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# Entire Catchment and Buffer Zone Approaches to Modeling Linkage Between River Water Quality and Land Cover —A Case Study of Yamaguchi Prefecture, Japan

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**Abstract:** This study investigated the linkages between river water quality and land use in river catchments in Yamaguchi Prefecture, the western Japan, in order to examine the effect of land use changes of both entire catchment and buffer zone on river water quality. Dissolved Oxygen (DO), pH, Biological Oxygen Demand (BOD), Suspended Solids (SS), *Escherichia coli*, Total Nitrogen (TN) and Total Phosphorus (TP) were considered as river water quality indicators. Satellite images were applied to generating the land use map. Multiple regression model was applied to linking the changes in the river water quality with the land uses in both entire catchment area and buffer zone. The results indicate that the integrative application of land use data from the entire catchment and the buffer zone could give rise to more robust model to predict the concentrations of Suspended Solids ($r^2$=0.88) and Total Nitrogen ($r^2$=0.90), rather than models which separately considered land use data in catchment and buffer zone.

**Keywords:** land use; water quality; buffer zone; entire catchment; Yamaguchi Prefecture; Japan

## 1 Introduction

Surface water can be contaminated by human activities through point sources such as sewage discharge and non-point sources like runoff from urban and agricultural areas (Sliva and Williams, 2001). Non-point source pollutants, such as nutrients, pesticides, heavy metals, and solid contaminants, are transported by air, surface water and groundwater. As the amount, source, and geographical boundary are difficult to be identified, the process through which non-point source pollutant enters the water source is still unclear (Chen et al., 2002).

Based on the theory of “source-sink” ecological process, some landscape types play a source-like role, serving as a contributing zones, which contribute nutrients and other non-point source pollutants to surface and sub-surface water; some types play a sink-like role, serving as nutrient retention zones or nutrient transformation zones, wherein dissolved and suspended nutrients and sediments move downstream; and others play a transportation role during the course of non-point pollution (Fu et al., 2005).

The correlations between land use and water quality have been frequently reported (Woli et al., 2002). There is always potential to improve water quality with proper land use management practices, if the role of different land use combinations within a contributing area is known (Basnyat et al., 1999).

Studies in this field began in the late 1960s. In the past decades since then, many researches (Amiri and Nakane, 2006; Jarvie et al., 2002; Chen et al., 2002; Jones et al., 2001; Sliva and Williams, 2001; Norton and Fisher, 2000; Basnyat et al., 1999; Johnson et al., 1997) have examined the impacts of land use/cover changes in buffer zone on river water quality and focused on determining the functions (sink/source) of land use/cover types in regulating the water quality of the rivers. They approached the problem by determining the sink or source functions of the land use/cover types by some regression models. The dominant approach to model the linkage between river water quality and land use was to separately consider land uses in the entire catchment area and the buffer zone. Few studies have investigated the regulating functions of different land use/cover types

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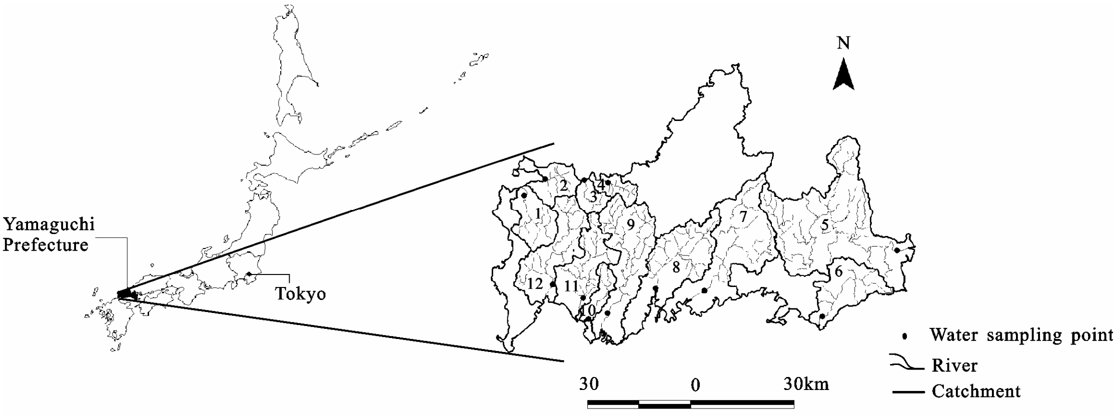
by integrating the land use data from both whole catchment and buffer zone. The objectives of this paper are 1) to study the relationship between river water quality and the land use of both entire catchment and buffer zone; and 2) to develop multiple regression models to describe the linkages between land use types and water quality variables, which will determine the regulating functions (source and/or sink) of land use types.

## 2 Materials and Methods

### 2.1 Study area

The present study was conducted in Yamaguchi Prefecture, Japan, which is located between 33°53′58″ – 34°28′38″N, and 130°56′11″–132°16′11″E, with a total area of 5809km$^2$ (Fig. 1). The predominant rock is rhyolite in the northern and northeastern areas, Mesozoic sedimentary formations (sandstone/shale/pudding stone) in the western and southwestern areas; and crystalline schist, dolerite and gravel/clay in the southern area. Ochric cambisols, dystric regosols and rhodic acrisols are the dominant soil types that can be observed in each catchment. The population of this area is 1,527,964 reported by Statistic Bureau of Ministry of Internal Affairs and Communications of Japan (http://www.stat.go.jp)

There are 18 major rivers in Yamaguchi Prefecture, of which 12 were selected in this study, based on the available water quality data (Fig. 1). The generalized classification of land use (including urban, forest, agriculture, grassland and water body types) was considered to examine the effect of land use on water quality because aggregating land use classes can improve the accuracy of the study (Zhu et al., 2000). Forest is the dominant land use type in the study area. The proportion (%) of the land use types in different catchments and the 30-m buffer zones of each catchment are depicted, respectively (Fig. 2 and Fig. 3). The area and population density of each catchment are shown in Table 1.



1. Awano; 2. Kakefuchi; 3. Fuka; 4. Misumi; 5. Nishki; 6. Shimada; 7. Saba; 8. Washino; 9. Kotou; 10. Ariho; 11. Asa; 12. Koya

Fig. 1 Location of study area in Japan and catchment division

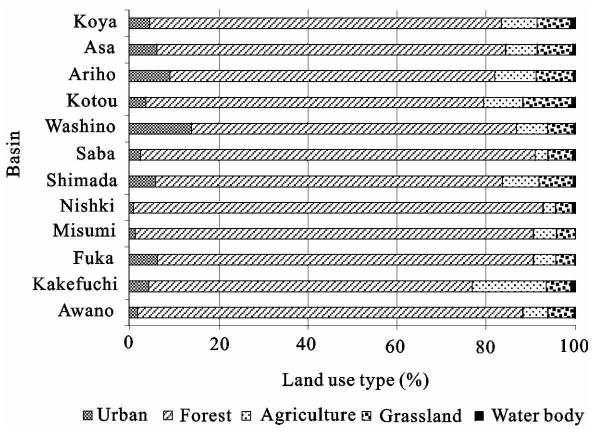


Fig. 2 Ratios of land uses in different catchments

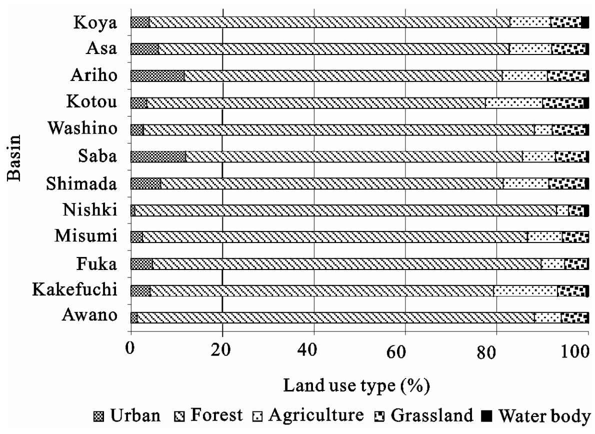


Fig. 3 Ratios of land uses in 30-m buffer zones

Table 1 Area and population density of different catchments in Yamaguchi Prefecture

| No. | River | Area ($km^2$) | Population density ($person/km^2$) |
|---|---|---|---|
| 1 | Awano | 182 | 63 |
| 2 | Kakefuchi | 85 | 106 |
| 3 | Fuka | 72 | 150 |
| 4 | Misumi | 67 | 70 |
| 5 | Nishki | 932 | 165 |
| 6 | Shimada | 284 | 267 |
| 7 | Saba | 572 | 225 |
| 8 | Washino | 300 | 434 |
| 9 | Kotou | 416 | 253 |
| 10 | Ariho | 98 | 477 |
| 11 | Asa | 226 | 109 |
| 12 | Koya | 299 | 362 |

## 2.2 Data

Dissolved oxygen (DO), pH, biological oxygen demand (BOD), suspended solids (SS), *Escherichia coli*, total nitrogen (TN), and total phosphorus (TP) were selected as the factors representing the water quality of the rivers. The water quality data derived from the Ministry of Land, Infrastructure and Transport of Japan (http://www. river.go.jp), Yamaguchi Prefecture Office (http://www. pref.yamaguchi.jp), who is responsible for carrying out river water sampling and analysis monthly. Water quality variables were analyzed according to the Japanese Industrial Standard (JIS) (http://www.apecvc.or.jp). Sampling method, transport and analysis procedures could be obtained at the website of the Japanese Standards Association (http://www.jsa.or.jp). For the present study, the annual mean of water quality data in 2001 was used without normalizing the data set (Table 2). Population data were based on the 2000 population census carried out by the Statistic Bureau of the Ministry of Internal Affairs and Communications of Japan (http://www.stat.go.jp/data/kokusei/2000/final/zuhyou/008-02.xls). Digital topographical maps on the scale of 1:200,000 were obtained from the Japan Geographical Survey Institute (JGSI) and applied to delineating the catchments (Fig. 1). Satellite images (NASA Landsat-5 TM, 2000/05/04) were used to generate land use map of the study area.

Table 2 Mean annual values of water quality factors of rivers in study area in Yamaguchi Prefecture

| River No. | pH | | | DO (mg/L) | | | BOD (mg/L) | | | SS (mg/L) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Median | Min. | Max. | Median | Min. | Max. | Median | Min. | Max. | Median | Min. | Max. |
| 1 | 7.40 | 7.20 | 7.50 | 9.00 | 8.00 | 12.00 | 0.50 | 0.50 | 0.60 | 2.00 | 1.00 | 5.00 |
| 2 | 7.55 | 7.20 | 7.60 | 9.75 | 7.80 | 12.00 | 0.70 | 0.50 | 1.00 | 3.00 | 2.00 | 5.00 |
| 3 | 7.45 | 7.30 | 7.60 | 10.00 | 8.30 | 12.00 | 0.50 | 0.50 | 0.90 | 1.00 | 1.00 | 2.00 |
| 4 | 7.45 | 6.60 | 7.30 | 9.45 | 6.10 | 12.00 | 0.50 | 0.50 | 0.60 | 3.00 | 1.00 | 6.00 |
| 5 | 7.50 | 7.20 | 7.60 | 9.80 | 8.10 | 11.00 | 0.50 | 0.50 | 1.00 | 1.00 | 1.00 | 8.00 |
| 6 | 7.50 | 7.30 | 7.60 | 9.85 | 7.40 | 12.00 | 0.60 | 0.50 | 0.90 | 3.00 | 1.00 | 8.00 |
| 7 | 7.80 | 7.10 | 8.00 | 9.15 | 7.80 | 12.20 | 0.55 | 0.50 | 1.10 | 3.00 | 1.00 | 5.00 |
| 8 | 7.70 | 7.50 | 8.10 | 9.90 | 6.20 | 13.00 | 0.90 | 0.50 | 2.20 | 15.50 | 6.00 | 31.00 |
| 9 | 7.70 | 7.60 | 8.00 | 8.90 | 6.80 | 12.00 | 0.70 | 0.50 | 1.20 | 10.50 | 2.00 | 23.00 |
| 10 | 7.50 | 7.30 | 7.60 | 6.90 | 5.80 | 12.00 | 0.85 | 0.50 | 2.20 | 10.00 | 2.00 | 19.00 |
| 11 | 7.60 | 7.50 | 7.80 | 9.00 | 7.00 | 13.00 | 1.05 | 0.50 | 1.80 | 4.00 | 1.00 | 11.00 |
| 12 | 7.40 | 7.10 | 8.20 | 8.50 | 5.40 | 12.00 | 0.55 | 0.50 | 1.80 | 8.50 | 2.00 | 27.00 |

| River No. | *E.coli* (MPN/100 mL) | | | TN (mg/L) | | | TP (mg/L) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Median | Min. | Max. | Median | Min. | Max. | Median | Min. | Max. |
| 1 | 3150 | 1400 | 33000 | 0.52 | 0.31 | 0.58 | 0.02 | 0.02 | 0.05 |
| 2 | 12000 | 4900 | 24000 | 0.66 | 0.49 | 0.82 | 0.03 | 0.03 | 0.07 |
| 3 | 3850 | 700 | 13000 | 0.61 | 0.53 | 0.71 | 0.03 | 0.02 | 0.05 |
| 4 | 4200 | 1300 | 7900 | 0.74 | 0.59 | 0.93 | 0.02 | 0.02 | 0.04 |
| 5 | 4750 | 330 | 49000 | 0.47 | 0.41 | 0.64 | 0.01 | 0.01 | 0.02 |
| 6 | 7900 | 790 | 33000 | 0.73 | 0.56 | 0.88 | 0.03 | 0.02 | 0.07 |
| 7 | 1500 | 140 | 17000 | 0.50 | 0.40 | 0.77 | 0.05 | 0.03 | 0.06 |
| 8 | 2600 | 330 | 28000 | 1.62 | 1.03 | 3.06 | 0.17 | 0.08 | 0.28 |
| 9 | 4750 | 330 | 49000 | 0.76 | 0.54 | 0.94 | 0.04 | 0.02 | 0.09 |
| 10 | 17500 | 3300 | 330000 | 1.24 | 0.78 | 5.55 | 0.05 | 0.03 | 0.08 |
| 11 | 12000 | 3300 | 130000 | 0.74 | 0.56 | 0.89 | 0.05 | 0.03 | 0.10 |
| 12 | 1600 | 170 | 24000 | 0.71 | 0.50 | 1.00 | 0.08 | 0.03 | 0.13 |

### 2.3 GIS and remote sensing

The Geographic Information System (GIS) was established by the ArcView 3.2 to facilitate the spatial analysis and determination of morphological attributes of the catchments and land use types. Since the source and process of non-point source pollution are uncertain, GIS and mathematical models have been proved to be useful tools to simulate the effect of landscape patterns and land management practices on non-point source pollution, nutrient loss and transport (Chen et al., 2002). For each sampling point, catchment boundaries were drawn by hand on the 1∶200,000 topographic quadrangle maps. All databases were transformed into common digital formats and projected onto a common coordinate system, Universal Transverse Mercator (UTM) (zone 52).

The population density map was initially generated by linking the county-scale population database with the digital map of counties. It was then overlaid and aggregated by the catchments map to generate a catchment-scale population density map.

One scene of satellite data (NASA- Landsat-5, 2000/05/04) was used to draw the land use map of the study area. The satellite image was geo-referenced to generate the color composite map. Optimum Index Factor Analysis was carried out to find the better thermal band composition (bands 1, 4 and 5). The supervised classification method was applied to classifying land uses, including forest, agriculture, grassland, urban and water body (wetland, natural and artificial lakes).

The preparation, interpretation and analysis of the satellite images were carried out in the Integrated Land and Water Information System (ILWIS 3.2 Academic Version) (ILWIS, 2004). The hydrological (river) network was drawn by hand on the 1∶200,000 digital topographical maps (JGSI) in each catchment. A 30-m buffer zone (equal to satellite image resolution) was then generated in the hydrological network by ArcView 3.1. The buffer zone and catchment maps were superimposed on the land use map to calculate the area of land use types of each catchment. The real extent of each type of land use (for the entire catchments) was subtracted by that of the related land use (at buffer zone). The result was subsequently divided by the related catchment and buffer zone areas to determine the percentage of the catchment and buffer zone covered by each type of the land use.

### 2.4 Statistical analysis

All water quality variables and land use data were tested for normality by using the Sharpio-Wilk test with a significance level of *p*-value less than 0.05. The multiple regression modeling was applied by the backward method to determining the linkage between land use and river water quality and to achieving the most appropriate model for a given water quality variable. Inter-variable collinearity of the models was investigated by referring to their Variance Inflation Factor (VIF). The land use and river water quality data were used in regression model without any power transformations, normality of residuals of the models was examined by the Sharpio-Wilk test ($p<0.05$). For a given water quality variable, the appropriate model was selected on the basis of regression ($r^2$, *p*-value). Moreover, the significance of coefficients of the model and the normally distributed residuals were considered as additional criteria in choosing final regression model. Finally, the goodness-of-fit of the statistically significant regression models was evaluated by scatter plot and simple linear regression of observed data versus predicted ones (Ahearn et al., 2005) was performed. Statistical analyses were completed by Excel Add-ins (XLSTAT$^{\mathrm{TM}}$ 2006) and SPSS in Windows Release 10.

## 3 Results and Discussion

### 3.1 Land use-river water quality linkage modeling

Result of normality test, which was applied to all variables, indicated that all land use types either in whole catchment or in buffer zone were normally distributed. Moreover, out of seven water quality factors as shown in Table 3, only two factors including DO and BOD followed a normal distribution. A backward approach was applied in order to decide on a final regression model representing the relationship between land use and river water quality. For each regression model, the initial fixed variables were population density ($P$) (person/km$^2$), compositional attributes (%) of land use area in the entire catchment (urban ($U$), forest ($F$), agriculture ($A$), grassland ($G$) and water body ($W$)) and in buffer zone (urban ($U_{\mathrm{b}}$), forest ($F_{\mathrm{b}}$), agriculture ($A_{\mathrm{b}}$), grassland ($G_{\mathrm{b}}$) and water body ($W_{\mathrm{b}}$)), and the river water quality variables (pH, DO (mg/L), BOD (mg/L), SS (mg/L), *E. coli* (MPN/100mL), TN (mg/L) and TP (mg/L)). Although applying the present approach could not be resulted in developing appropriate multiple regression model for *E. coli* and BOD, the results of multiple regression modeling for other water quality variables such as pH, DO, SS, TN and TP are summarized in Table 4.

The pH regression model was developed:

$$pH=-8.57\times10^{-4}P+7.08\times10^{-2}U-6.24\times10^{-2}A+6.01\times10^{-2}G+1.004W-3.78W_b+7.1 \quad (1)$$

In Equation (1), of the five land uses in the entire catchment, only the proportion of forest was excluded, and the water body in buffer zone was introduced into the model by multiple regression modeling. Equation (1) suggests that the increase in proportion of urban and grassland areas at the catchment scale would give rise to pH increase downstream. The contribution of the urban area is stronger than that of grassland. Water body area has different functions in regulating pH depending on its location. When the proportion of water body area increases in the entire catchments, pH would increase. Contrarily, increase in the proportion of water body area in the buffer zone would cause pH to decrease in the rivers. In addition, the contribution of water body area in the buffer zone is more than three times that of water body area in the entire catchment.

The DO regression model was expressed as:

$$DO=-1.28\ln G+11.76 \quad (2)$$

In Equation (2), grassland area was chosen as the explanatory variable at catchment level. Other variables were eliminated, as they were not selected during the backward approach. No significant land use type in buffer zone was introduced into the model. Equation (2) indicates that increase in the proportion of grassland in the entire catchment would decrease DO in the rivers.

The SS regression model was represented:

$$SS=2.50\times10^{-2}P-0.68U_b+1.42G_b-2.75 \quad (3)$$

In Equation (3), population density, urban area and grassland area in buffer zone were observed as significant explanatory variables. Other variables including forest, agriculture and water body at both scales of catchment and buffer zone were not selected as significant variables. Equation (3) reveals that an increase of population density and the proportion of grassland in the buffer zone would have a positive effect on SS in the rivers. If their proportions increase, SS would increase downstream. On the contrary, urban area in the buffer zone has a negative effect on SS in the rivers, which could be the result of decreasing soil erosion rate in the urbanized area. The SS model indicated that both population density and grassland area in the entire catchment and the buffer zone played a source role in supplying SS in the rivers. Although, the urbanized area in the buffer zone played a sink role and could mitigate SS in the rivers.

The TN regression model could be expressed as follows:

$$TN=2.50\times10^{-2}P+0.68U-0.44W_b+0.34 \quad (4)$$

Population density, urban area in entire catchments, water body area in buffer zone were indicated as significant variables in the TN model. About 90% variations of TN were explained by an alteration in the urban area in the entire catchment, combined with water body area in buffer zone and population density. Equation (4) suggests that urban area at the entire catchment scale would play a source role in supplying different types of nitrogen, but water body area at the buffer zone scale would play a sink role in regulating total nitrogen in the rivers. In addition, increasing population density would make the concentration of total nitrogen in the rivers increase.

The TP regression model was presented:

$$TP=-3.89e^{0.14U} \quad (5)$$

In Equation (5), only urban area was indicated as an explanatory variable. The model shows that urban area is a major contributor of TP in the rivers in the study area. Equation (5) suggests that urban area at the catchment scale played a source-role in regulating TP in the rivers.

Table 3 Results from normality test of river water quality variables and compositional attribute of land uses at catchment and buffer zone scales

| Variable | Sharpio-Wilk (catchment-scale) | | Sharpio-Wilk (buffer zone-scale) | |
|---|---|---|---|---|
| | Statistics | Sig. | Statistics | Sig. |
| pH | 0.847 | 0.038 | – | – |
| DO | 0.918 | **0.333** | – | – |
| BOD | 0.862 | **0.057** | – | – |
| SS | 0.833 | 0.025 | – | – |
| *E.coli* | 0.660 | 0.010 | – | – |
| TN | 0.655 | 0.010 | – | – |
| TP | 0.731 | 0.010 | – | – |
| Population density | 0.918 | **0.336** | – | – |
| Urban | 0.893 | **0.167** | 0.892 | **0.157** |
| Forest | 0.915 | **0.313** | 0.616 | **0.100** |
| Agriculture | 0.873 | **0.079** | 0.977 | **0.937** |
| Grassland | 0.939 | **0.475** | 0.898 | **0.202** |
| Water body | 0.961 | **0.746** | 0.940 | **0.478** |

* All bold values are significant at $p<0.05$

Collinearity of the regression models was investigated by referring to VIF (Table 4). VIF>10 could be considered as severe collinearity within variables in the models (Neter et al., 1996; Chatterjee et al., 2000), and all models have revealed no collinearity (VIF<2). Normality of residuals of the models was tested by the Sharpio-Wilk ($p<0.05$) to validate whether or not they follow a normal distribution. The results (Table 4) suggest that the residuals of all models were normally distributed ($p<0.05$). A simple linear regression analysis of observed value versus the predicted values by the relevant models was carried out and plotted to validate the goodness-of-fit. The relationship between the observed and predicted values of river water quality variables (pH, DO, SS, TN and TP) in the study area were depicted in Fig. 4.

### 3.2 Performance analysis of regression models

The performance of the developed regression models in this study was compared with those developed by using land use data in either entire catchment or buffer zone in the study area (Amiri and Nakane, 2006) in order to determine which trial would be able to generate more robust regression models. Average Percentage of Deviation (APD) was applied:

$$APD = \frac{1}{n}\sqrt{\left(\frac{X_{\text{obs}} - X_{\text{pred}}}{X_{\text{obs}}}\right)} \times 100 \tag{6}$$

where $X_{\text{obs}}$ is observed value; $X_{\text{pred}}$ predicted value and $n$ stands for number of observations.

The accuracy of regression models was promoted by integrating the land use data of buffer zone with entire catchment (Table 5). It might also be noted that the improvements in the performance of the developed regression models were observed when integrating land use data of entire catchment with those of buffer zone for the models of SS and TN (Table 5). The simultaneous application of these approaches could result in the development of a regression model of pH. Nevertheless, the separate

Table 4 Results of multiple regressions modeling between river water quality and land use at catchment and buffer zone scales

| Model | | Statistics | | | | Sharpio-Wilk test | |
|---|---|---|---|---|---|---|---|
| Dependent | Independent | S.E. | $r^2$ | $p$ | VIF | Statistics | Sig. |
| pH | | | 0.870 | 0.041 | | 0.923 | 0.394 |
| | Cons | 0.113 | | | | | |
| | $P$ | 0.000 | | | 3.480 | | |
| | $U$ | 0.018 | | | 3.875 | | |
| | $A$ | 0.018 | | | 3.786 | | |
| | $G$ | 0.021 | | | 1.709 | | |
| | $W$ | 0.288 | | | 5.561 | | |
| | $W_b$ | 0.200 | | | 6.111 | | |
| DO | | | 0.400 | 0.039 | | 0.892 | 0.199 |
| | Cons | 0.991 | | | | | |
| | $G$ | 0.529 | | | 1.000 | | |
| SS | | | 0.880 | 0.000 | | 0.858 | 0.066 |
| | Cons | 2.559 | | | | | |
| | $P$ | 0.005 | | | 1.514 | | |
| | $U_b$ | 0.189 | | | 1.391 | | |
| | $G_b$ | 0.472 | | | 1.685 | | |
| TN | | | 0.900 | 0.000 | | 0.818 | 0.021 |
| | Cons | 0.122 | | | | | |
| | $P$ | 0.001 | | | 2.937 | | |
| | $U$ | 0.024 | | | 2.468 | | |
| | $W_b$ | 0.162 | | | 1.449 | | |
| TP | | | 0.668 | 0.001 | | 0.977 | 0.930 |
| | Cons | 0.196 | | | | | |
| | $U$ | 0.032 | | | 1.000 | | |

Notes: $A$. agriculture in entire catchment; $G$. grassland in entire catchment; $U$. urban in entire catchment; $W$. water body in entire catchment; $G_b$. grassland in buffer zone; $U_b$. urban in buffer zone; $W_b$. water body in buffer zone; Cons. constant; $P$. human population density

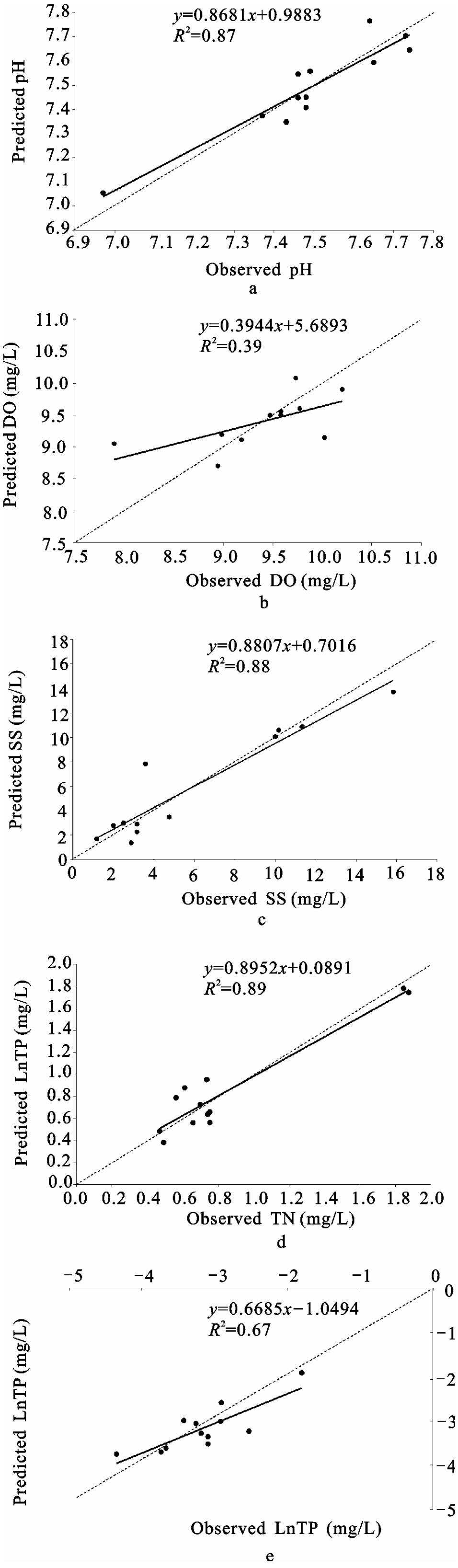


Fig. 4 Relationships between predicted and observed pH (a), DO (b), SS (c),TN (d) and TP (e) in entire catchment and buffer zone

application of land use data in the entire catchment or buffer zone could not develop a regression model representing the relationship between pH and land use types.

It should be mentioned that no incremental improvement was observed in the performance of the model of DO when all variables were considered. Although a statistically significant regression model of BOD was developed by using the land use data in entire catchments (First trial), no statistically significant model appeared by using the land use data in buffer zone (Second trial) or by using the land use data in both buffer zone and entire catchment (Third trial).

The decrease of accuracy was observed in the regression model of TP in the Third trial, compared with the accuracy of that in the First trial. It can be concluded that the Third trial has higher accuracy than other two trials regarding predicting SS and TN in this study.

## 4 Conclusions

Application the present approach for modeling the relationship between land use and stream water quality could result in some incremental improvements in pH, TN and SS based on the result of performance analysis as shown in Table 5. It might be implied that using the entire catchment and buffer zone land use might be considered as another option for modeling the linkage between land use and river water quality. It should be mentioned that the developed regression models might not be affected by annual fluctuations of hydrological conditions, since annual mean concentrations of all river water quality variables were input to develope the regression models to predict the water quality variables (pH, DO, SS, TN and TP) in the study area. Although the multiple regression models developed in this study have a coefficient of determination in a moderate level ($0.40< r^2<0.90$), they are restricted to catchments whose area varying between 67–932km$^2$, since the local variation might play an important role in smaller river basins. Moreover, these variations could not be recognized at a larger scale. Land use planning and environmental impact assessment are the two main measures to achieve sustainable development. The first, land use planning, prevents the outbreak of adverse environmental issues induced by improper site selection on a regional scale; and the second, environmental impact assessment, is designed to protect environment by controlling the im-

Table 5 Performance analyses of developed regression models

| Model | First trial (Entire catchment) | | Second trial (Buffer zone) | | Third trial (Entire catchment and buffer zone) | |
|---|---|---|---|---|---|---|
| | $R^2$ | APD | $R^2$ | APD | $R^2$ | APD |
| pH | – | – | – | – | 0.87 | 0.15 |
| DO | 0.39 | 0.86 | – | – | 0.40 | 0.86 |
| BOD | 0.72 | 37.24 | – | – | – | – |
| SS | 0.72 | 18.64 | 0.86 | 16.6 | 0.88 | 7.16 |
| TN | 0.86 | 7.01 | 0.91 | 6.16 | 0.89 | 3.74 |
| TP | 0.68 | 1.37 | – | – | 0.67 | 1.90 |

plementation of projects, which might have adverse impacts on the environment. Depending on the nature of the projects, implementation of the plans of land use planning would cause extensive changes in compositional structure of the land use in a given study area. These extensive changes in land use would, in turn, create many changes in the water quality of the river. Therefore, these consecutive changes in environmental quality should be considered before implementation of the findings of land use planning in order to achieve one of the main objectives of land use planning: the sustainable supply of water which meets environmental standards. The results of the present study provide the required mathematical models that local land managers need to validate land use planning proposals, and to assess if the proposal would adversely affect the environmental quality of a river in the targeted catchments. Another alternative integrates the proposed mathematical models into the land use planning process. This integration would lead to the application of the models in site-allocation for human activities in the land use planning process in the study area.

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