Determining Water Conditions in the Northeastern Rivers of Thailand Using Time Series and Water Quality Index Models

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Abstract: Dissolved oxygen, biochemical oxygen demand, nitrate-nitrogen, total phosphorus, fecal coliform bacteria, and suspended solids were used to evaluate water quality in the northeastern rivers of Thailand: Lam Chi, Lam Pao, Lam Seaw, Loei, and Nam Oon. The mean observed values of the six water quality parameters in each river over a 5-year period (2003–2007) were used to compute the present water quality index ($WQI_{present}$) of each river in the wet (June–November) and dry (December–May) seasons. The mean observed values of the study parameters of each river by season over a 14-year period (1994–2007) were used to build a set of time series models for predicting the values of the associated parameters of each river in the next 5-year period (2008–2012). These mean predicted values were used to compute the WQI_{future} by season for each river. According to the results, the water quality at many sampling stations was in good condition. However, the water quality in Lam Chi and the Loei River will tend to decrease in the next 5-year period unless proper management is undertaken to reduce the concentrations of certain contaminants such as total phosphorus and fecal coliform bacteria in the rivers. This study revealed that the time series models with the best predictions among the stations were often not the same types. Several time series models should be used and their prediction accuracy should be compared. Water quality parameters considered in developing a WQI and the index use may be limited to a watershed for which it has been developed.

Keywords: freshwater; aquatic system, physical; chemical; geometric mean.

1. Introduction

Water pollution is one of the most critical environmental problems in Thailand, and the situation will tend to be worse in the future unless proper measures undertaken. The rapid expansion of population and commercial and industrial growth with their increasing demands for water use are the major causes of water resource deterioration in Thailand (e.g., [1-4]). For better understanding and managing of water resources, the quality of water in an area of interest should be determined in terms of either its physical, chemical, or biological parameters, or all of these factors. Additionally, the integrated situation of water in a study area should be evaluated using an appropriate technique, such as the water quality index (WQI). The WQI was first developed by in 1965. Since then, it has been widely applied for generating trends, evaluating, and communicating the overall quality of water for the public to be able to understand, and for allowing comparisons among different watercourses or different locations in the same watercourse (e.g., [5-8]). The WQI concept integrates magnitudes of all water quality parameters of interest into scores that can assess water quality for multiple purposes [9]. Four steps for developing WQI suggested by Boyacioglu [10] were (1) selecting a set of water quality parameters of interest, (2) developing sub-indices-transforming the different units and dimensions of water quality parameters to a common scale, (3) assigning weights to the water quality parameters based on their relative importance to overall water quality, and (4) aggregating sub-indices to produce an overall index.

In Thailand, the Pollution Control Department (PCD) has modified the WQI of Brown et al. [6]. This WQI is considered to be the basis of opinion research in this field [11] for evaluating the overall water quality in Thailand's rivers since 1995. Following the suggestions of Landwehr [12], an unweighted WQI is applied for evaluating the overall water quality by the PCD [13], in which all water quality parameters of interest are assumed to have equal importance. Before determining the WQI in each area, the values of each water quality parameter included in the WQI model have to be converted into sub-index scores between 0 and 100 using the rating curve technique developed for Thailand's rivers [13].

In this study, a set of time series models in Ragsdale [14] was used to determine the changing patterns of six important water quality parameters, including dissolved oxygen, biochemical oxygen demand, nitrate-nitrogen, total phosphorus, fecal coliform bacteria, and suspended solids in five rivers located in the Northeast of Thailand. A time series method is simple and efficient for analyzing the past behavior of a time series variable in order to predict its future behavior when causal independent variables influencing the time series variable are unknown or cannot be determined [14]. This modeling technique requires uncomplicated data sets (only the time series data for each water quality parameter of interest) and less time needed for computation. Other factors influencing water quality (e.g., changes in land use and population growth) are assumed to indirectly reflect the changing patterns of the six water quality parameters in each study river. The unweighted WQI [13] was then used to estimate the overall water quality in the study river and categorize its conditions into classes.

The objectives of this study were, thus, to (1) determine the present and future situations of the six water quality parameters in five rivers located in the Northeast of Thailand using a set of time series models, (2) determine the overall water quality for each river using the unweighted WQI, and (3) categorize the conditions of water quality for each river into classes following the guidelines of Notification No. 8: Surface water quality standard, the 1992 Thailand Enhancement and Conservation of National Environmental Quality Act [15].

2. Methodology

2.1 Study sites and water quality data

The sampling stations (for observing water quality parameters in each of the five rivers located in the Northeast of Thailand) were stratified and then randomly selected (Fig. 1). The first river, Lam Chi, is a tributary of the Mun River and is located between 15°17'28.01" N, 103°30'19.91" E and 14°48'7.2" N, 103°17'19.14" E. The river flows through Buriram and Surin provinces. Five sampling stations in Lam Chi were started from station LC01 (at the river mouth) to station LC05, about 85 river kilometers (RM) from the river mouth (Fig. 1). The mean water temperature and the precipitation in the Lam Chi basin during 2003–2007 were 29.4ºC and 151.4 mm, respectively in the wet season (June-November), and 30.2ºC and 47.6 mm, respectively in the dry season (December-May). The second river, Lam Pao, is a tributary of the Chi River, and is located between 16°15'33.62" N, 103°41'26.53" E and 16°36'0.28" N, 103°27'19.33" E. The river flows through Kalasin and Roiet provinces. Five sampling stations in Lam Pao started from station LP01 (about 5 RM from the river mouth) to station LP05 (about 96 RM from the river mouth, Fig. 1). Mean water temperature and precipitation in the Lam Pao basin during 2003–2007 were 28.8ºC and 153.4 mm, respectively in the wet season, and 27.4ºC and 55.4 mm, respectively in the dry season.

The third river, Lam Seaw, is a tributary of the Mun River and is located between 15°24'42.47" N, 104°3'47" E and 16°0'0" N, 103°7'32.76" E. The river flows through Maha-sarakham, Roiet, and Sisaket provinces. Five sampling stations in Lam Seaw started from station LS01 (at the river mouth) to station LS05 (about 303 RM from the river mouth, Fig. 1). The mean water temperature and the in the Lam Seaw basin during 2003–2007 were 28.7ºC and 150.8 mm, respectively in the wet season, and 28.0ºC and 52.3 mm, respectively in the dry season. The fourth river, Loei, is a tributary of the Mekong River, and is located in Loei province between 17°51'40.20" N, 101°36'41.33" E and 17°14'13.75" N, 101°42'50.92" E. Five sampling stations in the Loei River started from station L01 (about 2 RM from the river mouth) to station L05 (about 90 RM from the river mouth, Fig. 1). The mean water temperature and the precipitation in the Loei River basin during 2003–2007 were 28.0ºC and 145.2 mm, respectively in the wet season, and 27.1º C and 61.1 mm, respectively in the dry season.

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The last river, Nam Oon, is a tributary of the Songkhram River and is located between 17°37'58.93" N, 104°14'31.75" E and 17°20'16.83" N, 103°46'22.76" E. The river flows through Nakhon-phanom and Sakonnakhon provinces. Four sampling stations in Nam Oon started from station NO01 (about 1 RM from the river mouth) to station NO04 (about 180 RM from the river mouth, Fig. 1). The mean water temperature and the precipitation in the Nam Oon basin during 2003–2007 were 28.7ºC and 199.4 mm, respectively in the wet season, and 26.6ºC and 67.3 mm, respectively in the dry season. The water in the five rivers is mainly used for agricultural purposes and livestock farming. Some water from Lam Seaw and the Loei River has been used for tap water production in Roiet and Loei provinces, respectively.

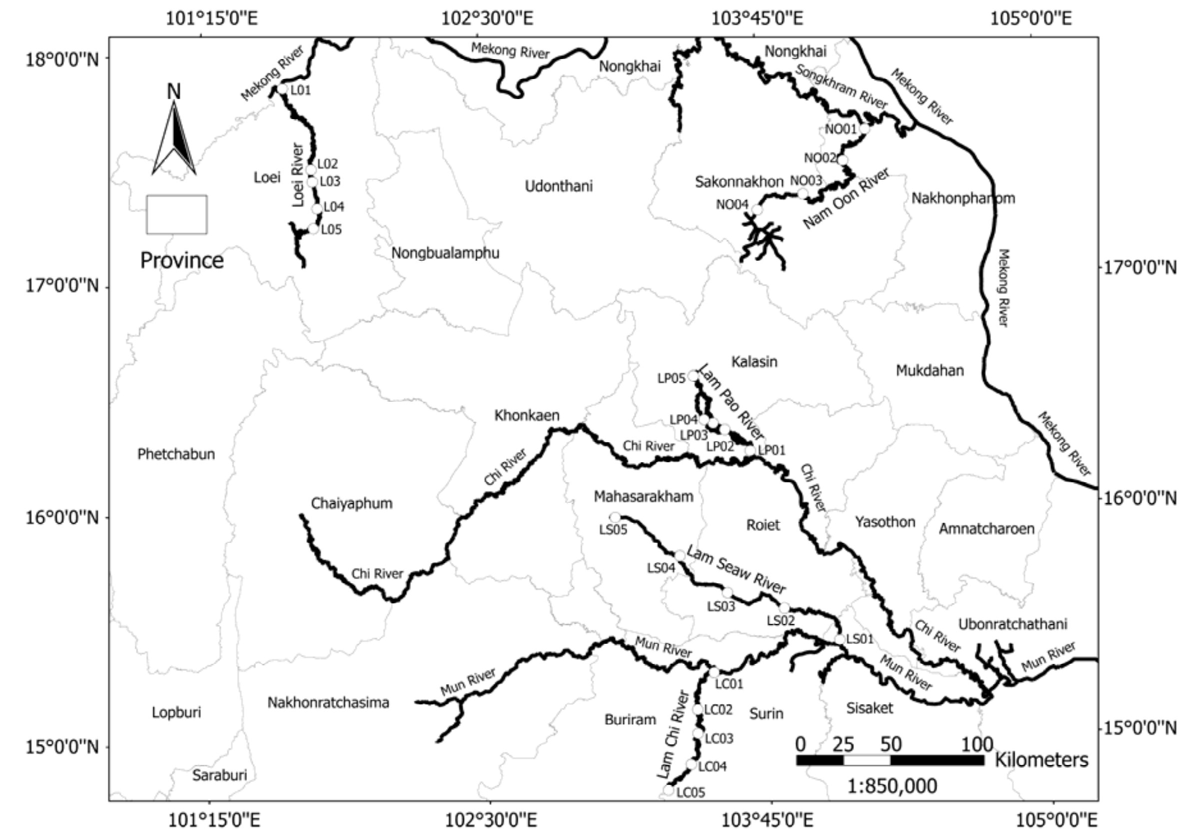


Figure 1. Five rivers with sampling stations (circles) located in the Northeast of Thailand including Lam Chi, Lam Pao, Lam Seaw, Loei, and Nam Oon rivers.

The water quality data used in this study were collected 2 to 3 times a season at each station in each of the five rivers during 1994–2007 by the Water Quality Management Bureau's Inland Water Division, PCD, Thailand. The water samples were preserved in the field and brought for laboratory analysis following standard methods [16]. The six water quality parameters used for evaluation of the overall water quality at each station in each river were dissolved oxygen (DO), biochemical oxygen demand (BOD), nitrate-nitrogen (NO_3–N), total phosphorus (TP), fecal coliform bacteria (FCB), and suspended solids (SS).

2.2 Water quality parameter determination

The values of each water quality parameter at each sampling station in each river were averaged by season over five years of field observations (2003–2007). These mean values for all six water quality parameters were used to compute the present water quality index ($WQI_{present}$). Additionally, mean observed values of the six water quality parameters by season in each river over a 14-year period of observations (1994–2007) were used to build a set of time series models for forecasting values of the associated water quality parameters in each river for the next 5-year period (2008–2012). The basic time series function is:

$$\hat{Y}_{t+1} = f(Y_t, Y_{t-1}, Y_{t-2}, ...) \tag{1}$$

$\hat{Y}_{t+1}$ represents the predicted value for the time series variable in time period t+1. Y_t represents the value of the time series variable in time period t. Y_{t-1} represents the value of the time series variable in time period t–1, and so forth [14].

According to Eq. (1), a time series method is simple and efficient for analyzing the past behavior of a time series variable in order to predict its future behavior when causal independent variables influencing the time series variable are unknown or cannot be determined [14]. However, because of the model's simplicity, other environmental factors that may influence water quality (e.g., changes in land use and population growth) are not explicitly accounted for by a time series model. In other words, the effects of changes in land use and other human activities along the riversides as well as population growth were assumed to indirectly reflect the integrated changes in the six water quality parameters for each river.

In this study, eight types of time series models were used to predict the values of each water quality parameter that might have different time series behaviors. The first two model types, single moving average and single exponential smoothing models, are developed for capturing the behaviors of stationary data (no strong upward or downward trend) without repeating seasonal patterns. The second two types, seasonal additive and seasonal multiplicative models, are developed for capturing the behaviors of stationary data with repeating seasonal patterns. The third two types, double moving average and double exponential smoothing models, are developed for capturing the behaviors of non-stationary data (a strong upward or downward linear or nonlinear trend) without repeating seasonal patterns. The last two types, Holt-Winters' additive and Holt-Winters' multiplicative models, are developed for capturing behaviors of non-stationary data with a repeating seasonal pattern. The characteristics of each model type are summarized in Table 1 (see details in Ragsdale [14]).

Table 1. Characteristics of the eight time series models' parameters and coefficients.

Model parameters and coefficients	
1. Single moving average model $\hat{Y}_{t+1} = Y_t + Y_{t-1} + Y_{t-k+1}$ $\hat{Y}_{t+2} = (\hat{Y}_{t+1} + Y_t)/2$	$\hat{Y}_{t+1}$ = the predicted value at time t + 1. Y_t, Y_{t-1} = the observed value at t and t-1, respectively. k = seasonal period (= 2 for this study).
2. Single exponential smoothing model $\hat{Y}_{t+1} = \alpha Y_t + \alpha(1-\alpha)Y_{t-1} + \alpha(1-\alpha)^2 Y_{t-2} + ... + \alpha(1-\alpha)^n Y_{t-n} + ...$ $\hat{Y}_{t+2} = \hat{Y}_{t+1} + \alpha(Y_{t+1} - \hat{Y}_{t+1})$ $0 \le \alpha \le 1$	$\hat{Y}_{t+n}$ = the predicted value at time t + n. Y_t, Y_{t-1}, Y_{t-2} = the observed value at t, t-1 and t-2, respectively. α = the coefficient that causes the least prediction error.
3. Seasonal additive model $\hat{Y}_{t+n} = E_t + S_{t+n-p}$, where $E_t = \alpha(Y_t - S_{t-p}) + (1-\alpha)E_{t-1}$ $S_t = \beta(Y_t - E_t) + (1-\beta)S_{t-p}$ $0 \le \alpha \le 1$ and $0 \le \beta \le 1$ At the initial stage: $E_t = \sum_{i=1}^{p} \frac{Y_i}{p}, t = 1, 2, ..., p$ $S_t = Y_t - E_t, t = 1, 2, ..., p$	$\hat{Y}_{t+n}$ = the predicted value at time t + n. Y_t = the observed value at time t. α, β = the coefficients that caused the least prediction error. p = number of seasons (= 2 for this study). E_t = level of time series at time t. S_t = seasonal factor of expected time series at time t.

4. Seasonal multiplicative model

$\hat{Y}_{t+n} = E_t \times S_{t+n-p}$, where

$E_t = \alpha(Y_t / S_{t-p}) + (1-\alpha)E_{t-1}$

$S_t = \beta(Y_t / E_t) + (1-\beta)S_{t-p}$

$0 \le \alpha \le 1, 0 \le \beta \le 1$

At the initial stage:

$E_t = \sum_{i=1}^{p} \frac{Y_i}{p},\ t = 1,2,\ldots,p$

$S_t = Y_t / E_t, t = 1,2,\ldots,p$

$\hat{Y}_{t+n}$ = the predicted value at time $t + n$.

Y_t = the observed value at time t.

α, β = the coefficients that caused the least prediction error.

p = number of seasons (= 2 for this study).

E_t = level of time series at time t.

S_t = seasonal factor of expected time series at time t.

5. Double moving average model

$\hat{Y}_{t+n} = E_t + nT_t$, where

$E_t = 2M_t - D_t$

$T_t = 2(M_t - D_t)/(k-1)$

$M_t = (Y_t + Y_{t-1} + \ldots + Y_{t-k+1})/k$

$D_t = (M_t + M_{t-1} + \ldots + Y_{t-k+1})/k$

$\hat{Y}_{t+n}$ = the predicted value at time $t + n$.

E_t = level of time series at time t.

T_t = predicted trend at time t.

M_t = mean value in the season k at time t.

D_t = mean M_t at time t.

6. Double exponential smoothing model

$\hat{Y}_{t+n} = E_t + nT_t$, where

$E_t = \alpha Y_t + (1-\alpha)(E_{t-1} + T_{t-1})$

$T_t = \beta(E_t - E_{t-1}) + (1-\beta)T_{t-1}$

$0 \le \alpha \le 1,\ 0 \le \beta \le 1$

$\hat{Y}_{t+n}$ = the predicted value at time $t + n$.

E_t = level of time series at time t.

T_t = predicted trend at time t.

α, β = the coefficients that caused the least prediction error.

7. Holt-Winters' additive model

$\hat{Y}_{t+n} = E_t + nT_t + S_{t+n-p}$, where

$E_t = \alpha(Y_t - S_{t-p}) + (1-\alpha)(E_{t-1} + T_{t-1})$

$T_t = \beta(E_t - E_{t-1}) + (1-\beta)T_{t-1}$

$S_t = \gamma(Y_t - E_t) + (1-\gamma)S_{t-p}$

$0 \le \alpha \le 1,\ 0 \le \beta \le 1, 0 \le \gamma \le 1$

At the initial stage

$S_t = Y_t - \sum_{i=1}^{p} \frac{Y_i}{p}, t = 1,2,\ldots,p$

$\hat{Y}_{t+n}$ = the predicted value at time $t + n$.

E_t = level of time series at time t.

T_t = predicted trend at time t.

S_{t+n-p} = the seasonal effect value at time period $t+n-p$.

$\alpha, \beta, \gamma,$ = the coefficients that caused the least prediction error.

8. Holt-Winters' multiplicative model

$\hat{Y}_{t+n} = (E_t + nT_t)S_{t+n-p}$, where

$E_t = \alpha \frac{Y_t}{S_{t-p}} + (1-\alpha)(E_{t-1} + T_{t-1})$

$T_t = \beta(E_t - E_{t-1}) + (1-\beta)T_{t-1}$

$S_t = \gamma \frac{Y}{E_t} + (1-\gamma)S_{t-p}$

$0 \le \alpha \le 1,\ 0 \le \beta \le 1, 0 \le \gamma \le 1$

At the initial stage

$S_t = Y_t / \left(\sum_{i=1}^{p} \frac{Y_i}{p} \right), t = 1,2,\ldots,p$

$\hat{Y}_{t+n}$ = the predicted value at time $t + n$.

E_t = level of time series at time t.

T_t = predicted trend at time t.

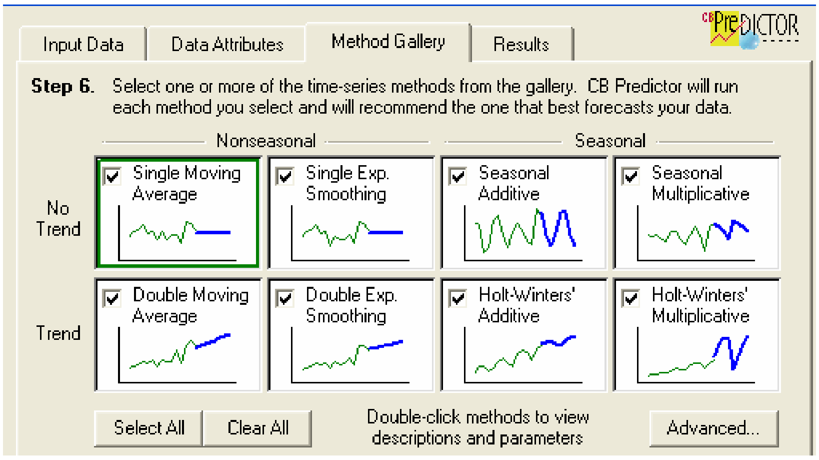
S_{t+n-p} = the seasonal effect value at time period $t+n-p$.

$\alpha, \beta, \gamma,$ = the coefficients that caused the least prediction error.

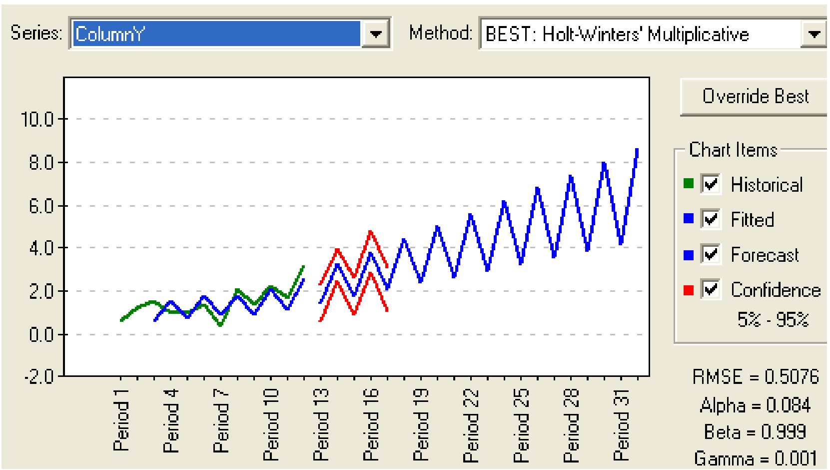
Crystal Ball (CB) predictor in Crystal Ball software version 7 (Professional) was used to simulate the eight time series models at the same time and generate a report of the predicted results obtained from the eight models in a Microsoft Excel spreadsheet. The best model type that showed the best fit (within the 5% and 95% confidence interval with the least root mean square error, RMSE) to the current observed values of a water quality parameter at each station was selected for predicting the values of that water quality parameter in the associated station by season over the next 5-year period (2008–2010). The predicted values of the six water quality parameters at each station were used to compute the WQI_{future} in the associated station. Statistically, the predicted results obtained from the best time series models are reliable when they fall within the 5% and 95% confidence intervals [14]. Meanwhile, the time series models with the best predictions among stations were often not the same types. This is reasonable and more realistic because the changing patterns of water quality parameters among the stations in the five rivers were generally not the same. The examples of model selection, prediction, and results are summarized in Table 2.

Table 2. The examples of using Crystal Ball predictor to simulate the eight time series models and choosing the best fitted model with the least root mean square error (RMSE).

1) The eight time series models were selected to predict each water quality parameter at each station in each river.



2) The best fit model forecast to the observed (historical) data with the least RMSE between the 5% and 95% confidence interval was shown.



3) The eight models were listed in order with the best model having the least RMSE value ranked first.

	Method	RMSE	MAD	MAPE
Best:	Holt-Winters' Multiplicative	0.5076	0.4655	39.64%
2nd:	Holt-Winters' Additive	0.5478	0.4838	40.28%
3rd:	Seasonal Multiplicative	0.6065	0.5588	43.60%
4th:	Seasonal Additive	0.6072	0.5208	39.82%
5th:	Double Exponential Smoothing	0.6314	0.4971	44.33%
6th:	Single Moving Average	0.6763	0.56	46.43%
7th:	Single Exponential Smoothing	0.7366	0.5765	45.31%
8th:	Double Moving Average	0.8726	0.7236	67.17%

2.3 Water quality index and classification

The mean observed and predicted values of each water quality parameter were converted into sub-index scores for the parameter in the present and future, respectively using the rating curve for the associated parameter of the Water Quality Management Bureau, PCD ([13], Fig. 2). These rating curves were modified from the transformation curves of Brown et al. [6]. At an early step of creation, questionnaires were sent to about 100 water quality experts in Thailand asking them to independently select the important water quality parameters and give scores (ranging from the poorest, 0, to the best, 100) to each range of values of their selected parameters [13]. Other information influencing water quality (e.g., land use change, water consumption, and human activities along the riversides) was also aggregated from the water quality experts' opinions. The data obtained from the water quality experts and Brown et al. [6] were used to create the rating curves for eight water quality parameters, including DO, pH, FCB, BOD, NO_3-N, TP, SS, and TS (total solids) for PCD. The eight rating curves were tested for a year using the values of the associated water quality parameters observed at 746 sampling stations in 45 rivers of Thailand in 1999 with their suitability adjusted for better determining water conditions in Thailand's rivers [13]. The techniques for creating similar sub-index transformation curves for some water quality parameters can be seen in detail in Prakirake et al. [17].

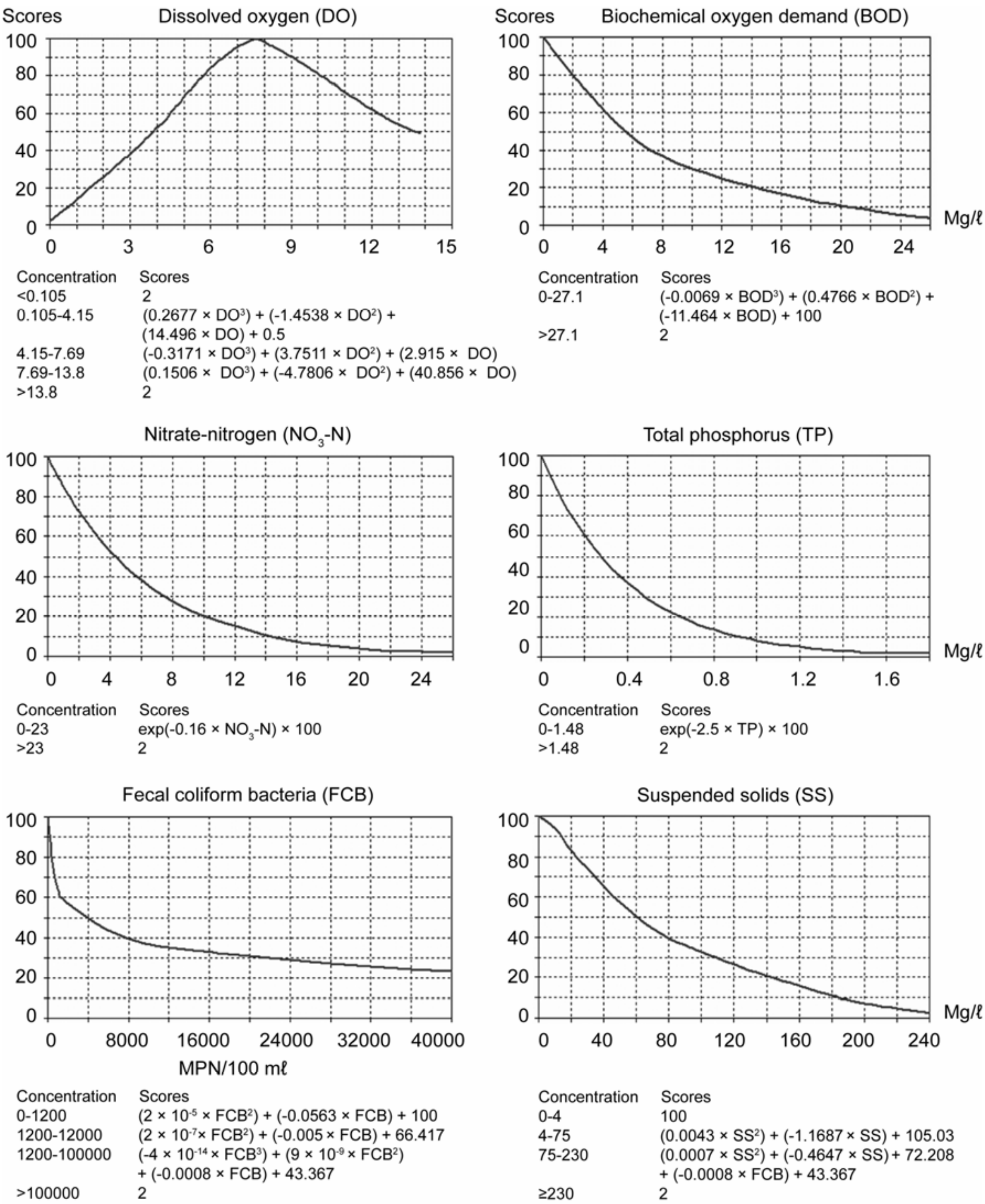


Figure 2. The rating curve of each water quality parameter and its associated formulas for converting the parameter values into scores between 0 and 100 [13].

The sub-index scores for all water quality parameters from both observation and prediction at each station in each river were then used to evaluate the overall water quality in the associated river in the present and future, respectively using the unweighted geometric mean WQI [13] as follows:

$$\mathrm{WQI} = \left(\prod_{x=1}^{N} S_x \right)^{1/N} \quad (2)$$

S_x represents the sub-index scores of a water quality parameter x after conversion, where x is each water quality parameter in this study (i.e., DO, BOD, NO_3–N, TP, FCB, and SS). N is the total number of the selected water quality parameters (i.e., 6). To obtain the WQI between 0 and 100 at each station in each river, the product of all S_x in Eq. (2) was normalized with the power of 1/N.

The WQI scores for all stations in each river were used to categorize the overall water quality into classes following Notification No. 8: Surface water quality standard, the 1992 Thailand Enhancement and Conservation of National Environmental Quality Act [15]. The five surface water quality classes with specific characteristics are as follows:

- Class I: Very good condition, without any pollutant contamination, suitable for (1) consumption after customary disinfection process and (2) the natural breeding of living organisms and ecosystem conservation. The WQI scores for this water class are 91–100.
- Class II: Good condition, with some pollutant contamination, suitable for (1) consumption after customary water treatment and disinfection processes, (2) aquatic organism conservation, (3) fisheries, and (4) swimming, water sport, and other forms of recreation. The WQI scores for this water class are 71–90.
- Class III: Fair condition, with some pollutant contamination, suitable for (1) consumption after customary water treatment and disinfection processes and (2) agriculture. The WQI scores for this water class are 61–70.
- Class IV: Poor condition, with some pollutant contamination, suitable for (1) consumption after customary water treatment and disinfection processes and (2) industry. The WQI scores for this water class are 31–60.
- Class V: Very poor, with some pollutant contamination, suitable for navigation only. The WQI scores for this water class are 0–30.

3. Results and Discussion

3.1 Results

The mean observed and predicted values of TP and FCB in Lam Chi during 2003–2007 and 2008–2012, respectively tended to increase at station LC01 in both the wet and dry seasons. The mean observed values of all study parameters (except FCB in the wet season) at station LC02 during 2003–2007 were similar to the mean predicted ones in the same season during 2008–2012 (Table 3). The mean predicted values of all study parameters (except DO) at station LC03 will tend to increase in the next five years (Table 3). At station LC04, the concentration of TP will tend to increase in both seasons in the next five years (Table 3). The mean observed values of all study parameters (except TP and FCB in the dry season) at station LC05 during 2003–2007 were similar to the predicted ones during 2008–2012 (Table 3). The estimated values of $WQI_{present}$ and WQI_{future} revealed that the overall water quality at many stations in Lam Chi was in Class II during 2003–2007 and 2008–2012, respectively, except at station LC01, where water quality in the dry season deteriorated in both observed and predicted periods (Fig. 3A). The water quality at station LC02 was in Class II during 2003–2007 and 2008–2012. The water quality at station LC03 was in Class II, but it will tend to be in Class III during 2008–2012 (Fig. 3A). The water quality at stations LC04 and LC05 will tend to be in Class IV during 2008–2012 with high TP concentration (Fig. 3A).

Table 3. Mean observed values over the 5-year period (2003–2007) and mean predicted values over the next 5-year period (2008–2012) of each water quality parameter at each station in Lam Chi in the wet (June-November) and dry (December-May) seasons.

Station	Season	Methods	Mean value of each water quality parameter*					
			DO	BOD	NO_3-N	TP	FCB	SS
LC01	Wet	Observe	5.46	1.51	0.07	0.18	728.00	34.80
		Predict	6.14	1.90	0.09	0.65	3901.81	19.67
	Dry	Observe	7.97	1.83	0.12	1.73	1064.00	27.15
		Predict	8.20	1.94	0.09	8.06	3887.95	17.05
LC02	Wet	Observe	5.42	1.34	0.24	0.17	265.00	26.40
		Predict	6.02	1.44	0.31	0.30	978.00	37.33
	Dry	Observe	6.45	1.92	0.13	0.11	808.00	9.40
		Predict	6.02	2.66	0.27	0.30	978.00	14.50
LC03	Wet	Observe	5.70	2.18	0.18	0.18	714.00	26.60
		Predict	6.09	3.72	0.33	0.47	602.86	30.90
	Dry	Observe	6.85	3.14	0.14	0.20	210.00	24.36
		Predict	6.09	3.89	0.30	0.52	602.86	31.63
LC04	Wet	Observe	5.80	1.65	0.09	0.29	540.00	25.60
		Predict	6.19	2.23	0.09	1.80	389.22	25.78
	Dry	Observe	5.86	1.80	0.10	0.69	169.00	17.89
		Predict	6.36	2.23	0.09	3.73	389.22	25.78
LC05	Wet	Observe	5.38	1.15	0.07	0.13	470.00	35.40
		Predict	6.74	2.28	0.08	1.51	949.68	16.95
	Dry	Observe	6.03	1.41	0.09	0.17	178.00	11.83
		Predict	7.20	2.40	0.08	1.72	41.23	16.95

*The six water quality parameters are dissolved oxygen (DO, mg/l), biochemical oxygen demand (BOD, mg/l), nitrate-nitrogen (NO_3–N, mg/l), total phosphorus (mg/l), fecal coliform bacteria (FCB, MPN/100 ml), and suspended solids (SS, mg/l).

In Lam Pao, the mean observed values of all study parameters (except FCB) by season during 2003–2007 were similar to the mean predicted ones in the same season during 2008–2012 (Table 4). Likewise, the $WQI_{present}$ and WQI_{future} were similar by season at each station indicating that the overall water quality from stations LP01 to LP04 was in Class II in both study periods (Fig. 3B). The water quality at station LP05 was in Class I over the time period of the study (Fig. 3B). In Lam Seaw, both mean observed and predicted values by season of all water quality parameters (except TP and FCB) were similar (Table 5). The concentration of TP will tend to increase in both seasons at station LS01 during 2008–2012. Additionally, the concentration of FCB will tend to increase in both seasons at stations LS01 and LS02 in the next five years (Table 5). According to the $WQI_{present}$ and WQI_{future}, the overall water quality at most stations in Lam Seaw was in Class II (from stations LS01 to LS04). The quality of water at station LS05 was in Class I in both seasons and study periods (Fig. 3C).

In the Loei River, both mean observed and predicted values by season of all water quality parameters (except FCB) were similar (Table 6). The concentration of FCB will tend to increase in both seasons at station L02 during 2008–2012 (Table 6). The overall water quality at many stations in the Loei River was in Class III (Fig. 3D) during 2003–2007. The water quality at station L02 in the dry season will tend to decrease to Class IV in the next five years with a dramatic increase of FCB concentration. In Nam Oon, the mean observed and predicted values of all water quality parameters (except FCB) were similar at each station by season (Table 7). The mean predicted value of FCB will tend to increase in the wet season at stations NO01 and NO02 during 2008–2012 (Table 7). The $WQI_{present}$ and WQI_{future} indicated that the overall water quality in Nam Oon was in Class II in both study periods (Fig. 3E).

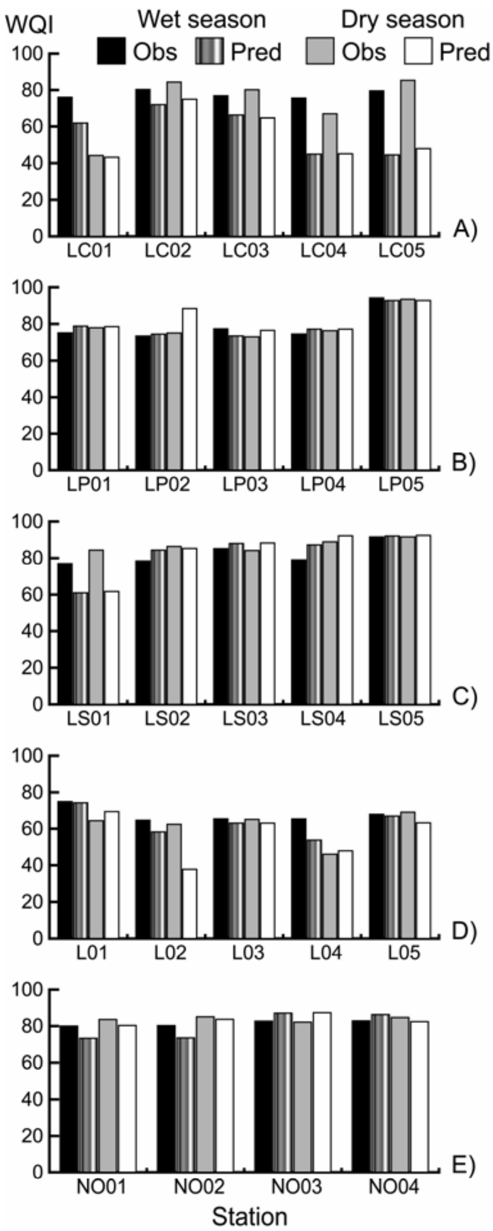


Figure 3. The water quality indexes (WQI) estimated from the mean observed and predicted values of the six water quality parameters at each station in each of the study rivers over the latest 5-year period (2003–2007) and the next 5-year period (2008–2012), respectively. The five rivers were A) Lam Chi, B) Lam Pao, C) Lam Seaw, D) Loei, and 5) Nam Oon. The surface water quality classes: I (very good), II (good), III (fair), IV (poor), and V (very poor) are indicated by the WQI values of 91–100, 71–90, 61–70, 31–60, and 0–30, respectively.

Table 4. Mean observed values over the 5-year period (2003–2007) and mean predicted values over the next 5-year period (2008–2012) of each water quality parameter at each station in Lam Pao in the wet (June-November) and dry (December-May) seasons.

Station	Season	Methods	Mean value of each water quality parameter*					
			DO	BOD	NO_3-N	TP	FCB	SS
LP01	Wet	Observe	5.70	1.48	0.40	0.11	112.00	79.00
		Predict	5.91	1.41	0.42	0.08	136.40	63.06
	Dry	Observe	6.03	1.33	0.13	0.12	185.00	64.85
		Predict	5.91	1.41	0.44	0.08	168.60	63.06
LP02	Wet	Observe	6.14	1.51	0.28	0.13	264.00	89.70
		Predict	6.25	2.18	0.16	0.09	161.67	88.39
	Dry	Observe	6.36	1.33	0.17	0.12	259.33	85.76
		Predict	6.25	2.27	0.16	0.09	161.67	88.39
LP03	Wet	Observe	5.87	1.39	0.29	0.10	328.00	61.70
		Predict	6.00	4.08	0.13	0.08	1094.97	63.09
	Dry	Observe	6.36	1.63	0.11	0.09	424.58	71.17
		Predict	6.00	4.36	0.13	0.08	1094.97	63.09
LP04	Wet	Observe	6.27	1.37	0.21	0.10	616.00	74.10
		Predict	5.72	1.30	0.13	0.08	408.00	77.88
	Dry	Observe	6.31	1.11	0.12	0.11	892.00	57.21
		Predict	5.72	1.30	0.13	0.08	408.00	77.88
LP05	Wet	Observe	7.03	0.98	0.20	0.05	16.00	8.20
		Predict	7.48	1.00	0.08	0.05	85.67	15.38
	Dry	Observe	7.68	1.16	0.07	0.05	149.67	7.97
		Predict	7.50	1.00	0.08	0.05	85.67	15.31

*The six water quality parameters are dissolved oxygen (DO, mg/l), biochemical oxygen demand (BOD, mg/l), nitrate-nitrogen (NO_3–N, mg/l), total phosphorus (mg/l), fecal coliform bacteria (FCB, MPN/100 ml), and suspended solids (SS, mg/l).

Table 5. Mean observed values over the 5-year period (2003–2007) and mean predicted values over the next 5-year period (2008–2012) of each water quality parameter at each station in Lam Seaw in the wet (June-November) and dry (December-May) seasons.

Station	Season	Methods	Mean value of each water quality parameter*					
			DO	BOD	NO_3-N	TP	FCB	SS
LS01	Wet	Observe	5.40	1.35	0.18	0.23	196.00	39.40
		Predict	5.54	1.38	0.24	0.77	419.56	34.58
	Dry	Observe	6.02	1.51	0.11	0.12	288.60	20.75
		Predict	5.54	1.52	0.25	0.73	433.46	34.58
LS02	Wet	Observe	4.00	1.47	0.14	0.14	145.60	19.00
		Predict	4.93	1.30	0.14	0.06	557.74	5.53
	Dry	Observe	5.85	1.24	0.11	0.12	401.50	9.51
		Predict	4.93	1.30	0.14	0.04	557.89	2.81
LS03	Wet	Observe	5.14	1.53	0.14	0.07	150.40	17.80
		Predict	6.81	1.41	0.11	0.06	421.99	16.77
	Dry	Observe	6.61	1.37	0.10	0.10	809.80	16.32
		Predict	6.99	1.41	0.11	0.06	422.01	16.77
LS04	Wet	Observe	4.42	1.44	0.12	0.08	308.00	31.60
		Predict	6.81	1.60	0.03	0.07	60.01	32.72
	Dry	Observe	6.07	2.08	0.05	0.04	246.01	7.80
		Predict	6.99	1.60	0.03	0.08	60.01	6.00
LS05	Wet	Observe	6.28	1.55	0.05	0.04	42.41	10.40
		Predict	7.02	1.74	0.06	0.04	46.24	13.75
	Dry	Observe	7.39	1.94	0.07	0.05	18.12	22.00
		Predict	7.02	1.74	0.06	0.04	7.48	13.75

*The six water quality parameters are dissolved oxygen (DO, mg/l), biochemical oxygen demand (BOD, mg/l), nitrate-nitrogen (NO_3–N, mg/l), total phosphorus (mg/l), fecal coliform bacteria (FCB, MPN/100 ml), and suspended solids (SS, mg/l).

Table 6. Mean observed values over the 5-year period (2003–2007) and mean predicted values over the next 5-year period (2008–2012) of each water quality parameter at each station in the Loei River in the wet (June-November) and dry (December-May) seasons.

Station	Season	Methods	Mean value of each water quality parameter*					
			DO	BOD	NO_3-N	TP	FCB	SS
L01	Wet	Observe	6.64	1.06	0.15	0.04	2585.00	68.00
		Predict	6.60	1.32	0.11	0.01	3388.88	71.36
	Dry	Observe	6.34	1.50	0.05	0.12	1414.76	135.73
		Predict	6.60	1.32	0.11	0.17	3581.97	71.36
L02	Wet	Observe	7.27	1.17	0.19	0.05	4582.00	139.60
		Predict	7.28	1.43	0.14	0.08	28890.52	136.50
	Dry	Observe	7.62	1.56	0.07	0.10	36560.00	82.20
		Predict	7.28	1.43	0.14	0.08	119334.83	136.50
L03	Wet	Observe	7.44	1.31	0.27	0.05	5860.00	125.00
		Predict	6.59	1.20	0.17	0.10	3845.75	139.21
	Dry	Observe	6.51	0.99	0.04	0.14	6943.47	101.13
		Predict	6.59	1.20	0.17	0.10	3845.75	139.21
L04	Wet	Observe	6.65	1.24	0.27	0.06	8174.00	106.80
		Predict	5.44	1.57	0.47	0.01	6643.57	186.02
	Dry	Observe	4.44	1.77	0.05	0.12	7363.47	203.63
		Predict	3.26	1.57	0.51	0.01	6643.57	186.02
L05	Wet	Observe	6.87	1.06	0.19	0.05	3826.00	116.20
		Predict	5.85	1.12	0.08	0.10	3160.30	104.63
	Dry	Observe	6.17	0.96	0.07	0.13	8486.36	57.80
		Predict	5.72	1.12	0.08	0.10	8550.30	104.63

*The six water quality parameters are dissolved oxygen (DO, mg/l), biochemical oxygen demand (BOD, mg/l), nitrate-nitrogen (NO_3–N, mg/l), total phosphorus (mg/l), fecal coliform bacteria (FCB, MPN/100 ml), and suspended solids (SS, mg/l).

Table 7. Mean observed values over the 5-year period (2003–2007) and mean predicted values over the next 5-year period (2008–2012) of each water quality parameter at each station in Nam Oon in the wet (June-November) and dry (December-May) seasons.

Station	Season	Methods	Mean value of each water quality parameter*					
			DO	BOD	NO_3-N	TP	FCB	SS
NO01	Wet	Observe	5.14	1.38	0.11	0.03	3246.00	12.00
		Predict	4.44	1.27	0.29	0.04	5806.91	22.83
	Dry	Observe	5.80	1.73	0.23	0.05	134.80	40.00
		Predict	4.44	2.08	0.29	0.04	312.16	22.83
NO02	Wet	Observe	5.14	1.49	0.14	0.03	1910.00	16.60
		Predict	4.37	1.28	0.18	0.04	7198.94	14.02
	Dry	Observe	4.66	1.08	0.22	0.05	393.60	11.63
		Predict	4.37	1.28	0.18	0.04	219.97	14.02
NO03	Wet	Observe	4.94	1.03	0.09	0.04	742.00	17.60
		Predict	5.06	0.90	0.12	0.02	564.65	0.00
	Dry	Observe	5.66	0.77	0.09	0.07	387.29	42.23
		Predict	5.06	0.90	0.12	0.01	564.65	0.00
NO04	Wet	Observe	6.08	0.91	0.25	0.06	1572.00	17.60
		Predict	6.63	0.11	0.21	0.08	1263.42	9.63
	Dry	Observe	7.45	0.77	0.08	0.05	611.33	42.23
		Predict	6.62	0.03	0.21	0.08	1263.42	33.05

*The six water quality parameters are dissolved oxygen (DO, mg/l), biochemical oxygen demand (BOD, mg/l), nitrate-nitrogen (NO_3–N, mg/l), total phosphorus (mg/l), fecal coliform bacteria (FCB, MPN/100 ml), and suspended solids (SS, mg/l).

3.2 Discussion

The evaluation of overall water quality is not an easy task [18], especially when it i Nuanchans applied to a water source with complex physicochemical processes and the influence of human activities. This study showed that the water quality in the five tributary rivers decreased downstream before emptying into the main associated rivers. Although temporal changes in amounts of the pollution indicators (e.g., DO, BOD, nutrients, and fecal coliform bacteria), which are the results of changes in human activities over time, were not directly estimated for each river, their trends in the near future were predicted using time series forecasting models. Since time series data can vary in nature over space and time (e.g., with or without trend, with or without seasonal effect), water quality modelers or water resources managers should be aware of different forecasting techniques and the types of problems they need to investigate [14]. Furthermore, in modeling time series data, it is often useful to try several types of time series models and compare their accuracy of prediction using statistical methods and a graphical inspection of how well the model fits the historical data [14]. To cope with the complexity for developing and simulating several types of times series models, the CB predictor was found to be a very user-friendly tool for fast simulating a number of time series models at the same time with good results reported and statistics summarized in a spreadsheet.

Using the unweighted WQI to evaluate comprehensive water quality in each river was helpful for alleviating ambiguous interpretation of the results when changes in the values of several water quality parameters were considered. PCD, which has used the unweighted WQI [13] since 1995, reported that the results obtained from the index provided a better understanding of the water conditions in a river than the results obtained from a comparison between the observed values and those stated in Thailand's surface water quality standard [15]. However, the major drawback of the unweighted WQI is the eclipsing effect that may occur when at least one sub-index parameter exhibits poor environmental quality [17]. For instance, the extremely increasing trend of FCB at station LO2 of the Loei River in the next five years was eclipsed by the good or fair sub-index scores of the remaining five parameters at the associated station.

It is still a question of which kind of WQI is the most reliable. Practically, a WQI should be developed using certain techniques that are appropriate for explaining the characteristics of water quality parameters in an area of interest. In general, water quality parameters considered in developing a WQI are of local importance [19]. In this study, each of the selected six water quality parameters was assumed to have equal importance in each river where no extremely poor water quality was observed. Consequently, the unweighted WQI seemed to be appropriate for estimating the overall water quality in the associated river. Nevertheless, different weights can be assigned to the water quality parameters in the WQI model as appropriate for evaluating the water quality in an area with extreme changes in the patterns of one or all of the considered water quality parameters. As a result, the application of a WQI may be limited to the aquatic ecoregion/ watershed for which it has been developed. In other words, a WQI should not be used unrestrictedly without consideration of its characteristics and limitations [20]. Meanwhile, for better evaluating water quality influenced by human activities, rating curves for converting the values of biotic parameters and the effects of changes in land use along the riversides into sub-index scores should be conducted for including in the WQI model estimation.

Although the overall water quality at many stations in Lam Chi was in good condition (Class II), the high amounts of TP (>1.7 mg/l) and FCB (>1,000 MPN/100 ml) from both observation and prediction, respectively in the dry season (Table 3) appeared to be the major cause of water quality deterioration at the river mouth (station LC01) over time. The amount of FCB in the surface water in Class II must not be more than 1,000 MPN/100 ml, according to Notification No. 8 [15]. The presence of FCB indicates that the water may have been contaminated with human or animal fecal material. If the counts of FCB are high at a site, it is very likely that pathogenic organisms are also present, and this site would not be recommended for swimming and other contact recreation [7].

The untreated wastewater from communities in Thatoom sub-district, Surin province directly drained into the river mouth of Lam Chi [21], which is connected with the Mun River. Consequently, the high amount of FCB at station LC01 in Lam Chi might be a result of elephant manure that has washed out into this station, which is located at Ban Ta Klang, a village in Surin province's Krapo sub-district, where many elephants are nurtured for preservation and as a tourist attraction. In Nam Oon, the overall water quality was in Class II; however, high observed and predicted amounts of FCB were at stations NO01 and NO02 in the wet seasons (Table 7). These might be the results of a high wash of wastewater from households and agricultural activities into the downstream portion of Nam Oon.

Whereas the maximum concentration of TP for classifying surface water classes is not currently specified in Thailand, a high amount of TP may lead to algae blooms, which are harmful to most aquatic organisms and may cause a decrease in DO concentration in the water [7]. The high concentration of TP found in the water could be attributed to agricultural production and surface runoff and erosion from agricultural farms near the forests [22]. The high TP concentrations upstream of Lam Chi (stations LC04 and LC05) were likely from wastewater discharged from nearby communities and agricultural areas [21]. Unlike TP, both observed and predicted mean concentrations of NO_3–N in each of the five rivers during the study periods were lower (<1.0 mg/l) than the maximum values specified for surface water Classes I (natural), II–IV (≤5 mg/l) and V (>5.0 mg/l) as indicated in Notification No. 8: Surface water quality standard [15].

In Lam Pao, the overall water quality from stations LP01 to LP04 was in Class II in both seasons although untreated wastewater from the communities directly drained into the river portion at Kalasin's Muang and Kamalasai municipalities before emptying into the Chi River [21]. Located right below the Lam Pao Dam with good water circulation and far from heavy human activities, the water quality at station LP05 was in very good condition (Class I) over the two study periods (Fig. 3B). In Lam Seaw, the overall water quality at many stations in this tributary to the Mun River was in Class II in both seasons (Fig. 3C). Similar to station LP05 in Lam Chi, the overall water quality at station LS05, which is located below Nong Boh reservoir, was in Class I in both seasons over the two study periods (Fig. 3C). At station LS05, water was well circulated with high DO concentration and low amounts of the remaining pollution indicators (i.e., BOD, NO_3–N, TP, FCB, and SS). Municipality

Running through the municipality of Loei province, the overall quality of water at many stations in the Loei River was in Class III (Fig. 3D). Untreated wastewater was discharged from communities in Loei's Muang and Wang Sapoong districts into the Loei River at station L02 and stations L04–L05, respectively [21]. As a result, the water quality at station L02 in the dry season might decrease to Class IV in the next five years unless proper management is undertaken to reduce the concentration of FCB that tends to dramatically increase in the dry season over time. Additionally, the predicted concentration of DO below 4 mg/l in the near future and high concentration of SS at station L04 in the dry season will apparently be the major causes of water quality deterioration at this station over time.

The decrease in DO concentration in a stream in the dry season is possibly a result of the high consumption of DO by microorganisms to mineralize dissolved organic matter released from urban and agricultural runoff [22]. The optimum concentration of DO in water for ensuring healthy aquatic life is 4.0–6.0 mg/l [15]. According to Notification No. 8 [15], the DO concentration in surface water in Classes II, III, and IV must not be less than 6, 4, and 2 mg/l, respectively. The DO in the surface water in Class I is assumed to be at a natural level as observed in surface water of very good condition, whereas its concentration for surface water Class V is less than 2.0 mg/l. Although the concentration of SS in water is not currently specified for determining surface water classes in Thailand, the rating curve of SS determined by Thai water quality experts indicated that high concentrations of SS would contribute to a lower WQI score (Fig. 2).

BOD has been used to determine the strength of oxygen required to stabilize domestic and industrial wastes [23]. In this study, based on the observed mean concentrations of BOD alone, the current water quality classes at many stations in the five rivers varied between Classes II (BOD ≤1.5 mg/l) and III (BOD ≤2.0 mg/l). However, the predicted mean concentrations of BOD at some stations in Lam Chi, Lam Pao, and Lam Seaw showed that the water quality at the associated river portions would shift from Class III to Class IV (BOD ≤4.0 mg/l) or Class V (BOD >4.0 mg/l) in the near future unless a proper management plan is undertaken to reduce the drainage of BOD loads into these rivers.

4. Conclusions

In this study, the time series models with the best predictions among stations were often not the same types. The model type that showed the best fit (within the 5% and 95% confidence interval with the least RMSE) to the current observed values of each water quality parameter at each station was selected for predicting the values of that water quality parameter in the associated station by season over the next 5-year period (2008–2010). Due to the model's simplicity, other factors that may influence water quality (e.g., changes in land use and population growth) are not explicitly accounted by a time series model. Instead, their effects were assumed to indirectly reflect the integrated changes in the six water quality parameters in each river. The major drawback of the unweighted WQI is the eclipsing effect that may occur when at least one sub-index parameter exhibits poor environmental quality. In general, the time series models were helpful for predicting the changing values of certain water quality parameters in a short future without complicated data sets required, whereas the unweighted WQI technique was helpful for alleviating ambiguous interpretation of results when changes in the values of several water quality parameters were considered. Both tools can assist a water resource manager to easier understand the overall situation of water quality in a water source of interest for better management in order to meet the standards for consumption and preservation purposes. In this study, the quality of water in all rivers, except the Loei River, was good. However, the water quality in Lam Chi and the Loei River will tend to decrease in the next 5-year period unless proper management is undertaken to reduce the concentrations of, for instance, TP and FCB in the river.

Acknowledgments

We thank the 9th, 10th, 11th, and 12th Regional Environment Offices in Udonthani, Khonkaen, Nakhonratchasima, and Ubonratchathani, respectively and the Inland Water Division, Water Quality Management Bureau, PCD, for supporting the observed water quality parameter data of the study rivers during 1994–2007. We thank the Environmental Quality and Laboratory Division, PCD, for analyzing some observed water quality data used in this study. Special thanks are due to Dolina Millar for proofreading and editing this manuscript and the anonymous reviewer for instructive comments and suggestions.

References

[1] Schaffner M, Bader, H-P, Scheidegger R, Modeling the contribution of point sources and non-point sources to Thachin River water pollution, *Sci Total Environ* 407 (2009) 4902–4915.

[2] Kruawal K, Sacher F, Werner A, Mqller J, Knepper TP, Chemical water quality in Thailand and its impacts on the drinking water production in Thailand, *Sci Total Environ* 340 (2005) 57–70.

[3] Dudgeon D, Endangered ecosystems: a review of the conservation status of tropical Asian rivers, *Hydrobiologia* 248 (1992) 167–191.

[4] Thanapakpawin P, Richey J, Thomas D, Rodda S, Campbell B, Logsdon M, Effects of landuse change on the hydrologic regime of the Mae Chaem river basin, NW Thailand, *J Hydrol* 334 (2006) 215–230.

[5] Horton R, An index number system for rating water quality, *J Water Pollut Con F* 37 (1965) 300–305.

[6] Brown RM, McClelland NI, Deininger RA, Tozer RG, A water quality index-Do we dare?, *Water Sewage Works* 117 (1970) 339–343.

[7] Said A, Stevens DK, Sehlke G, Environmental assessment: An innovative index for evaluating water quality in streams, *Environ Manage* 34 (2004) 406–414.

[8] Abrahão R, Carvalho M, WR da Silva Júnior, Machado TT V, Gadelha CL M, Hernandez MI M, Use of index analysis to evaluate the water quality of a stream receiving industrial effluents, *Water SA* 33 (2007) 459–465.

[9] Cude C, Oregon Water Quality Index: A tool for evaluating water quality management effectiveness, *J Am Water Res Assoc* 37 (2001) 125–137.

[10] Boyacioglu H, Development of a water quality index based on a European classification scheme, *Water SA* 33 (2007) 101–106.

[11] Sargaonkar AP, Gupta A, Devotta S, Dynamic weighting system for water quality index, *Water Sci Technol* 58.6 (2008) 1261–1271.

[12] Landwehr JM, *Water Quality Indices Construction and Analysis, Ph.D. Thesis* (1974), University of Michigan, Ann Arbor, Michigan, USA.

[13] Water Quality Management Bureau, Pollution Control Department, *General water quality index* (2004) Bangkok, Thailand, Available online http://iwis.pcd.go.th/IWIS/wqionline/wqi_online.php, Accessed: October 22, 2009.

[14] Ragsdale CT, *Spreadsheet modelling and decision analysis, 3rd edition, South-Western* (2001), College Publishing, New York.

[15] National Environment Board, *Notification No. 8: Surface water quality standard, the 1992 Thailand Enhancement and Conservation of National Environmental Quality Act*, Royal Thai government gazette, February 24, 1994.

[16] American Public Health Association, American Water Works Association, and Water Environment Federation, *Standard methods for the examination of water & wastewater, 21st edition* (2005), Port City Press, Maryland, USA.

[17] Prakirake C, Chaiprasert P, Tripetchkul S, Development of specific water quality index for water supply in Thailand, *Songklanakarin J Sci Technol* 31 (2009) 91–104.

[18] Bordalo AA, Nilsumranchit W, Chalermwat K, Water quality and uses of the Bangpakong River (Eastern Thailand), *Water Res* 35 (2001) 3635-3642.

[19] Sargaonkar AP, Gupta A, Devotta S, Dynamic weighting system for water quality index, *Water Sci Technol* 58 (2008) 1261–1271.

[20] Debels P, Figueroa R, Urrutia R, Barra R, Niell X, Evaluation of water quality in the Chillán River (Central Chile) using physicochemical parameters and a modified water quality index., *Environ Monit Assess* 110 (2005) 301–322.

[21] Water Quality Management Bureau, Pollution Control Department, *Operation plan and water quality management for the water basins in the Northeast, Report No. 3/14* (1997), Ministry of Science, Technology, and Environment, Bangkok.

[22] Tsegaye T, Sheppard D, Islam KR, Johnson A, Tadesse W, Atalay A, Marzen L, Development of chemical index as a measure of in-stream water quality in response to land-use and land cover changes, *Water, Air, Soil Pollut* 174 (2006) 161–179.

[23] Avvannavar SM, Shrihari S, Evaluation of water quality index for drinking purposes for river Netravathi, Mangalore, South India, *Environ Monit Assess* 143 (2008) 279–290.