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Effect of land use on water quality: A case study in Trang Watershed

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ABSTRACT

The existing condition and factors affecting the DO and BOD level in the Trang watershed were studied. The results indicated that the most dominant land use type was agriculture (73%). From 2003 to 2010, the area classified as urban, industry, water body and other increased, indicating urban expansion, while agricultural land decreased and was possibly converted to urban or other land. Surprisingly, the area of forest land increased (1.66%) in a significant manner indicating good reforestation activities in the watershed. The water quality of the Trang watershed in 2011 was within water quality standard class 3. Analysis showed that the correlation between DO and BOD with changing in land use types could be evaluated using simple linear regression analysis and the Pearson correlation coefficient (r_{xy}). Factors affecting DO in the Trang watershed are percentage of forest, agriculture, urban, industry, others land use, percentage development land use (PDLU), population density, temperature and electric conductivity, respectively. The BOD is affected by the percentage of urban, industry and EC, respectively. The predicted model of DO and BOD was acceptable and indicated that in the Trang watershed, DO and BOD can be estimated using multiple linear regression analysis. Therefore, higher percentages of developed land-including industrial, urban and agricultural-caused water quality degradation. On the other hand, the expansion of forest areas led to improved water quality.

Keywords: DO and BOD, Land use, percentage of developed land use (PDLU)

INTRODUCTION

Water quality can deteriorate as a result of human activity. The high demand for water for domestic use, agriculture, industry, power generation, and forestry practices leads to a deterioration in water quality (Carr and Neary, 2008). Many studies have confirmed that land use activities are one of the major causes of deterioration of water quality in rivers (Ren *et al*., 2003; Kannel *et al*., 2007; Tu, 2008; Liu and

Li, 2009) and in particular, the intensive and improper development of land for urbanization, industrialization, and agricultural activities (Lee *et al*., 2009; Rothenberger *et al*., 2009). Thus, pollution protection requires a better understanding of water quality and the impact of land use in the watershed.

One of the most well known issues associated with water quality is the reduction of dissolved oxygen (DO). The most important factor is the discharge of organic waste into the watershed from various land use types (Tu, 2008). The major sources of organic waste are from land use activities such as urbanization, industrialization, and agricultural activities. Therefore, DO relate to organic waste. Too much organic waste can boost bacterial growth for which oxygen is required to decompose a certain amount of organic waste. This phenomenon can be described as the biochemical oxygen demand (BOD). Subsequently, more bacteria use up oxygen in the water, thus leaving the water "oxygen depleted" so that the water may not be able to support aquatic life (Cox, 2003; Chang, 2005; Garg, 2006). Low levels of DO in water cause stress to aquatic life (Boyd, 1982) and DO concentrations less than 5 mg/l can create significant problems in the growth or even survival of fish, and 2 mg/l is the threshold concentration below which aquatic organisms can no longer survive. Thus, DO is a useful parameter to describe water quality, and BOD is a valuable parameter to describe/indicate the amount of organic waste in the water. Hence, DO and BOD are considered as the most important water quality parameters in aquatic life. In order to study water quality and how it is impacted by land use in the watershed, it is necessary first to consider DO and BOD levels in the water. Therefore, the objective of this study was to study the existing conditions of water quality and land use and to investigate its relationship with DO and BOD for better understanding of the links between land use and levels of DO and BOD in the watershed.

MATERIALS AND METHODS

Study area

The study was conducted in the Trang watershed located in southern Thailand (Figure 1). The watershed is about 130 km long from north to south and the total area is 3,435.57 square kilometers. The Trang watershed contains one of the most important rivers in Trang province which originates from the Khao Luang Range in Nakhon Si Thammarat province and flows through Thung Song municipality before passing through Kantang district, Trang province. It receives pollution loads from both point and nonpoint sources. The climate of the basin is influenced by two seasonal monsoons as well as tropical depressions and the temperature varies between 27.15 ºC and 28.68 ºC throughout the year. More than 73% of the watershed area is covered by agricultural land use, whereas only 18% is forest land, located mostly in mountainous areas and around the watershed boundary.

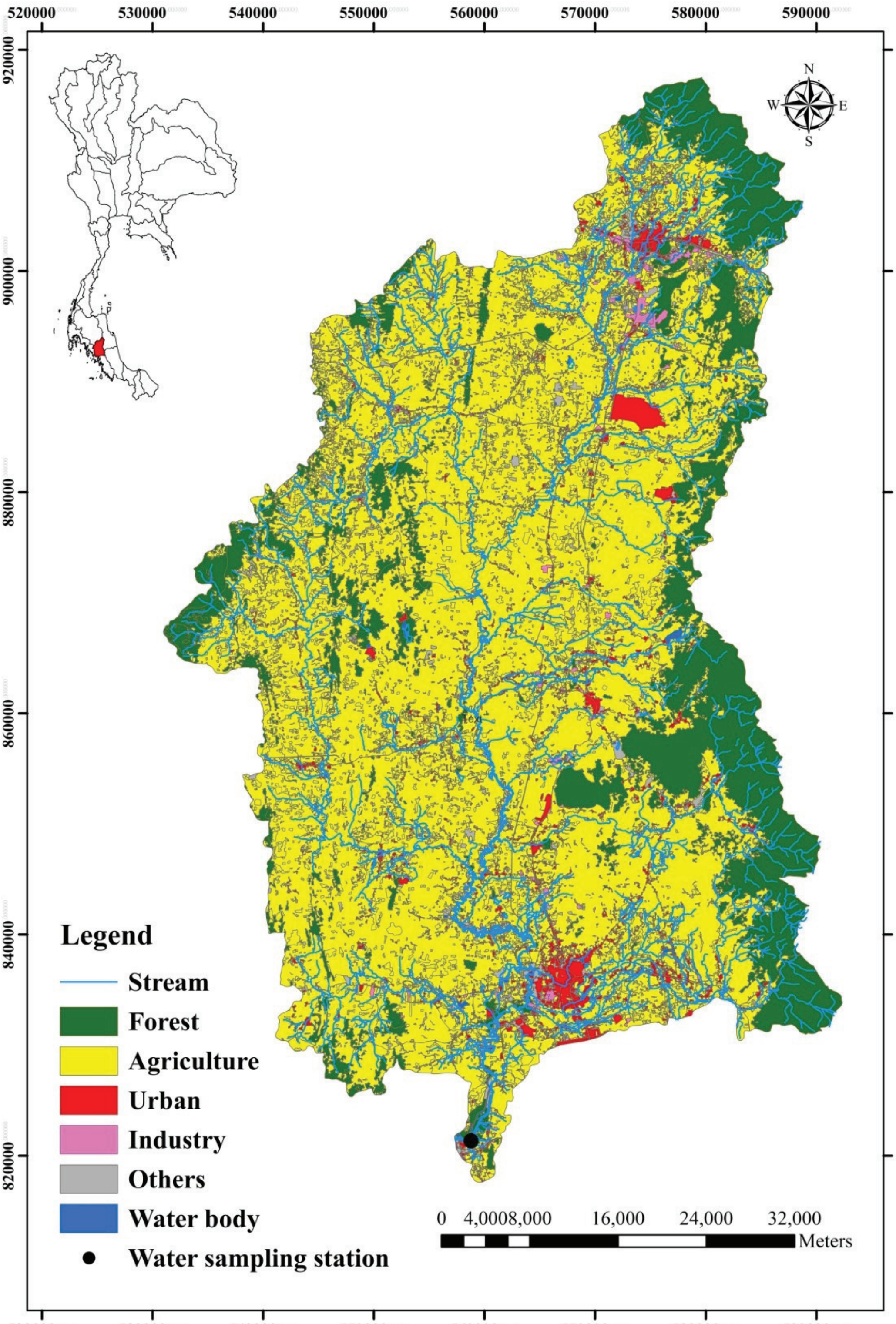

Figure 1 Land use in Trang watershed.

Water quality and land use data

To study the overview of the existing conditions in the Trang watershed, secondary water quality data for 2011 were collected from 12 sub-watershed stations (forest sub-watershed =F1,F2,F3, agriculture sub-watershed = Y1,Y2,Y3 and mainstream sub-watershed = S1 to S6) (Figure 2). The water quality parameters analyzed for this study were dissolved oxygen (DO), biochemical oxygen demanded (BOD), temperature, pH, electrical conductivity (EC) and turbidity. The categories of land use in 2010 provided by Land Development Department (2010) were interpreted using GIS techniques to determine the percentage of land use types (%) for Forest (Fo), Agriculture (Ag), Urban (Ur), Industry (In), Others (Ou) and Water body (Wa). The percentages of these land use types were used to find the relationships among land uses and water quality parameters in each sub-watershed. Moreover, population density (PD) was considered in every sub-watershed of the Trang watershed. Finally, land use was analyzed to provide the status of spatial and temporal variations in each sub-watershed.

Analysis of correlation

Three correlation methods were used to investigate the factors affecting the DO and BOD levels. First, simple linear regression was used to identify correlations between the %land use, water quality and population density in terms of the impact on the DO and BOD levels in the 12 watersheds (forest sub-watershed =3, agriculture sub-watershed = 3 and mainstream sub-watershed = 6). Second, the Pearson correlation coefficient (r_{xy}) was used to confirm the factors that affected the DO and BOD levels. Third, multiple linear regression was used to link the %land use, some water quality parameters and the population density with the DO and BOD levels. To identify the best predictive model for DO and BOD, regression equations were compared using R^2 values, which showed the amount of DO and BOD change explained by the %land use and other parameters. All the statistical analyses were performed using Excel for Windows.

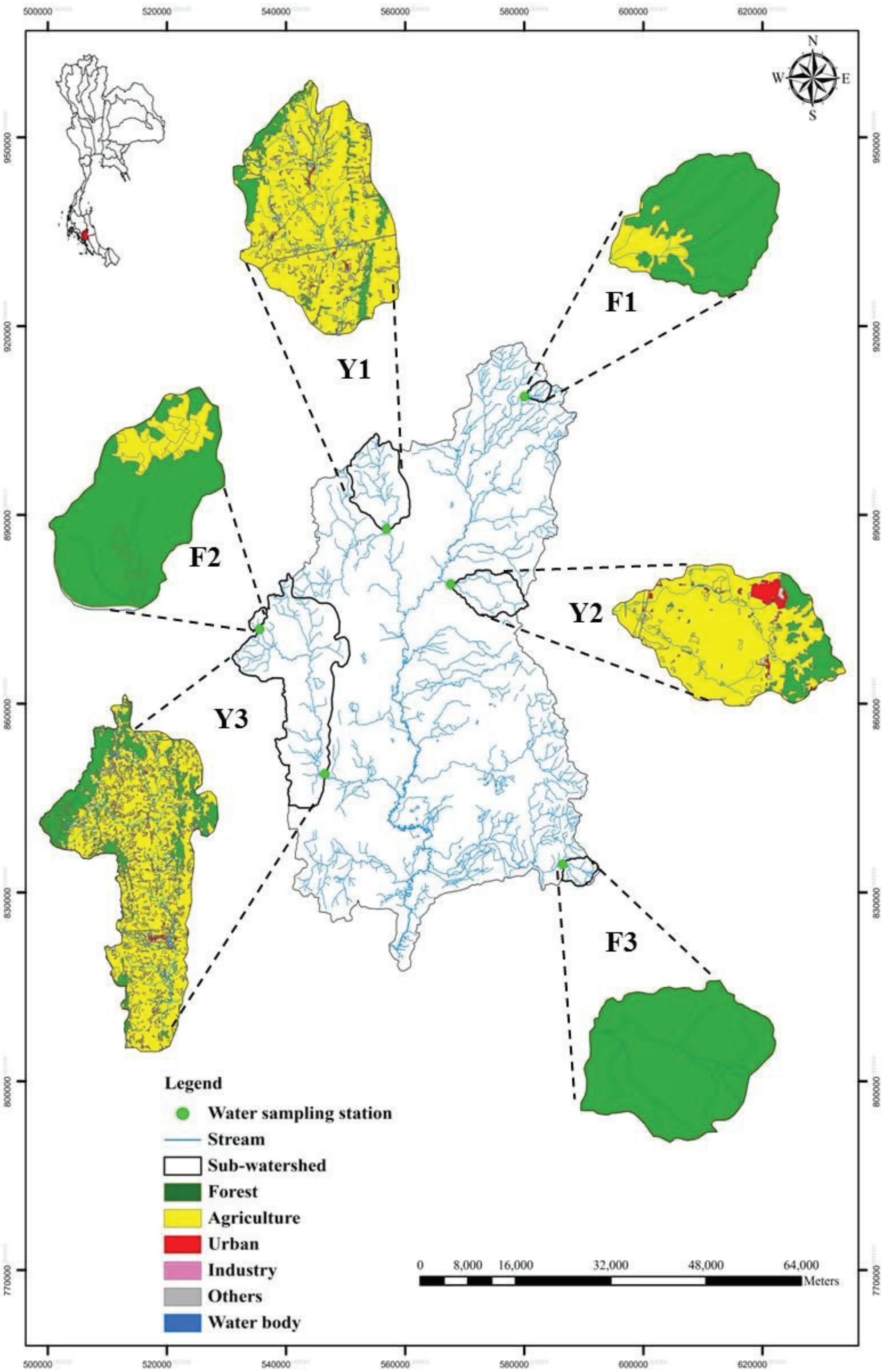

Figure 2a Forest and agriculture sub-watersheds.

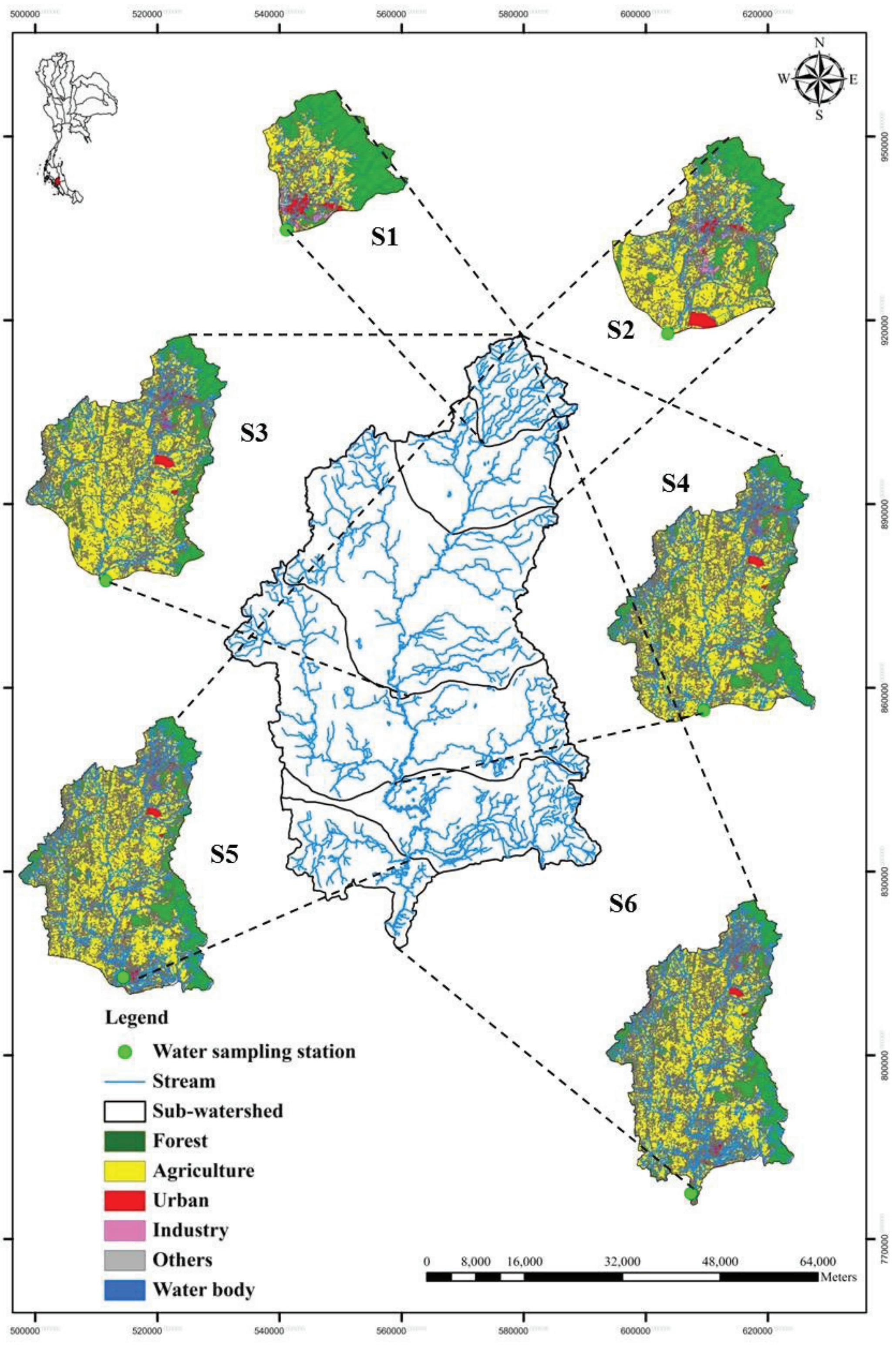

Figure 2b Mainstream sub-watersheds.

RESULTS AND DISCUSSION

Existing condition in Trang watershed

1) Land use

Different land uses were distributed over the 12 sub-watersheds of the Trang watershed (Figure 3). In 2010, the most dominant land use type was agriculture, ranging from 45.91 to 74.62% followed by forest land (16.64 to 43.08%) in the sub-watersheds. In most sub-watersheds, the percentages of the other land use types, such as urban, industry, other land and water body were generally less than 10%.

Temporal variations in land use are very important because these can be driving forces of global environmental changes and are essential in the debate over sustainable development (Lambin *et al*., 2000; Lepers *et al*., 2005). Therefore, land use is intensively used to evaluate the effects of human activities. In the case of the Trang watershed, based on an analysis of the land use types in the watershed from 2003 to 2010 (Table 1), agriculture was the dominating land use overall and covered 2675.56 km^2 (77.77%) in 2003 but had decreased to 2509.68 km^2 (73.05%) in 2010. On agricultural land, Para rubber was the most dominant land use but it also decreased significantly from 2003 to 2010. Surprisingly, other land uses like forest, urban, industry, other and water body increased significantly from 2003 to 2010. Therefore, this result showed that from the land use management aspect, there was no deforestation problem in the Trang watershed because the forest area was increasing but conversion of agricultural land to urban land was a major issue for sustainable development of the watershed. In conclusion, in the watershed, agriculture, especially rubber plantation, was the main economic activity. However nowadays, a decrease in this pattern might create an obstacle to economic development of the watershed in the future. In addition, the increase in the urban and industrial land in the Trang watershed is significant. Such urban development may affect water quality in the future.

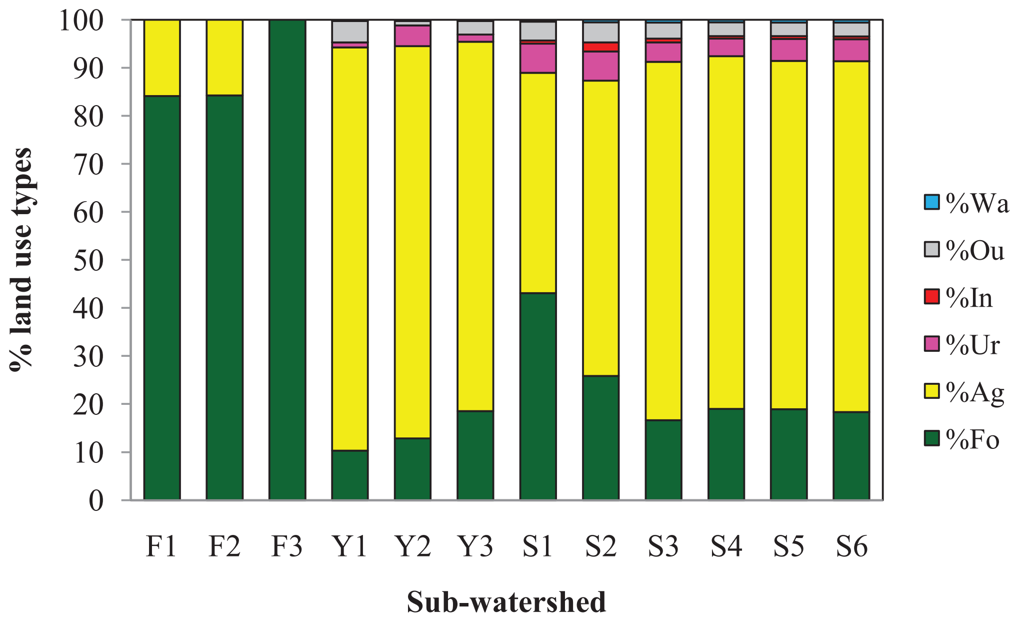

Figure 3 Land use distribution in 12 sub-watersheds of Trang watershed in 2010.

Table 1 Twelve sub-watersheds of Trang watershed and percentage change of land use from 2003 to 2010.

sub-watershed	Change in land use in percentage from 2003 to 2010						Area (km^2)
	%Fo	%Ag	%Ur	%In	%Ou	%Wa	
F1	+3.51	-3.48	0.00	0.00	0.00	0.00	9.66
F2	+6.02	-6.01	0.00	0.00	0.00	0.00	6.67
F3	0	0	0	0	0	0	19.98
Y1	-6.77	+2.89	+0.27	+0.02	+3.37	+0.22	104.44
Y2	+5.01	-7.90	+2.25	-0.02	+0.52	+0.13	63.3
Y3	-4.27	+3.01	+0.97	0.00	+0.07	+0.21	339.95
S1	+4.33	-8.43	-0.49	+0.68	+3.51	+0.40	112.99
S2	+3.42	-7.33	+0.13	+1.82	+1.59	+0.37	568
S3	+1.71	-4.85	+0.75	+0.58	+1.36	+0.44	1653.47
S4	+1.11	-3.85	+1.00	+0.14	+1.19	+0.42	2645.79
S5	+1.54	-4.53	+1.11	+0.18	+1.27	+0.43	3159.65
S6	+1.66	-4.72	+1.18	+0.20	+1.19	+0.49	3435.59

2) Water quality

The existing conditions based on the water temperature, pH, turbidity, EC, DO and BOD in the Trang watershed in dry and wet seasons are presented in Figure 4. The temperature, pH and turbidity were at acceptable water quality standards at the times of sampling. Most values of the EC, DO and BOD in the Trang watershed showed little fluctuation, with the only exception being station S1 where the water quality standard was exceeded as this station was located in Thung Song district and received discharged wastewater from urban areas with no treatment plant. However, the overview of water quality in the Trang watershed in 2011 was within water quality standard class 3 for consumption.

Factors affecting DO and BOD in Trang Watershed

Correlation analysis of land use and water quality

1) Simple linear regression analysis

The results from the simple linear regression analysis indicated that %land-use types were significantly correlated with DO and BOD in the sub-watershed (Figure 5). For example, DO had a significant, negative correlation with agriculture, urban and industry (R^2 = 0.74, 0.74 and 0.80) and DO had significant, positive correlation with forest and other land (R^2 = 0.80 and 0.49) with all these being significant at $P < 0.05$. Other parameters such as the percentage of development land use (%PDLU) and population density (PD) were significantly correlated with DO as well. DO had a significant, negative correlation with a %PDLU and PD (R^2 = 0.82 and 0.60). Furthermore, water quality parameters had a relationship with DO. For example, DO had a significant, negative correlation with temperature and EC (R^2 = 0.81and 0.95), while BOD had a significant, positive correlation with urban, industry and EC (R^2 = 0.46, 0.53 and 0.69, $P < 0.05$).

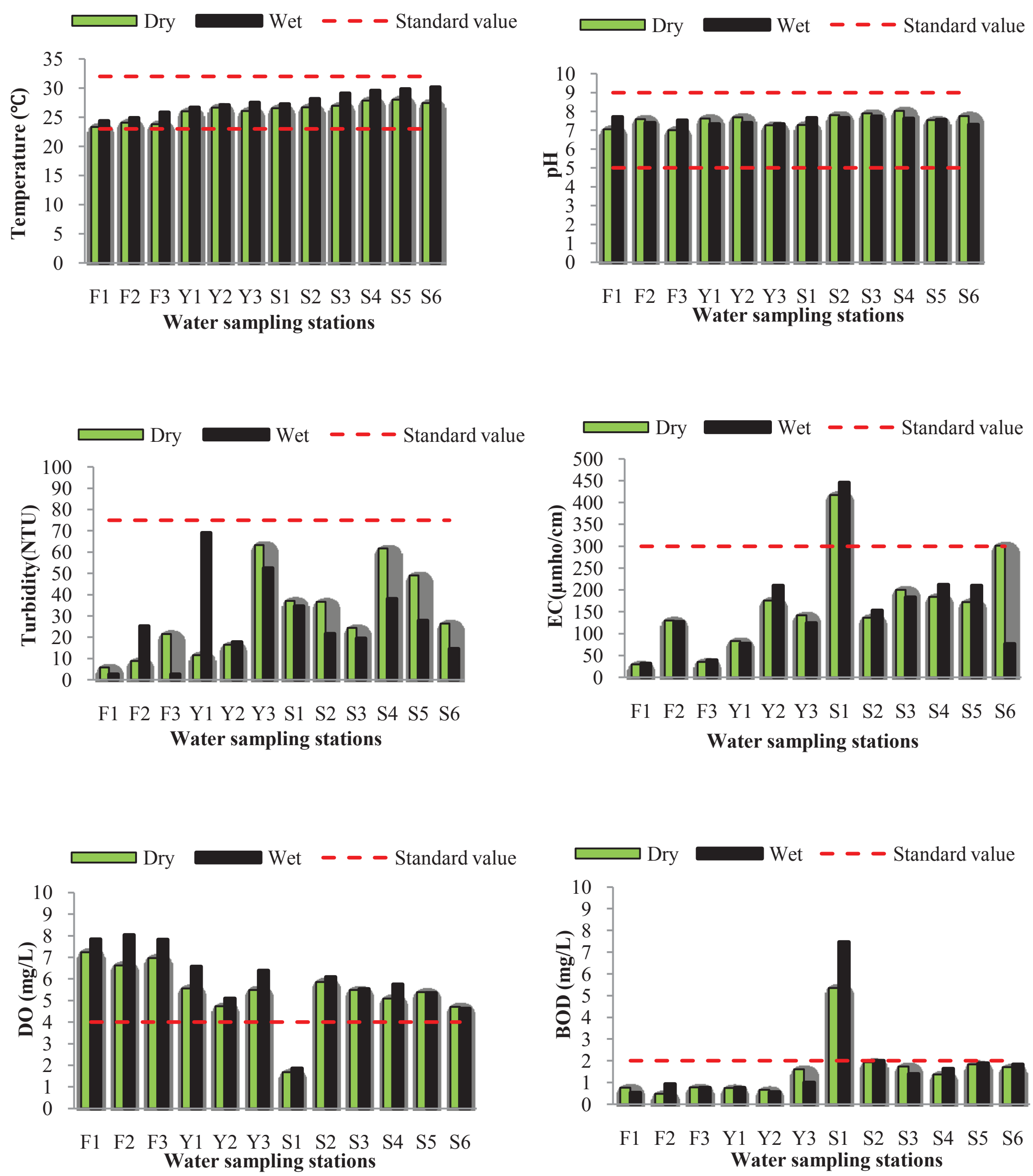

Figure 4 Water quality parameters at 12 water sampling stations in Trang watershed.

Many studies have revealed that surface water quality was degraded in many parts of the world due to poor land use practice and there was a significant relationship between water quality parameters and land use types (Li *et al.,* 2009, Zampella *et al.,* 2007, Tu, 2011). In the Trang watershed, the DO and BOD levels of the river were affected by the %land use type and it was believed that this was the main cause of changes in the DO and BOD levels. For instance, DO had a significant, negative correlation with agriculture, urban and industry. These results suggested that urban and industrial expansion could be the primary driving forces for DO. Therefore, expansion of urban and industrial areas was generally associated with poor DO water quality. According to Tu (2008), urban lands were usually the causes of poor water quality. Similarly, BOD had a significant, positive correlation with urban and industry. This suggests that urbanization was a major factor that had led to the decrease in the water quality of the river. The main source of deteriorating water quality was reported to be the changing pattern of urban land which had the potential to generate large amounts of pollution from waste discharge (Basnyat *et al.,* 1999). In contrast, the agricultural land did not show any positive relationship with increasing BOD (pollutant) and it protected the water quality in the Trang watershed. The dominating land use of the watershed was agricultural based on Para rubber which did not use excess amounts of BOD like traditional agricultural practices, and these lands were not open to surface runoff. This might be the reason that agriculture did not act as a source of pollution in the watershed. In the Trang watershed, agricultural land was decreasing whereas urban land was increasing; therefore, agricultural land was not associated with deteriorating water quality in this watershed. Urban areas were primarily located along the river networks in the Trang watershed, and their impacts on the water quality in watershed were expected. This result also suggests that urban expansion related to increasing residential, commercial, and industrial lands, and population density in suburbs was an important cause of water quality degradation in the study area. It was clear that this relationship may have been highly influenced by the pollution from point sources as well as non-point sources, which were commonly associated with urbanized areas. Another factor that also appeared important in this study was to determine the water quality changes in association with the extent of forest land coverage. In general, forest land had little impact on water quality. In this study, forest land had a positive correlation with DO indicating that if the forest land expanded, then the DO would increase.

2) Pearson correlation coefficient (r_{xy}).

Confirmation of factors affecting DO and BOD used the Pearson correlation coefficient (r_{xy}) with factors of %land use type, among water qualities and PD. The results from the Pearson correlation coefficients (r_{xy}) confirmed that %land-use types were significantly correlated with DO and BOD in the sub-watershed as shown in Table 2. First of all, DO had a significant, negative correlation with agriculture, urban and industry (r_{xy} = 0.86, 0.86 and 0.85) and DO had a significant, positive correlation with forest and other land (r_{xy} =0.90 and 0.71). Other parameters such as the percentage of development land use (%PDLU) and population density (PD) were significantly correlated with DO which had a significant, negative correlation with %PDLU and PD (r_{xy} = 0.81 and 0.78). Furthermore, water qualities had a relationship with DO. For example, DO had a significant, negative correlation with temperature and EC (r_{xy} = 0.90 and 0.98), while, BOD had a significant, positive correlation with urban, industry and EC (r_{xy} = 0.68, 0.73 and 0.69).

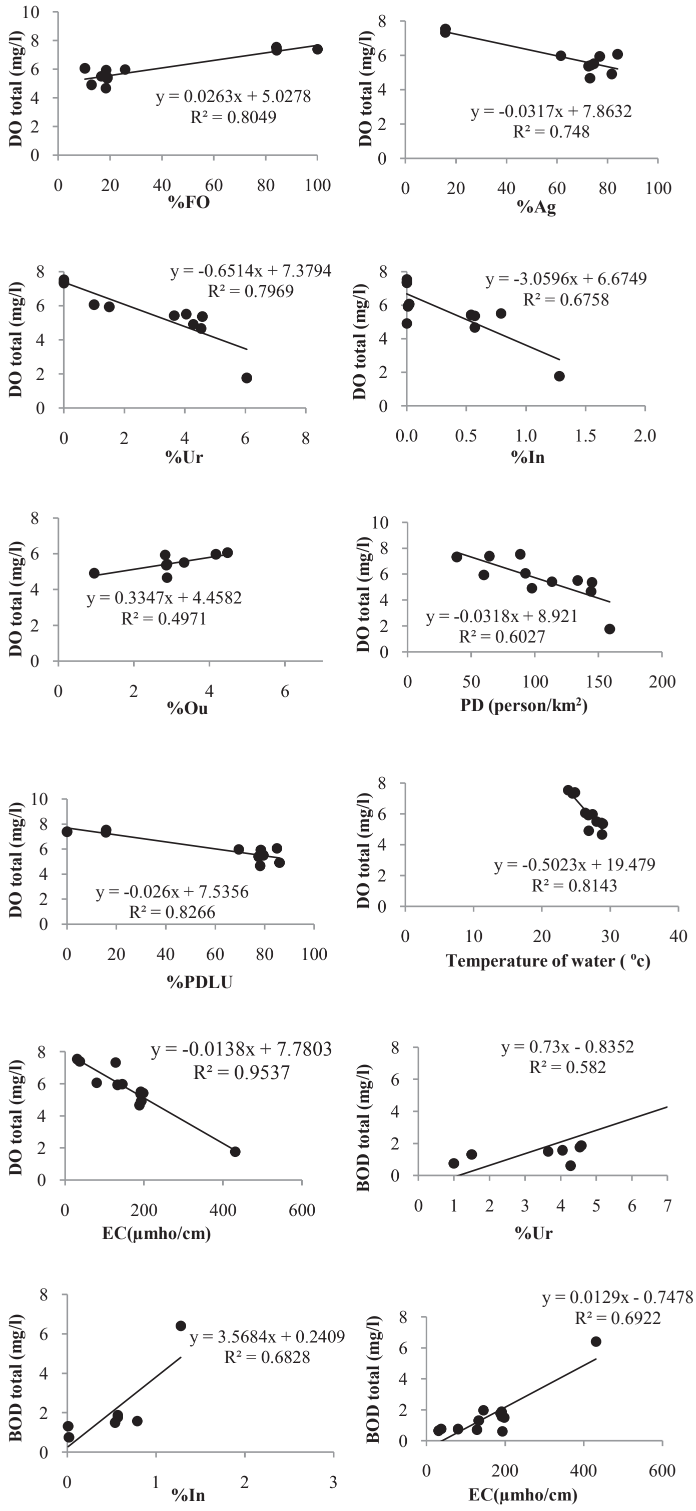

Figure 5 Simple linear regression analysis between %land use type and water quality parameters, and between population density and water DO and BOD parameters.

In summary, these results confirmed that the factors that affected DO in the Trang watershed were %Fo, %Ag, %Ur, %In, %Ou, PDLU, PD, temperature and EC. The BOD was affected by %Ur, %In and EC, respectively. This indicated that the higher percentage of developed land, including industrial, urban and agricultural land, tended to cause water pollution.

Table 2 Pearson correlation coefficients between %land use type, among water quality parameters, and population density with water DO and BOD parameters.

	DO	**%Fo**	**%Ag**	**%Ur**	**%In**	**%Ou**	**%Wa**	**BOD**	**PD**	**%PDLU**	**EC**	**Tur**	**pH**	**T**
DO	1.00													
%Fo	**0.90**	1.00												
%Ag	**-0.86**	-0.99	1.00											
%Ur	**-0.86**	0.75	-0.81	1.00										
%In	**-0.85**	0.62	-0.72	0.87	1.00									
%Ou	**0.71**	0.24	-0.29	-0.04	0.31	1.00								
%Wa	0.16	-0.05	-0.05	0.35	0.35	0.13	1.00							
BOD	**-0.81**	0.05	-0.23	**0.68**	**0.73**	0.16	-0.28	1.00						
PD	**-0.78**	-0.49	0.27	0.87	0.84	0.31	0.61	0.39	1.00					
%PDLU	**-0.81**	-1.00	0.99	-0.74	-0.64	0.96	0.99	-0.31	0.32	1.00				
EC	**-0.98**	0.88	-0.86	0.75	0.44	-0.11	-0.03	**0.69**	0.08	-0.76	1.00			
Tur	-0.09	0.05	0.02	-0.48	-0.51	0.23	-0.31	0.12	-0.65	-0.43	0.42	1.00		
pH	0.20	-0.30	0.20	0.15	0.33	0.04	0.69	-0.31	-0.26	-0.52	0.39	0.35	1.00	
T	**-0.90**	-0.09	0.03	0.26	0.07	-0.15	0.90	0.08	0.69	0.66	0.23	0.19	0.14	1.00

3) Multiple linear regression analysis

In this study, having found the factors affecting DO and BOD, the sub-watershed level was used to link factors (land uses, water quality and population density) with DO and BOD using multiple linear regression analysis. To develop multiple linear regression models, DO and BOD were assigned as dependent variables and land use, water quality and population density were assigned as independent variable. In regression analysis, the selection of the appropriate model is important. Generally, most researchers prefer the coefficient of determination (R^2) criteria for selection of the model, where a higher value of R^2 recommends the selection of that model (Zampella, 2007; Silva and Williams, 2001). In this study, the adjusted R^2 was used to select the appropriate regression model. The dataset for 2011 was used to select the best DO and BOD models as shown in Table 3.

Table 3 Multiple linear regression equations of DO and BOD models.

Equation	**(R^2)**	
DO = 0.041(%Fo)+0.043(%Ag)-0.538(%Ur)+1.169(%In)-0.173(%Ou) +0.003(PD)-0.023(T)+3.588	0.97	(1)
BOD = 0.28 (%Ur)+0.04(%In)+0.012(EC)+1.32	0.70	(2)

Test of regression equations

For the evaluation of multiple linear regression equations, the regression equations of DO and BOD were selected. In this study, to test the model, the dataset for 2014 was used for the evaluation of the multiple linear regression equations. The graphical features of observed and estimated data are presented in Figure 6. The results showed high R^2 values (0.90 and 0.89) for observed and estimated DO and BOD, respectively .Therefore, the predicted models of DO and BOD could be accepted and indicated that DO and BOD can be estimated by multiple regression analysis in the Trang watershed.

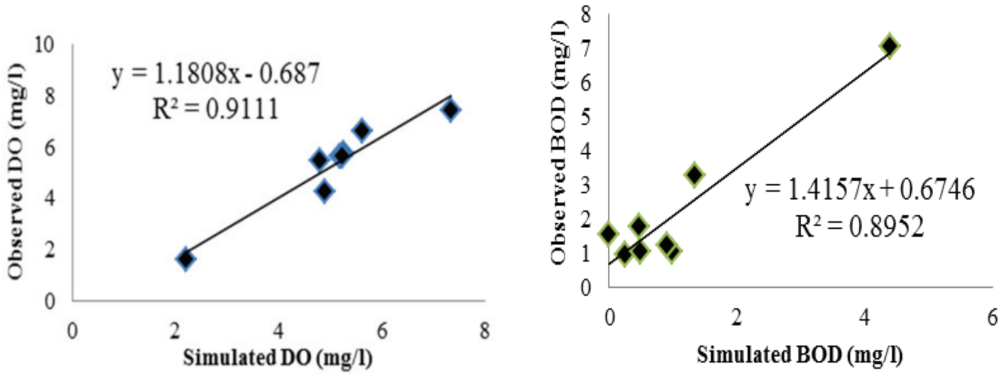

Figure 6 Test equation between observed and estimated values of DO and BOD of sub-watersheds in 2014.

CONCLUSION

This research studied existing conditions and investigated the factors affecting the DO and BOD levels in the Trang watershed through the analysis of the relationships between land use, population density and some water quality parameters. The results revealed that the water quality in the Trang watershed was still at the standard level and that the major land use type is agricultural land. From 2003 to 2010, the forest area had increased (1.66%) indicating good reforestation activities in the watershed. The area of urban, industry, water body and other had increased (1.18%, 0.20%, 0.49% and 1.19%, respectively) indicating urban expansion. Surprisingly, agricultural land had decreased (0.49%) and possibly been converted to urban land or other land. The correlation between DO and BOD with changing land use types could be evaluated using simple linear regression analysis and the Pearson correlation coefficient (r_{xy}). DO had a negative correlation with %Ag, %Ur, %In, %PDLU, PD, temperature and EC. DO had a positive correlation with %Fo and %other land, while BOD was positively related with %Ur, %In and EC. Therefore, the higher percentage of developed land, including industrial, urban, agricultural lands, tended to have caused water quality degradation. On the other hand, more forest areas with a lower percentage of developed land tended to be associated with good water quality. The prediction model of DO and BOD was acceptable and indicated that in the Trang watershed, DO and BOD could be estimated using multiple linear regression analysis.

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