et al*., 1999). Despite realizing their impacts, there has been no action to develop an ecosystem-response evaluation technique.

This study thus attempted to develop an evaluation approach with methods that considered the potential for land and water-body remediation. In particular a calibration technique was developed for estuarine zones which were affected by tidal flows. The study focused on defining relationships between utilization by the Ban Pho community and chlorophyll *a* response around the canal mouths and the middle parts of the main river. According to Nixon *et al*. (1996), nitrogen was the important limiting factor for marine phytoplankton, while phosphorus was the limiting factor for their freshwater counterparts. They added that nutrients were loaded in several forms and other factors concerning growth and recruitment of phytoplankton were used as indicators for the evaluation of the enrichment and response of the ecosystem. In addition, Bonnet and Wessen (2001) also reported a significant relationship between nutrient and chlorophyll illustrated by their 3 dimension water quality model. This research has thus considered the inter-relationships among nutrients, environmental factors and phytoplankton, in terms of their negative and positive responses to waste sources. Specifically, these positive responses include phytoplankton bloom. An integration of multidisciplinary knowledge on hydrology, geography, ecology and socio-economic information was used to assess the aquatic status and its potential carrying capacity for pollution and to understand the ecosystem response to human and natural impacts leading to a proposal for an appropriate zone management approach for sustainable utilization of the area.

## MATERIALS AND METHODS

### Clarification of land use and nutrient loads

Data on land-use and socio-economic parameters were collected through individual interviews, field surveys and secondary information gathered from the local government. The land-use database was then analyzed by

mapping the whole area, to indicate the location of land use types and important places associated with canals. The area was then classified based on types of land use into four catagories, namely; aquaculture, paddy fields, residential and others. The amounts of nutrient loads into each canal were estimated by summing all of nutrients loaded from these activities according to the following equation;

$$Y = f(X_1, X_2, X_3, X_4),$$

where, Y was total amount of nutrient loads (mg/$m^3$) in each canal receiving pollution and $X_1$ to $X_4$ were the load levels from the four types of activity explained above. The utilization of canal water and the nearby area by each activity was then assessed and reported as a percentage. This information and data were analyzed to evaluate and prioritize the pollution response of the canal to nutrient loading and the problems it faced.

In addition, nutrient loads of specific agricultural activities were determined three times a year at nine local village sites in the Ban Pho town ship (Figure 1; triangle marks). The sites represented: 2 crocodile cultural sites, 5 shrimp hatcheries, 4 pig farm, 3 artemia cultural sites, 6 fish culture sites, 4 rice farm, and 6 shrimp culture sites.

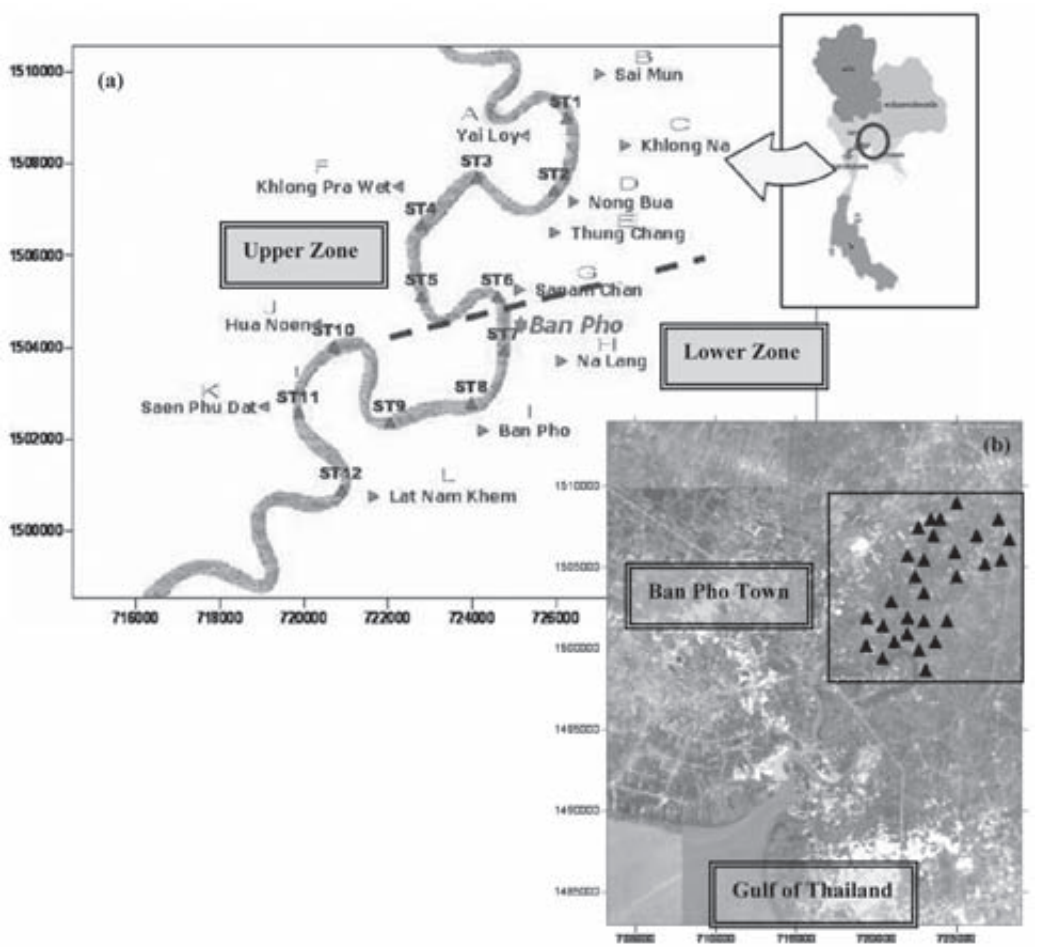


**Figure 1** (a) Map indicating the 12 survey stations in Bangpakong River and surrounding canals (A to L); (b) Location of pollution point source stations in Ban Pho, Chachoengsao Province, Thailand. The area is about 30 km inland from the Gulf of Thailand.

**Determination of aquatic resource situation**

Water quality parameters were analyzed once every two months from August 2004 to August 2005 from 51 field stations (12 stations in the middle of Bangpakong River (ST1 to 12), 12 stations at mouth of canals (A to L), and 29 stations from pollution point sources) (Figure 1). The high-load period was during August to October and the low-load period was during December to February. An attempt was made to determine the status of the aquatic resources existing in the study area.

Water quality parameters measured at the field stations were: dissolved oxygen and temperature (YSI, model 50/55), pH (pH meter, YSI pH100), salinity (salinity refractometer, NO.508-IIW), depth (depth meter, VA22066USA) and transparency (sechi disc). To determine total suspended solids (TSS) and dissolved inorganic nutrients, surface water samples (30 cm below the surface) were collected and filtered with GF/F (Whatman) filter paper. Filtrate samples for nutrient ($NH_4^+$, $NO_3^-$+$NO_2^-$, $Si(OH)_4$ and $PO_4^{3-}$) analysis were then determined by spectrophotometric methods using an autoanalyzer (SKALAR Type 1070).

**Evaluation on remediation potentials**

**Land remediation potential**

Land remediation potential was evaluated using the process of determining the nutrient elimination efficiency of canals which received loads from surrounding land point-sources. Data on final nutrient loads in each canal *($PL_C$; mg)* were used. Geological data integration involved the use of a bathrymetric map to verify area slopes, to precisely predict the runoff direction. The total amount of nutrient load into each canal *($PL_L$; mg)* was calculated by incoporating datasets of area size, the hydrological database (e.g. water volume and flow rates) and types of land utilization that varied seasonally. Natural elimination efficiencies of loads defined as the *Land Remediation Potential ($L_{RP}$)* were then calculated with the following equation:

$$L_{RP} = \frac{PL_L}{PL_C}$$

**River-water remediation potential**

The river-water remediation potential was analyzed by determining the nutrient elimination efficiency of mid-river receiving loads from nearby canals. Data on nutrient concentrations around each canal mouth *($PC_C$; mg/$m^3$)* and at the middle of the Bangpakong River *($PC_R$; mg/$m^3$)* were used. Natural elimination efficiencies of loads defined as the *River-water Remediation Potential ($W_{RP}$)* were calculated with the following equation:

$$W_{RP} = \frac{PC_C}{PC_R}$$

**Calibration of database affected by tidal phenomena**

Since dilution by tidal activities can change parameter concentrations, levels of the nutrients in this study were calibrated. By considering that most actual loads should occur at the mid-ebb tide period, *"net"* nutrients used here were the calibrated levels based on the *Dilution Coefficient (DF)* which was calculated from:

$$DF = \frac{T_{ob}}{T_H} \bullet \frac{H_{ob}}{H}$$

where, $T_{ob}$ was the observed time in the field, $T_H$ was the time at mid-ebb tide, $H_{ob}$ was the observed water height (m) and $H$ was the average water height during the ebb tide period (m). The net values *($Nutrient_{net}$;* mg $m^{-3}$*)* were determined from adjusting the observed nutrient concentrations ($Nutrient_{ob}$; mg $m^{-3}$) by the equation:

$$Nutrient_{net} = DF \bullet Nutrient_{ob}$$

**Evaluation of ecosystem response**

Since chlorophyll *a* is a major indicator of significant biological activity in aquatic systems, evaluating the ecosystem response focused on monitoring changes in chlorophyll *a* (or primary producer) concentrations at different

zones and at different times. According to the concept of natural balance in each aquatic ecosystem (Busch and Sly, 1992), the natural levels of chlorophyll *a* should be maintained for suitable conditions to prevail. The response of chlorophyll *a* here was determined by a correlation regression and multivariate analysis of the databases using chlorophyll *a* and important water quality factors. Multivariate models for factors (biotic and abiotic) were developed. In the models, related water quality factors were then prioritized for further management purposes.

## RESULTS AND DISCUSSION

### Nutrient load concentrations and amounts

Results obtained from this study indicated that the highest $NH_4^+$ concentration (5,407.68 mg/m$^3$) came from crocodile farms (Table 1). Other activities contributing to nutrient loads included domestic wastewater discharge, aquaculture and agriculture. However, domestic wastewater was often discharged into the aquatic environment at higher volumes than other activities. Therefore, total $NH_4^+$ loading from domestic zones provided the highest value of $298.48 \times 10^9$ mg. Similarly, total loading of $NO_3^-$ +$NO_2^-$, $Si(OH)_4$ and $PO_4^{3-}$ were the highest from domestic sources (Table 1).

The results showed that the highest waste discharge came from the residential areas in Ban Pho. Nutrient runoffs such as nitrogen and phosphorus are essential for primary production, but such high levels could result in negative impacts such as heavy phytoplankton bloom and eventually eutrophication. Thus, careful monitoring and conservative management of water bodies should be properly carried out.

Nutrient coming from land areas surrounding the canals flowed into the Bangpakong River (Table 2). Canals located in the lower zone of Ban Pho Town had higher levels of nutrients than those in the upper zone. Total pollutant loads of $NH_4^+$ and $PO_4^{3-}$ around each canal ranged between 6.5 and $64.0 \times 10^9$ and from 1.2 to $9.2 \times 10^9$ mg, respectively. Higher variation was apparent with $NH_4^+$, while silicate levels were excessive. The level of $NH_4^+$ may thus be of importance in controlling the phytoplankton response in the water system.

### Resource remediation potential

Because of the significant amount of $NH_4^+$ load in this area, focus was given to the *land remediation potential ($L_{RP}$)* for $NH_4^+$. In this study, $L_{RP}$ of the lower zone generally had higher values, particularly during the high-load period (Figure 2). However, the pollutant loads of $NH_4^+$ in the lower zone during that time were also high since the area around the canals in the lower zone was

**Table 1** Nutrient concentrations (mg/m$^3$) and total loads (x$10^9$mg) from different activities in Ban Pho Town ship, Chachoengsao Province from August 2004 to August 2005.

| Activities | $NH_4^+$ | | $NO_3^- + NO_2^-$ | | $Si(OH)_4$ | | $PO_4^{3-}$ | |
|---|---|---|---|---|---|---|---|---|
| | Conc | Total | Conc | Total | Conc | Total | Conc | Total |
| Crocodile culture | 5,407.68 | 0.03 | 286.25 | 0.001 | 6,401.10 | 0.03 | 10,846.90 | 0.06 |
| Shrimp hatchery | 1,355.06 | 0.35 | 209.30 | 0.05 | 1,941.67 | 0.50 | 202.94 | 0.05 |
| Pig farming | 1,471.39 | 0.49 | - | - | 2,603.11 | 0.86 | 5,248.50 | 1.73 |
| Artemia culture | 1,490.26 | 0.58 | 56.94 | 0.02 | 1,397.57 | 0.54 | 99.72 | 0.04 |
| Fish culture | 1,446.24 | 6.95 | 63.87 | 0.31 | 2,139.03 | 10.29 | 39.36 | 0.19 |
| Rice farming | 1,446.24 | 7.33 | 270.86 | 1.37 | 2,389.74 | 12.12 | 104.97 | 0.53 |
| Shrimp culture | 1,232.45 | 14.42 | 16.93 | 0.20 | 2,069.69 | 24.21 | 69.98 | 0.82 |
| Domestic | 1,446.24 | 298.48 | 107.73 | 22.23 | 5,760.99 | 1,188.98 | 2,729.22 | 563.27 |
| Total | - | 328.63 | - | 24.19 | - | 1,237.53 | - | 566.69 |

characterized by a dense population and high levels of anthropogenic activity. Such high $L_{RP}$ could, therefore, have less impact on load elimination.

In the case of $PO_4^{3-}$ remediation potential, the levels in high-load periods were also higher than in the low-load periods. Each canal normally provided moderate-to-high remediation potentials during high-load periods. Unfortunately, nutrient loads of $PO_4^{3-}$ during low-load periods indicated higher levels. Such phenomena may lead to future environmental deterioration problems.

The river-water remediation potential ($W_{RP}$) showed apparently lower values (Figure 2). Levels less than 1 implied a low remediation potential. There was no pollution potential for $NO_2^-$+$NO_3^-$, $Si(OH)_4$ and $PO_4^{3-}$. In terms of $NH_4^+$ remediation potential, it was true only during the dry period at some stations. It was found that the river could help with the natural elimination of $NH_4^+$ only in areas close to the Tung Chang, Nong Bua and Na canals (with moderate $W_{RP}$ of 5.71, 5.26, and 4.71, respectively).

Figure 2 shows the water quality problem and priority areas based on the overall results. Na Lang and Lat Num Khem canals were found to have high nutrient loads because the areas around them are densely populated. Nevertheless, Lat Num Khem canal still depicted some ability to remediate itself all year round. Therefore, its problem was not considered as serious as that for the other canals. For Na Lang, Yai Loy and Nong Bua canals the remediation potential for most nutrients was low. In addition, they received comparatively high $NO_3^-$, $NO_2^-$ and $Si(OH)_4$ loads. This implied that Na Lang, Yai Loy and Nong Bua canals may not be efficient in remediation and priority should be given to these canals in addressing their pollution potential.

**Ecosystem response using integrated models and their application**

In this study, chlorophyll *a* concentrations of all sampling sites were found to exceed 5 mg/l. The levels fluctuated and sometimes were higher than 180 mg/l during high-load periods. Accoding to Soontornprasit *et al*. (2006), this evidence revealed the eutrophic status of the water. The results from the mutivariate analysis of data on chlorophyll *a* (Chl*a*) together with various environmetal factors in canals provided significant

**Table 2** Total nutrients flowing from areas around the canals into the Bangpakong river in Ban Pho Town ship, Chachoengsao Province from August 2004 to August 2005.

| Zones | Name of canals | Total nutrient loading (x $10^9$mg) | | | |
|---|---|---|---|---|---|
| | | $NH_4^+$ | $NO_3^-$+$NO_2^-$ | $Si(OH)_4$ | $PO_4^{3-}$ |
| Upper | **A: Yai Loy** | 6.5 | 1.0 | 14.4 | 3.5 |
| | **B: Sai Mun** | 10.8 | 1.8 | 18.1 | 1.2 |
| | **C: Khlong Na** | 11.3 | 1.9 | 19.1 | 1.2 |
| | **D: Nong Bua** | 20.6 | 3.6 | 37.3 | 4.1 |
| | **E: Thung Chang** | 13.1 | 2.3 | 23.6 | 2.5 |
| | **F: Pra Wet** | 28.1 | 4.9 | 52.1 | 6.6 |
| Lower | **G: Sanam Chan** | 19.5 | 3.4 | 36.0 | 4.4 |
| | **H: Na Lang** | 49.0 | 8.5 | 85.0 | 6.7 |
| | **I: Ban Pho** | 64.0 | 11.8 | 107.1 | 5.6 |
| | **J: Hua Noen** | 15.9 | 2.8 | 27.6 | 2.3 |
| | **K: Saen Phu Dat** | 39.0 | 6.8 | 67.2 | 5.3 |
| | **L: Lat Nam Khem** | 32.2 | 5.3 | 61.6 | 9.2 |
| | **Total** | **329.3** | **57.5** | **582.6** | **55.4** |

(P<0.05) relationships for the upper zone shown in the integrated equations for the high-load period and low-load period, respectively, as follows:

$$Chla = -6816-288NH_4^+ +573pH+74Temp+16Tran+168NO_2^- +NO_3^- \ (R^2=0.92)$$

$$Chla = -2447-302NH_4^+ +300PO_4^{3-} +10Tran+223NO_2^- +NO_3^- \ (R^2=0.53)$$

In the lower zone, the integrated relationships for high- and low-load periods were as follows;

$$Chla = -878+963NH_4^+ -13194PO_4^{3-} +0.03TSS+171NO_2^- +NO_3+808Si(OH)_4 \ (R^2=0.96)$$

$$Chla = -38+119NH_4^+ +0.02TSS \ (R^2=0.88)$$

Comparative significances for each factor during specific times in the two zones are shown in Figure 3. Based on the analysis, aquatic environmental factors playing significant roles on chlorophyll *a* production varied seasonally. Among all factors, two types of nutrients ($NH_4^+$ and $PO_4^{3-}$) and TSS in the water column seemed to have the most influence.

In order to maintain the current water quality conditions in the Bangpakong river in Ban Pho town, chlorophyll *a* levels at each zone should be controlled to reduce fluctuations. Thus, the integrated models shown above were applied.

Based on the integrated models, during the high-load period concentrations of $NH_4^+$ at the canal mouths should be urgently controlled. Calculated results indicated that $NH_4^+$ should be less than 0.07 mg/l and 0.02 mg/l for the upper

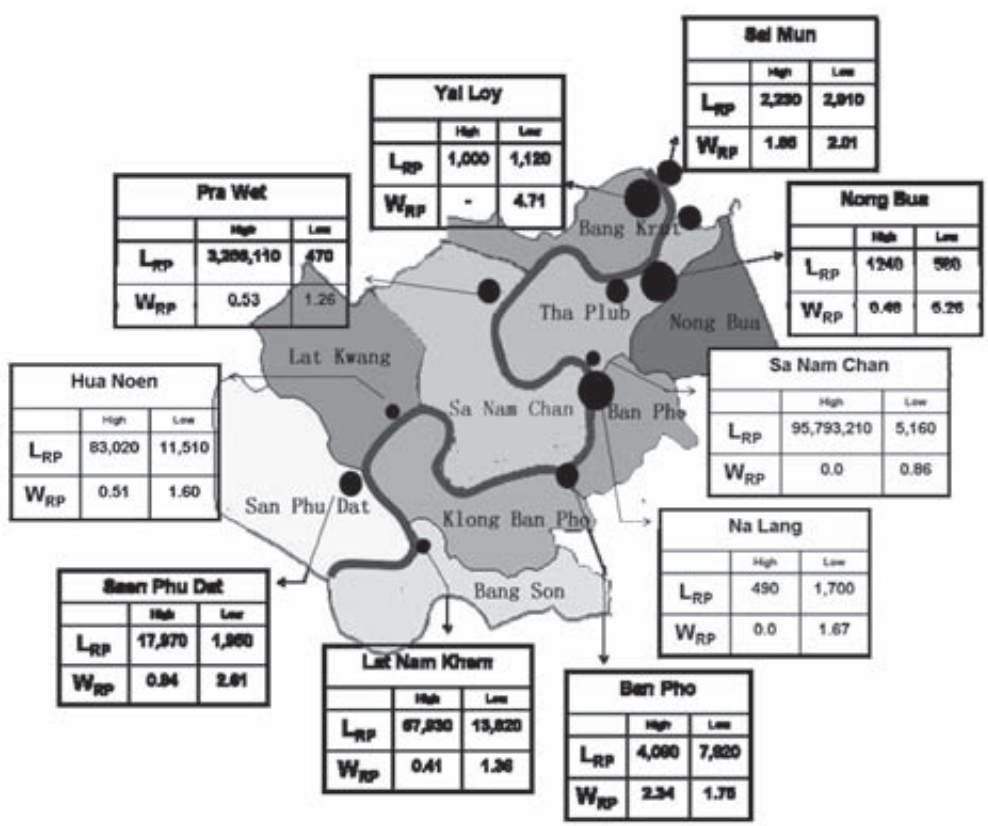


**Figure 2** Results of land remediation potential ($L_{RP}$) and river-water remediation ($W_{RP}$) potential in high-load (high) and low-load (low) periods in focus areas in Ban Pho Town, Chachoengsao Province (large to small circles in the map indicate more to less problem priority area urgent management).

and the lower zones, respectively. During low-load periods, $NH_4^+$ in the upper zone should be less than 0.78 mg/l whereas it should be less than 0.56 mg/l in the lower zone. The priority problem areas in each zone (as depicted in Figure 3) were considered to evaluate a suitable approach for the management strategy to apply in the specific areas. For example, Na Lang canal and the adjacent area should develop a community waste water treatment system for the runoffs, while Nong Bua canal and its adjacent area should be concerned with the treatment of waste water from pig farms and other aquacutural waste.

## CONCLUSION

In this study, an evaluation of land and water-body natural elimination efficiencies with regard to waste loads was developed for a zone management approach for the Ban Pho Township, Chachoengsao Province, Thailand. The study revealed that Na Lang and Ban Pho canals were the most affected by human activities and the environment. These areas should receive more attention for urgent monitoring and management. In addition, the areas around the Hua Noen and Saen Phu Dat canals should also be attended to because of their low remediation potential during the dry season.

Results of multivariate analysis on ecosystem responses indicated that the presence of $NH_4^+$, $PO_4^{3-}$ and total suspended solids in the aquatic system significantly influenced chlorophyll *a* changes. The functional roles of various factors varied seasonally. Based on the results, it is proposed that a priority action should

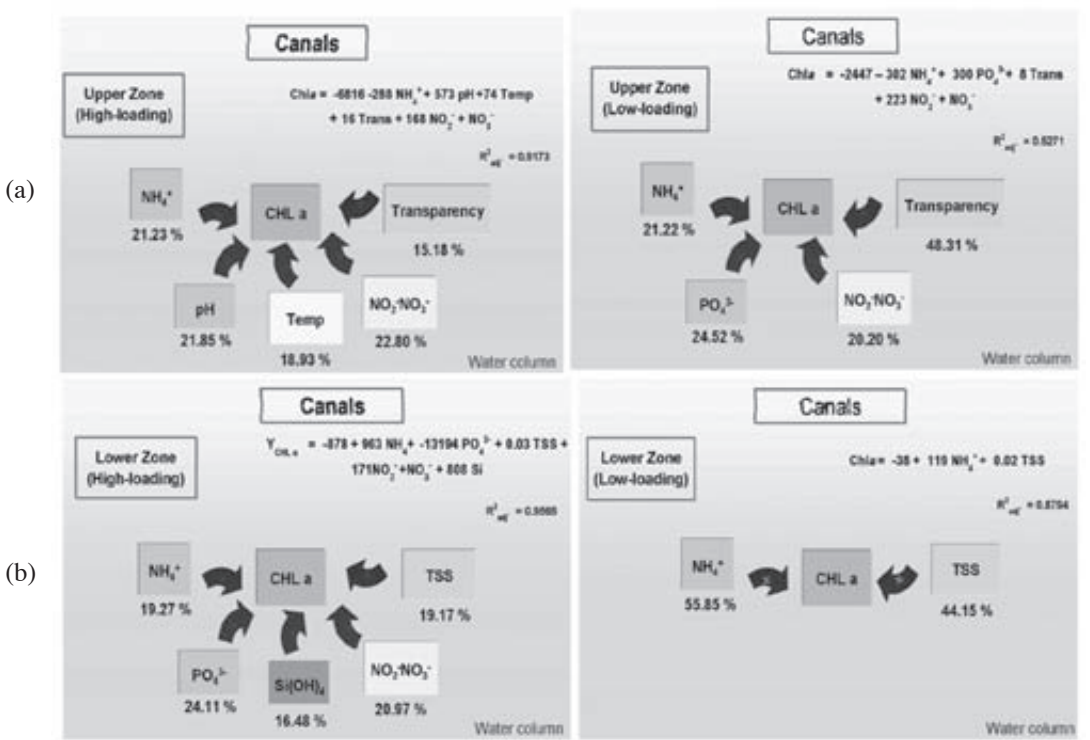


**Figure 3** Results of multivariate analysis of ecosystem response models for upper-zone Canals (a) and lower-zone canals (b). Flow-flowing into Bangpakong River in Ban Pho Town. Top and botton figures show high- and low-load periods. Figures below each box indicates percentages of significance ($P<0.01$) during survey times.

be area zoning of Ban Pho Town. The findings from this research showed the importance of the roles of terrestrial and river natural habitats. Thus, a precise understanding of the ecosystem process was considered necessary for effective management of the area.

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