The Relationship Between Land Use and Water Quality in Bangpakong Estuary, Thailand

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ABSTRACT

The relationship between land use and water quality has been widely acknowledged. The land use within the watershed of the Bangpakong estuary has been continually changed by increasing industrialization and urbanization. Remarkable alteration in water quality has been recorded simultaneously with the changes of land use. Therefore, land use and basin development planning must take into account the issue of water quality alteration since water is a fundamental resource for all activities of an organism. Typically, water quality monitoring relies on field-based measurement, which is time consuming and costly. Therefore, this study aimed to develop a model for the assessment of the association of land use and water quality in Bangpakong estuary. Data regarding land use and water quality parameters were collected from May 2013 to April 2014. The correlation between land use and these parameters was investigated, and then the water quality variables that presented a significant relationship with land use were used to produce linear regression models. Our results clearly indicated that there were eleven water quality variables that were suitable for use in linear regression models. All parameters explicated conformity with regression conditions and all had a level of accuracy higher than 50 percent. The models demonstrated that the expansion of urbanization and the reduction of aquaculture and mangrove forest could result in an increase in total ammonia, nitrogen and orthophosphate, while the development of industrialized areas could result in a decrease in pH. It is obvious that land used increasingly for urbanization and industrialization can lead to the deterioration of water quality in the Bangpakong estuary.

Keywords: land use, water quality, Bangpakong estuary, statistical model

INTRODUCTION

The Bangpakong River is one of the most important rivers in the eastern part of Thailand and it flows into the Gulf of Thailand in Chachoengsao Province. The upper reach of the river is a freshwater ecosystem while the lower reach is a brackish water ecosystem. Large numbers of plant and animal species inhabit these different ecosystems and the river is regarded as one of Thailand's most important aquatic ecosystems due to its high biodiversity. The river receives nutrient-enriched discharge from land-based activities and eventually flows through the estuary. Data collected by the Office of Natural Resources and Environmental Policy and Planning in 2012

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revealed that land use of the Bangpakong estuary has rapidly changed from a mix of natural mangrove forests and agricultural areas to industrialized and urbanized areas. In addition, the number of fish cages in the river has increased rapidly, and this situation has caused a significant impact on the aquatic environment. Meanwhile, the rapid growth of industrial and urban areas has adversely affected the water quality of the river. Menasveta (1996) concluded that three main land use types including community, industry, and agriculture led to increased pollutants in the water. These land uses could be non-point sources of turbidity, sediment, biological oxygen demand, nitrogen, orthophosphate, total coliform bacteria, pesticides, and metal elements. Runoff from different land use types can carry many different contaminants (Tong and Chen, 2002). It has been accepted that runoff characteristics are important factors in changing the hydrological system (Mander *et al*., 1998) and that runoff can be a cause of the degradation of water quality. In addition, altering land use coverage has been shown to be a primary factor in modifying the quality of receiving surface waters (Changnon and Demissie, 1996).

Although it has been widely accepted that land use change plays a key role in altering the quality of water sources, the significance of impacts of land use on water flows and the quality of water in the Bangpakong River is still uncertain. Geographical characteristics of an estuary can actually produce a complex intrinsic relationship between land use and water quality (Liu *et al*., 2009). Since the Bangpakong estuary has its own unique geographical characteristics, this study aimed to examine the relationship between land use and water quality by applying a land use based approach, and to quantify the relative impacts of different types of land use on water quality parameters. The information obtained could be used to generate guidelines for planners and decision makers in efforts to protect and solve environmental problems in the Bangpakong estuary.

MATERIALS AND METHODS

Data collection

The total area of the Bangpakong estuary was divided into ten zones for water sampling (Figure 1). In each zone, samples were collected approximately monthly from May 2013 to April 2014. These zones were comprised of six different major types of land use: industry, urban, aquaculture, mangrove, wetland and canals. Satellite imagery (PLEIADES satellite 50 cm. 2-meter multispectral 13-02-2013) and Geographic Information System (GIS) technology were used for classification of land use by visual interpretation. Water samples taken at mid-depth were collected by vertical water sampler. Water samples were analyzed using standard methods for examination of water and wastewater (APHA, AWWA, WPCF, 1998) including pH, water temperature (WT), transparency, turbidity, conductivity, total alkalinity (TA), total hardness (TH), dissolved oxygen (DO), biological oxygen demand (BOD), total ammonia nitrogen (TAN), nitrite nitrogen, nitrate nitrogen, total Kjeldahl nitrogen (TKN), orthophosphate, silicate, chlorophyll *a*, and total coliform bacteria (TCB).

For land use data, it was assumed that runoff through the ten zones selected could be contaminated by different pollutants, depending on the zone's land use, before flowing into the waterways. Therefore, roads were considered as topographic divides of impact within land use zones in this GIS technique.

Data Analyses

To achieve the aim of the study, correlation analysis was applied to examine a general association of land use and water quality. Where a relationship between land use and water quality was found, regression analysis was subsequently applied to quantify influence of land use on water quality. Water quality and proportion of land use types were the main data acquired for this study.

The association of land use and water quality was assessed by applying correlation analysis. All correlation values were calculated using Excel (Microsoft Office 2013). The Pearson Correlation was applied to examine the correlation between proportion of land use types and annual average water quality parameters. This test was done for each pair of land use type and water parameters. Water quality values were square root-transformed prior to correlation analysis, while land use proportions were arcsine-transformed. The results of these correlation tests were used to determine which water parameters could be further used for regression analysis.

The linear regression models were implemented via an Excel spreadsheet (Microsoft Office 2013). These models considered only the water quality parameters that had correlation with land use types with statistical significance at a 0.05 level. The results acquired from the regression models were necessary to investigate regression conditions, namely 1) mean error equivalents are 0, 2) the distribution of error must have a normal distribution, 3) the error does not depend on others, and 4) variance of error must be constant at every independent value (X).

RESULTS AND DISCUSSION

In this study ten dominant land use zones impacting the Bangpakong estuary were investigated, as shown in Figure 2. The annual averages of water quality parameters (mean ± SD) of the ten zones are presented in Table 1. A land use map was used to determine the proportions of major land use types within each zone. For this study, land use types included urban, industries, aquaculture, wetland, mangrove, and canals. Land use data for the ten zones are presented in Table 2.

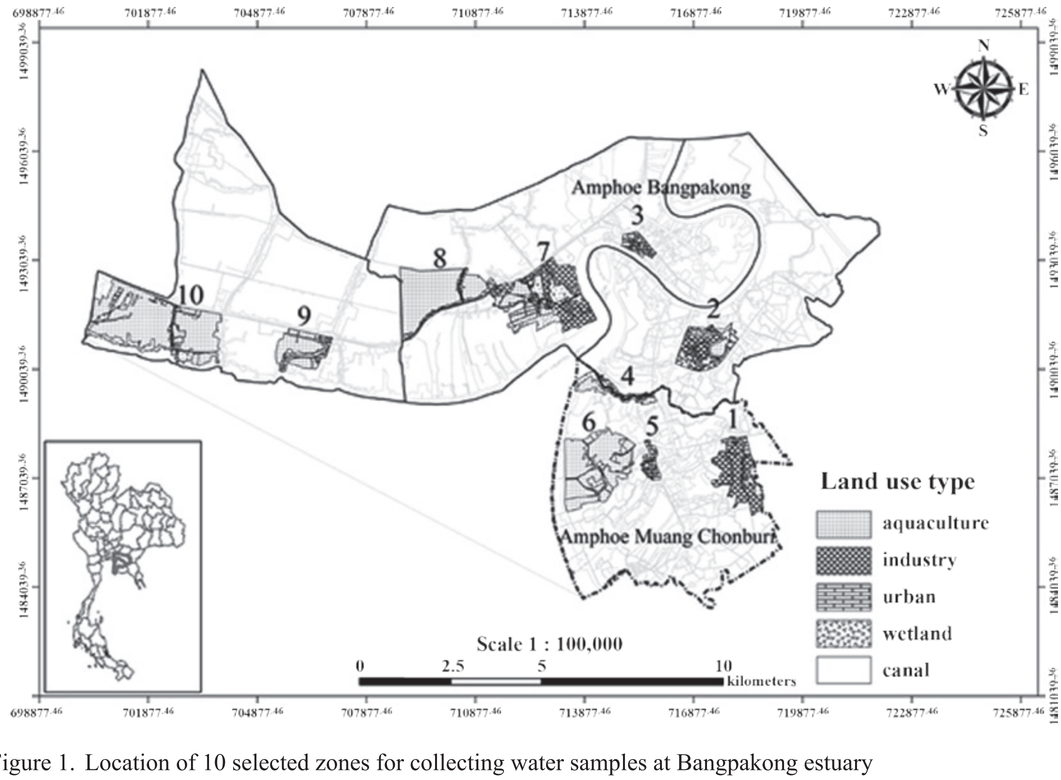

Figure 1. Location of 10 selected zones for collecting water samples at Bangpakong estuary

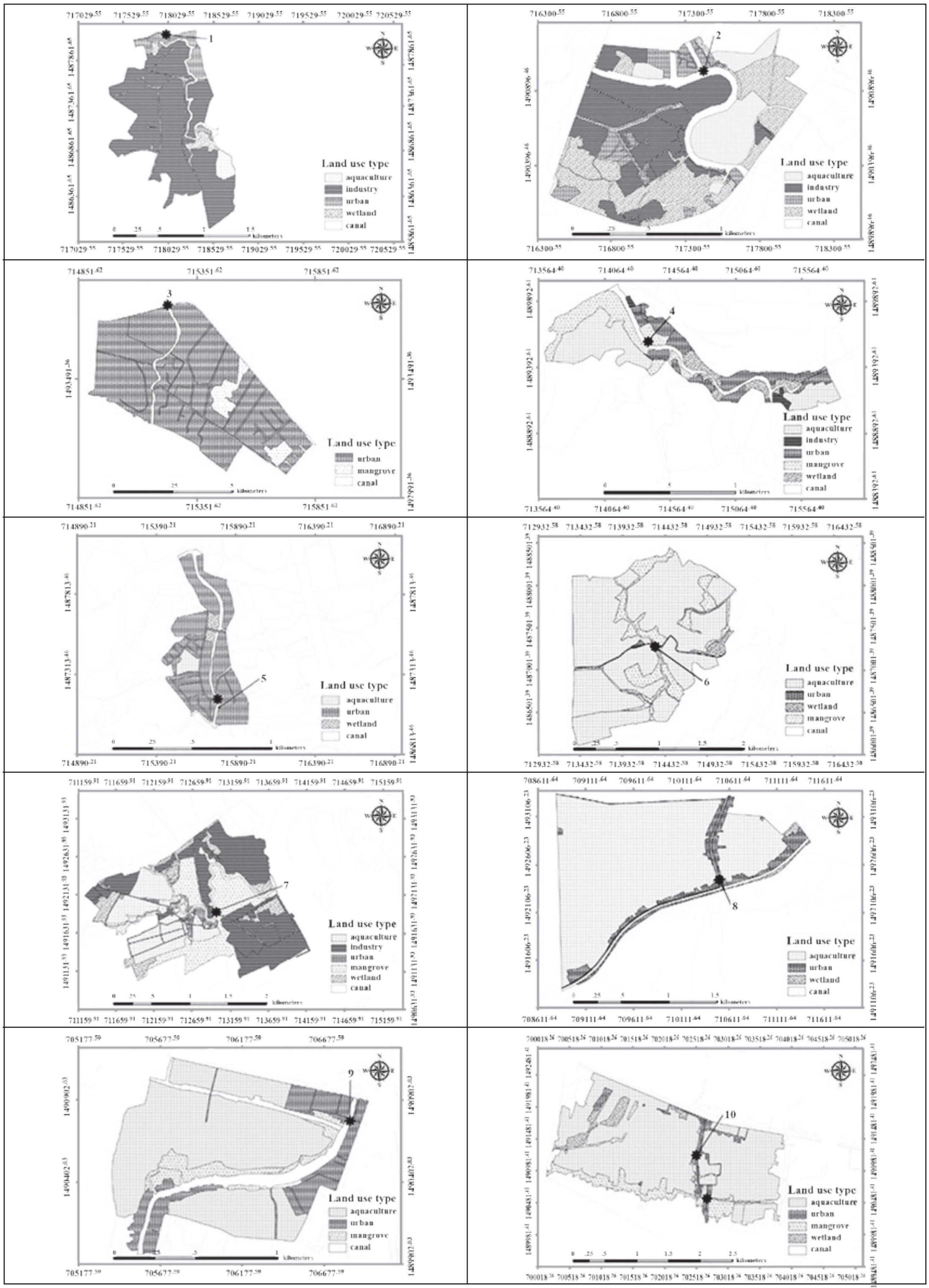

Figure 2. Ten zones of dominant land use impact of Bangpakong estuary

Table 1. Annual average water quality parameters from land use zones in the Bangpakong estuary (May 2013 to April 2014).

Water quality parameters	Land use zone										
	1	2	3	4	5	6	7	8	9	10	Mean
WT (^oC)	27.65	27.42	28.49	30.31	27.63	27.49	29.41	29.12	29.13	29.03	26.06±0.99
Transparency (cm)	37.08	28.33	12.50	34.50	33.33	16.25	31.67	20.83	27.08	16.88	24.28±0.86
Turbidity (NTU)	16.47	36.54	36.88	76.04	49.31	224.13	43.83	39.97	41.61	142.02	70.07±64.01
Salinity (psu)	2.34	14.82	2.82	23.62	26.21	26.21	16.73	6.15	32.15	32.83	17.77±11.61
Conductivity (mS/cm)	1.29	1.21	11.19	25.56	17.81	25.36	22.23	4.64	23.29	29.80	15.74±10.81
TA (x10) (mg/l)	18.02	13.73	24.13	9.08	1.25	1.13	9.14	2.12	1.11	9.93	8.87±7.92
TH (x100) (mg/l)	3.01	2.06	17.44	30.42	29.32	39.83	34.64	8.59	39.88	44.55	24.16±15.99
pH	7.17	7.07	7.40	7.48	7.29	7.34	7.31	7.71	7.46	7.56	6.73±0.19
DO (mg/1)	0.19	1.60	0.00	3.97	2.13	4.11	3.78	5.08	5.11	4.38	2.93±1.92
BOD (mg/1)	20.13	11.42	40.61	2.26	7.63	5.97	4.61	8.25	4.21	3.98	10.97±11.63
TAN (mg/1)	3.88	2.19	4.50	0.34	1.37	0.29	0.29	0.85	0.51	0.32	1.46±1.57
Nitrite-N (mg/1)	0.07	0.04	0.02	0.05	0.11	0.04	0.06	0.02	0.05	0.11	0.05±0.03
Nitrate-N (mg/1)	0.26	0.18	0.33	0.58	0.65	0.44	0.40	0.13	0.17	0.18	0.32±0.18
Orthophosphate (mg/1)	1.14	0.73	1.19	0.14	0.32	0.13	0.10	0.29	0.20	0.14	0.44±0.42
Silicate (mg/1)	5.30	4.33	5.98	2.56	3.47	2.82	2.89	4.40	3.16	2.44	3.51±1.22
Chlorophyll *a* (μg/1)	32.82	60.56	13.00	10.83	20.19	18.82	7.45	106.24	31.89	16.24	31.67±30.37
TKN (mg/1)	11.27	5.11	15.60	-	2.09	1.61	1.78	3.38	2.73	1.26	4.99±5.05
TCB (x10,000) (MPN/100ml)	89.53	2.84	597.67	3.50	9.55	-	1.64	-	30.72	0.20	104.69±206.55

Table 2. Proportions of land use types within ten zones of Bangpakong estuary

Zone	Area of each land use type in square kilometer (%)					
	Urban	Industry	Aquaculture	Wetland *	Mangrove**	Canal
1	14.13 (33.90)	13.57 (32.56)	0.94 (2.26)	0.00 (0.00)	1.04 (2.50)	12.00 (28.79)
2	1.76 (11.74)	5.00 (33.36)	2.19 (14.61)	0.00 (0.00)	4.55 (30.35)	1.49 (9.94)
3	3.37 (90.84)	0.00 (0.00)	0.00 (0.00)	0.22 (5.93)	0.00 (0.00)	0.12 (3.23)
4	1.55 (22.86)	0.13 (1.92)	2.30 (33.92)	1.56 (23.01)	0.62 (9.14)	0.62 (9.14)
5	2.70 (83.33)	0.00 (0.00)	0.15 (4.63)	0.00 (0.00)	0.11 (3.40)	0.28 (8.64)
6	0.21 (0.68)	0.00 (0.00)	25.46 (82.18)	4.34 (14.01)	0.47 (1.52)	0.50 (1.61)
7	1.75 (5.07)	13.47 (39.04)	6.32 (18.32)	8.83 (25.59)	3.07 (8.90)	1.06 (3.07)
8	3.16 (4.42)	0.00 (0.00)	66.13 (92.40)	0.00 (0.00)	0.31 (0.43)	1.97 (2.75)
9	2.08 (16.56)	0.00 (0.00)	8.13 (64.73)	0.97 (7.72)	0.00 (0.00)	1.38 (10.99)
10	2.02 (4.01)	0.00 (0.00)	40.49 (80.45)	5.37 (10.67)	2.13 (4.23)	0.32 (0.64)

Remarks: *area of lowland and swamps with temporary water saturation in rainy season
**area of small trees or shrubs that grow in coastal saline or brackish water

We found that the proportions of several land use types were significantly correlated with water quality parameters (Table 3). Eleven water quality parameters showed a relationship with proportion of at least one of the land use types at a statistical significance level of 0.05. Salinity, conductivity and TH were associated with proportion of canal areas. Conductivity, TA, TH, TAN, orthophosphate and silicate were related with proportion of mangrove areas, while pH was associated with industrial areas. Chlorophyll *a* and pH were correlated with aquaculture area, while salinity, conductivity, TH, DO, TAN, TKN, orthophosphate and silicate were correlated with urban areas. As a result, those parameters were used to quantify possible influence of the proportion of individual land use types on water quality.

As an intrinsic land use effect on water quality within a river basin/sub-basin was difficult to elaborate, a more holistic influence of land use on water quality was used. Landscape pattern change has been mainly caused by the change in land cover and land use (Bai *et al*., 2013). This could result in nutrient enrichment of waterways. Based on the significant correlations between proportions of land use and water quality parameters, related pairs of data were applied to linear regression models. The models were disqualified if they were not verified by their regression conditions. It was found that all models had mean error equal to 0, which fulfilled the first condition. The distribution of error values of all models was near the line of normal P-P Plot, suggesting a normal distribution. This means all models passed the second condition of the regression model. The third step was to test the independence of error values by using the Durbin-Watson value of the regression model. The Durbin-Watson value of all models in this study were higher than 1.5, therefore all models were acceptable by this test. The last condition needed to be met was for constant variance of error values for independent variables (X), which was assessed by scatterplot. The variance of error values of all regression models was approaching 0. Thus, it was likely that all of the regression models were harmonious with the regression conditions.

In order to apply a regression model, the accuracy of the model (R-square value) is important and the acceptance of the model is implied by the model significance value, generally at 0.05. In the case of this study, if the R-square approaches 1, it is possible that the change of water quality is greatly influenced by changing land use proportions.

Table 3. Pearson correlation coefficients between proportions of land use types and water quality parameters (using annual mean values).

Water quality parameters	Proportion of land use types					
	Urban	**Industry**	**Aquaculture**	**Wetland**	**Mangrove**	**Canal**
Salinity	- 0.649*	- 0.412	0.008	- 0.057	0.391	- 0.566*
Conductivity	- 0.605*	- 0.396	0.023	- 0.275	0.607*	- 0.618*
TA	0.438	- 0.041	0.188	- 0.303	- 0.611*	0.308
TH	- 0.580*	- 0.387	0.043	- 0.315	0.596*	- 0.590*
pH	- 0.294	- 0.569*	0.746*	- 0.519	0.047	- 0.345
DO	- 0.584*	- 0.299	0.525	0.031	0.415	- 0.436
TAN	0.635*	0.240	- 0.378	- 0.042	- 0.622*	0.498
TKN	0.577*	0.280	- 0.198	- 0.053	- 0.418	0.463
Orthophosphate	0.648*	0.247	- 0.346	0.009	- 0.633*	0.534
Silicate	0.576*	0.212	- 0.139	- 0.108	- 0.625*	0.464
Chlorophyll *a*	0.148	- 0.133	0.578*	0.068	- 0.545	0.214

Remarks: asterisk indicates the significance level of 0.05.

According to regression conditions and model significance level of 0.05 (Table 4), the regression models that were of most interest were for pH, TAN and orthophosphate. Further, R-square values of the regression models revealed the probability that more than 50 percent of differences in pH, TAN and orthophosphate resulted from differences in proportion of land use types (Table 5).

According to the results of correlation, differences in most water quality variables were influenced by land use differences, with statistical significance level of 0.05. The models indicated that increased proportion of urbanization with a decrease in aquaculture and mangrove area could increase TAN and orthophosphate. Likewise an increase of industrial area and a decrease of aquaculture area could decrease pH of Bangpakong estuary. These findings were consistent with those reported by Tong and Chen (2002). They found that nitrogen, phosphorus and coliform bacteria were significantly correlated with land use of the East Fork Little Miami River Basin. It was found that highest nutrient concentrations in the Piedmont ecoregion of North Carolina were caused by the agricultural lands (Lenat and Crawford, 1994). The land use change could have influence on variation in water quality parameters. The association between water quality variables and land use was locally specific. Increasing percentages of urban and industrial areas could deteriorate water quality if the current trends continue without environmental impact mitigation/prevention measures.

Table 4. Applicable regression models produced from water quality variables and proportions of land use types

Regression model	Sig	R Square	Durbin-Watson
Salinity = 5.201 – (58.07 x urban area) + (36.22 x canal area)	0.109	0.469	1.50
Conductivity = 3.267 + (20.54 x urban area) + (28.16 x mangrove area) – (43.78 x canal area)	0.112	0.606	1.857
TA = 12.575 – (42.701 x mangrove area)	0.060	0.374	2.63
TH = 41.542 + (228.36 x urban area) + (329.52 x mangrove area) + (488.44 x canal area)	0.145	0.568	1.85
pH = 2.71 – (0.223 x industry area) + (0.091 x aquaculture area)	0.02*	0.673	2.199
DO = 1.956 – (11.72 x urban area)	0.076	0.342	1.415
TAN = 1.013 + (7.325 x urban area) – (9.055 x mangrove)	0.04*	0.587	1.976
TKN = 1.276 + (16.658 x urban area)	0.081	0.577	2.354
Orthophosphate = 0.576 + (3.688 x urban area) – (4.532 x mangrove area)	0.03*	0.610	1.716
Silicate = 1.909 + (3.162 x urban area) – (4.819 x mangrove area)	0.067	0.538	2.023
Chlorophyll *a* = 4.307 + (5.565 x aquaculture area)	0.08	0.334	1.673

Remarks: area of each land use must be back transformed by arcsine to km^2, and asterisk indicates the significance level of 0.05.

Table 5. Statistically significant regression models of water quality parameters and proportions of land use types

Regression model	Sig	R Square	Durbin-Watson
pH = 2.71 – (0.223 x industry area) + (0.091 x aquaculture area)	0.02	0.673	2.199
TAN = 1.013 + (7.325 x urban area) – (9.055 x mangrove)	0.045	0.587	1.976
Orthophosphate = 0.576 + (3.688 x urban area) – (4.532 x mangrove area)	0.037	0.610	1.716

Remarks: area of each land use must be back transformed by arcsine to km^2

Regression modeling is a useful process as it identifies land use data that has influence on water quality. Regression models of relationships between water quality and land use in Bangpakong estuary can enable decision-makers to properly plan for land use which conserves the holistic environment and improves the quality of life for people living around the Bangpakong estuary.

CONCLUSION

The land use differences within the Bangpakong estuary clearly affected water quality in the river. Regression models can be used in forecasting water quality in Bangpakong estuary, particularly prediction of pH, TAN, and orthophosphate. The results can provide important scientific reference for land use optimization and water pollution control and guidance for the formulation of policies to coordinate the exploitation and protection of the water resource. However, impacts on water quality are not only the result of various land use activities in the study area, but also related to spatial-temporal characteristics, including influence of adjacent areas, seasonal changes and climate variation. A long-term urban and industrial plan could be developed appropriately by taking into account the carrying capacity of the estuary, and more importantly, in compliance with environmental legislation. Increasing the proportion of land used for urbanization and industrialization must be strictly controlled in association with water resource management.

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