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Modeling the Relationship between Land Cover and River Water Quality in the Yamaguchi Prefecture of Japan

Amiri, Bahman Jabbarian* and Kaneyuki Nakane

Division of Environmental Dynamics and Management, Graduate School of Biosphere Science, Hiroshima University,
1-7-1 Kagamiyama, Higashi-Hiroshima 739-8521, Japan

ABSTRACT: This study investigated the relationship between land cover and the water quality variables in the rivers, which are located in the Yamaguchi prefecture of West Japan. The study area included 12 catchments covering 5,809 Km^2. pH, dissolved oxygen, suspended solid, *E. coli*, total nitrogen and total phosphorus were considered as river water quality variables. Satellite data was applied to generate land cover map. For linking alterations in land cover (at whole catchment and buffer zone levels) and the river water quality variables, multiple regression modeling was applied. The results indicated that non-spatial attribute (%) of land cover types (at whole catchment level) consistently explained high amounts of variation in biological oxygen demand (72%), suspended solid (72%) and total nitrogen (87%). At buffer zone-scale, multiple regression models that were developed to represent the linkage between the alterations of land cover and the river water quality variables could also explain high level of total variations in suspended solid (86%) and total nitrogen (91%).

Key words: Land cover, Modeling, Population density, Water quality

INTRODUCTION

The water quality of rivers is generally linked to the land use in the catchment. Land use can affect the quality and quantity of runoff during and after rainfall (Richards and Host 1994). Most water pollution problems are caused by changes in land use patterns on catchments as human activities increase (Lee and Bastemeijer 1991). Tong (1990) found that urban development in the catchment caused a substantial modification in the flood runoff and water quality in the catchment. Changing land use and land management practices are regarded as the main factors behind the alteration of the hydrological system, causing changes in runoff (Wu and Haith 1993, Mander 1998) as well as the quality of receiving water (Changnon and Demissie 1996). Higashi et al. (1985) studied the relationship between turbidity and land use in the Seno river of Japan. Their study revealed the existence of a negative correlation between the turbidity and the percentage of forest area in the four catchments and a positive correlation between the turbidity and that of cultivated or residential land.

Most studies have assessed the impact of land use on either the quality or the quantity of runoff. Moreover, some studies are very specific to a locality at one geographical scale, most of which focus on either statistical, spatial, or modeling analysis. Examples of such work include those done by Meissner et al. (1991), Ferrier et al. (1995), Mattikalli and Richards (1996), Wu and Haith (1993), Hulme et al. (1993) and Bouraoui et al. (1998). Current methods on predicting the river water quality based on land use pattern are still developing and most research work is confined to field studies. Only a few studies have employed an integrated approach that involves the use of statistical and spatial analysis, as well as hydrologic modeling to examine the hydrologic effects of land use on both regional and local scale (Tong and Cheng 2002). The objectives of this study are 1) to investigate the relationship between the land cover and water quality variables like pH, dissolved oxygen, suspended solid, *E. coli*, total nitrogen, total phosphorus, and 2) to develop multiple regression models to represent relationships between land cover types and water quality variables at whole-catchment and buffer zone levels in the rivers of this study area.

MATERIALS AND METHODS

Study Site

The present study was carried out in the Yamaguchi prefecture of Japan which is in the west of Honshu island within 34° 04' 00" N and 131° 38' 00" E. It includes 12 rivers and covers 5,809 km^2 (Fig. 1). The underlying geology is largely rhyolite in the north and northeastern parts; Mesozoic sedimentary formations (sandstone/ shale/ pudding stone) in the west and southwestern section; and crystalline schist, dolerite and gravel/clay in the southern parts of the study area. Ochric cambisols, dystric regosols and rhodic acrisols are the dominant soil types that can be observed in each

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* Corresponding author; Phone: +81-82-424-6510, e-mail: amiri@hiroshima-u.ac.jp

catchment. There are 1,527,964 inhabitants in the study area (Statistic Bureau of Ministry of Internal Affairs and Communications: http://www.stat.go.jp).

Forest is the dominant land cover type in the study area. Population density, area of each catchment and the land cover types at whole-catchment and the compositional attribute (%) of land cover at a 30 meter-buffer zone around river network within the each catchment were summarized in Tables 1 and 2, respectively. There are 18 major rivers in the Yamaguchi Prefecture, which 12 out of 18 were selected as our study area based on the availability of water quality data (Fig. 1).

Data Sets

pH, dissolved oxygen (DO), suspended solid (SS), *E. coli*, total nitrogen (TN), total phosphorus (TP) were selected as the factors representing the water quality of the rivers. The water quality data were obtained from the Ministry of Land, Infrastructure and Transport (http://www1.river.go.jp) and Yamaguchi Prefecture Office (http://www.pref.yamaguchi.jp) that is responsible for carrying out the river water sampling and analysis on the monthly intervals. Water quality variables are analyzed according to JIS standard method (http://www.apec-vc.or.jp). Details of sampling method, transport and analysis procedures could be obtained by accessing the website of Japanese Standards Association (http://www.jsa.or.jp). For present study, annual mean of water quality data in 2001 were used without any data power transformations (Table 3). Population data were based on the population census in 2000 that carried out by Statistic Bureau of Ministry of Internal Affairs and Communications (http://www.stat.go.jp/data/kokusei/2000/final/zuhyou/008-02.xls).

Digital topographical maps (scale: 1:200,000) were obtained from Japan Geographical Survey Institute (JGSI) and applied to delineate the catchments (Fig. 1). Satellite images (NASA Landsat-5 TM, 2000/

Table 2. Compositional attribute of the land cover at the 30 meter-buffer zone from river network in each catchment

Catchment No.	Land covers (%)				
	Urban	Forest	Agriculture	Grassland	Water body
1	1.3400	86.5250	5.8630	5.6710	0.2090
2	4.1724	75.0970	13.9789	6.2248	0.5269
3	4.6799	85.0060	5.1961	4.8332	0.2723
4	2.5000	84.2061	7.6741	5.6199	0.0000
5	0.7519	92.2243	2.6653	3.4657	0.8749
6	6.4308	74.8488	10.0090	7.9549	0.6663
7	11.9106	73.6096	7.2196	6.7366	0.4503
8	2.6506	85.5618	3.8944	7.3398	0.5734
9	3.4426	74.0487	12.5662	8.9208	1.0217
10	11.5680	69.5841	9.8596	8.6294	0.3589
11	5.9458	76.7274	9.2921	7.4211	0.5795
12	4.0050	78.7000	8.8189	6.6864	1.5395

Table 1. Land cover and population density at the whole-catchment level in the Yamaguchi prefecture

Basin number	River name	Area (km^2)	Land covers (%)					Population density (Person/km^2)
			Urban	Forest	Agriculture	Grassland	Water body	
1	Awano	182	1.97	86.61	5.62	5.89	0.28	63
2	Kakefuchi	85	4.36	71.94	16.35	5.42	1.04	106
3	Fuka	72	6.39	84.17	5.01	4.27	0.10	150
4	Misumi	67	1.36	88.41	5.05	4.18	0.00	70
5	Nishki	932	1.04	91.76	2.76	3.72	0.71	165
6	Shimada	284	5.91	77.75	8.14	7.72	0.43	267
7	Saba	572	2.62	88.35	2.89	5.61	0.53	225
8	Washino	300	13.99	72.84	6.96	5.89	0.30	434
9	Kotou	416	3.8	75.64	8.83	10.91	0.79	253
10	Ariho	98	9.23	72.76	9.24	8.34	0.44	477
11	Asa	226	6.24	78.09	7.14	7.94	0.52	109
12	Koya	299	4.67	78.67	7.97	7.46	1.07	362

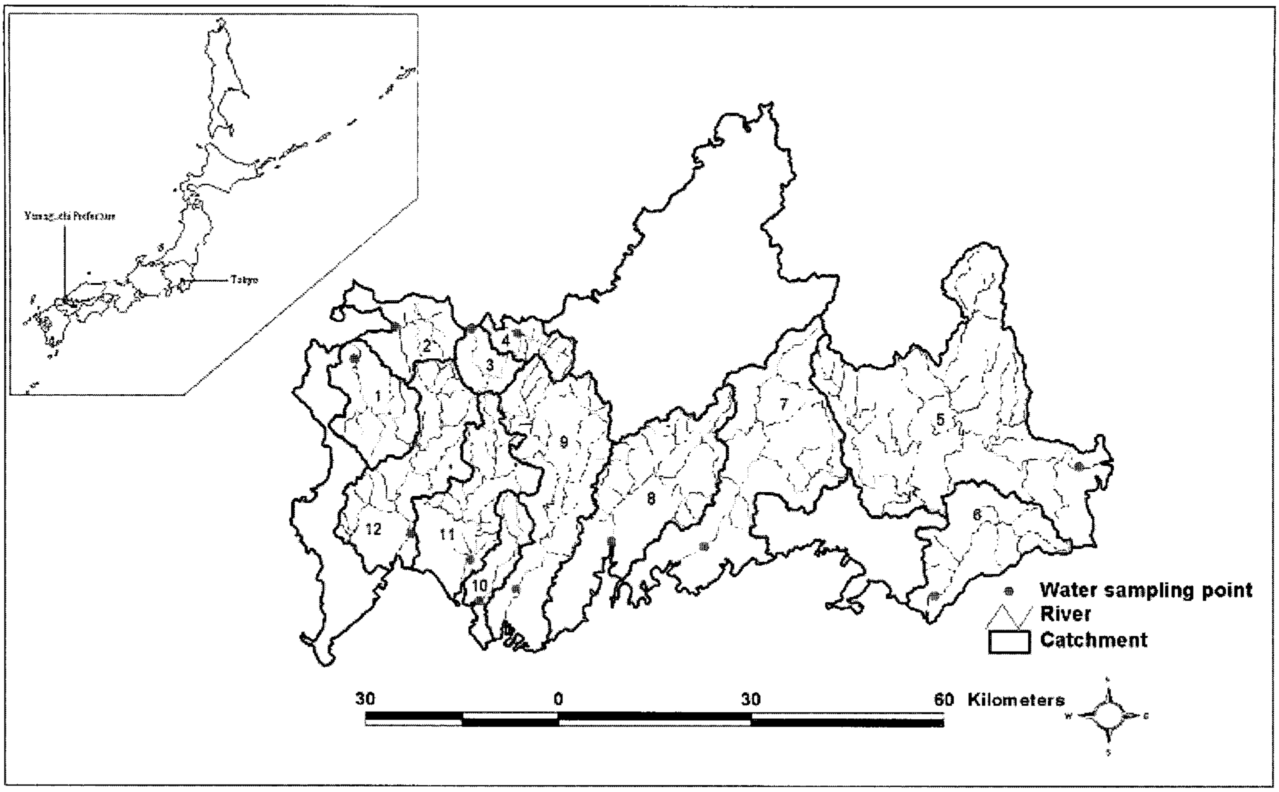


Fig. 1. Geographical situation of the study area.

Table 3. Descriptive statistics of the annual mean of water quality data of rivers in the study area

Catchment No.	Water quality variables																				
	pH			DO (mg/L)			BOD (mg/L)			SS (mg/L)			*E. coli* (MPN/100 mL)			TN (mg/L)			TP (mg/L)		
	Median	Min	Max	Median	Min	Max	Median	Min	Max	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	3150	1400	33000	0.52	0.31	0.58	0.02	0.02	0.05
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	12000	4900	24000	0.66	0.49	0.82	0.03	0.03	0.07
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	3850	700	13000	0.61	0.53	0.71	0.03	0.02	0.05
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	4200	1300	7900	0.74	0.59	0.93	0.02	0.02	0.04
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	4750	330	49000	0.47	0.41	0.64	0.01	0.01	0.02
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	7900	790	33000	0.73	0.56	0.88	0.03	0.02	0.07
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	1500	140	17000	0.50	0.40	0.77	0.05	0.03	0.06
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	2600	330	28000	1.62	1.03	3.06	0.17	0.08	0.28
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	4750	330	49000	0.76	0.54	0.94	0.04	0.02	0.09
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	17500	3300	330000	1.24	0.78	5.55	0.05	0.03	0.08
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	12000	3300	130000	0.74	0.56	0.89	0.05	0.03	0.10
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	1600	170	24000	0.71	0.50	1.00	0.08	0.03	0.13

05/04) were used to generate land cover maps of the study area.

GIS and Remote Sensing Analysis

The present study was conducted using a tempo-spatial analysis. This approach involves analyzing environmental conditions by selecting as many study units (in this case, catchments) as possible in the study area in a given time period. In order to facilitate the spatial analysis and determination of morphological attributes, Geographical Information System was established using the ArcView 3.2 (ESRI 1999). For each water sampling point, catchment boundaries were hand-digitized by using 1:200,000 topographic quadrangle maps. Topographic-based boundaries were edited to reflect the influence of major storm water drain systems on drainage patterns. All databases were transformed into a common digital format, projected onto a common coordinate system (UTM, zone 52).

Population density map was firstly generated by linking the county-scale population database with the digital map of counties. It was then overlaid by the catchments map and aggregated in order to find the catchment-scale density map in the study area.

For generating land cover maps in the study area, one scene of satellite data (NASA-Landsat-5, 2000/05/04) was used. The satellite image was geo-referenced by the affine procedure with a sigma value equal to 1.19. This measurement tells us how well the transforms of the control points coordinates match with their photo coordinates. In order to generate the color composite map, Optimum Index Factor Analysis was carried out for finding the best probable thermal band composition (bands 1, 4 and 5). Following on from this, the supervised classification method was applied to classify land covers, which included forest, agriculture, grassland, urban and water body (wetlands, natural and artificial lake). The supervised classification method extracts thematic data from digital images. Before image analysis is undertaken, knowledge on the principal land cover types in a given region are collated. This forms the basis of the training sites, created by the user, as a means of training the classification algorithm to seek areas of similar spectral properties, which will be classified as the same type.

The generated land cover map was validated using JGSI maps. Preparing, interpreting and analyzing the satellite images were carried out using the Integrated Land and Water Information System (ILWIS 3.2 Academic Version, 2004). Hydrological (river) network was hand digitized using 1:200,000 digital topographical maps (JGSI) for each catchment. A 30-meter buffer zone (equal to satellite image resolution) was then generated using the hydrological network in each catchment by ArcView 3.1. The land cover map was then superimposed by the buffer zone and catchment maps for calculating the real extend of each land cover within the buffer zone and catchment, which was subsequently divided by the buffer zone and catchment areas to drive the percentage of the buffer zone and catchment covered by each type.

Statistical Analysis

All water quality variables and land cover data were tested for normality using the Sharpio-Wilk test with a p-value of less than 0.05 (Table 4). Spearman rank correlation analysis was then used to determine if any of the water quality variables were correlated with changes in compositional attribute (%) of land cover at catchment (Table 5) and buffer zone levels in the study area as normal distribution was not revealed for pH, SS, *E. coli*, TN and TP.

For determination of linkage between land cover and river water qualities, multiple regression modeling methods (linear, logarithmic, power and exponential) were applied using backward approach in order to achieve the best fit model for a given water quality variable. Inter-variable collinearity of the models was investigated referring to Variance Inflation Factor (VIF). Although land cover and river water quality data set were used for regression modeling in their initial form without any power transformations, normality of residuals of the models were then examined by Sharpio-Wilk test with a p-value<0.05 (Tables 6 and 7). For a given water quality

Table 4. Results from normality test of the river water quality variables and compositional attribute of land covers at catchment and buffer zone levels

Variable	Sharpio-Wilk (catchment-scale)		Sharpio-Wilk (buffer zone-scale)	
	Statistic	Sig.	Statistic	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.

variable, the appropriate model was selected based on regression statistics (r^2, p-value) and considering the significance of the coefficients of the model provided that the residuals of the model was normally distributed.

Finally, the goodness-of-fit of the statistically significant regression models was evaluated by scatter plot (Figs. 2a, b, 3a~e); and simple linear regression of observed *versus* equivalent model prediction (Ahearn et al. 2005).

Statistical analyses were completed using Excel Add-ins (XLSTAT^{TM} 2006) and SPSS for Windows Release10.

Table 5. Spearman correlation analysis of water quality variables and land cover

Water quality variable	Population density	Urban	Forest	Agriculture	Grassland	Water body
PH	**0.568***	0.414	**−0.551**	0.351	**0.601**	0.418
DO	−0.259	0.021	0.13	−0.329	**−0.567**	−0.196
BOD	**0.64**	**0.724**	**−0.801**	**0.615**	**0.657**	0.38
SS	**0.655**	0.518	**−0.673**	**0.644**	**0.74**	0.259
ECOLI	0.091	0.294	**−0.574**	**0.557**	0.449	0.165
TN	0.539	**0.564**	**−0.578**	0.532	0.533	−0.109
TP	**0.697**	**0.718**	**−0.637**	0.483	**0.646**	0.35

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

RESULTS AND DISCUSSION

Land Cover-River Water Quality Linkage

The Spearman correlation coefficient analysis (Table 5) suggests that pH ($r=0.60$, $p<0.05$), BOD ($r=0.66$, $p<0.01$), SS ($r=0.74$, $p<0.01$) and TP ($r=0.65$, $p<0.01$) are positively related to the grassland area (%). It also revealed a negative significant correlation between DO ($r=-0.57$, $p<0.05$) and alteration in the proportion of the grassland area. This could be related to the transforming of the vegetation from forest to grassland in general and to the improper management of grasslands in particular, which can cause degradation of water quality due to soil erosion and sediment transportation into rivers.

There was a negative significant relationship between pH ($r=-0.55$, $p<0.05$), BOD ($r=-0.80$, $p<0.01$), SS ($r=-0.67$, $p<0.01$), *E. coli* count($r=-0.57$, $p<0.05$), TN ($r=-0.58$, $p<0.01$) and TP ($r=-0.64$, $p<0.01$), and the forest area (%). It would be related to the lower erosion rate on forested lands that in turn decreases the transportation of elements attached to soil particles into rivers (Kaste et al. 1997). The erosion rate of different land cover types was predicted using Modified Universal Soil Loss Equation (MUSLE) and Revised Universal Soil Loss Equation (RUSLE) by Erskine et al. (2002). They found that sediment yield of forest basins (3.1 t ha^{-1} year^{-1}) are significantly lower than that of grazed pasture basins (3.3 t ha^{-1} year^{-1}) and that of the cultivated basins (7.1 t ha^{-1} year^{-1}). Ngoya and Machiwa (2004) also reported the lowest value of turbidity in forested areas based on direct measurements.

Positive significant correlations were revealed between BOD (r=

Table 6. Results from multiple regression modeling between river water quality variables and compositional attribute of land cover at a 30 meter-buffer zone around the hydrographical (river) network

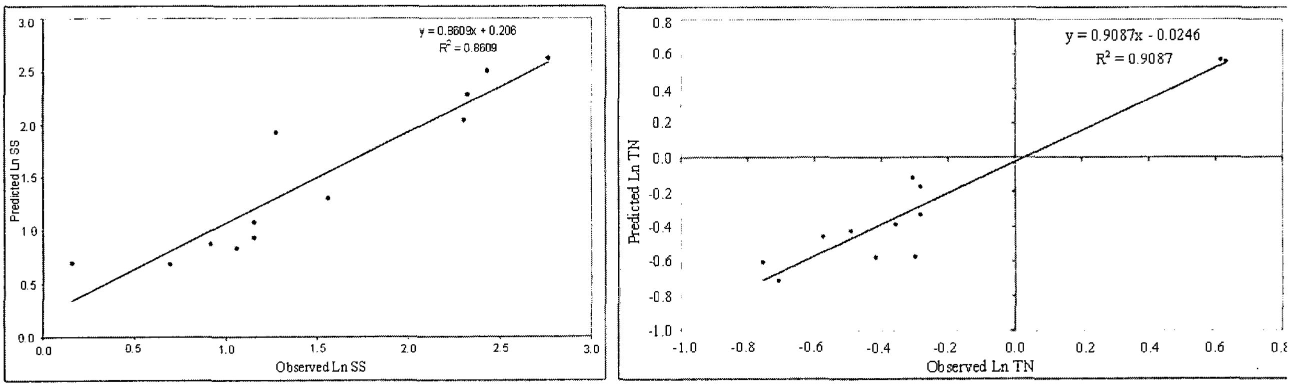
Model	Regression model	Variable		Coefficient	Statistics				Sharpio-Wilk test	
		Dependent	Independent		S.E.*	r^2	p	VIF	Statistics	Sig.
Buffer zone-scale:										
	Exponential	SS	*Cons.*	−0.913	0.476	0.861	0.001		0.786	0.011
			Population density	0.003	0.001			1.518		
			Urban	−0.102	0.035			1.406		
			Grassland	0.334	0.086			1.661		
	Exponential	TN	*Cons.*	−0.937	0.233	0.909	0.001		0.958	0.693
			Population density	0.003	0.000			1.697		
			Urban	−0.044	0.018			1.937		
			Grassland	−0.089	0.042			1.672		
			Water body	−0.637	0.148			1.420		

*S.E.: Standard error.

Table 7. Results from multiple regression modeling between river water quality variables and compositional attribute of land cover at catchment level

Model	Regression model	Variable			Statistics				Sharpio-Wilk test	
		Dependent	Independent	Coefficient	S.E.*	r^2	p	VIF	Statistics	Sig.
Catchment-scale:										
	Logarithmic	DO	*Cons.*	11.764	0.991	0.394	0.039		0.892	0.199
			Grassland	−1.280	0.529			1.000		
	Power	BOD	*Cons*	−0.680	0.119	0.720	0.006		0.923	0.392
			Urban	0.330	0.074			1.089		
			Water body	0.152	0.078			1.089		
	Power	SS	*Cons.*	−4.559	1.387	0.722	0.006		0.955	0.651
			Grassland	1.417	0.532			1.146		
			Population density	0.651	0.260			1.146		
	Exponential	TN	*Cons.*	−0.900	0.152	0.866	0.001		0.990	0.990
			Agriculture	0.057	0.019			1.375		
			Water body	−0.720	0.203			1.402		
			Population density	0.003	0.000			1.032		
	Exponential	TP	*Cons.*	−3.892	0.196	0.668	0.001		0.985	0.985
			Urban	0.142	0.032			1.000		

* S.E.: Standard error.



(a) (b)

Fig. 2. Predicted to observed values for SS (a) and TN (b) from which were generated from the model using land cover at a 30-meter buffer zone scale. The line shown in the graphs represent regression line between observed and predicted values.

0.72, $p<0.01$), TN ($r=0.56$, $p<0.05$), TP($r=0.72$, $p<0.01$) and the urban area (%), and between BOD ($r=0.61$, $p<0.05$), SS ($r=0.64$, $p<0.01$) and *E. coli* ($r=0.56$, $p<0.05$); and the agricultural area (%) (Table 5).

E. coli count revealed a negative relationship ($r=-0.57$, $p<0.05$) with the area of forest area (%) and a positive association ($r=0.56$, $p<0.05$) with agricultural area (%) (Table 5). *E. coli*, as a species of fecal coliform, enters streams directly from domestic or wild animals, storm runoff from agricultural land carrying waste, and from human sewage. The water quality of rivers and other water bodies would be badly affected by the presence of high levels of fecal coliform bacteria, which is indicative of contamination by feces

(Hubbard et al. 2004). Kelsey et al. (2004) examined the effects of land-use on fecal coliform counts using GIS techniques and regression analysis. They found that proximity to areas with septic tanks, and rainfall runoff from urbanized areas was important predictors of fecal coliform count.

TN levels indicated a negative association (r=−0.58, p<0.05) with the forest area (%) and a positive relationship (r=0.56, p<0.05) with that of urban (Table 5). Nitrogen exists in soil as NO_2, NO_3, or NH_4, or in organic forms within the soil organic matter fraction. Nitrate ions are repelled by the clay particles in the soil and generally are not absorbed within the soil matrix. Hence, as water moves through the soil, N generally moves freely with the water (Hubbard et al. 2004). Nitrogen could generally originate from human sewage and over-fertilization of lawns (Hubbard and Sheridan 1989). Human sewage might be affected by some factors like population density and level of sewage treatment. Considering the controlling function of forests on the Nitrogen cycle (absorption and storage), it could reduce the rate of the free movement of Nitrogen from soil

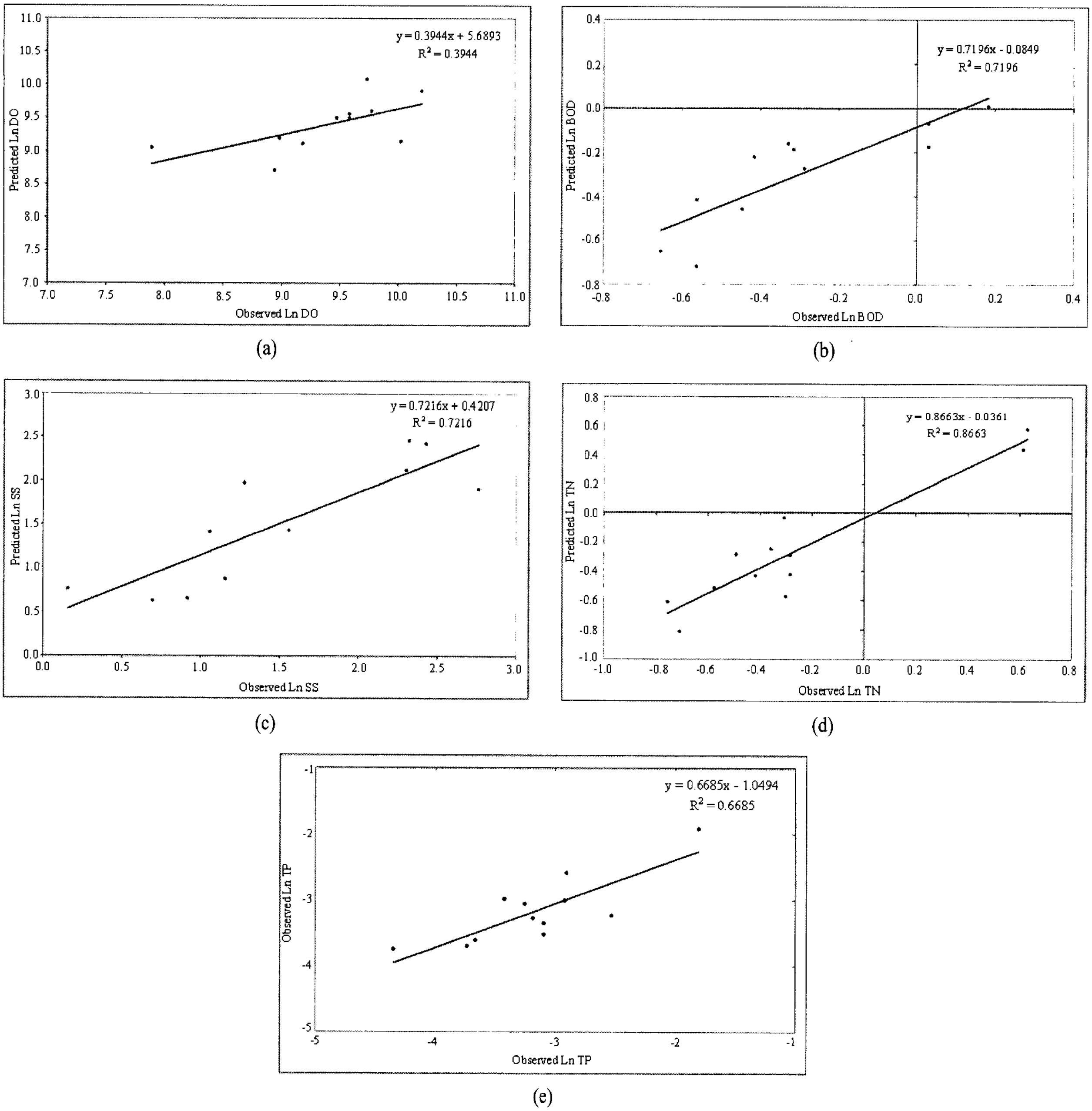


Fig. 3. Predicted to observed values for DO (a), BOD (b), SS (c), TN (d) and TP (e) from which were generated from the model using a whole-catchment land cover data. Lines shown in the graphs represent regression line between observed and predicted values.

particles into streams (Kaste et al. 1997).

Consequently, an inverse relationship between the concentration of TN and the area of forest would be related to the controlling role of forest in the movement of Nitrogen in the ecosystem of catchments. Although Tong and Cheng (2002) reported a strong positive relationship between concentrations of TN, TP and the areas of urban and that of agricultural land, the negative relationship between the area of forest and concentration of TN was also confirmed by Norton and Fisher (2000), and Tong and Cheng (2002).

The river TP levels showed a significant relationship with population density, the urban and grassland areas (%); and a negative association with the forest area (%). Tong and Chen (2002) suggest a strong relationship between TP levels with urban area (%) and that of agricultural lands. Ngoye and Machiwa (2004) reported that the concentration of TP was higher at measuring stations in urban and agricultural areas, as well as river mouths, than at measuring stations in forested areas.

Land Cover - River Water Quality Linkage Modeling

A backward approach was applied for determining a final regression model representing the linkage between land cover and river water quality variables at catchment and buffer zone levels. For each regression model, the initial fixed variables were compositional attributes (%) of land cover variables (*urban, forest, agriculture, grassland* and *water body*), the river water quality variables (*pH, DO, BOD, SS, E. coli, TN* and *TP*) and *population density*. The results of multiple regression modeling were summarized in Tables 6 and 7 that are described as follows:

In the DO logarithmic regression model (r=0.40, p<0.05), *grassland area* (%) was chosen as an explanatory variable at catchment level. Other variables were eliminated, as they were not selected during backward approach. No significant regression model was achieved to represent the linkage between the river DO levels and compositional attribute (%) of land cover at buffer zone level.

In the BOD power regression model (r=0.72, p<0.01), the explanatory variables like *forest, grassland* and *population density* were excluded from the final model. Only *urban* and *water body* were considered as significant predictors of BOD at catchment level. At buffer zone level, alterations in compositional attribute of land cover could not explain the BOD levels.

In the SS power regression model (r=0.72, p<0.01), *grassland* and *population density* were observed as significant explanatory variables. Other variables (*urban, forest, agriculture* and *water body*) were not indicated as significant variables explaining the linkage between compositional attribute (%) of land covers and the SS levels at catchment level. At buffer zone level, 86% of the total variations in the river SS levels would be explained by alterations in compositional attribute (%) of *urban, grassland areas* and *population density*.

In the TN exponential regression model (r=0.87, p<0.01), although two land cover variables (*agriculture* and *water body*) out of five land cover variables played key role in explaining the total variations in the TN levels at catchment level, three variables (*water body, urban* and *grassland*); and *population density* indicated as significant explanatory variables in the TN model at buffer zone-scale. It was observed that about 91 % of the total variations in the TN levels were explained by alteration in compositional attribute (%) of land cover at buffer zone scale.

In the TP exponential regression model (r=0.67, p<0.01), only one land cover variable (*urban*) out of five land cover variables (*forest, agriculture, grassland* and *water body*) was indicated as an explanatory variable at catchment-scale. For the TP, no compositional attribute of other land cover was observed as a significant explanatory variable.

Inter-variable collinearity of the regression models was investigated by referring to VIF (Tables 6 and 7). While a VIF>10 could be considered as severe collinearity within variables in the models (Neter et al. 1996, Chatterjee et al. 2000), all models have revealed no collinearity (VIF<2).

Normality of residuals of the models were tested using the Sharpio-Wilk test with a p<0.05 whether they follow a normal distribution. The results of the test were summarized in Tables 6 and 7. It suggests the residuals of all models were normally distributed at significance level of p<0.05.

For validating of the goodness-of-fit of the statistically significant models, simple linear regression analysis of observed value *versus* the values predicted by the relevant models was carried out and plotted. Figs. 2a, b, 3a ~ e depicted the relationship between the observed and predicted values of stream water quality variable (SS and TN) in buffer zone level analysis and those of stream water quality variable (DO, BOD, SS, TN and TP) at catchment level analysis, respectively.

The developed regression models might not be affected by annual fluctuations of hydrological conditions, since concentration (mg/L) of all river water quality variables were used as input data for developing the regression models and could be used to predict the water quality variables (DO, BOD, 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<0.91), their uses are restricted to the specific range of variables for catchments approximately 67 ~ 932 km^2. Below this level, there is always the possibility of local variation, which may play an important role. It seems that these variations may not be recognizable at higher scale.

CONCLUSION

The results of this investigation indicated that grassland act as a source for suspended solid at catchment and buffer zone scales, and as the proportion of grassland increases, suspended solid levels downstream increases. Degrading impact of grassland area on DO levels was observed as the proportion of grassland area (%) increases at catchment level, it downstream would be decreased.

Urban area (%) revealed a degrading impact on the river water quality (BOD and TP levels) as the proportion of urban area increases at catchment level, it would give rise to increase BOD and TP levels. It also regulated suspended solid and TP levels at buffer zone-level as the proportion of urban increases, it will exponentially decrease suspended solid and TN levels.

Water body acted as a sink for TN levels at buffer zone and catchment levels, as the proportion of water body increases, TN levels downstream decrease.

The present study indicated that TN levels would exponentially be explained by alterations in the compositional attribute (%) of the land cover at both buffer zone and catchment levels. Different functions (sink and source) were not observed for a given land cover at different scale (buffer zone and catchment levels) in this study.

Implementing the land use plans would sometimes create drastic changes in the compositional structure of land use in the catchments. It seems to be necessary to assess the impact of altering the compositional structure of land use on quality and quantity of water generated by catchments. The suggested models would be utilized as a significant managerial tool for land cover planners in the Yamaguchi prefecture in order to predict the probable alterations in BOD, SS and TN induced by changing the compositional structure of land cover. On the other hand, it may also be applied to supplement the land use change model to predict changes in the pollution levels of rivers. Moreover, they would be used in assessing the environmental impact (from the viewpoint of water quality) of future projects, which inherently affect the land use in the study area.

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LITERATURE CITED

Ahearn DS, Sheibley RW, Dahlgren RA, Anderson M, Johnson J, Tate KW. 2005. Land use and land cover influence on water quality in the last free-flowing river draining the western Sierra Nevada, California. J Hydrol 313: 234-247.

Bouraoui F, Vachaud G, Chen T. 1998. Prediction of the effect of climatic changes and land use management on water resources. Physics Chem Earth 23(4): 379-384.

Changnon SA, Demissie M. 1996. Detection of changes in stream flow and floods resulting from climate fluctuations and land use drainage changes. Climatic Change 32: 411-421.

Chatterjee S, Hadi AS, Price B. 2000. The use of regression analysis by example. John Wiley and Sons, New York, USA.

Erskine WD, Mahmoudzadeh A, Myers C. 2002. Land use effects on sediment yields and soil loss rate in small basins of triassic sandstone near Sydney, Australia. CATENA 49: 271-287.

ESRI (Environmental Systems Research Institute). 1999. ArcView GIS Software. Redlands, California, USA.

Ferrier RC, Whitenhead PC, Sefton C, Edwards AC, Pugh K. 1995. Modeling impacts of land use change and climate change on nitrate-nitrogen in the River Don, North East Scotland. Water Research 29(8): 950-956.

Higashi T, Nakane K. 1985. Relationship between turbidity in a river water and land use types in the basin, Mem. Faculty of Integrated Arts and Science, Hiroshima University, Series IV, 10: 69-83.

Hubbard RK, Newton GL, Hill GM. 2004. Water quality and the grazing animal. J Animal Sci 82 (E. Suppl.): 255-263.

Hubbard RK, Sheridan JM. 1989. Nitrate movement to groundwater in the southeastern Coastal Plain. J. Soil Water Conserv 44: 20-27.

Hulme M, Hossel JE, Parry ML. 1993. Future climate change and land use in the UK. Geograph J 159(2): 131-147.

Integrated Land and Water Information System (ILWIS). 2004. The Remote Sensing and GIS Software. ITC, the Netherlands.

Jensen JR. 1998. Introductory digital image processing: A remote sensing approach (2nd ed). Prentice Hall.

Kaste O, Henriksen A, Hindar A. 1997. Retention of atmospherically-deriven nitrogen in subcatchments of the Bierkreim river in Southwestern Norway. Ambio 26: 269-303.

Kelsey H, Porter DE, Scott G, Neet M, White D. 2004. Using geographic information systems and regression analysis to evaluate relationships between land use and fecal coliform bacterial pollution. J Exper Marine Biol Ecol 298: 197- 209.

Lee MD, Bastemeijer TF. 1991. Drinking water source protection: a review of environmental factors affecting community water supplies. Occasional Paper 15. IRC Int'l Water Sanitation Center, The Hague, Holland. pp 5-34.

Mander U, Kull A, Tamm V, Kuusements V, Karjus R. 1998. Impact of climatic fluctuations and land use change on runoff and nutrient losses in rural landscape. Landsc Urban Plan 41: 229-238.

Mattikalli NM, Richards KS. 1996. Estimation of surface water quality changes in response to land use change: application of the export coefficient model using remote sensing and geographical information system. J Environ Manag 48: 263-282.

Meissner R, Seeger J, Rupp H, Balla H. 1999. Assessing the impacts of agricultural land use changes on water quality. Water Sci Tec 40(2): 1-10.

Neter J, Kutner HM, Nachtsheim CJ, Wasserman W. 1996. Applied Linear Statistical Models. Irwin, Chicago, Illinois, USA.

Ngoye E, Machiwa J. 2004. The influence of land use patterns in the Ruvu river catchment on water quality in the river system. Physics Chem Earth 29: 1161-1166.

Norton MM, Fisher TR. 2000. The effects of forest on stream water quality in two coastal plain watersheds of the Chesapeake Bay. Ecol Engin 14(4): 337-361.

Richards C, Host G. 1994. Examining land use influences on stream habitats and macroinvertebrates. Water Resourc Bull 30: 729-739.

Tong STY. 1990. The hydrologic effects of urban land use: A case study of the Little Miami River Basin. Landsc Urban Plan 19: 99-105.

Tong STY, Chen W. 2002. Modeling the relationship between land use and surface water quality. J Environ Manag 66: 377-393.

Wu RS, Haith DA. 1993. Land use, climate and water supply. J Water Resourc Plan Manag 119(6): 685-704.

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