Evaluation of Spatial Variation in Water Quality of the Lower Lam Takhong River, Thailand

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Abstract—Multivariate statistical techniques such as factor analysis (FA), discriminant analysis (DA) to evaluate water quality in lower Lam Takhong. Totally 7 parameters of water quality were monitored during 2 years at 14 stations along the river. The result from water quality parameters showed that the river could be separated into two sections according to surface water quality standards in Thailand. For the upstream section, FA resulted in three components explaining 67.0% of total variation, represents pollution for domestic wastewater, nutrient, and industrial pollution, respectively. While FA resulted in three components which explained 81.2% of total variance for downstream section. The components obtained represents source from domestic areas, agricultural runoff and industrial effluents, respectively. DA suggested the influenced parameters including DO, BOD, TP, TKN with 86.9% correct assignment. This study illustrate the benefit of multivariate statistical techniques for analysis and interpretation of water quality data for effective river water quality management.

Keywords—Statistical methods, Surface water quality, Water pollution, Lam Takhong river

I. Introduction

WATER quality become one of the environmental concerns worldwide and is influenced by natural processes such as precipitation inputs, erosion, weathering crustal materials, as well as the anthropogenic influences viz. urban, industrial and agricultural activities, increasing exploitation of water resource [10]. Due to spatial pattern and in water quality monitoring are recognized for representative and reliable evaluation of surface water quality [3]. Establishing and maintaining a program of water quality monitoring is a huge job. The application of multivariate statistical approaches such as factor analysis (FA), and discriminant analysis (DA) helps for interpretation of complex data matrices to better understanding the surface water quality [11]. The multivariate statistical analysis has been applied for water quality. Alkarkhi *et al.* [1] used multivariate statistical techniques such as FA and DA for evaluation of spatial variations and interpretation of water quality data set of Juru and Jejawi rivers, Malasia. Gyawali *et al.* [7] applied multivariate statistical techniques such as CA, DA and FA to evaluate the temporal and spatial of water quality and identify potential pollution source of U-Tapao River Basin, Thailand. Li *et al.* [9] used CA, FA and DA to evaluate the spatial and temporal in Songhua River, China.

In this paper, report of the study of water quality of the lower Lam Takhong river of Thailand and statistical analysis. The analysis is done to identify significant parameters responsible for spatial variations in water quality, to examine the influences of possible source in water quality. Furthermore this study to provide information and scientific understanding to local decision makers for suitable management.

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II. Material and Methods

A. Study area

The LamTakhong river is situated at northeastern of Thailand. The river can be divides into two area by The Lam Takhong dam; the upper and the lower areas. In this study is lower of Lam Takhongriver with the area of 2,210 sq.km. (Fig.1). During course of 120 km., it receives pollution loads from municipal, agricultural and industrial wastewater. The river is influenced by two monsoon; the southwest and northwest monsoon with average annual rainfall approximately 1,129.1 mm. In the river basin consists of agricultural areas, forest area, residential areas, various areas and water areas.

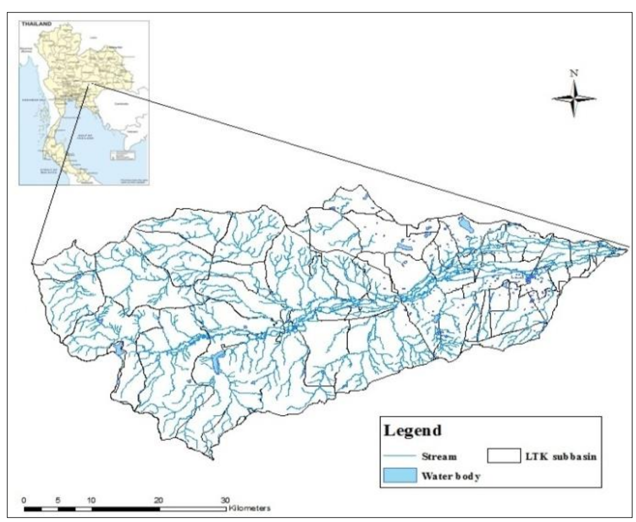

Fig. 1 Map of Lam Takhong river.

B. Analytical Methods

The data of 7 water quality parameters: pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), total phosphorus (TP), total kjeldahl nitrogen (TKN), ammonia nitrogen (NH_3), nitrate nitrogen (NO_3^-). Water quality data were collected from 14 monitoring stations of rivers during 2 years (June 2010-May 2011 and Feb 2013-Feb 2014). Before collecting the water samples, all sample bottle were washed with different types of chemicals and rinsed with distilled water. The water samples were kept in low temperature (stored in ice), until the samples were transferred to laboratory for analysis. Analysis techniques were based on APHA Standard Methods for Examination of Water and Wastewater [2]. The parameters, unit and methods are given in Table I.

TABLE I
PARAMETERS, UNIT AND ANALYTICAL METHODS OF SAMPLES.

Parameters	Unit	Abb.	Analytical methods
pH	-	pH	Multi-parameter analyzer (Cornsort, C532 model)
Dissolved oxygen	$mg.l^{-1}$	DO	Multi probe meter (YSI, Professional Plus model)
Biochemical oxygen demand	$mg.l^{-1}$	BOD	Azide modification method
Total phosphorus	$mg.l^{-1}$	TP	Ascorbic acid method
Total kjeldahl nitrogen	$mg.l^{-1}$	TKN	Kjeldahl method
Ammonia nitrogen	$mg.l^{-1}$	NH_3	Titrimetric method
Nitrate nitrogen	$mg.l^{-1}$	NO_3^-	Brucine method

C. Multivariate statistic techniques

Factor analysis is designed to transform the original variables into new uncorrelated variable called factors, which are linear combinations of the original variables. The FA is a data reduction technique and suggests how many variates are important to explain the observed variance in the data. Principal component analysis (PCA) is used for extraction of different factors. The axis defined PCA is rotated to reduce the contribution of less significant variables [1].

Discriminant analysis is a supervised pattern recognition technique multivariate techniques used for two purposes the first purpose is description of group separation in which linear functions of the several variables (discriminant function) are used to describe or explain the differences between two or more groups and identifying the relative contribution of all variable to separation of the group. Second purpose is prediction or allocation of observation to group in which linear or quadratic functions of the variable (classification function) are used to assign an observation to one of groups [1], [11].

III. RESULTS AND DISCUSSION

Descriptive statistics including maximum, minimum, mean, and standard deviation are summarized in Table II.

TABLE II
DESCRIPTIVE STATISTICS OF SELECTED WATER QUALITY PARAMETERS IN LOWER LAM TAKHONG RIVER.

Parameter	Minimum	Maximum	Mean	Std. Dev.
BOD	0.1	29.4	5.0	4.9
DO	0.0	10.0	4.1	2.2
NH_3	0.0	15.3	1.6	2.6
NO_3^-	0.0	0.3	0.1	0.1
pH	4.8	8.8	7.5	0.5
TKN	0.0	16.7	3.3	3.0
TP	0.0	2.7	0.3	0.5

A. Factor analysis

The river had been classified by authority as critical in terms of water pollution for several years due to heavy utilization and neglect. The results could be separated into two sections according to surface water quality standards in Thailand. The upstream section had DO higher than 4 mg/L while the downstream section had lower than 2 mg/L. Factor analysis was performed on 7 variables to identify the various factors that influence each of stations.

Water quality data from the upstream section were retained for three components with the total variance of 67.0% explained, according to factor analysis as shown in Table III and Table IV. Eigen values greater than 1 were taken as criterion for extraction of the principal components required for explaining the source of variances in the data set. Factor loading is classified as strong, moderate, and weak corresponding to absolute loading values of >0.75, 0.75-0.50 and 0.50-0.30 respectively [7].

The component 1 had accounts for 24.9% of total variance that factor 1 has strong positive loadings correlated with ammonia nitrogen indicating possible source from untreated domestic wastewater. Water quality deteriorated in large municipal such as Sung Noen municipal.

Component 2 explained the 24.1% of total variance with strong absolute loadings with total phosphorus and nitrate nitrogen, the second factor is related to indicating possible nutrient pollution from agricultural non-point source. Fertilizers rich in nitrogen and phosphorus are applied on paddy fields. Nutrients are transported to the river by runoff, and erosion.

Component 3 had a strong positive loadings for pH, which 17.9% of total variance. The source of this pollutions is mainly related to industrial effluents was possible. Navanakhon and Suranaree industrial zones were two industrial zones in the upstream section.

The dataset from downstream section were retained for three components which explained 81.2% of total variance shown as Table V and Table VI.

Component 1, which explained 47.8% of total variance, had strong positive loading on biochemical oxygen demand, total phosphorus, ammonia nitrogen, and total kjeldahl nitrogen that indicate the source from domestic areas. The river downstream received discharge from the fifth largest municipality in Thailand. New residential areas have been developed at the bereavement of removing agricultural areas especially backyard garden in MuengNakhonRachasima municipal.

Component 2, accounted for 18.0% of total variance, had strong positive loading on nitrate nitrogen. it was explains the pollution from concentrated livestock operations, including pig and cattle farms, and received fertilizers from paddy fields.

Component 3, on the other hands explained 15.4% of total variance and was positive loading on pH. This component associated with the possible source from untreated industrial discharge. Pollutants directly in to water affect the pH of water.

Overall, there were two group of pollution in the lower of Lam Takhong: organic pollution and nutrients. Although the source of this pollutions from domestic, agricultural and industrial areas.

TABLE III
EXTRACTED VALUES OF VARIOUS FACTOR ANALYSIS FOR WATER QUALITY PARAMETERS (UPSTREAM).

Component	Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	1.8	25.7	25.7	1.7	24.9	24.9
2	1.6	23.5	49.3	1.7	24.1	49.0
3	1.2	17.7	67.0	1.3	17.9	67.0

Extraction Method: Principal Component Analysis

TABLE IV
ROTATED COMPONENT MATRIX (UPSTREAM).

Parameter	Component		
	1	2	3
NH_3	0.8	0.2	0.1
TP	0.2	0.9	-0.1
BOD	0.4	-0.2	0.4
DO	-0.6	0.0	0.6
TKN	0.7	0.0	0.1
pH	0.2	0.1	0.8
NO_3^-	-0.1	0.9	0.1

Rotation Method: Varimax with Kaiser normalization

TABLE V
EXTRACTED VALUES OF VARIOUS FACTOR ANALYSIS FOR WATER QUALITY PARAMETERS (DOWNSTREAM).

Component	Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.5	50.5	50.5	3.3	47.8	47.8
2	1.1	16.0	66.5	1.3	18.0	65.8
3	1.0	14.7	81.2	1.1	15.4	81.2

Extraction Method: Principal Component Analysis

TABLE VI
ROTATED COMPONENT MATRIX (DOWNSTREAM).

Parameter	Component		
	1	2	3
NH_3	1.0	-0.1	-0.1
TP	0.9	0.0	0.0
BOD	0.8	-0.2	0.0
DO	-0.2	0.7	0.4
TKN	0.9	-0.2	-0.1
pH	0.0	0.0	0.9
NO_3^-	-0.1	0.8	-0.2

Extraction Method: Principal Component Analysis.

B. Discriminant Analysis

Spatial variations in river quality evaluated through discriminant analysis (DA). DA was applied on raw data after dividing the whole datasets into three spatial groups (Less, Moderate, and High regions) obtained through cluster analysis (CA), CA with Ward method, used Euclidean distance. The result of DA explained 100% of the total variance, had two discriminant functions (DFs) were found. The first function explained 90.5% of total variance between sites while the second function explained only 9.5% of total variance between sites as shown in Table VII. Wilks' Lamda test the statistically significance were 0.2 and 0.7 for discriminant function 1 and 2 respectively. The DA gave the classification matrix with 86.9% of original grouped cases correctly classified (Table VIII). Thus, the result showed dissolved oxygen, total kjeldahl nitrogen, ammonia nitrogen, and nitrate nitrogen were discriminant parameters (Table VIII). The trends of four variations suggested a large load of dissolved organic matter at Less sites (Table IX).

TABLE VII
EIGEN VALUES FOR THE DISCRIMINANT FUNCTIONS OF SPATIAL VARIATION.

Function	Eigen value	% of Variance	Cumulative %	Canonical Correlation
1	3.7	90.5	90.5	0.9
2	0.4	9.5	100.0	0.5

TABLE VIII
CLASSIFICATION FUNCTION COEFFICIENTS FOR DISCRIMINANT ANALYSIS OF SPATIAL VARIATION.

Parameter	Site		
	Less	Moderate	High
DO	2.4	1.3	1.1
BOD	0.3	0.5	1.1
TP	-1.6	-1.8	1.2
TKN	0.8	1.1	2.7
(Constant)	-8.7	-5.3	-21.1

Fisher's linear discriminant functions

TABLE IX
CLASSIFICATION MATRIX OF SPATIAL VARIATION.

Site			Predicted Group Membership			Total
			Less	Moderate	High	
Original	Count	LP	146	22	0	168
		MP	14	93	0	107
		HP	0	8	53	61
	%	LP	86.9	13.1	0	100
		MP	13.1	86.9	0	100
		HP	0	13.1	86.9	100

86.9% of original grouped cases correctly classified.

V. CONCLUSION

In this study, difference of multivariate statistical techniques were used to examine variations in surface water quality of the lower Lam Takhong River. Discriminant analysis gave the useful results for spatially, the DA used four parameters (dissolved oxygen, total kjeldahl nitrogen, ammonia nitrogen, and nitrate nitrogen) with close to 86.9% of correct classification. In addition FA did not significant data reduction for variation in river quality. It helps indicated that parameter responsible for water quality variations are mainly related to three possible sources from domestic waste, agriculture runoff, and industrial pollution both the upstream and downstream of the river.Thus, this study illustrate the usefulness of the techniques of multivariate statistical techniques for analysis and interpretation of water quality. It could also helps the local decision-maker on suitable management, might reduce the monitoring stations for cost benefit purpose.

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