Available online at http://www.ssstj.sci.ssru.ac.th

**Suan Sunandha Science and Technology Journal**


# Applying STELLA model to optimize land allocation in watershed based on DO and BOD dynamics

**Treeranut Srisunont[1*], Sittichai Tantanasarit[2], Chayarat Srisunont[3]**

[1]Faculty of Science and Technology, Valaya Alongkorn Rajabhat University under the Royal Patronage, Pathum Thani 13180, Thailand
[2]Faculty of Forestry, Kasetsart university, Bangkok 10900, Thailand
[3]Faculty of Science and Technology, Bansomdejchaopraya Rajabhat University, Bangkok 10600, Thailand
**Corresponding author e-mail: *treeranut@vru.ac.th**
**Received:** *24 April, 2018* / **Revised:** *26 June 2019* /**Accepted:** *3 July, 2019*

**Abstract**: Urban expansion with intensive and improper plan of land use can cause water deterioration along the watershed. This study aimed to find optimization of land allocation for sustainable development without water pollution in the Trang watershed, located in Nakhon Si Thammarat and Trang Province, Thailand by using STELLA software. Dissolve oxygen (DO) and biological oxygen demand (BOD) were used as water quality parameter to indicate water deterioration. Changes of DO and BOD over time in the study area were developed by STELLA. Then, they were simulated from scenario with variation in percentage of land use types: forest (Fo), agriculture (Ag), urban (Ur) and industry (In). Results revealed that the correlation between the simulated and observed values of DO and BOD was in good agreement. The simulation of scenarios showed that when percentage of Ur and In were less than 5 or the percentage of Fo and Ag were larger than 95, water will be very clean (DO > 6 mg/L and BOD < 1.5 mg/L). Higher Ur and In, reduction of DO and increasing of BOD were found in this study. Water would be deteriorated (DO < 2 mg/L and BOD > 4 mg/L) when In and Ur were more than 25%. The model developed by STELLA could be used to describe DO and BOD variation over time and help in finding optimization of land allocation without disturbing the water quality in Trang watershed. Furthermore, the model can be applied in other watersheds for sustainable land development.

**Keywords**: STELLA, land use, optimization, DO, BOD

## 1. Introduction

Water quality can be deteriorated by human activity such as domestic use, agriculture, industry, power generation, and forestry practices (Carr and Neary, 2008; Nas et al., 2008). Land use activities are one of the major causes of deterioration of water especially intensive and improper development: urbanization, industrialization, and agricultural activities (Ren et al., 2003; Kannel et al., 2007; Lee et al., 2007; He et al., 2008; Tu, 2008; Liu and Li, 2009; Rothenberger et al., 2009; Gyawali, 2013). Trang watershed was chosen as representative of watershed with good water quality and low development area (Pollution Control Department, 2011). The watershed is possibly arranged the optimization of land allocation with proper development. Otherwise, water pollution can be occurred. Thus, pollution management requires a better understanding in the impact of land use variation on water quality.

In this study, Dissolve Oxygen (DO) and Biological Oxygen Demand (BOD) were considered as important water parameters that directly affect from land use (Fan and Wang, 2008; Tu, 2008). DO has been used for design and operation of industrial and municipal treatment plants while representing the overall health of an aquatic ecosystem (Zhang, 2012). Large input of organic wastes can boost bacteria growth which oxygen is required to decompose a certain amount of organic waste (Toma, 2012). This phenomenon can be described as BOD. Subsequently, the more bacteria use up oxygen in the water, thus leaving the water "oxygen depleted" that the water may not be able to support aquatic life. 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 (Cox, 2003; Chang, 2005; Garg, 2006). Thus, DO and BOD are valuable parameters describing amount of organic waste in water caused by activities on land.

STELLA or Structural Thinking Experimental Learning Laboratory with Animation is a software package that has been widely used in biological, ecological, and environmental sciences (Hannon

**Suan Sunandha Science and Technology Journal**


and Ruth, 1994; Peterson and Richmond, 1996; Costanza et al., 2002; Aassine and Jai, 2002; Ouyang, 2008). STELLA program can predict the direction of development in watershed while other models cannot predict the direction of development. It only can evaluate distance between point source and point affect. The STELLA program is a user-friendly that allows the user to simulate systems without any advanced programming language just only clarify conceptual model. The user can create an iconographic interface to facilitate the construction of dynamic system models which are diagrams of the interrelationships between the components of a model that describes the problem of interest, and then solves it numerically (Iseesystems, 2014; Ouyang et al., 2010). Due to these advantages, STELLA was used in this research.

Objectives of this study were: (1) to develop a system dynamic model for describing the DO and BOD variation over time in Trang watershed using STELLA program and (2) to find optimization of land allocation for sustainable development without water pollution. Then by the simulated model and its predictions the land development capacity in the watershed which is the optimum ratio of land use types for forest, agriculture, urban and industry that would support a healthy water quality was achieved. Finally, our results suggested that STELLA can be used as practical tool for water quality management in order to achieve sustainable development and protect the environment with visualize of complex dynamic systems.

## 2. Materials and methods

### 2.1 Study area

The study was conducted at Trang watershed which located in southern part of Thailand (Figure 1). The watershed is about 130 km long from north to south and total area is about 3,435.57 km$^2$. Trang watershed is one of the most important rivers of Trang Province which originates from Khao Luang range mountain in the Nakhon Si Thammarat Province and flows through Thung Song municipality before into the outlet part in 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 temperature of the area which varies between 27.15 ºC and 28.68 ºC throughout the year. In the watershed, more than 73% of area is covered by agricultural land use, whereas only 18% forest land is located mostly in mountainous areas and around boundary of watershed.

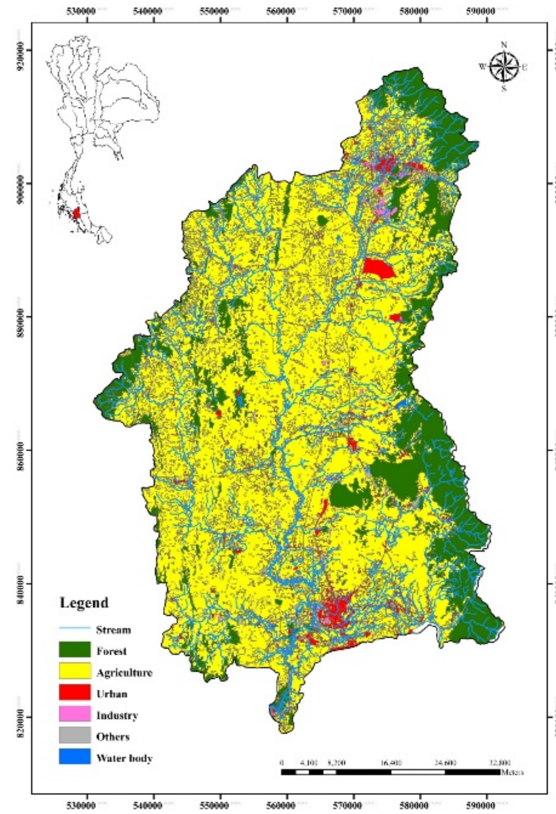



**Figure 1.** Land use in Trang watershed.

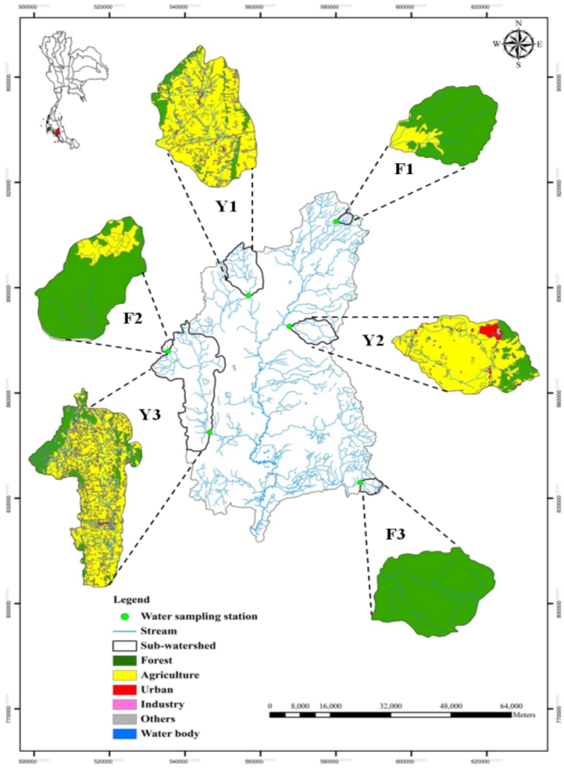
### 2.2 Data collection

The study area was divided into 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 (a) and (b)). Each station, Dissolved Oxygen (DO), Biochemical Oxygen Demanded (BOD), temperature, pH, Electrical Conductivity (EC) and turbidity were collected in year 2011 and were analyzed by descriptive statistics. The categories of land use in year 2010 were interpreted by GIS technique consist of percentages of land use types: Forest (Fo), Agriculture (Ag), Urban (Ur), Industry (In), Others (Ou) and Water body (Wa), provided by Land Development Department, Thailand. Population Density (PD) in each sub-watershed was analyzed from Provincial Administration Department, Thailand. Then, the relationship between percentages of land uses and water quality

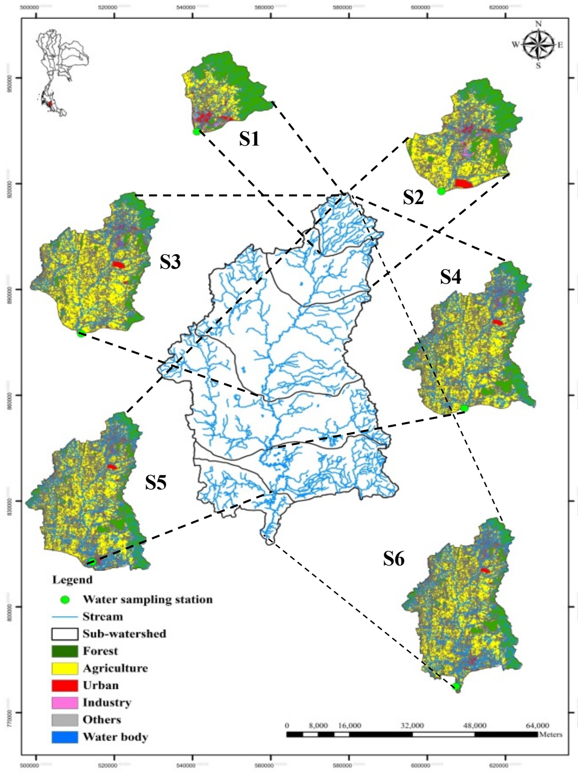


Vol.05, No.2 DOI: 10.14456/ssstj.2019.6

parameters in each sub-watershed were analyzed. Pearson correlation coefficient ($r_{xy}$) was used to evaluate the strength of the relationship. Finally, DO and BOD concentrations were simulated by using multiple regression analysis to input in STELLA as $DO_{reg}$ and $BOD_{in}$, respectively. The regression equations were compared with determination coefficient ($R^2$) values.




(a) forest and agriculture sub-watershed




(b) mainstream sub-watershed

**Figure 2.** 12 Sub-watersheds in Trang Watershed.

## 2.3 Model development by STELLA

### 2.3.1 Model conceptualization

The conceptual model of DO and BOD changes over time consists of reoxygenation and deoxygenation processes (applied from Toma, 2012) as shown Figure 3. Reoxygenation is the exchange of oxygen between atmosphere and water surface, result in oxygen mixed into the water. Reoxygenation rate ($k_2$) was calculated by velocity and depth. In This study, dissolved oxygen regression ($DO_{reg}$) was simulated by multiple regression analysis as described in previous section. Deoxygenation that decreases the dissolved oxygen by bacterial activity referred as BOD in the water. The reduction rate of DO is presented as $k_1$.

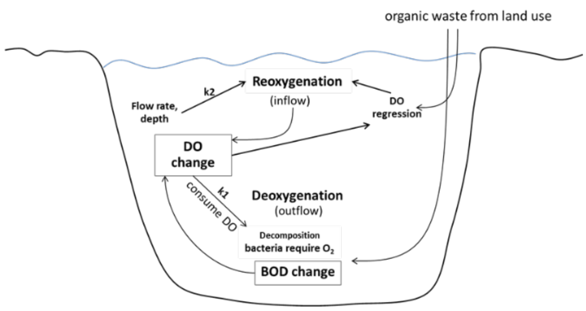



**Figure 3.** The conceptual model of DO and BOD change over time.

### 2.3.2 Model construction by STELLA

The model was applied to 12 sub-watersheds for prediction DO and BOD in Trang watershed by STELLA (Figure 4). The model was constructed using the four components (1) DO and BOD storages (2) DO inflow (3) BOD inflow and (4) DO and BOD outflows (applied from Feng et al., 2012; Mandal et al., 2012; Bulagao et al., 2013).

**Suan Sunandha Science and Technology Journal**

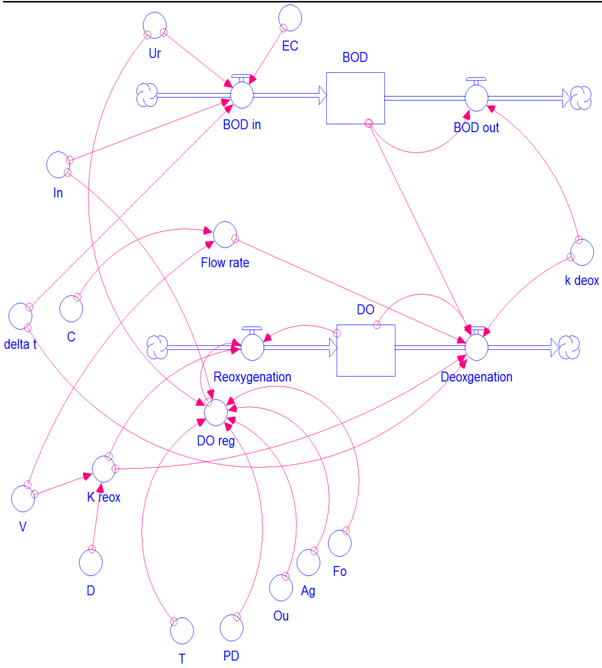




**Figure 4.** Flow diagram of DO and BOD in Trang Watershed using STELLA

***DO and BOD storage***

The model considered two processes that affect the DO level which were reoxygenation and deoxygenation as equation 1.

$$\frac{dDO}{dt} = \text{reoxygenation} - \text{deoxygenation} \qquad (1)$$

Where: DO is the concentration of dissolved oxygen (mg/L); t is time (month); reoxygenation and deoxygenation are the main processes affecting the DO balance; reoxygenation based on the data from multiple regression analysis as the water is affected by % land use; deoxygenation is to consume DO in the river through the consumption of the organic waste. BOD storage was calculated by equation 2.

$$\frac{dBOD}{dt} = BODin - BODout \qquad (2)$$

Where: BOD is the concentration of biochemical oxygen demand (mg/L); t is time (month); $BOD_{in}$ and $BOD_{out}$ are the main processes affecting the BOD balance. $BOD_{in}$ is increased naturally in the river when organic matter flows into the system, which was estimated by result of analysis correlation section in this study. $BOD_{out}$ is consumed by decomposition that equals the reduction of DO.

***DO inflow***

DO inflow is reoxygenation process. It was determined by a reoxygenation coefficient ($K_{reox}$) multiply with the difference between DO regression and the actual dissolved oxygen concentration (McCutcheon, 1989) as equation 3.

$$Reoxygenation = K_{reox}(DO_{reg}-DO) \qquad (3)$$

Where: $DO_{reg}$ is DO regression (mg/L); and, DO is the dissolve oxygen concentration (mg/L).

Reoxygenation coefficient ($K_{reox}$) was determined by equation 4 (O'Connor and Dobbins, 1958).

$$Kreox = 1.72\, V^{0.5} / D^{1.5} \qquad (4)$$

Where: V is river velocity (m/s); and, D is river depth (m).

DO regression ($DO_{reg}$) was estimated by multiple regression as equation 5.

$$DO_{reg} = 0.041(\%Fo)+0.043(\%Ag) - 0.538(\%Ur)+1.169(\%In)-0.173(\%Ou)+0.003(PD)-0.023(T)+3.588 \qquad (5)$$

Where: %Fo is percentage of forest land; %Ag is percentage of agriculture land; %Ur is percentage of urban land; %In is percentage of industrial land; %Ou is percentage of other land; PD is population density (person/km$^2$); and, T is temperature (°C).

***BOD inflow***

BOD inflow ($BOD_{in}$) was estimated by multiple regressions as equation 6.

$$BOD_{in} = 0.21(\%Ur)+0.55(\%In) +0.012(EC)+0.191 \qquad (6)$$

Where: % Ur is percentage of urban land; %In is percentage of industry land; and, EC is electric conductivity (µmho/cm).

***DO Outflow***

DO outflow is deoxygenation reaction. The dissolved oxygen that depleted by microbacteria consumption, represent as $DO_{out}$ (mg/L) as shown equation 7.

$$DO_{out} = k_{deox}\, BOD \qquad (7)$$

Where: $k_{deox}$ is deoxygenation coefficient; and BOD is concentration of biochemical oxygen demand (mg/L).

BOD outflow is the rate of BOD decrease when amount of BOD in the water is decomposed by bacteria, represent as $BOD_{out}$ (mg/L) as shown equation 8.

$$BOD_{out} = k_{deox}\, BOD \qquad (8)$$

Where: $k_{deox}$ is deoxygenation coefficient; and, BOD is concentration biochemical oxygen demand(mg/L).



Vol.05, No.2 DOI: 10.14456/ssstj.2019.6

**Suan Sunandha Science and Technology Journal**


**2.3.3 Model calibration and validation**

The calibration of DO and BOD model developed from STELLA was run using observed value of each sub-watersheds in year 2011 and $k_{deox}$ was used within range of 0.1-0.3 (Nemerow, 1991; Chapra, 1997). The parameters defined in the model calibration are shown in Table 1. The program run until its simulation similar conditions had good agreement with the observe value of DO and BOD data. A model calibration sequence was started with the changes of DO and BOD in average yearly data and then average monthly calibration compare with determination coefficient ($R^2$) values. Model validation was tested by two methods using STELLA program, the model was validated using the data from 12 sub-watersheds in year 2014 at the same water sampling in 2011, the model was validated using other sub-watershed (C1 and C2) data in year 2014 for development in other watershed (Figure 5). However, the model collect data in year 2010 and 2011 for calibration, then validation in year 2014, if model high accuracy in result that mean the model can apply or predict other watershed in future, if we use this method.

**Table 1.** The result of parameters defined in the model calibration.

| Parameters | Unit | Symbols | Range | Verified | References |
|---|---|---|---|---|---|
| **1. DO and BOD storage** | | | | | |
| 1.1 Dissolved oxygen | mg/L | DO | Varied | DO values in field | Field survey |
| 1.2 Biochemical oxygen demand | mg/L | BOD | Varied | BOD values in field | Field survey |
| **2. DO inflow** | - | Reoxgenation | - | - | McCutcheon,1989 |
| 2.1 DO regresstion | mg/L | $DO_{reg}$ | - | Actual values in field | This study |
| 1) Percentages of forest land | % | %Fo | Varied | Actual values in field | This study |
| 2) Percentages of agricultural land | % | %Ag | Varied | Actual values in field | This study |
| 3) Percentages of urban land | % | %Ur | Varied | Actual values in field | This study |
| 4) Percentages of industrial land | % | %In | Varied | Actual values in field | This study |
| 5) Percentages of open undeveloped land | % | %Ou | Varied | Actual values in field | This study |
| 6) Population density | person/km$^2$ | PD | Varied | Actual values in field | This study |
| 7) Temperature | °C | T | Varied | Actual values in field | Field survey |
| 2.2 Reoxygenation coefficient | m s$^{-1}$ | $K_{reox}$ | - | - | O'Connor&Dobbins,1958 |
| 1) River velocity | m s$^{-1}$ | V | Varied | Actual values in field | This study |
| 2) River depth | m | D | Varied | Actual values in field | This study |
| **3. BOD inflow** | - | $BOD_{in}$ | - | - | Streeter&Phelps, 1925 |
| 3.1 Percentages of urban land | % | %Ur | Varied | Actual values in field | This study |
| 3.2 Percentages of industrial land | % | %In | Varied | Actual values in field | This study |
| 3.3 Electrical Conductivity | µmho/cm | EC | Varied | Actual values in field | Field survey |
| **4. DO and BOD outflows** | - | Deoxgenation | - | - | Streeter&Phelps, 1925 |
| 4.1 Deoxygenation coefficient | days$^{-1}$ | $k_{deox}$ | 0.1-0.3 | Varied | Chapra, 1997 |
| 4.2 Flow rate | - | - | - | - | This study |
| 1) River cross section | m$^2$ | C | Varied | Actual values in field | This study |
| 2) River velocity | m s$^{-1}$ | V | Varied | Actual values in field | This study |
| **5. Other parameters** | | | | | |
| 5.1 Delta *t* | t | *t* | - | 0.25 | This study |



Vol.05, No.2 DOI: 10.14456/ssstj.2019.6

**Suan Sunandha Science and Technology Journal**

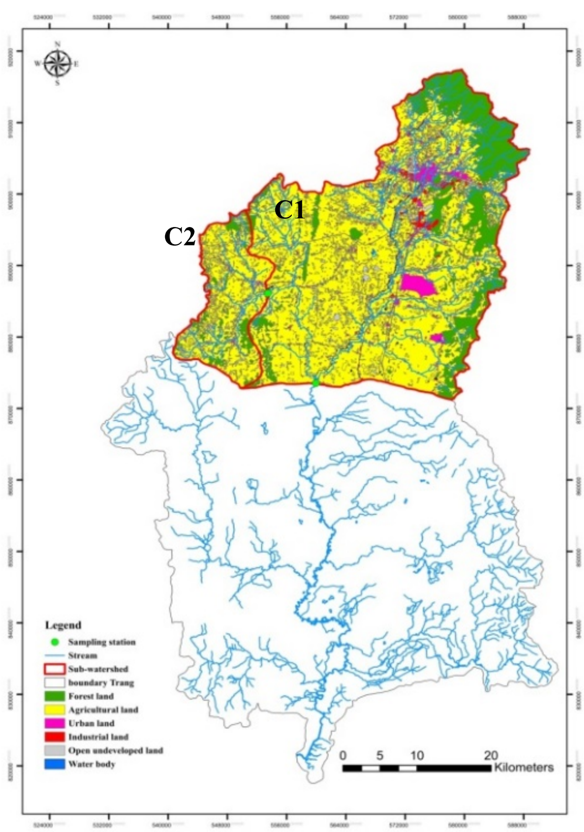




**Figure 5.** The other sub-watershed (C1 and C2) for model validation

## 2.4 Scenario

The objectives of scenarios were to find the suitable development plan which DO and BOD could meet the standard and classifications. Scenario was simulated in the sub-watershed (C2) because it was not in the conservation area with low urbanization. The STELLA model simulated five years (2014-2018). DO and BOD change over time. Scenarios of planning approach were varied by percentage of land use; Fo, Ag, Ur and In. Scenarios were divided into four methods. First, all of four parameters had different percentages of land use types (total scenarios was 24 scenarios). Second, there were two parameters that had equal percentages of land use types (total scenarios was 60 scenarios). Third, there were three parameters that had equal percentages of land use types (total scenarios was 25 scenarios). Finally, the new idea of combination percentages of urban and industry were 5, 10 and 15 (total scenarios was 186 scenarios).

# 3. Results and discussion

## 3.1 Correlation analysis

Results from the Pearson correlation coefficients ($r_{xy}$) found that percentage of land-use types were significantly correlated with DO and BOD in the sub-watershed as shown in Table 2. First of all DO had significant negative correlation with Ag, Ur and In ($r_{xy}$ = 0.86, 0.86 and 0.85, respectively). DO had significant positive correlation with Fo, Ou ($r_{xy}$ = 0.90 and 0.71, respectively). Population density (PD) was significantly negative correlation with DO ($r_{xy}$ = 0.78). Considering water parameters, DO had significant negative correlation with temperature and EC ($r_{xy}$ = 0.90 and 0.98, respectively). While, BOD had significant positive correlation with Ur, In and EC ($r_{xy}$ = 0.68, 0.73 and 0.69, respectively). These correlations were significant at P-value < 0.05.

Result showed that in Trang watershed, DO and BOD were affected by agriculture, urban and industry activities. These results suggest that urban and industry expansion could be the primary driving forces in DO. Therefore, expansion of urban and industry were generally associated with poor water quality in DO. Urban land has the potential to generate large amount of pollution from waste discharge (Basnyat et al., 1999; Zampella et al., 2007; Li et al., 2009; Katarzyna et al., 2016; Muhammad et al., 2018). Tu (2008) reported that urban lands were usually related to be the causes of poor water quality. Similarly, BOD had significant positive correlation with urban, industry. Urban and industry expansions cause increasing in BOD. Likewise, Yingrong et al. (2017) reported that increasing in BOD will have to make treatment from 1.1 billion in 2000 to 2.5 billion in 2050 due to increasing urbanization. Thus, results suggest that urbanization is a major factor that has led to the decrease DO and increase BOD in water. In contrast, the agricultural land did not show any positive relationship with BOD. Normally traditional agricultural practices cause excess amount of BOD. However, the dominate agriculture activities in Trang watershed was Para rubber plantation which is commercial forest unlike others. These lands are not open for surface runoff resulting low BOD. This might be the reason that

**Suan Sunandha Science and Technology Journal**


agriculture have not acted as the source of pollution in Trang watershed.

Result showed that agricultural land decreased whereas urban land increased. Urban areas are primarily located along the river networks in the Trang watershed, and their impacts on the water quality in watershed were expected. Urban expansion related to the increasing residential, commercial, and industrial lands, and population density in suburbs (Xian et al., 2007). It was clear that water degradation have been highly influenced by the pollution from point sources as well as non-point sources, which are commonly associated with urbanized areas. Result also showed that the extent of forest land coverage had effect on water quality. In this study, forest land had positive correlation with DO. Extant forest area can cause increasing in DO. Thus, it is used as protector of water quality of Trang watershed.

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

| | DO | %Fo | %Ag | %Ur | %In | %Ou | %Wa | BOD | PD | 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 | | | | |
| **EC** | **-0.98** | 0.88 | -0.86 | 0.75 | 0.44 | -0.11 | -0.03 | **0.69** | 0.08 | 1.00 | | | |
| **Tur** | -0.09 | 0.05 | 0.02 | -0.48 | -0.51 | 0.23 | -0.31 | 0.12 | -0.65 | 0.42 | 1.00 | | |
| **pH** | 0.20 | -0.30 | 0.20 | 0.15 | 0.33 | 0.04 | 0.69 | -0.31 | -0.26 | 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 | 0.23 | 0.19 | 0.14 | 1.00 |

**Note: Bold** ($P< 0.05$)

## 3.2 Multiple regression analysis

In this study, after found factor affecting DO and BOD, the sub-watershed was used to link factors (land uses, water quality and population density) with DO and BOD by multiple regression analysis. In this study, Adjusted $R^2$ was used to select the appropriate regression model. The data set of annual year 2011 to select the best one of DO and BOD models as shown in Table 3. Result showed value of observed and estimated DO and BOD with $R^2$ (0.97 and 0.70). Therefore, the predicted model of DO and BOD could be accepted. It indicated that DO and BOD can be estimated by multiple regression analysis in Trang watershed.

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

| Equations | ($R^2$) | |
|---|---|---|
| *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* | *(9)* |
| *BOD = 0.28 (%Ur)+0.04(%In)+0.012(EC)+1.32* | *0.70* | *(10)* |

## 3.3 Model calibration

### 3.3.1 Model calibration of DO and BOD for average year value

The conceptual model of DO and BOD results revealed that the correlation between the simulated and observed values of DO and BOD in average yearly calibration for 12 sub-watersheds during year 2011 was shown in Figure 6. The slopes of the correlation line for 12 sub-watersheds were close to 1 and correlation ($R^2$) was close to 0.94 and 0.96, indicating a good agreement between predicted and observed values. Therefore, the model can predict the average yearly value of DO and BOD change overtime in Trang watershed.



Vol.05, No.2 DOI: 10.14456/ssstj.2019.6

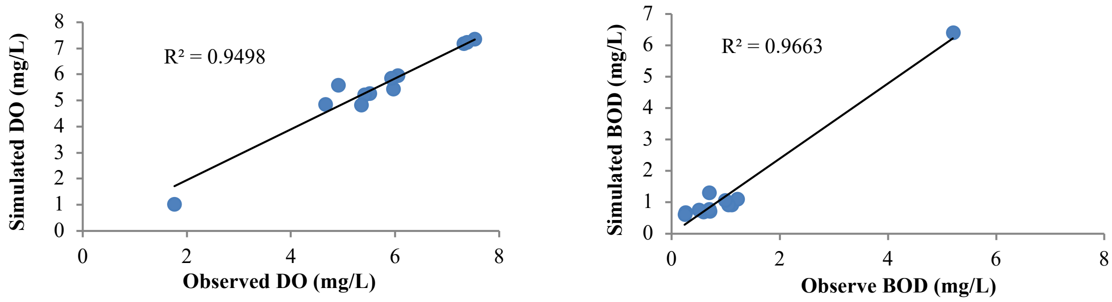



**Figure 6.** Correlation between simulated and observed values of DO and BOD in average yearly calibration for 12 sub-watershed during year 2011.

For parameters of DO inflow, BOD inflow and DO and BOD outflows processes, actual values in field of each sub-watershed were used in model calibration as shown in Table 1. Except the model parameters of $k_{deox}$ which were adjusted to 0.3 for forest and agriculture sub-watershed (F1, F2, F3, Y1, Y2 andY3) and 0.1 for mainstream sub-watershed (S1 to S6).

### 3.3.2 Model calibration of DO and BOD for average month value

Results of the simulated and observed values of DO and BOD changes over time in average monthly calibration for 12 sub-watersheds during year 2011 were shown in Figure 7. The simulated DO and BOD in average monthly calibration could not fit exactly with the observed DO and BOD results; however, the model showed a reasonable good trend of DO and BOD changes overtime. This also indicated that the model can possibly predict the trend of average monthly variation of DO and BOD overtime in Trang watershed.

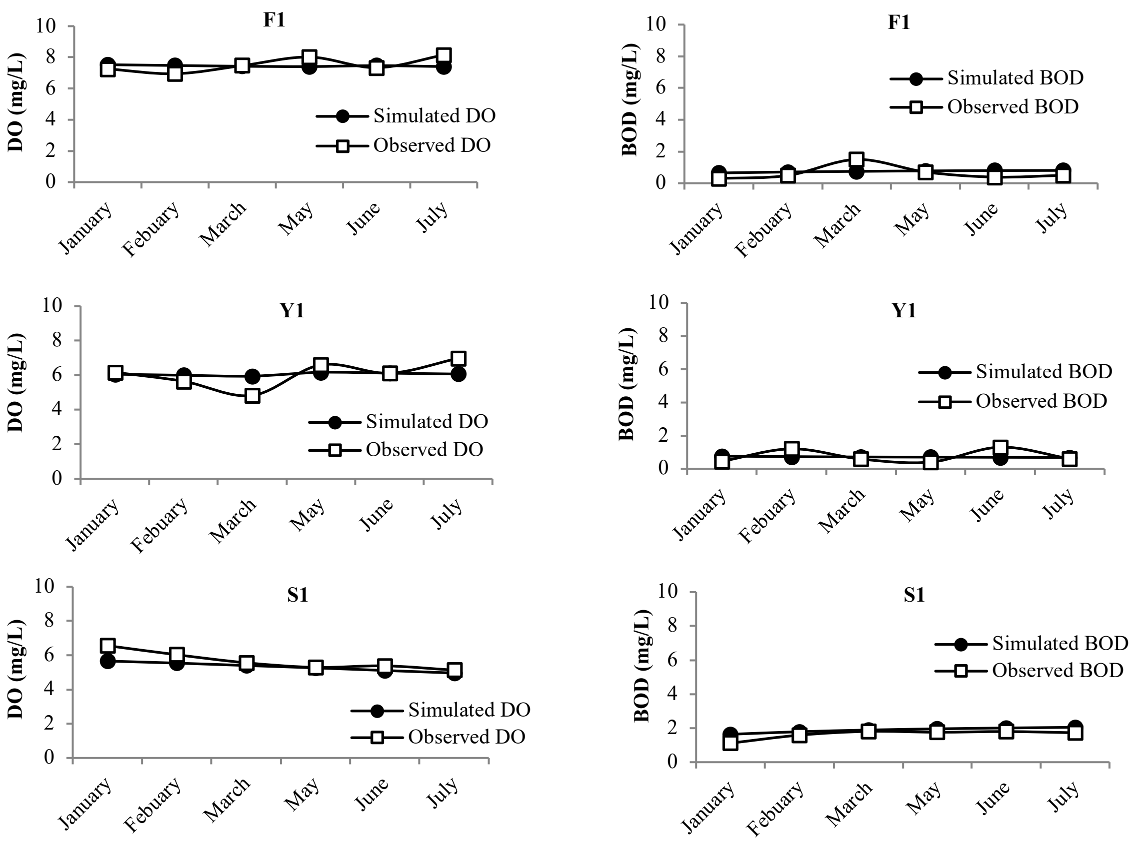


**Figure 7.** Simulated and observed values of DO and BOD change overtime in average monthly calibration for 12 sub-watershed during year 2011.

## 3.4 Model validation

### 3.4.1 Model validation of DO and BOD for average year value

Results revealed that the correlation between the simulated and observed values of DO and BOD in average yearly validation for 12 sub-watersheds during year 2014 was shown in Figure 8. The slopes of the correlation line for 12 sub-watersheds were close to 1 and correlation ($R^2$) was close to 0.90 and 0.97, which supported a good model validation. Therefore, the model can predict the average yearly values of DO and BOD changes overtime.

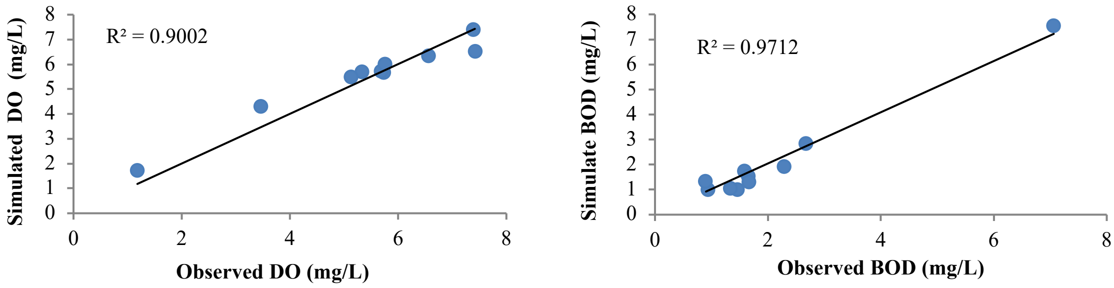
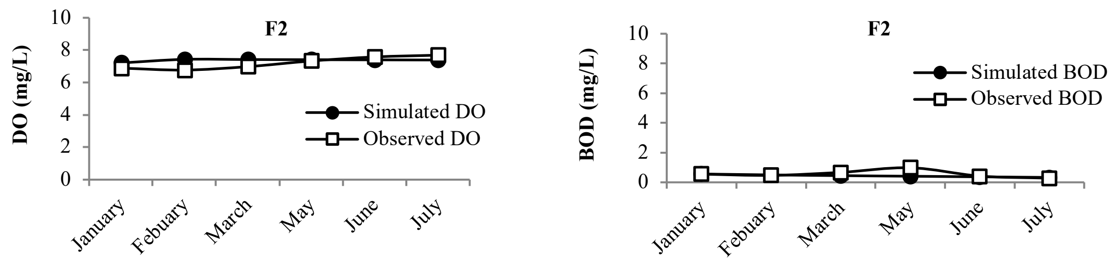



**Figure 8.** Correlation between simulated and observed values of DO and BOD in average yearly validation for 12 sub-watershed during year 2014.

For parameter of DO inflow, BOD inflow and DO and BOD outflows processes, an actual value in field of each sub-watershed were used in model validation as shown in Table 1. Except the model parameters of $k_{deox}$ which were adjusted by 0.3 for forest and agriculture sub-watershed (F1, F2, F3, Y1, Y2 andY3) and 0.1 for mainstream sub-watershed (S1 to S6).

### 3.4.2 Model validation of DO and BOD for average month value

Results of the simulated and observed variation values of DO and BOD over time in average monthly validation for 12 sub-watersheds during year 2014 were shown in Figure 9. The model shows a reasonable good trend of DO and BOD variation overtime, which also supported a good model validation. Hence, this confirmed that the model can possibly predict the trend of DO and BOD changes overtime in Trang watershed.



**Suan Sunandha Science and Technology Journal**

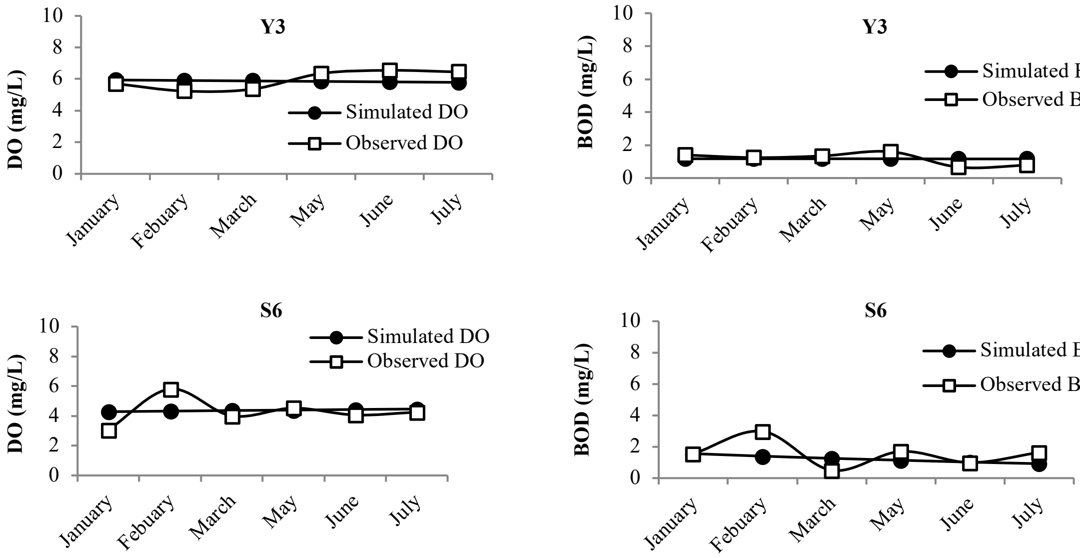




**Figure 9.** Simulated and observed values of DO and BOD change overtime in average monthly validation for 12 sub-watershed during year 2014.

### 3.4.3 Model validation for C1 and C2

The comparison of simulated and observed values of DO and BOD change over time in model validation for other watersheds (C1 and C2) were shown in Table 4. Standard Deviation (SD) was used to compare between observed and simulated in DO and BOD. Table 4 shows results of SD which are less different (0.08, 0.06 and 0.24). Thus, the observed and simulated values of the DO and BOD in C1 and C2 were in good agreement. It can be seen the trend between observed and simulated of DO and BOD change overtime. Therefore, the developed model in this study could be used to describe the DO and BOD change over time in other watershed. This indicated that this model could be used to find suitable development plan in Trang and other watershed.

## 3.4 Model validation

The objective of this scenario is to find the optimization of land allocation for suitable development plan which DO and BOD meet in the standard and classifications by STELLA program. The scenario planning approach was applied to the study area of the sub-watershed (C2) as shown in Table 5.

**Table 4.** Result of model validation for prediction in other watersheds (C1 and C2).

| Sub-watershed | Month | DO (mg/L) | | BOD (mg/L) | |
|---|---|---|---|---|---|
| | | Simulated | Observed | Simulated | Observed |
| C1 | January | 6.03 | 5.77 | 1.89 | 2.39 |
| | February | 5.98 | 6.1 | 1.84 | 2.11 |
| | March | 5.94 | 5.35 | 1.79 | 1.88 |
| | May | 5.89 | 6.49 | 1.75 | 1.77 |
| | June | 5.85 | 6.35 | 1.72 | 1.64 |
| | July | 5.81 | 6.10 | 1.68 | 1.54 |
| Average | | 5.92 | 6.03 | 1.78 | 1.89 |
| SD | | 0.08 | | 0.08 | |
| C2 | January | 6.27 | 6.27 | 1.55 | 1.68 |
| | February | 6.23 | 6.12 | 1.4 | 1.75 |
| | March | 6.2 | 6.63 | 1.26 | 1.03 |
| | May | 6.16 | 5.88 | 1.13 | 1.65 |

**Suan Sunandha Science and Technology Journal**


| | | | | | |
|---|---|---|---|---|---|
| | June | 6.14 | 6.15 | 1.02 | 1.85 |
| | July | 6.11 | 6.58 | 0.92 | 1.35 |
| Average | | 6.19 | 6.27 | 1.21 | 1.55 |
| SD | | 0.06 | | 0.24 | |

**Table 5.** Estimated DO and BOD from scenarios using C2 sub-watershed.

| %Fo | %Ag | %Ur | %In | %Fo+%Ag | %Ur+%In | DO | BOD | Water Quality |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 100 | 0 | 0 | 100 | 0.00 | 22.52 | Deteriorated |
| 0 | 0 | 75 | 25 | 0 | 100 | 0.00 | 17.52 | Deteriorated |
| 5 | 5 | 70 | 20 | 10 | 90 | 0.00 | 16.18 | Deteriorated |
| 10 | 10 | 70 | 10 | 20 | 80 | 0.00 | 15.85 | Deteriorated |
| 5 | 20 | 70 | 5 | 25 | 75 | 0.00 | 15.68 | Deteriorated |
| 20 | 5 | 70 | 5 | 25 | 75 | 0.00 | 15.68 | Deteriorated |
| 20 | 5 | 65 | 10 | 25 | 75 | 0.00 | 14.68 | Deteriorated |
| 5 | 20 | 65 | 10 | 25 | 75 | 0.00 | 14.68 | Deteriorated |
| 10 | 15 | 65 | 10 | 25 | 75 | 0.00 | 14.68 | Deteriorated |
| 15 | 10 | 65 | 10 | 25 | 75 | 0.00 | 14.68 | Deteriorated |
| 20 | 10 | 65 | 5 | 30 | 70 | 0.00 | 14.52 | Deteriorated |
| 10 | 20 | 65 | 5 | 30 | 70 | 0.00 | 14.52 | Deteriorated |
| 15 | 15 | 55 | 15 | 30 | 70 | 0.00 | 12.52 | Deteriorated |
| 20 | 20 | 50 | 10 | 40 | 60 | 0.00 | 11.18 | Deteriorated |
| 25 | 25 | 50 | 0 | 50 | 50 | 0.00 | 10.85 | Deteriorated |
| 30 | 30 | 30 | 10 | 60 | 40 | 0.91 | 6.52 | Deteriorated |
| 70 | 5 | 20 | 5 | 75 | 25 | 1.43 | 4.02 | Deteriorated |
| 10 | 65 | 20 | 5 | 75 | 25 | 1.49 | 4.02 | Deteriorated |
| 5 | 70 | 20 | 5 | 75 | 25 | 1.52 | 4.02 | Deteriorated |
| 75 | 10 | 12 | 3 | 85 | 15 | 3.62 | 2.08 | Fairly clean |
| 70 | 15 | 12 | 3 | 85 | 15 | 3.63 | 2.08 | Fairly clean |
| 80 | 5 | 12 | 3 | 85 | 15 | 3.63 | 2.08 | Fairly clean |
| 85 | 0 | 12 | 3 | 85 | 15 | 3.63 | 2.08 | Fairly clean |
| 60 | 25 | 12 | 3 | 85 | 15 | 3.65 | 2.08 | Fairly clean |
| 65 | 20 | 12 | 3 | 85 | 15 | 3.66 | 2.08 | Fairly clean |
| 55 | 30 | 12 | 3 | 85 | 15 | 3.68 | 2.08 | Fairly clean |
| 50 | 35 | 12 | 3 | 85 | 15 | 3.69 | 2.08 | Fairly clean |
| 35 | 50 | 12 | 3 | 85 | 15 | 3.84 | 2.08 | Fairly clean |
| 30 | 55 | 12 | 3 | 85 | 15 | 3.85 | 2.08 | Fairly clean |
| 45 | 40 | 12 | 3 | 85 | 15 | 3.85 | 2.08 | Fairly clean |
| 40 | 45 | 12 | 3 | 85 | 15 | 3.87 | 2.08 | Fairly clean |
| 10 | 75 | 12 | 3 | 85 | 15 | 3.89 | 2.08 | Fairly clean |
| 25 | 60 | 12 | 3 | 85 | 15 | 3.89 | 2.08 | Fairly clean |
| 20 | 65 | 12 | 3 | 85 | 15 | 3.91 | 2.08 | Fairly clean |
| 15 | 70 | 12 | 3 | 85 | 15 | 3.92 | 2.08 | Fairly clean |
| 85 | 5 | 8 | 2 | 90 | 10 | 4.86 | 1.12 | Medium clean |
| 90 | 0 | 8 | 2 | 90 | 10 | 4.87 | 1.12 | Medium clean |

**Suan Sunandha Science and Technology Journal**


| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 40 | 50 | 8 | 2 | 90 | 10 | 4.95 | 1.12 | Medium clean |
| 70 | 20 | 8 | 2 | 90 | 10 | 4.97 | 1.12 | Medium clean |
| 80 | 10 | 8 | 2 | 90 | 10 | 4.97 | 1.12 | Medium clean |
| 75 | 15 | 8 | 2 | 90 | 10 | 4.98 | 1.12 | Medium clean |
| 55 | 35 | 8 | 2 | 90 | 10 | 5.00 | 1.12 | Medium clean |
| 65 | 25 | 8 | 2 | 90 | 10 | 5.00 | 1.12 | Medium clean |
| 60 | 30 | 8 | 2 | 90 | 10 | 5.01 | 1.12 | Medium clean |
| 50 | 40 | 8 | 2 | 90 | 10 | 5.03 | 1.12 | Medium clean |
| 50 | 40 | 8 | 2 | 90 | 10 | 5.03 | 1.12 | Medium clean |
| 45 | 45 | 8 | 2 | 90 | 10 | 5.04 | 1.12 | Medium clean |
| 90 | 5 | 4 | 1 | 95 | 5 | 6.12 | 0.15 | Very clean |
| 95 | 0 | 4 | 1 | 95 | 5 | 6.12 | 0.15 | Very clean |
| 85 | 10 | 4 | 1 | 95 | 5 | 6.13 | 0.15 | Very clean |
| 80 | 15 | 4 | 1 | 95 | 5 | 6.15 | 0.15 | Very clean |
| 70 | 25 | 4 | 1 | 95 | 5 | 6.16 | 0.15 | Very clean |
| 75 | 20 | 4 | 1 | 95 | 5 | 6.16 | 0.15 | Very clean |
| 60 | 35 | 4 | 1 | 95 | 5 | 6.18 | 0.15 | Very clean |
| 65 | 30 | 4 | 1 | 95 | 5 | 6.18 | 0.15 | Very clean |
| 55 | 40 | 4 | 1 | 95 | 5 | 6.20 | 0.15 | Very clean |
| 50 | 45 | 4 | 1 | 95 | 5 | 6.21 | 0.15 | Very clean |
| 45 | 50 | 4 | 1 | 95 | 5 | 6.21 | 0.15 | Very clean |
| 50 | 45 | 4 | 1 | 95 | 5 | 6.21 | 0.15 | Very clean |
| 40 | 55 | 4 | 1 | 95 | 5 | 6.23 | 0.15 | Very clean |
| 100 | 0 | 0 | 0 | 100 | 0 | 8.22 | 0.00 | Very clean |

**Note:** Deteriorate is DO < 2 mg/L and BOD > 4 mg/L
Fairly clean is DO 2-4 mg/L and BOD 2-4 mg/L
Medium clean is DO 4-6 mg/L and BOD 1.5-2 mg/L
Very clean is DO > 6 mg/L and BOD < 1.5 mg/L

As shown in Table 5, results revealed that the suitable development plan in Trang watershed for very clean water quality was urban and industrial land less than 5% or forest and agricultural land more than 95%. If urban and industrial land increase to 10% and forest and agricultural land decrease to 90%, the water quality would be medium clean. When urban and industrial land are more than 15%, water quality begin to fairly clean. Finally, water will be completely deteriorated if urban and industrial are more than 25% or forest and agricultural land are less than 75% as shown in Table 6. Consequently, the model developed by STELLA can be used to describe DO and BOD change over time and help in finding optimization of land allocation which does not disturb water quality in Trang watershed. For Further research, the model can be applied in other watersheds or forecasting the environmental events as self-purification capability of river for solving river quality problem.

**Table 6.** The conclusion of suitable development plan in Trang watershed

| %(Fo + Ag) | %(Ur + In) | Water Quality level |
|---|---|---|
| 95 | 5 | Very clean |
| 90 | 10 | Medium clean |
| 85 | 15 | Fairly clean |
| <75 | >25 | Deteriorated |

## 4. Conclusions

The model was developed for describing the DO and BOD changes over time in Trang watershed

**Suan Sunandha Science and Technology Journal**


using STELLA program in four components of DO inflow, BOD inflow and DO and BOD outflows system. It had good agreement with the observed results. For finding optimization of land allocation for sustainable development without water pollution, it was found that if the percentage of urban and industrial land were less than 5% and also the percentage of forest and agricultural land were 95% the water quality would be very clean. If percentage of urban and industrial land increased to 10% and the percentage of forest and agricultural land was 90 %, the water quality in Trang watershed was still medium clean. If the percentage of urban and industrial land would be more than 15 % water quality would begin to fairly clean and if they were more than 25 % of total area and also the percentage of forest and agricultural land were less than 75 % of total area in watershed it would start to become the deteriorated water quality. Concerning water pollution for suitable development plan % of urban and industrial should not be over than 25% of total area, otherwise water quality would be deteriorated. Also, this indicating that STELLA program could simulate DO and BOD changes overtime in Trang watershed and other watershed. Therefore, STELLA program can be used as an appropriate tool for finding out suitable development plan with standard water quality.

## References

Carr, G. M., & Neary, J. P. (2008). *Water Quality for Ecosystem and Human Health* (2nd ed.). Burlington, Ontario, Drukarnia MiW.

Nas, S. S., Bayram, A., Nas, E., & Bulut, V. N. (2008). Effects of Some Water Quality Parameters on the Dissolved Oxygen Balance of Streams. *Polish Journal of Environmental Studies*, 17(4), 531-538.

Ren, W., Zhong, Y., Meligrana, J., Anderson, B., Watt, W., Chen, J., & Lueng, H. (2003). Urbanization, landuse, and water quality in Shanghai 1947–1996. *Environment International*, 29(5), 649–659.

Kannel, P. R., Lee, S., Kannel, S. R., Khan, S. P., & Lee, Y.S. (2007). Spatial–temporal variation and comparative assessment of water qualities of urban river system: a case study of the river Bagmati (Nepal). *Environmental Monitor Assessment Journal*, 129, 433–459.

Katarzyna, G. L., Iwona, G., Józef, K., Anna, G. P., Monika, H., & Andrzej, R. (2016). The impact of urban areas on the water quality gradient along a lowland river. *Environmental Monitor Assessment Journal*, 188: 624, 1–15.

Lee, S. W., Hwang, S. J., Lee, S. B., Hwang, H. S., & Sung, H. C. (2007). Landscape ecological approach to the relationships of land use patterns in watersheds to water quality characteristics. *Landscape and Urban Planning,* 92, 80–89.

Muhammad, A. H. R., Malik, M. M., & Sana, M. (2018). Urbanization and Its Effects on Water Resources: An Exploratory Analysis. *Asian Journal of Water, Environment and Pollution,* 15, 67–74.

He, H., Zhou, J., Wu, Y., Zhang, W., & Xie, X. (2008). Modelling the Response of Surface Water Quality to the Urbanization in Xi'an, China. *Journal of Environmental Management,* 86(4), 731-749.

Tu, J. (2008). *Assessing the Impact of Long-Term Land Use Changes on Water Quality in Eastern Massachusetts*. (Doctoral dissertation). University of New York. USA.

Liu, Z., Li, Y., & Li, Z. (2009). Surface water quality and land use in Wisconsin, USA a GIS approach. *Journal of Integrative Environmental Sciences*, 6(1), 69-89.

Rothenberger, M. B., Burkholder, J. M., & Brownie, C. (2009). Long term effects of changing land use practices on surface water quality in a coastal river and lagoonal estuary. *Environmental Management*, 44, 505-523.

Gyawali, S. (2013). *Integrating Land Use Planning and Surface Water Quality for River Basin Management: a Case Study of U-tapao River Basin, Thailand.* (Doctoral dissertation). Prince of Songkla University, Thailand.

Pollution Control Department. 2011. Thailand State of Pollution Report 2011 (PCD. No. 06-042). Pollution Control Department, Ministry of Natural Resources and Environment, Bangkok, The Interest E-mail Printing Office. Retrieved from http:// www. http://infofile.pcd.go.th/mgt/Report_Eng2554.pdf

Fan, C., & Wang, W. S. (2008). Influence of Biological Oxygen Demand Degradation

**Suan Sunandha Science and Technology Journal**


Patterns on Water Quality Modeling for rivers Running through Urban Area. *Annals of the New York Academy of Sciences*, 1140, 78-85.

Zhang, Y. (2012). *Predicting river aquatic productivity and dissolved oxygen before and after dam removal in central Ohio, USA.* (MS Thesis). Ohio State University, USA.

Toma, P. D. (2012). Impact on rivers of untreated wastewater discharge. *Mathematical Modeling in Civil Engineering*, 3, 38-46.

Cox, B. A. (2003). A review of currently available in-stream water-quality models and their applicability for simulating dissolved oxygen in lowland rivers. *Science of the Total Environment*, 314, 335-377.

Chang, H. (2005). Spatial and temporal variations of water quality in the river and its tributaries, Seoul, Korea, 1993–2002. *Water, Air, and Soil Pollution*, 161, 267-321.

Garg, S. K. (2006). Sewage disposal and air pollution engineering. *Environmental Engineering*, 18 (2), 228–278.

Hannon, B., & Ruth, M. (1994). *Dynamic modeling*. New York, Springer-Verlag.

Peterson, S., & Richmond, B. (1996). *STELLA research technical documentation.* Hanover, High Performance Systems.

Costanza, R., Voinov, A., Boumans, R., Maxwell, T., Villa, F., Voinov, H., & Wainger, L. (2002). Integrated ecological economic modeling of the Patuxent river watershed, Maryland. *Ecological Monographs*. 72, 203–231.

Aassine, S., & Jai, M. C. E. (2002). Vegetation dynamics modelling: a method for coupling local and space dynamics. *Ecological Modelling,* 154, 237–249

Ouyang, Y. (2008). Modeling the mechanisms for uptake and translocation of dioxane in a soil–plant ecosystem with STELLA. *Journal of Contaminant Hydrology*, 95, 17–29.

Isee Systems. (2014). Technical document for the iThink and STELLA software. Retrieved 22 March 2015: http://www.iseesystems.com.

Ouyang, Y., Zhang, J. E., Lin, D., & Liu, G.D. (2010). A STELLA model for the estimation of atrazine runoff, leaching, adsorption, and degradation from an agricultural land. *Journal of Soils and Sediments,* 10, 263-271.

Feng, M. L., Sun, T., Zhang, L. X., & Shen, X. M. (2012). Net Ecosystem Metabolism Simulation by Dynamic Dissolved Oxygen Model in Yellow River Estuary, China. *Procedia Environmental Sciences*, 13, 807–817.

Mandal, S., Roy, M., Debnath, M., Ray, S., & Ray, S. (2012). Dynamic modeling of dissolved oxygen in the creeks of Sugar island, West Bengal, India. *Applied Mathematical Modelling,* 36, 5952–5963.

Bulagao, B. F. R., Pulvera, P. R. N., & Relampagos, J. C. O. (2013). System Dynamics Model of Dissolved Oxygen in Butuanon River. (Research Paper). Philippine Science High School, Central Visayas Campus, Talaytay, Argao, Cebu.

McCutcheon, S. C. (1989). *Water Quality Modeling Vol.1 Transport and Surface Exchange in River.* Boca Raton, CRC Press, Inc.

O'Connor, D. J., & Dobbins, E. (1958). Mechanism of reaeration in natural streams. *American Society of Civil Engineers,* 123, 641–684.

Nemerow, N. L. (1991). *Stream, Lake Estuary and Ocean Pollution.* New York, Van Nostrand Reinhold.

Chapra, S. C. (1997). *Surface Water Quality Modeling.* New York, McGraw-Hill Boston.

Streeter, H. W., & Phelps, B. E. (1925). A Study of Pollution and Natural Purification of the Ohio River. *Public Health Bulletin*, No. 146.

Basnyat, P., Teeter, L. D., Flynn K. M., & Lockaby, B. G. (1999). Relationships between landscape characteristics and nonpoint source pollution inputs to coastal estuaries. *Environmental Management*, 23(4), 539-549.

Zampella, R. A., Procopion, N. A., Lathrop, R. G., & Dow, C. L. (2007). Relationship of land-use/land-cover pattern and surface-water quality in the Mullica river basin. *Journal of American Water Resources Association,* 4(3), 594-604.

Li, S., Gu, S., Tan, X., & Zhang, Q. (2009). Water quality in the upper Han river basin, China: The impacts of land use/land cover in riparian buffer zone. *Journal of Hazardous Materials*, 165, 317-324.

Yingrong, W., Gerrit, S., & Nick, V. de G. (2017). Organic pollution of rivers: Combined threats of urbanization, livestock farming and global

**Suan Sunandha Science and Technology Journal**


climate change. *Scientific Reports,* 7:43289, 1-9.

Xian, G., Crane, M., & Su, J. (2007). Analysis of urban development and its environmental impact on the Tampa Bay watershed. *Journal of Environmental Management,* 85, 965–976.