Trend of Water Quality and Model for Forecasting Eutrophication Occurrence in Songkhla Lake, Thailand

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Abstract

The Songkhla Lake Basin is one of rapid economic growth region, with associated discharges of waste products and conflicts of land use change. This study aims to investigate water quality and develop a statistical model for estimating when water quality conditions are conducive given Chlorophyll-a concentration exceeds 10 mg/l. The model is based on multivariate correlations between Chlorophyll-a concentration and limnological characteristics, season, climatic factors and water quality parameters from official data at 25 stations around Songkhla Lake collected by the National Institute of Coastal Aquaculture (NICA), Department of Fisheries of Thailand, from March 1992 to December 2003. The resultant forecasting model gave an r-squared of 50.5% and statistically significant associations with Lake Zone, season, climatic factors (air temperature and rainfall) and water quality parameters (temperature, salinity, dissolved oxygen, pH, transparency, total organic carbon, orthophosphate and ammonia). This model can provide a practical lake management tool for eutrophication surveillance. Furthermore, the study raised the problem of high potential risk and exceeding the relevant the surface water standards of some water quality parameter. We suggest that environmental awareness among the public is the first key to success in sustainable development of the Songkhla Lake Basin.

Key words: regression model, eutrophication surveillance, tropical lake management

Introduction

Eutrophication phenomena, one serious undesirable disturbance of Songkhla Lake ecosystem, effects from anthropogenic waste and annual flooding leaching the over – enrichment of nutrient to the Lake that causing the occurrence of nuisance algal blooms in surface water and this resulting causes such problems as foul smelling and unpleasant taste of lake water, dissolved oxygen depletion, fisheries damage and loss of scenery beauty (Kira, 1984; Anderson et al;, 2002, Stanley et al., 2003). Songkhla Lake, the largest lagoonal water body of Thailand, covering 8,729 sq. km of the Lake Basin or 1,017 sq. km of main lake water body, has a multifunctional ecosystem ranging from tropical rain forest in upstream watershed area to freshwater, brackish and saline water from its junction with the Gulf of Thailand (Emsong, 1978; Tansakun, 1987).

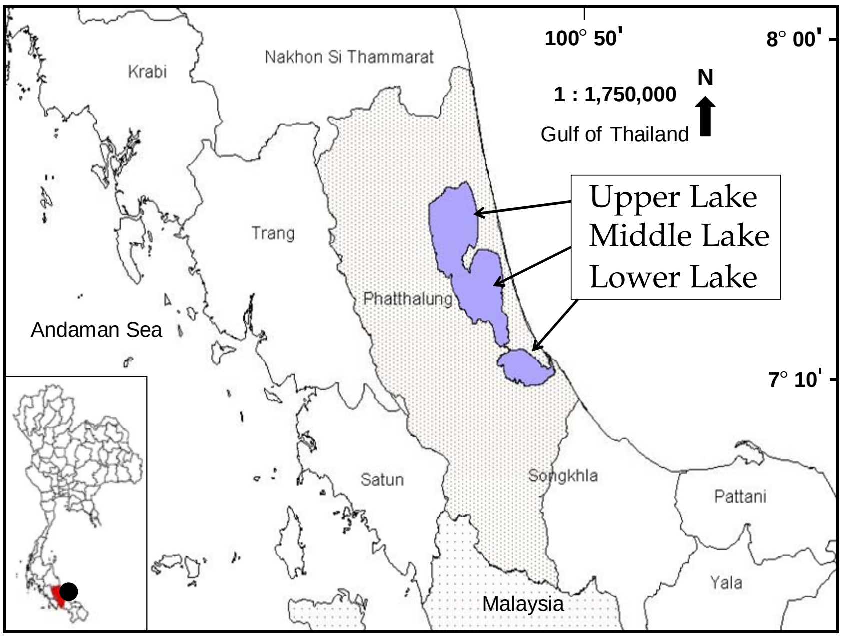

Figure 1 Map of Songkhla Lake and three mains of Lake Zone

Degradation of the Lake water quality is a major worry issue and continually causing fisheries damage (Ratanachai and Kanchanasuwan, 2005). In order to minimize the eutrophication, the variation and relationship of Chlorophyll-a concentration to seasonal water quality must be well understood and predictable because Chlorophyll-a is regularly used as an estimate of algal biomass with blooms being estimated to occur when Chlorophyll-a concentrations exceed 10 mg/l (Nedwell et al., 2002). The objectives of this study aim to investigate water quality and to identify significant climatic and water quality parameters when conducive to high Chlorophyll-a levels (exceed 10 mg/l) subsequently fitting the empirical model to forecast occurrence of algae bloom (eutrophication). These results will be the significant lake management tool.

Methodology

Data source

The time series of monthly water quality parameters were collected by National Institute of Coastal Aquaculture (NICA), Department of Fisheries of Thailand, from 25 stations of water sampling around three zones of the Lake from March 1992 to December 2003 as well as the monthly climatic parameters obtained from Southern Meteorological Center (East Coast), The Meteorological Department of Thailand. The investigated parameters of climatic and water quality were already shown in table 1.

Statistical Analysis

Pearson's correlation coefficients were used for measuring the strength of a linear relationship between quantitative variables and to create a regression equation for Chlorophyll-a concentration. Pearson correlations are strongly sensitive to data that deviate from normality and are strongly influenced by observations that are extreme. Therefore, some water parameters were transformed to square root (total organic carbon, silicate, total suspended solid and transparency) and natural logarithms (the rest variables) in order to ensure that statistical assumptions of normality and constant variance were satisfied. Furthermore, the day of sampling affected the relationship between parameters in some cases, and therefore, partial correlation coefficients were used. Odds ratio for eutrophication occurrence in each lake zone were also analyzed.

Results and Discussion

3.1 Trend of water quality

The result indicated that water qualities generally are in the optimal range of Thailand surface water quality standards class 2: Very clean used for (1) consumption which requires ordinary water treatment processes (2) aquatic organism conservation (3) fisheries, and (4) recreation (Pollution Control Department, 2007). However, there are 8 major water qualities parameters may take high potential risk and exceeded the relevant Thailand surface water quality standards class 2 or criteria of water quality for aquatic organism protection (Table 1) as follows. 1). Total suspension solid (69.62%), 2). Transparency (60.65%), 3). Ammonia (60.41%), 4). Chlorophyll-a (50.44%), 5) BOD (47.51%), 6) Dissolved oxygen (32.67%), 7) Total nitrogen (18.42%) and (8) Total phosphate (12.14%)

Table 1 General statistics of the Lake climatic and water quality parameters; 1992 -2003

Parameters	Unit	Mean	Std. Dev	Min	Max	WQ Standard*	Percent Exceed
Air temperature	°C	27.96	0.95	23.20	30.50	-	-
Relative humidity	%	78.03	4.05	66.00	91.00	-	-
Evaporation	mm	4.30	0.94	1.90	7.04	-	-
Cloudiness	1-10	5.32	1.40	2.63	8.90	-	-
Sun duration	hour	6.58	1.67	2.90	10.15	-	-
Wind speed	knot	2.32	1.55	0.00	7.90	-	-
Rainfall	mm	179.38	195.32	0.00	936.50	-	-
Depth	meter	2.06	1.35	0.40	9.00	-	-
Transparency	meter	0.54	0.34	0.05	2.50	30-60**	60.65
Water temperature	°C	29.48	1.55	25.00	38.00	23-32**	7.04
Salinity	psu	10.29	11.56	0.00	36.00	-	-
Dissolved oxygen	mg/l	6.66	1.68	1.26	13.82	□ 6.0*	32.67
pH	-	7.81	0.66	3.41	9.80	6-9*	4.63
Nitrite	mg/l	0.01	0.06	0.00	2.00	0.71***	0.18
Nitrate	mg/l	0.09	0.22	0.00	3.03	5.0*	0
Ammonia	mg/l	0.09	0.22	0.00	2.59	0.02**	60.41
Silicate	mg/l	2.04	1.27	0.00	7.46	-	-
Orthophosphate	mg/l	0.02	0.08	0.00	0.79	0.11***	3.34
Total nitrogen	mg/l	0.81	0.65	0.02	4.71	1.3***	18.42
Total phosphate	mg/l	0.07	0.08	0.00	1.78	0.12***	12.14
Chlorophyll-A	mg/l	19.58	22.86	0.75	186.39	10*****	51.44
Total suspension solid	mg/l	58.61	48.52	2.50	398.00	30**	69.62
Total organic carbon	mg/l	4.77	4.02	0.02	23.24	4.8-5.2***	3.75
BOD	mg/l	1.91	1.63	0.10	12.20	1.5*	47.51
COD	mg/l	41.53	25.53	0.25	152.75	120****	1.11

Remarks : * Class I National Surface Water Quality Standards, PCD, Thailand (PCD, 2007)

** Criteria of water quality standard for aquatic organism protection. (PCD, 2007)

*** Florida Department of Environmental Protection, (USGS, 2007)

**** Industrial Effluent Standards of Thailand. (PCD, 2007)

***** Nedwell et al. (2002)

Water quality has been degraded in large parts of Songkhla Lake by mainland human activities and seasonal intervention that result in high nutrient discharge and generally over-enrichment entering into the Lake. The main wastewater sources are (1) domestic and tourism wastewater; (2) industrial effluents; (3) agriculture, husbandry (swine - chicken) and shrimp farms; (4) deforestation and (5) and real estate construction (PCD and Office of Environmental Region 16, 2004a). All these influence factors conductive the trend of water quality worsens and has an effect on human well-being and environmental health of the Lake (Chevakidagarn, 2006).

3.2 Model for forecasting eutrophication occurrence

The study found that Chlorophyll-a concentration in Upper Lake zone, shown highly significant higher than those in the Middle and Lower zones, especially between February to July year round. Furthermore, the percentages of eutrophication occurrences in the Upper, Middle and Lower zone were 85.95, 15.97 and 36.67, respectively. In addition eutrophication occurrences in the Upper and Lower Lake zone are 47.09 and 3.05 times higher than the Middle Lake zone (Table 2). Due to there are many swine and chicken farms in the western mainland of the Upper Lake zone usually high dense in Phatthalung province. Whereas in the eastern comprise of many shrimp farms in district of Ka Sae Sin and Ra Nod of Songkhla province (PCD and Office of Environmental Region 16, 2004b). Most of these agriculture farming have discharged nitrogenous wastewater directly into the Lake. These supplies of wastewater (nutrient enrichment) promote the growth of algae, phytoplankton and aquatic macrophyte blooming. These phenomena usually exhibit densely packed aquatic macrophyte on shallow water surface while in deeper the appearance will be microalgae or phytoplankton (La-ongsiriwong, 2004).

Table 2 Eutrophication occurrence from 1992 – 2003 and its probability in each Lake zone

Lake zone	Non eutro. N=827 (%)	Eutro. N = 878 (%)	OR (95%CI)	p-value
Upper lake	57 (10.05)	510 (89.95)	47.09 (30.27-73.25)	0.000
Middle lake	200 (84.03)	38 (15.97)	1 (baseline)	0.000
Lower lake	570 (63.33)	330 (36.67)	3.05 (2.10 – 4.42)	0.000

The resultant forecasting model (Table 3) gave an r-squared of 50.5% and statistically significant associations with Lake Zone, season (dry and moderate rain), climatic factors (air temperature and rainfall) and water quality parameters (temperature, salinity, dissolved oxygen, pH, transparency, total organic carbon, orthophosphate and ammonia). As the reasons mention above, the Upper Lake zone is turbid windswept region together with high nitrogenous waste discharge. Therefore, this zone is the highest Chlorophyll-a concentration.

Table 3 The forecasting model for eutrophication occurrence in the Lake

Linear Regression Analysis: Outcome = ln(Chlorophyll-A)					
Determinant	Coefficient	Std. Error	95% CI		p-value
Constant	4.979	2.1285	0.8071,	9.1509	0.0194
Lake Zone	baseline:	Upper Lake			0.0000
Middle Lake	-1.2074	0.0674	-1.34	-1.08	0.0000
Lower Lake	-0.7257	0.0647	-0.85	-0.60	0.0000
Month	Baseline:	Jan			0.0015
Feb	-0.23	0.09	-0.42	-0.05	0.0146
Mar	-0.19	0.10	-0.38	0.00	0.0504
Apr	-0.24	0.10	-0.44	-0.04	0.0172
May	-0.32	0.10	-0.52	-0.13	0.0014
Jun	-0.19	0.10	-0.39	0.00	0.0493
Jul	-0.22	0.10	-0.41	-0.03	0.0237
Aug	-0.04	0.10	-0.23	0.15	0.6996
Sep	-0.06	0.10	-0.25	0.13	0.5139
Oct	-0.05	0.10	-0.23	0.14	0.6334
Nov	0.03	0.09	-0.15	0.21	0.7254
Dec	-0.14	0.09	-0.32	0.03	0.1090
lnAirTemp	-1.34	0.61	-2.54	-0.15	0.0278
lnRainfall	-0.04	0.02	-0.07	-0.01	0.0119
waterTemp	0.06	0.01	0.03	0.09	0.0001
salinity	-0.01	0.00	-0.01	0.00	0.0011
dissOxygen	0.08	0.01	0.06	0.11	0.0000
water pH	0.18	0.04	0.11	0.25	0.0000
sqrtTranspa	-0.97	0.10	-1.16	-0.78	0.0000
sqrtTOC	0.05	0.02	0.00	0.09	0.0389
lnOrthophosp	0.07	0.02	0.03	0.10	0.0002
lnAmmonia	-0.04	0.02	-0.07	0.00	0.0305
r-sq: 0.5079 df: 1681 RSS: 926.2574 s: 0.7423					

Moreover, in January showed higher significance than those in February to July because the great amount of organic matters and nutrient loading were eroded into the Lake by annual flood between Octobers to December. Eutrophication occurrence frequently found in the Upper Lake zone all year round while the Middle Lake and the Lower Lake found at end of year. Recently, a severe eutrophication problem occurred in the Middle Lake. In 2002 a rapid microalgae bloom, mostly of the *Najas* sp., covered an area more than 160 sq. km in the Upper Lake. The wet weight of this has been estimated at 0.6 million tons. In 2003 there was a widespread *Najas* sp. all-year-round bloom covering the western Upper Lake up to Klong Lum Pum estuary. Moreover, there were dense green macroalgae (*Cladaophora*) on top of the *Najas* sp. over a vast area (La-ongsiriwong, 2004; Ratanachai and Kanchanasuwan, 2005). In addition, pollution from waste water discharge and eutrophication effects is also likely to have damaged the fish stock in the Lake.

Environmental conditions within the Lakes Basin all influence eutrophication. Rivers and streams are major routes of transfer of nitrogen; phosphorus and organic carbon both integrate point and non-point sources of algal nutrients. Deforestation and erosion of upland forests have been contributing to sedimentation causing shallow of the Lake water. Intensive agriculture is demanded excessive water and flushing nutrients and organic matter into the Lake. This, together with wastewater produced by industry and domestic settlements, is contributing to increasing incidents of eutrophication. Fish stock will decrease as water quality declines and economic losses result. The conflicting land use changes have degraded the watershed and have changed the rainfall pattern and runoff, which eventually impacted on the salinity patterns and water quality in the Lake (Chufamanee et al, 2003).

This study can identify those serious water quality parameters which evidence a significant relationship to algal biomass in the Lake causing from activities of human around the basin. We recommend that ammonia; orthophosphate and total organic carbon are most likely the primary limiting factors for eutrophication occurrence. While air temperature and rainfall are periodic oscillation of seasonal intense intervention and salinity, water temperature, water pH, dissolved oxygen and transparency are interaction outcome between human and seasonal forcing. For effective management of the Songkhla Lake environment and planning for sustainable development in the future, we also fitted a plot of the time series of data with the forecasts based on the model (Figure 2). This forecasting model can provide a practical lake management tool for eutrophication surveillance.

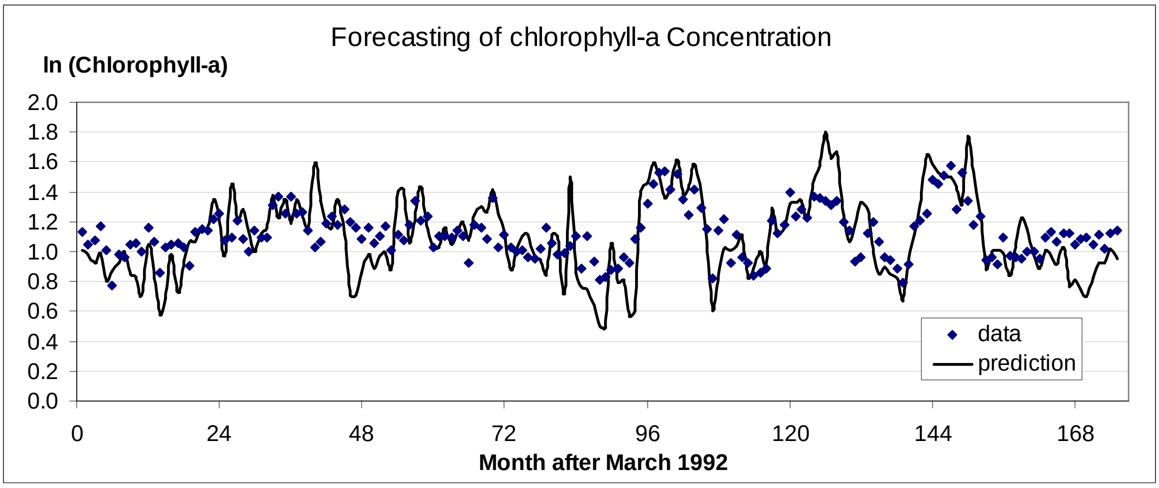

Figure 2 A plots of the time series of data with the forecasts based on the model

The primary step in the reduction of eutrophication of the Lake is to limit, divert or treat inputs of this nutrients and associated particles. Two major essentials that should be included in management of eutrophication are information about the loading of nutrients and an assessment of their impacts. Consequently, the broad of multidisciplinary or knowledge –based approach is needed. We suggest that environmental awareness among the public is the first key to success in sustainable development of the Songkhla Lake Basin.

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