Effect of climate change on nutrient discharge in a coastal area, western Japan

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Abstract This study investigates the effect of climate change on nitrogen and phosphorus discharges from a watershed in western Japan. Numerical simulations for a 30-year period (1978–2007) demonstrate a decrease in the annual precipitation as well as in the loads of nitrogen and phosphorus, over the study period. Nutrient fluxes were estimated using the Soil and Water Assessment Tool (SWAT) model. The estimated phosphorus flux is more highly correlated with precipitation than the nitrogen flux. The results suggest a high correlation between phosphorus and discharge, but during the high precipitation years, phosphorus loads have decreased. A sensitivity analysis of parameters for phosphorus discharge showed that the most sensitive parameter is the support practice factor. Consequently, phosphorus flux could decrease from the Asahi River watershed in the future, because precipitation and flood events have decreased and so has the driving force for soil erosion, which is the primary source of the nutrients.

Key words nutrient load; precipitation; SWAT model; western Japan

INTRODUCTION

Climate changes, such as significant increases in temperature and precipitation, have been observed in many places worldwide. These changes are commonly recognized to be a result of natural phenomena and human activity (Intergovernmental Panel on Climate Change (IPCC), 2007). An increase in temperature and precipitation would affect the hydrological cycle in a watershed system. For example, it would cause changes in discharge, sediment yield and nutrient loading in a watershed (Chang *et al.*, 2001). Recently, changes in coastal ecosystems have been observed throughout the world. These seem to have been caused by the changing nutrient flux from watersheds because discharge from watersheds is one of the important nutrient sources for a coastal environment (Yamamoto, 2003; Oczkowski & Nixon, 2008). There has been a lot of research on the effects of climate on nutrient discharge in European countries (Bouraoui *et al.*, 2004; Andersen *et al.*, 2006; Wade, 2006), although the effects have not been well understood in Eastern Asia. It is important to confirm the effect of climate change on the variation in nutrient flux under these climate changes because Eastern Asia has been experiencing increasing drought events and decreasing amounts of precipitation owing to decreasing winter monsoon (IPCC, 2007). The objective of this research is to evaluate the effect of climate change on nitrogen and phosphorus discharges from a watershed in western Japan, using a numerical simulation for a period of 30 years from 1978 to 2007.

STUDY AREA

The Asahi River watershed, located in the middle part of the Okayama prefecture in Japan, has a catchment area of 1810 km^2 and a total stream length of 142 km (Fig. 1). The Asahi River drains Asanabewashi Mountain (1081 m) in the northern region of the watershed, an area dominated by Cretaceous rhyolite and granite. Geologically, the mid regions of the watershed are composed of soft sediments, such as Palaeozoic mudstone, tuff and diorite, whereas the downstream regions consist of alluvial lowlands and reclaimed land (National Land Agency, 1994).

Precipitation varies throughout the watershed, with the mean annual precipitation declining from a maximum of 2000 mm in the headwaters to 1200 mm in the lower reaches. Heavy rain occurs during the summer months (June to September) and this is mainly associated with monsoonal activity and several typhoons. Present land uses in the watershed are given in Table 1. The watershed is mainly covered by forest, and there were few land-use changes in the last 30 years.

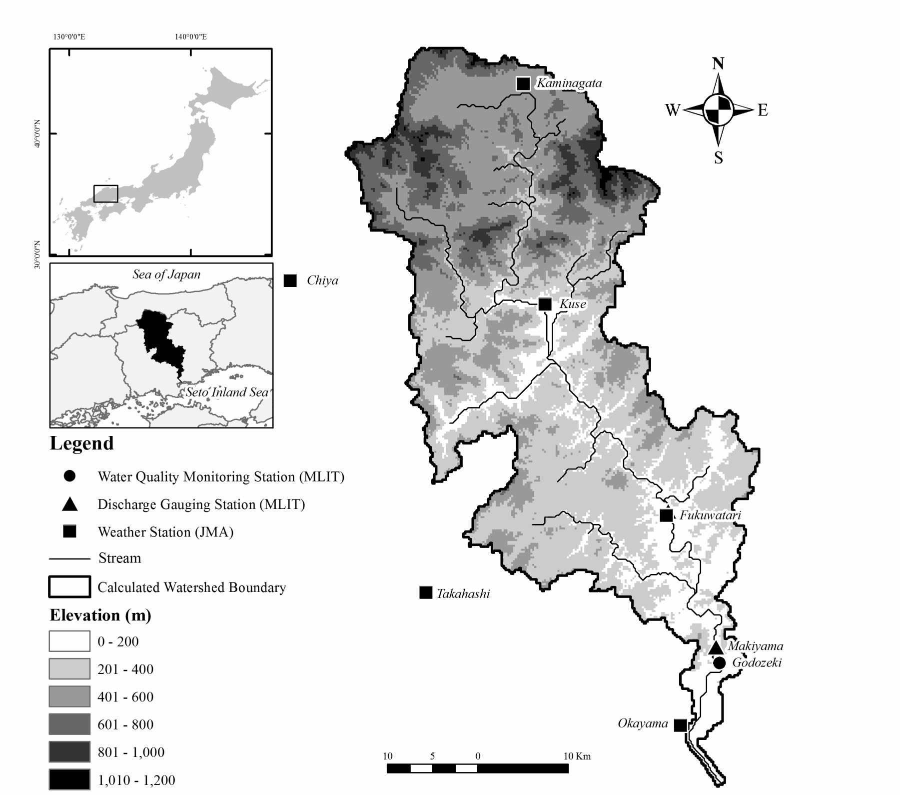

Fig. 1 The study watershed.

Table 1 Land-use change in the Asahi River watershed (units: area in km^2).

Classes	1976	1987	1991	1997	2006
Paddy field	170.8	159.3	158.9	161.4	160.4
Arable land	59.3	59.6	63.8	67.2	60.5
Forest	1198.9	1202.7	1195.0	1182.4	1182.4
Waste land	17.2	19.2	19.1	18.5	17.9
Residence	16.9	21.7	21.7	23.0	25.2
Road	2.0	2.0	4.7	5.5	5.5
Water	25.6	25.8	25.7	26.4	26.4
Other utilities	4.4	4.8	6.3	10.6	16.8

*Source: Digital national land information (http://nlftp.mlit.go.jp/ksj/).

METHOD

The Soil and Water Assessment Tool (SWAT version 2005) was selected for estimating the nutrient discharge. SWAT is a conceptual, continuous, time series model that was developed in the early 1990s as a tool to assist water-resource managers in assessing the impact of land-management and climate on the water supply and nonpoint-source pollution in watersheds and large river basins (Arnold & Fohrer, 2005). SWAT was designed to predict the impact of land-management practices and climate change on water, sediment and nutrient yields in large complex basins with varying soil types, land use, and land-management conditions over long periods of time (Arnold *et al.*, 1998). Precipitation, temperature, wind speed, and relative humidity were observed at six weather stations at Okayama, Takahashi, Fukuwatari, Kuse, Chiya and Kaminagata.

Meteorological data were obtained from the Japan Meteorological Agency (JMA) (http://www.jma.go.jp/jma/index.html). Solar radiation data were obtained from the National Institute for Agro-Environmental Sciences (http://meteocrop.dc.affrc.go.jp/), because the observed data were not available from the JMA. Evaporation was estimated by the Penman-Monteith method

(Monteith, 1965) using SWAT. Geographical data, soil maps, land-use maps and elevation maps required in SWAT were obtained from the following sources. The soil data were obtained from the 1:200 000 digital soil map of Okayama prefecture by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) (http://tochi.mlit.go.jp/tockok/). The soil types were categorized into Humic Cambisols (72.4%), Haplic Andosols (14.6%), Fluvic Gleysols (7.3%), and others (5.7%). The land-use map with a 100-m grid was obtained from the National and Regional Planning Bureau of MLIT (http://nlftp.mlit.go.jp/ksj/). The land-use data of 2006 were categorized into eight types (Table 1). The elevation map with a 50-m grid was obtained from the Japanese Geographical Survey Institute (GSI). Agricultural information, such as tillage and fertilizer application, was obtained from the Okayama branch of Japan Agricultural Cooperatives (JA). Monthly discharge data at the Makiyama gauging station (Fig. 1) were obtained from the Japan River Association. Concentrations of Total-Nitrogen (T-N), Total-Phosphorus (T-P), and suspended solids (SS) in the river water at the Godozeki monitoring station, located about 3 km downstream of the Makiyama station, were obtained from the MLIT through the Water Information System (http://www1.river.go.jp/). Analyses of nutrient and SS concentrations were conducted according to the Water Quality Testing Manual for River (Ministry of Construction, 1997). T-N, ammonia, nitrate and nitrite were determined spectrophotometrically using the alkaline peroxodisulfate digestion method, indophenol blue method and cadmium-copper reduction method (nitrate and nitrite), respectively. T-P and phosphate were determined spectrophotometrically using the molybdenum blue method. Acidic peroxodisulfate digestion was conducted before analysis for T-P. SS was determined by measuring the weight of the solids after filtering of the sampling water using glass fibre filters. The discharge data were available for the 30-year period (1978–2007). The nutrient and sediment data were available from 2000 to 2007. Therefore, sediment, organic nitrogen, inorganic nitrogen (nitrate, nitrite, and ammonium), organic phosphorus and sediment-attached phosphorus (mineral phosphorus) were estimated on a monthly basis using SWAT for the 30-year period. The model was calibrated for the period from 2000 to 2003 using the Shuffled Complex Evolution (SCE) method after sensitivity analysis by the Latin Hypercube One-factor-At-a-Time (LH-OAT) method. The model was validated for the period from 2004 to 2007. The Pearson's correlation coefficient (r) and the Nash-Sutcliffe index (E_{NS}) (Nash & Sutcliffe, 1970) were used to evaluate the performance of the model. The variance in the simulated data explained by the observed data is reported as a fractional percentage (r). The E_{NS} value indicates how well the plot of the observed values *versus* the simulated values fits the 1:1 line. The E_{NS} value ranges from $-\infty$ to 1. If the r and E_{NS} values are nearly equal to zero, the model performance is considered unacceptable. If these values are equal to one, the model simulation is considered to be perfect (Moriasi *et al.*, 2007). To identify the significant trend and magnitude in the time series data, a non-parametric trend test including Sen's slope method using Mann-Kendall test was conducted.

RESULTS AND DISCUSSION

Trends in the air temperature and the water budget in the watershed

Temporal trends in the annual precipitation and maximum daily precipitation at the Okayama weather station and maximum daily discharge and average daily discharge at the Makiyama station for the 30 years from 1978 to 2007 are listed in Table 2. A significant increase in the air temperature was observed at the Okayama weather station. Evapotranspiration has also increased with the increasing air temperature. Annual precipitation decreased by more than 290 mm during this period. Annual discharge decreased in proportion to the climatic variation in the watershed. This result suggests that a decrease in discharge may be affected by the increase in evapotranspiration and the decrease in precipitation during the study period.

Trends in nutrient flux

At first, it was necessary to confirm the reproducibility of river discharge and nutrient concentrations for the estimation of nutrient flux. There is good correlation between the simulated

Table 2 Trends of air temperature and major water budget components in the watershed during the study period.

	Units	Slope	Intercept	Significance
Air temperature	ºC	0.1	15.0	***
Precipitation	mm	–10	1479	*
Evapotranspiration	mm	3	380	*
Discharge	mm	–11	1037	*

*: p<0.1, ***: p<0.01

and observed values of the monthly river discharge with the best fit being at $r = 0.93$ ($p < 0.01$) and $E_{NS} = 0.80$. The best fits for SS, nitrate and phosphate concentrations were at $r = 0.87$ ($p < 0.01$) and $E_{NS} = 0.69$, $r = 0.82$ ($p < 0.01$) and $E_{NS} = 0.66$, and $r = 0.80$ ($p < 0.01$) and $E_{NS} = 0.63$, respectively. These correlations were lower than that of the monthly river discharge, but these were statistically significant and acceptable results.

Figure 2 shows the variation of the estimated fluxes of sediment (a), phosphorus (b) and nitrogen (c) from 1977 to 2007. The average sediment flux during the period was 1.2×10^5 MT year^{-1} (Fig. 2(a)). The average fluxes of mineral phosphorus and organic phosphorus during the period were 2.7×10^4 and 8.7×10^3 kg year^{-1}, respectively (Fig. 2(b)) and more than 60% of the phosphorus was in mineral form. Although overall variation in nitrogen fluxes were the same as phosphorus fluxes, there is little difference when compared with phosphorus (Fig. 2(c)). The average fluxes of nitrate, nitrite, ammonium and organic nitrogen during the period were 1.6×10^6, 2.4×10^4, 5.2×10^4 and 7.8×10^4 kg year^{-1}, respectively. Nitrate was the most dominant form of nitrogen flux. Sediment and nutrient fluxes decreased during the study period (Table 3). Significantly decreasing trends for sediment flux, nitrate flux, organic phosphorus and mineral phosphorus due to discharge, which was affected by the climate change, were confirmed.

Future prospects on phosphorus flux

Sediment and mineral phosphorus have a significantly decreasing trend (Table 3). These results show that the flux of mineral phosphorus has been decreasing with large annual variation.

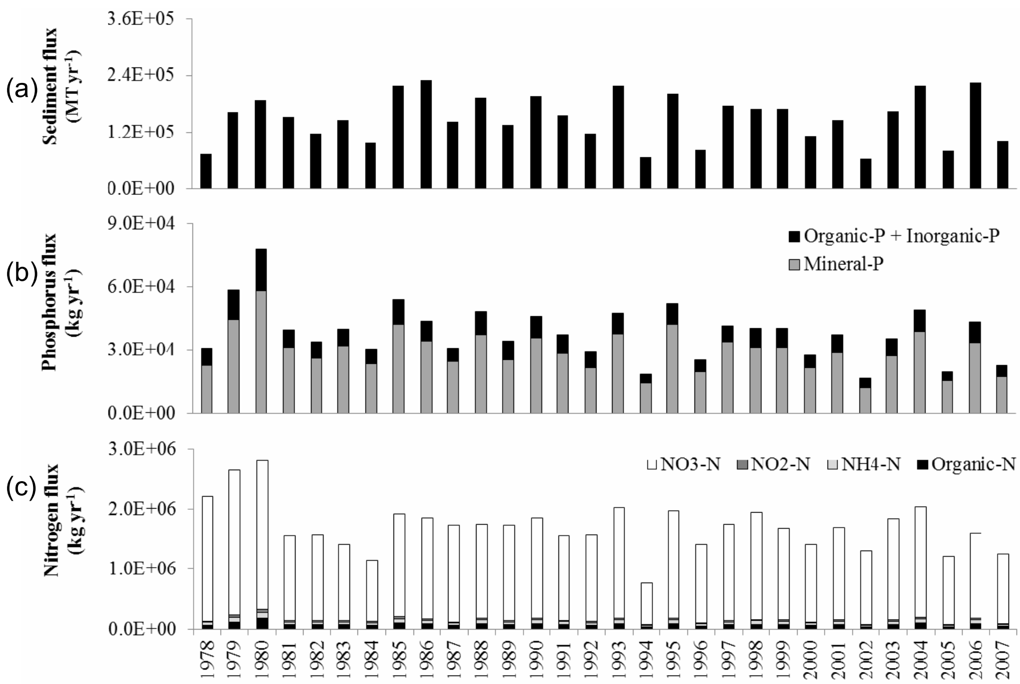

Fig. 2 Variation of estimated sediment and nutrient flux from the Asahi River; (a) sediment, (b) phosphorus, (c) nitrogen.

Table 3 Trends of estimated sediment and nutrient flux during the study period.

	Units	Slope	Intercept	Significance
Sediment	metric tons	-2.5×10^3	1.5×10^5	**
Organic nitrogen	kg	-7.7×10^2	8.9×10^4	
Nitrate	kg	-1.6×10^4	1.8×10^6	*
Nitrite	kg	-2.0×10^2	2.7×10^4	
Ammonium	kg	-5.3×10^2	5.8×10^4	
Organic phosphorus	kg	-1.1×10^2	1.0×10^4	*
Mineral phosphorus	kg	-5.4×10^2	3.5×10^4	**

* $p < 0.1$, ** $p < 0.05$

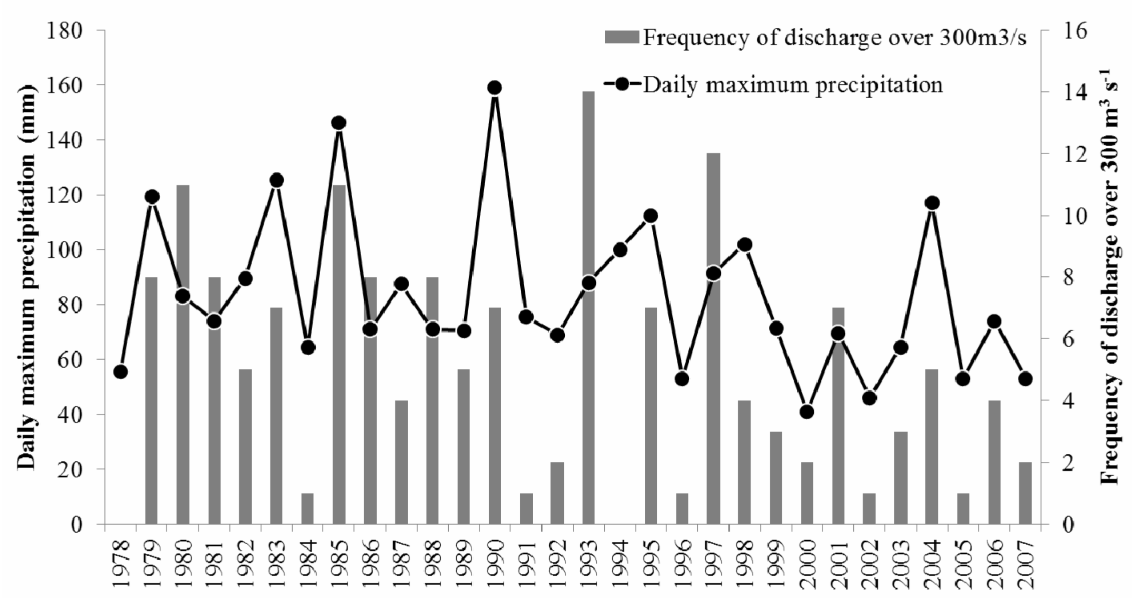

Fig. 3 Variation of observed daily maximum precipitation and observed frequency of flood events.

Figure 3 shows the variation of the observed daily maximum precipitation at the Okayama weather station and the variation of observed frequency of flood events when discharge is over 300 $m^3 s^{-1}$ at the Makiyama station. The daily maximum precipitation has a significantly decreasing trend (slope: −1.1, $p < 0.05$), and so do flood events (slope: −0.2, $p < 0.05$). Therefore, heavy rain and flood events have been decreasing in recent years. Generally, most of the phosphorus is transported with suspended sediment during floods, because phosphate is readily adsorbed by soil particles (Withers & Jarvie, 2008). Consequently, phosphorus flux has decreased with sediment flux due to a decrease of flood event.

SWAT estimates the sediment yield using the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1995). Results of sensitivity analysis of parameters for phosphorus discharge showed that the most sensitive parameter is the Support Practice Factor (*USLE_P*), which represents the intensity of resistance against soil erosion. Accordingly, this result indicates that *USLE_P* was more effective than the soil type or the slope factor. As a result, the phosphorus flux of the Asahi River mainly comes from arable land and paddy fields, which are located on hill slopes. The phosphorus flux would decrease from the Asahi River watershed in the future, because precipitation that drives soil erosion is decreasing.

CONCLUSIONS

The objective of this study is to confirm the effect of climate change on sediment and nutrient discharges from a natural watershed in western Japan. The results were summarized as follows:

1. The total amount of precipitation has decreased, while the total amount of evaporation has increased in the watershed. The discharge from the Asahi River watershed has been affected by precipitation and evapotranspiration. The results indicate that river discharge has been decreasing gradually.
2. It has been confirmed that 66% of the phosphorus flux consisted of mineral phosphorus, and more than 90% of the nitrogen flux consisted of nitrate. Fluxes of sediment, nitrate, organic phosphorus and mineral phosphorus have especially shown a significantly decreasing trend, thus confirming that these fluxes were affected by the climate change. The estimated total fluxes of mineral phosphorus have significant variation. These fluxes seem to be greatly affected by changes in sediment flux.
3. The number of flood events has decreased owing to a decline in the intensity of rainfall in the watershed. It has been suggested that sediment flux and mineral phosphorus flux correspond to the flood events, because a decrease in flood events indicates that soil erosion has also been decreasing.
4. Results of sensitivity analysis of parameters for phosphorus discharge showed that the most sensitive parameter is support practice factor. Phosphorus flux would decrease from the Asahi River watershed in the future, because the climate change has decreased its precipitation as a driving force for soil erosion.

Acknowledgements This study was supported by the Ministry of Education and Science in Japan (no. 18201007).

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