Estimation of organic matter and nutrient loadings from point and non point sources into the Fuji River, Japan: Export coefficient modeling approach

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Abstract: A simple export coefficient modeling approach was used to estimate loadings of organic matters and nutrients from both point and non point sources into Fuji River, Japan. First, we estimated land use export coefficients of organic matters (biochemical oxygen demand (BOD) and chemical oxygen demand (COD_{Mn})), and nutrients (nitrate nitrogen (NO_3-N) and inorganic dissolved phosphorus (PO_4-P)) specific to Fuji river basin. Semi-monthly water quality monitoring data of BOD, COD_{Mn}, NO_3-N and PO_4-P from 8 stations, 6 years stream discharge from 3 stations and land use information were used to estimate land use export coefficients using available hydrological, statistical and spatial tools. A distributed hydrological model, Blockwise use of TOPMODEL with Muskingum-Cunge routing (BTOPMC), was used to estimate discharge for those stations where continuous discharge data was not available. A seven parameter log linear model was used to estimate loadings using historical water quality concentration along with observed and estimated discharge for each sub basins. The annual, seasonal, wet/dry season, high/low flow season and monthly yield as dependent variable and land use proportion in each sub basins as independent variables were used to derive the land use export coefficients through multiple regression technique. These land use export coefficients were used to estimate the total loadings and relative contribution of point and non point source loadings of organic matters and nutrients within the basin by developing an empirical source-contribution model. It was observed that forest is the dominant source of organic matters and inorganic dissolved phosphorus loadings and agriculture is the dominant source of nitrate nitrogen loadings within the basin. Point source organic matters and nutrients loadings represent a much smaller portion of the overall loadings as compared to non point source loadings. Therefore, this study shows that proper management practices has to be developed to reduce organic matters and inorganic dissolved phosphorus loadings from forest and nitrate nitrogen loadings from agriculture to reduce current and future water quality problems in the basin.

***Keywords**:* land use export coefficients; organic matters; nutrients; loadings

1. INTRODUCTION

The waters of Fuji river basin represent a valuable water resource contributing to the prefectural economic base through industrial, agricultural, recreational activities and hydropower operation. Nevertheless, the long term consequences of resulting pressure and demands on the prefectural water resource remain unknown. Of particular concern is the response of waters to increasing non-point source pollutant loadings due to watershed development and land use activities. While the watershed nutrient budget measurement has been continued, the recent cut in funding has limited the resources for current and future watershed diagnostic studies. So far, no attempt has been made to review the existing data provided from long term water quality monitoring and investigate whether basin wide land use export coefficients can be developed to estimate the relative contribution of point and non point source loadings. Land use export coefficients representing the rate of pollutant loadings by land area are often recommended as a way to estimate loadings from non point sources [Loehr *et al.*, 1989; Reckhow *et al.*, 1980], particularly given the short time schedule and limited data for the management practices to improve the water quality within the basin. Therefore, the major objective of this study is to develop land use export coefficients of organic matters and nutrients specific to Fuji river basin using readily available statistical, hydrological and spatial tools and to estimate the total loadings and relative contribution of point and non point sources loadings into the Fuji River.

2. STUDY AREA

Fuji river basin study area, drained by the Fuji River, is located in the central part of Japan (Figure 1). The basin area is 3,570 km^2 and the mainstream length is 128 km.The river originates, as the Kamanashi River, from Mount Komagatake in the north of the Southern Alps, and as the Fuefuki River from the north of Yamanashi Prefecture. These two rivers flow together in the south of Kofu Basin as the Fuji River and subsequently, flows to Pacific Ocean at Suruga Bay.

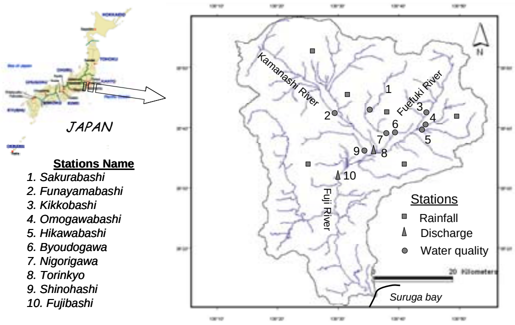

Figure 1. Map of location, rainfall, discharge and water quality monitoring stations of the study area.

The basin has hot and humid summers and cold winters, with average temperatures of 26°C (max.) and 3°C (min.), respectively. The basin receives a mean annual precipitation of ~2100mm.

3. METHODS

The semi-monthly/monthly water quality data of biochemical oxygen demand (BOD), chemical oxygen demand (COD_{Mn}), nitrate nitrogen (NO_3-N) and inorganic dissolved phosphorus (PO_4-P) from 8 stations and 6 years (1995-2000) daily discharge of 3 stations were obtained from Environment Divison of Yamanashi Prefecture (EDYP) and Ministry of Land Infrastructure and Transportation (MLIT) respectively. Rainfall and other meterological data were obtained from MLIT. Similarly, landuse data were obtained from Ministry of Environment. Other relevent information were obtained from literature survey. The methodology outlined below was followed to estimate land use export coefficients for nonpoint source of BOD, COD_{Mn}, NO_3-N and PO_4-P:

a. Determine the major land uses and their proportion in the draingae area above each monitoring site within the river basin. A sub basin map defining drainage area for each sampling site was generated from a digital elevation map (250m) using ArcGIS 8.3 and Arc Hydro tools according to water quality monitoring stations. Land cover map (1:50000) was overlayed and proportion of major landuses in each subbasins were calculated.

b. Estimate discharge at ungauged sites within the basin using distributed hydrological model in those stations where continuous discharge is not available. In order to estimate the discharge at six ungauged sites, a distributed hydrological model, Blockwise use of TOPMODEL with Muskingum-Cunge routing (BTOPMC) [Takeuchi *et al*., 1999] was used. Rainfall and meteorological data of six stations, DEM, land use map, soil map (FAO) were used as input to the model.

c. Estimate loadings by regression modelling using measured, estimated discharge and water quality concentration. A seven parameter log linear model [Cohn *et al*., 1992] (equation below) was used to estimate loadings from each sub basin.The model calculates loads of nutrients (and other constituents) carried by rivers employing a statistical regression model, where the constituent concentrations are estimated based on stream flow and time/season.

$$\ln[L] = \beta_o + \beta_1 \ln\left[\frac{Q}{Q'}\right] + \beta_2 \left\{\ln\left[\frac{Q}{Q'}\right]\right\}^2 + \beta_3[T-T'] + \beta_4[T-T']^2 + \beta_5 Sin[2\pi T] + \beta_6 Cos[2\pi T] + \varepsilon$$

Where *ln* [] denotes the natural logarithm function; L is the estimated daily load (kg/day); Q is the daily discharge (ft^3/s); T is time measured in years; β_0 is a constant; β_1 and β_2 describe the relation between concentration and discharge; β_3 and β_4 describe the trend in concentration data; β_5 and β_6 describe the seasonal variation in concentration data; and ϵ is the combined independent random error.

d. Apply multiple regression model to determine the optimal estimates of export coefficients for major land uses using estimated loadings and land use information. Typically, land use export coefficients are determined by monitoring land uses, such as forest, row crop or urban, using field plots to isolate individual land uses [Reckhow *et al*., 1980]. However, monitoring single land uses watershed may be ideal, most watersheds even small ones, are generally comprised of variety of different land uses [McFarland, 2001]. Therefore to isolate the loading contribution from the heterogeneous drainage areas, multiple regression techniques were used to develop the organic matter/nutrient export coefficients for the major land uses in the watershed based on procedures described by Hodge and Armstrong [1993]. The dependent variable was the annualized nutrient loading and independent variables were landuse proportion in each subbasins.

e. Compare estimated land use export coefficients with available literature values to evaluate the reasonableness of derived coefficients.

f. Develop an empirical source-contribution model to estimate point and non point source loadings

4. RESULTS AND DISCUSSION

4.1 Determination of land uses above stream sampling sites

The size of the drainage area and percentage of major land uses above each sampling site is presented in Table 1. The land use categories and their area included in the classification are forest, agriculture, grassland and urban.

Table 1. Land uses associated with the drainage area above sampling sites in Fuji River basin.

Sites	Forest (%)	Agriculture (%)	Grassland (%)	Urban (%)	Other (%)	Total area (10^3ha)
Kikkobashi	83.91	8.7	4.89	1.57	0.93	24.34
Hikawabashi	78.27	12.72	4.59	2.86	1.55	11.11
Omobashi	59.05	32.41	1.56	6.28	0.7	10.88
Sakurabashi	82.75	9.58	2.78	0.85	4.04	15.50
Funayamabashi	77.23	15.56	2.06	2.91	2.24	48.04
Shinobashi	84.79	6.32	3.81	2.37	2.7	5.95
Nigorigawa	4.62	66.07	1.82	27.08	0.41	1.57
Byoudogawa	65.25	17.55	3.45	12.58	1.17	23.15

While choosing the sampling sites, a careful consideration was given to exclude the major point sources influence into rivers. Although some variations in land use are expected to occur over time, but for this study, land use was assumed to be stable.

4.2 Estimation of discharge

In order to reduce uncertainty in discharge estimation, a calibration of hydrological model was carried out manually minimizing the error between the observed and simulated time series of discharge. A detail description on calibration can be found in Shrestha *et al.* [2005]. The whole basin was divided into two sub basins and calibration of the model for 1995-2000 was carried out by comparing observed and estimated discharge at Fujibashi and Torinkyo stations.

The performance of the model was evaluated by Nash and Sutcliffe (NE) efficiency and water balance component i.e. ratio of simulated to observed volume of discharge. The model performed well in replicating the low and high flows (Figure 2). The Nash efficiencies of 70% and 75% were obtained for Fujibashi and Torinkyo respectively during calibration period. Similarly, the ratio of simulated volume of discharge to the observed volume of discharge (Qsim/Qob) is more than 80% in both stations. In other words, model has slightly underestimated (<20%) the volume of discharge. Therefore, discharge at ungauged sites located at the upstream of the calibrated stations was taken for the further study.

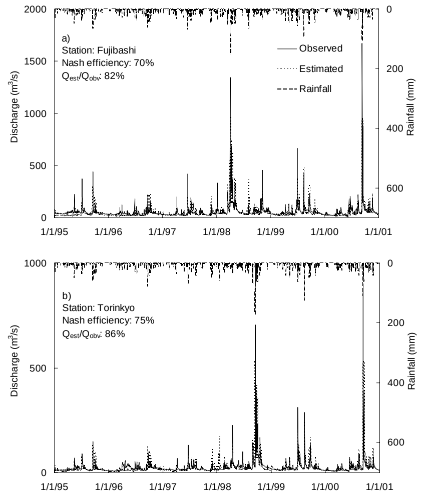

Figure 2. Comparison between observed and estimated discharge at a) Fujibashi and b) Torinkyo.

4.3 Estimation of loadings

A seven parameter log linear model performed very well in estimating loadings. The coefficients of determinations (R^2) for loadings in all basins are >85%. Figure 3 shows a typical case from two sub basins for NO_3-N loading estimation. The lack of fit in estimation was also tested by plotting probability plot correlation coefficient (PPCC) [Vogel, 1986] of the residuals, and found to be normally distributed. Similarly, residuals are plotted against the explanatory variables and against the predicted values; they appeared to be reasonably homoscedastic.

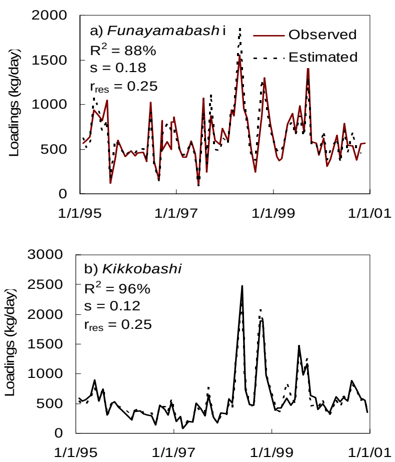

Figure 3. Comparison between observed and estimated NO_3-N loadings in a) Funayamabashi and b) Kikkobashi (*as a typical case*).

Annual, seasonal, wet and dry period, high flow and low flow period, and monthly mean yield of BOD, COD_{Mn}, NO_3-N and PO_4-P are calculated from each sub basins in order to set it as dependent variables in the multiple regression modeling to derive the land use export coefficients. Four seasons defined are spring (March-May), Summer (June-August), Autumn (September-November) and Winter (December-February). Wet (June-September) and dry season (October-May) are defined according to the temporal rainfall distribution. In order to identify high and low flow event, average monthly flow of Fujibashi and Torinkyo was used. During study period, the highest monthly flow conditions occurred in April, 1998 while the lowest monthly flow condition occurred in February, 2000.

4.4 Determination of export coefficients for major land uses

Annual, seasonal, wet and dry period, high flow and low flow period, and monthly land use export coefficients were estimated using multiple regression technique. The results of multiple regression analysis (only annual and monthly export coefficients) are summarized in Table 3a and 3b. Most of the coefficients for the land use variables are significant at α equal to 0.05 and has coefficient of determination (R^2) more than 85% for all regression models. This indicates that the land use categories used as independent variables explain a large proportion of the variability in loadings.

Table 3a. Export coefficient (kg/ha/yr) estimates for land use variables versus loadings using a zero-intercept multiple regression model.

Land use	BOD	COD_{Mn}	NO_3-N	PO_4-P
Forest	1.00	0.75	2.12	0.71
Agriculture	0.62	0.64	1.06	0.42
Grassland	0.54	0.52	0.46	0.59
Urban	2.63	1.48	3.80	1.73

Annual land use export coefficients from different studies within Japan also has been reviewed and compared with the present study. The export coefficients of NO_3-N for forest and urban land use and PO_4-P for forest and agriculture land use are within the literature values. Similarly, the export coefficients of COD_{Mn} for forest and urban land uses are comparable with literature values. The derived export coefficients of NO_3-N and COD_{Mn} for agriculture are lesser and PO_4-P for urban land uses is greater when compared with literature values. These wider differences in comparison can be attributed to the specific basin characteristics for loading of these water quality constituents and the methodology used for deriving export coefficients. For example, a recent study conducted by Nakamura et al. [2005] shows that the NO_3-N concentration, applied as fertilizers in agriculture area, in groundwater is higher than the river water in Fuji river basin. Therefore, a lower rate of nitrate loading is expected as compared to the actual field studies in other basins. Similarly, in this study the concentration of PO_4-P was influenced by the domestic wastewater discharge but the literature values do not account the influence of domestic wastewater. Therefore, a higher rate of PO_4-P loading is expected as compared to the actual field studies in other basins.

Table 3b. Export coefficient (kg/ha/month) estimates for land use variables versus loadings using a zero-intercept multiple regression model.

Export coefficients (kg/ha)				
BOD				
	Forest	**Agriculture**	**Grassland**	**Urban**
January	0.89	1.03	0.81	1.48
February	1.20	1.27	0.73	1.44
March	1.06	1.11	0.74	1.48
April	0.82	1.01	0.86	1.29
May	0.78	0.58	1.08	1.84
June	0.60	0.75	1.20	1.46
July	0.55	0.98	1.08	1.28
August	0.56	1.04	1.12	1.34
September	0.57	1.52	1.03	1.10
October	0.70	0.97	0.94	1.32
November	0.73	1.13	1.02	1.23
December	0.95	1.04	0.86	1.43
COD_{Mn}				
January	0.86	1.26	0.81	1.15
February	1.17	1.63	0.76	1.10
March	1.01	1.37	0.76	1.11
April	0.78	1.10	0.89	1.00
May	0.78	0.57	1.01	1.51
June	0.61	0.76	1.12	1.14
July	0.60	1.01	0.93	1.05
August	0.60	1.07	0.96	1.08
September	0.59	1.73	0.99	0.86
October	0.71	1.06	0.87	1.05
November	0.74	1.40	1.00	0.95
December	0.93	1.30	0.86	1.07
NO_3-N				
January	1.04	1.51	0.89	1.16
February	1.45	2.12	0.89	1.09
March	1.38	2.08	0.89	1.05
April	1.13	1.59	0.99	0.96
May	1.10	0.74	1.07	1.43
June	0.87	0.93	1.18	1.14
July	0.86	1.17	0.99	1.10
August	0.80	1.07	1.01	1.24
September	0.63	1.27	1.10	1.04
October	0.87	0.92	0.92	1.32
November	0.93	1.47	1.00	1.05
December	1.19	1.42	0.90	1.17
PO_4-P				
January	1.17	1.02	1.57	2.17
February	1.36	0.95	1.61	2.15
March	1.30	0.96	1.56	2.20
April	1.24	0.98	1.62	2.15
May	1.27	0.68	2.04	2.87
June	0.99	0.98	1.96	2.01
July	0.86	1.16	1.77	1.76
August	0.89	1.45	1.69	1.63
September	0.81	1.24	1.69	1.84
October	0.95	1.01	1.60	2.03
November	1.08	1.61	1.59	1.51
December	1.23	1.32	1.50	1.73

4.5 Calculation of wastewater treatment plants loadings

Loadings of BOD, COD_{Mn}, NO_3-N and PO_4-P from three major waste water treatment plants in the basin were estimated from monthly discharge and concentration records provided by Kofu, Kyoto and Kamanashi city waste water treatment plants. Monthly average concentration were integrated with monthly effluent values and summed to obtain total loadings from the WWTPs for 1995-2000 (Table 4).

Table 4. Total and annualized point source loadings ($x10^3$kg) from major wastewater treatment plants (WWTPs) in Fuji river basin during 1995-2000.

WWTPs	Total loadings			
	BOD	COD_{Mn}	NO_3-N	PO_4-P
Kofu	969.62	1213.34	807.33	195.83
Kyoto	175.88	696.16	501.58	14.20
Kamanashi	17.08	68.32	28.98	1.74
Annualized loadings	387.43	659.28	445.96	70.59

4.6 Development of an empirical source-contribution model

The export coefficient values, land use classification, and point source data for the Fuji river basin were combined into empirical source-contribution model. This model allows an estimation of the loading of BOD, COD_{Mn}, NO_3-N and PO_4-P. This simple empirical model can be expressed as:

$$L_{i,m} = \sum (EC_{j,m} \ x \ SA_{i,j}) + PS_{i,m}$$

where $L_{i,m}$ = annualized loading for organic matter and nutrient m to point i (kg/yr), i = a location within the Fuji river basin for which land use information within the drainage site is defined; m = organic matters/nutrients: m = 1 for BOD, m = 2 for COD_{Mn}, m = 3 for NO_3-N and m = 4 for PO_4-P; j = non point sources: j = 1 for forest, j = 2 for agriculture, j = 3 for grassland, j = 4 for urban; $EC_{j,m}$ = land use export coefficient for source j and organic matters/nutrients m; $SA_{i,j}$ = land use surface area within the drainage above location i associated with source j (ha); and $PS_{i,m}$ = the annualized point source contribution in the drainage area above location i for nutrient m (kg/yr). This equation can be used to estimate the total organic matter and nutrient loadings at any location in the basin by assigning the appropriate values to the variables.

4.7 Compare estimated loadings with monitored loadings

The empirical source-contribution model was validated by comparing loadings from Torinkyo where continuous monitoring data is available. Since only COD_{Mn} concentrations are available, only observed COD_{Mn} loadings were used to compare with estimated loadings. Derived annual, seasonal, wet and dry season, high flow and low flow and monthly export coefficients were input into the source-load contribution model. The model underestimated the loadings by 3-6 times while using annual, seasonal, wet/dry season and high/low flows export coefficients, whereas only 1.2 times underestimation is observed while using the monthly export coefficients.

4.8 Estimation of total loadings and percent contribution by land use sector of organic matter and nutrients

Although the model was only validated for COD_{Mn} loading, it was also used to estimate BOD, NO_3-N and PO_4-P loadings based on the assumption that monthly land use export coefficients represents the most appropriate values. The total loadings and percent of loadings from point and non point sources were estimated using source-contribution model for the river basin outlet i.e. Fujibashi station (Figure 4).

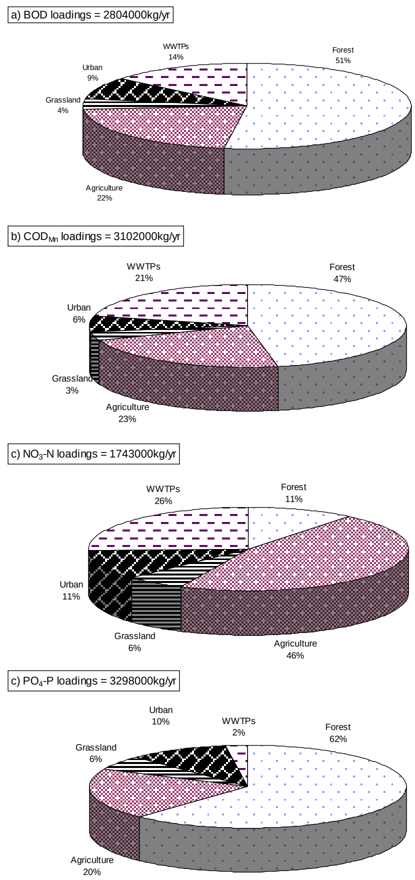

Figure 4. Estimated loadings and percent contribution by source within Fuji river basin during 1995-2000.

The highest loadings of BOD (51%) and COD_{Mn} (47%) were estimated from forest. Whereas point source BOD and COD_{Mn} loadings was estimated about 14% and 21% respectively. These results showed that forest is the dominant source of organic matter loadings. Agriculture land use representing about 22% of the basin area at Fujibashi, contributed the largest percentage of NO_3-N loadings with 46% of the estimated loadings. Chemical fertilizer is likely the source of most of the nitrate nitrogen loadings from agricultural land use. In case of inorganic dissolved phosphorus, forest (62%) represents the most dominant source whereas agriculture (20%) was observed to be second dominant source. The contribution of point source of inorganic dissolved phosphorus loadings observed to be the minimum as compared to the non point source contribution.

5. CONCLUSION

The export coefficients of organic matters and nutrients for major land uses are developed using available statistical, hydrological and spatial tools and these export coefficients are used to estimate the total loadings and percent contribution from point and non point sources by developing empirical source-contribution model specific to Fuji River basin. Most of the land use export coefficients are significant at α equal to 0.05 and the land use categories used in the multiple regression models explained more than 85% variability in loadings. However, some export coefficients are underestimated/overestimated when compared with literature values and it represents the site specific variations in management and environmental conditions of specific basins. These export coefficients represents the average of conditions and practices (e.g., soils, slopes, tillage practices, fertilization timing and amounts etc). It was estimated that non point sources are the major contributor of organic matter and nutrient loadings where forestry observed to be the most dominant source of organic matters and inorganic dissolved phosphorus loadings and agriculture observed to be the dominant source of nitrate nitrogen loadings. The derived export coefficients can be used to evaluate the impacts of human activities, agricultural practices, land use changes particularly given the short time schedule and limited data for the management practices to improve the water quality within the Fuji river basin.

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