14. INTEGRATED MODEL FOR ESTIMATING SEDIMENT DISCHARGE TO COASTAL ENVIRONMENT FROM RIVER BASIN- *A CASE STUDY OF SAKAWA RIVER*

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Abstract

In this study an integrated model to estimate total sediment discharge from the river basin to the coastal environment is developed. Simulated and measured sediments discharge at the river mouth is compared and there is a good agreement. Also the effect of land use and climate change to the sediment yield is analyzed. The land use data derived from remotely sensed images of 1976 and 1997 is used as the basis for comparison to see the effect of land use change. It was observed that using the land use data for the year 1997, total sediment discharge to the coastal environment increased as compared to the year 1976; this is mainly due to the increased agricultural areas and residential areas and also decreases in forest area. For analyzing the effect of climate change, HadCM2 model is used to generate mean daily precipitation for the month for the period 2040-2050 and then daily rainfall amount is generated from this data using exponential distribution. The results of the sediments discharge to the coastal environment using this generated data show a decrease in the average annual sediment discharge.

Keywords: Integrated model, Land use change and Climate change.

1. Introduction

Water erosion is one of the most serious forms of land degradation in the world (Sohan and Lal, 2001). Changes in land use due to urbanization and agricultural expansion have led to accelerated and spatial increase in erosion. Soil erosion not only reduces soil depth, but also reduces the capacity of soils to hold water and depletes plant nutrients in the soil. Moreover, water erosion creates environmental problems, such as water pollution, siltation of reservoirs, canals, drainage channels and degradation of coastal ecosystems. Therefore, there is a need to develop a methodology to estimate sediment yield from the river basin and discharge to the coastal environment.

2. Methodology

2.1 Soil Erosion equations

Modified Universal Soil Loss Equation (MUSLE), (Williams, 1975) is used to estimate soil erosion caused by rainfall and runoff

$$sed = 11.8(Q_{surf} * q_{peak} * area_{hru})^{0.56}.K_{USLE}.C_{USLE}.P_{USLE}LS_{USLE} \quad (1)$$

Where sed is the sediment yield on a given day (metric tons), Q_{surf} is the surface runoff volume (mm H_2O), q_{peak} is the peak runoff rate (m^3/s), K_{USLE} is the soil erodibility factor, LS_{USLE} is the slope length factor and C_{USLE} and P_{USLE} are land cover and land management factors respectively.

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2.2 River profile change model

(1) Flow equation

One-dimensional steady flow, momentum equation is used for the flow calculation:

$$\frac{\partial H}{\partial x}+\frac{Q^2}{2g}\frac{\partial}{\partial x}\left(\frac{1}{B^2h^2}\right)+\frac{Q^2n^2}{B^2h^{10/3}}=0 \qquad (2)$$

Where: x is the distance from the river mouth, H is the water surface elevation, Q is the river discharge, B is the river width, and h is the water depth in the channel.

(2) Sediment equations

(i) Bed load equations

The bed load transport rate per unit width is calculated by Ashida and Michiue's formula (1972):

$$\frac{q_{Bi}}{\sqrt{sgd_i^3}}=p_i17\gamma_{*i}^{'3/2}\left(1-\frac{\gamma_{*ci}}{\gamma_{*i}}\right)\left(1-\frac{u_{*ci}}{u_*}\right) \qquad (3)$$

$$\frac{u_{*ci}^2}{u_{*cm}^2}=\left[\frac{\log 23}{\log\left(21\frac{d_i}{d_m}+2\right)}\right]\frac{d_i}{d_m} \qquad (4)$$

Where: q_{Bi} is the bed load, d_i the diameter of the bed material, p_i is the volumetric fraction of the sediment particles, s is the specific gravity of the sediment particles, γ_{*i} is the non-dimensional shear stress, γ_{*ci} the non-dimensional critical shear stress, u_{*ci} and the critical shear velocity.

(ii) Suspended load equations

The pick-up rate of the suspended load per unit area is calculated by the formula of Itakura and Kishi (1980).

$$q_{sui}=p_iK\left(\alpha_*\frac{\rho_s-\rho}{\rho_s}\frac{gd_i}{u_*^{'}}\Omega_i-w_{fi}\right) \qquad (5)$$

$$\Omega_i=\frac{\gamma_{*i}^{'}}{B_{*i}}\frac{\int_{a'}^{\infty}\xi\frac{1}{\sqrt{\pi}}\exp\left(-\xi^2\right)d\xi}{\int_{a'}^{\infty}\frac{1}{\sqrt{\pi}}\exp\left(-\xi^2\right)d\xi}+\frac{\gamma_{*i}^{'}}{B_{*i}\eta_0}-1 \qquad (6)$$

Where: q_{sui} is the suspended volume from the bottom per unit area, w_{fi} is the fall velocity of suspended sediment according to diameter. The volumetric fraction of the bed material grain size is obtained from:

$$\delta\frac{\partial p_i}{\partial t}+p_i^*\frac{\partial\eta}{\partial t}+\frac{1}{1-\lambda}\left[\frac{1}{B}\frac{\partial\left(q_{Bi}B\right)}{\partial x}+q_{sui}-w_{fi}c_{bi}\right]=0 \qquad (7)$$

Where: δ is the thickness of the exchange layer and λ is the porosity of the bed material/void ratio
The time-dependent bottom profile change is obtained from the continuity of bed material transport:

$$\frac{\partial \eta}{\partial t}+\frac{1}{1-\lambda}\left[\frac{1}{B}\frac{\partial \sum_i (q_{Bi}B)}{\partial x}+\sum_i \left(q_{sui}-w_{fi}c_{bi}\right)\right]=0 \tag{8}$$

2.3 Sediment routing

Sediment transport in the channel is the function of two processes, deposition and degradation, operating simultaneously in the reach. The maximum amount of sediment that can be transported from a reach segment is calculated as:

$$T = aV_{pk}^{\ b} \tag{9}$$

Where T, is the transport capacity (ton/m^3); V_{pk} is the peak channel flow velocity (m/s); a and b are constants.
The maximum concentration of sediment calculated with equation (9) is compared to the concentration of sediment in the reach at the beginning of the time step, C_{in}. If $C_{in} > T$, deposition is the dominant process in the reach segment and if $C_i < T$, degradation is the dominant process in the reach segment and the net amount of sediment reentrained is calculated:

$$Sed_{\deg} = (T - C_{in}) * V_{ch} * K_{ch} * C_{ch} \tag{10}$$

Where $Sed_{\deg}$ is the amount reentrained in the reach segment (metric tons), K_{ch} and C_{ch} are the channel coefficients. Once the amount of deposition and degradation has been calculated, the final amount of sediment in the reach is determined:

$$Sed_{ch} = sed_{ch,i} - sed_{dep} + sed_{\deg} \tag{11}$$

where Sed_{ch} is the amount of suspended sediment in the reach (metric tons), $sed_{ch,i}$ is the amount of suspended sediment in the reach at the beginning of time period (metric tons). The amount of sediment transported out of the reach is calculated:

$$sed_{out} = sed_{ch} * \frac{V_{out}}{V_{ch}} \tag{12}$$

Where sed_{out} is the amount of sediment transported out of the reach (metric tons), V_{out} is the volume of outflow during the time step (m^3), and V_{ch} is the volume of water in the reach segment (m^3).

3. Effect of land use change

In this part the effect of land use change to the sediment discharge to the coastal environment is analyzed. Land use data are compiled from remote sensed images for the years 1976, 1987, 1991 and 1997. There is no significant change in the land use between 1976 and 1987 and also between 1991 and 1997. Significant Land use change can be observed between years 1976 and 1997. Hence, the land use data for the years 1976 and 1997 are used for analyzing the effect of land use change to sediment discharge. Using the land use cover for the years 1976 and 1997, the sediment yield and hence sediment discharge to the river mouth is calculated for each land cover and the comparison of the results were made.

4. Climate change

The climate change scenarios are simulated using General Circulation Models (GCMs). As the evaluation of Takahashi et al., (2001), HadCM2 model developed at the Hadley Centre gives comparatively high accuracy. From the mean daily rainfall data for the month for the period 2040-2050 generated using HadCM2 model, the daily rainfall is generated using stochastic weather data generator model, WXGEN (Sharpley and Williams, 1990). The rainfall generator model, WXGEN, use the first order Markov chain model developed by Nicks (1974). With the first order Markov chain, the probability of rain on any given day is conditioned by the wet or dry status of the previous day. A wet day is defined as a day with rainfall greater than 0.1mm. Given the wet-dry probabilities, the model stochastically determines the occurrence of rainfall in a particular day. For this study, the amount of rainfall in a wet day is calculated using exponential distribution.

$$R_{day} = \mu_{month}(-\ln(rnd_1))^{r\exp} \qquad (13)$$

where R_{day} is the amount of rainfall on a given day (mm), rnd_1 is the random number between 0.0 and 1.0 and $r\exp$ is a constant with value between 1.0 and 2.0. From the generated amount of daily rainfall for the period 2040-2050, amount of sediment discharge to the river mouth is calculated and the results were compared with the 1990-2000 results.

5. Results and discussion

5.1 Total sediment discharge to coastal environment

Fig. 1 shows the relationship between sediment discharge and the river flow; generally there is strong relationship between the two, the periods with high sediment discharge corresponds to high river flow and periods with low sediments discharge correspond with low river flow periods; the comparison between the simulated sediments and the measured sediments at the river mouth for the period between 1990 and 2000 are as shown in Fig.2. Since the only available measured data is yearly data, the comparison was done only on annual basis. It can be observed that there is a good agreement between the observed and measured sediments data.

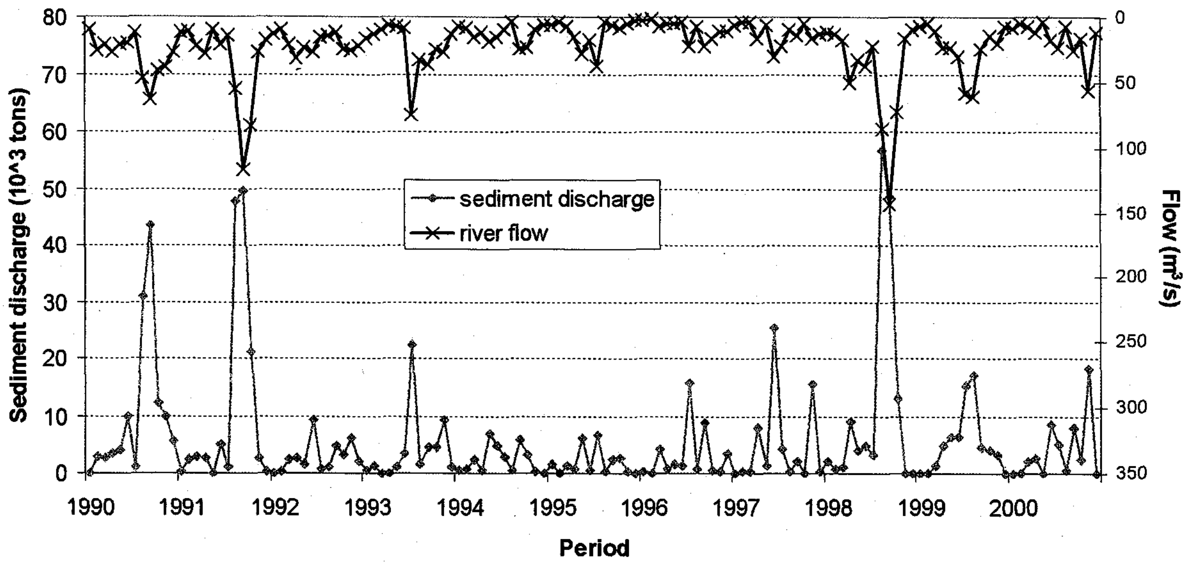

Figure 1 Comparison between sediment discharge and river flow

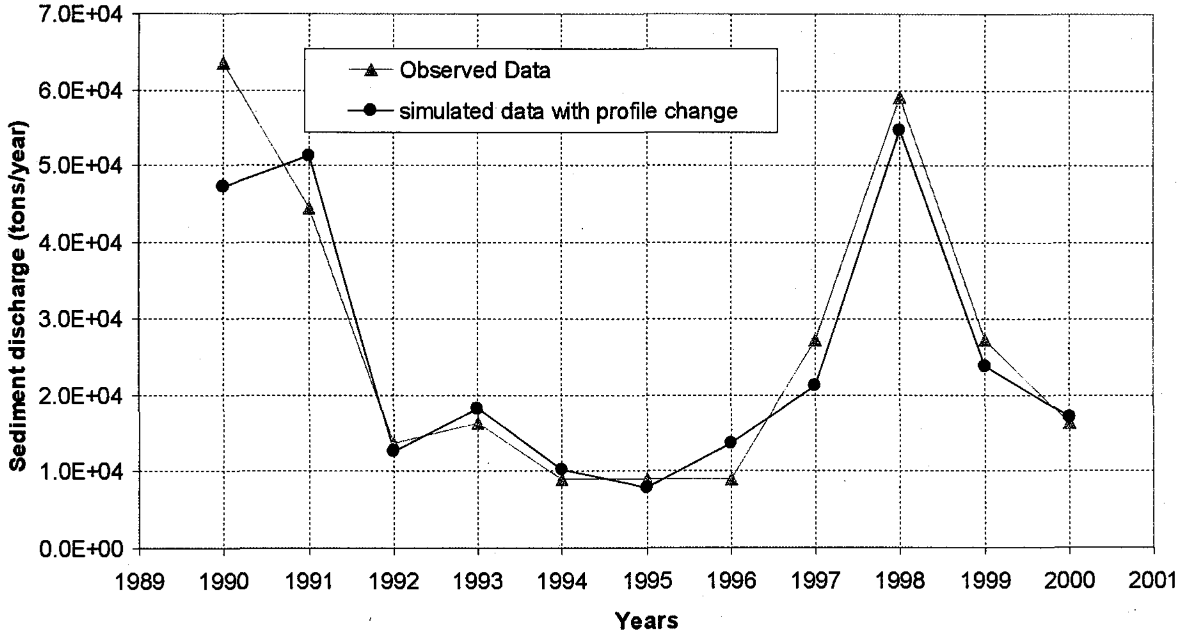

Figure 2 Observed and simulated sediments for the period 1990-2000 at Iizumi

5.2 Effect of climate change

Fig. 3 shows the total annual sediment discharge for the periods 1990-2000 and 2040-2050 and Fig.4 shows the simulated mean monthly sediments discharge at the river mouth for the present and future climate scenarios. From both figures, it can be seen that there is no clear trend for the sediment discharge at the river mouth that can be deduced despite the fact that there are some years e.g. 2050 with highest total sediment discharge.

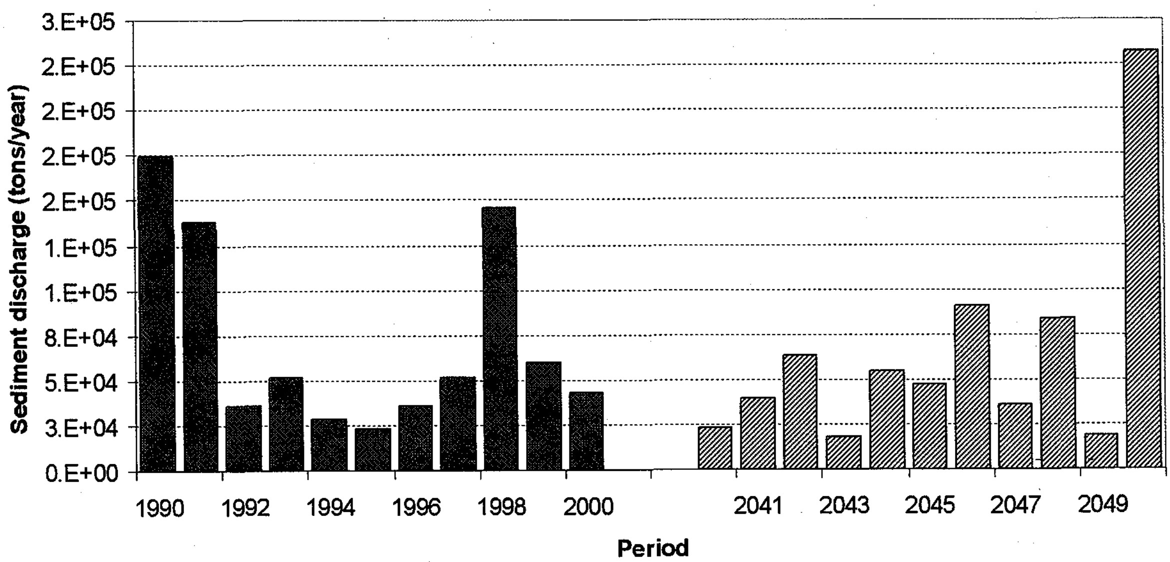

Figure3 Total sediment discharges for the periods 1990-2000 and 2040-2050

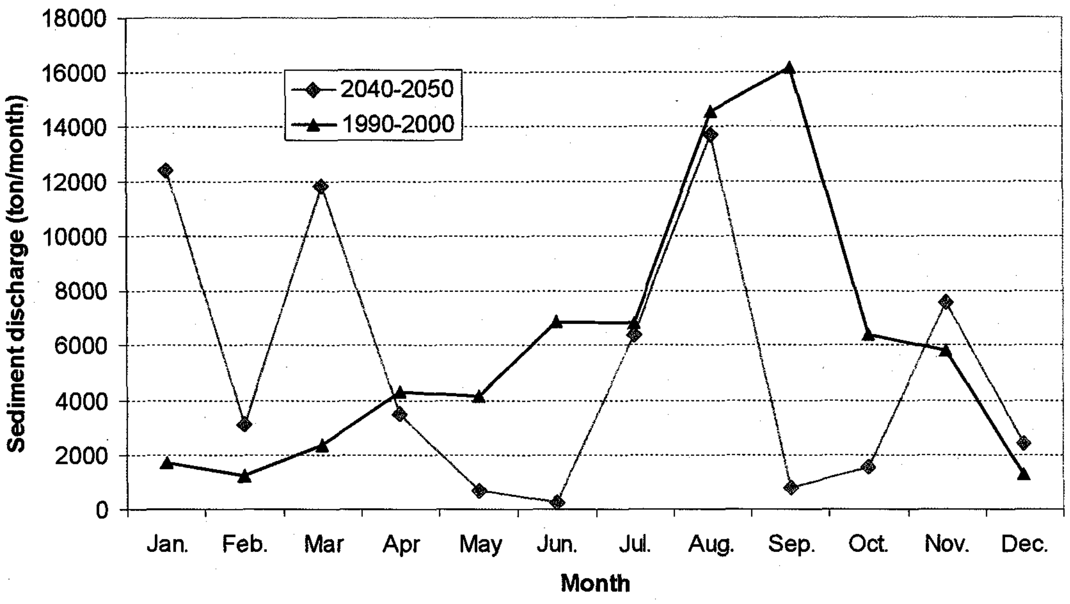

Figure 4 Simulation results for the years 1990-2000 and 2040-2050

6. Conclusion

Sediment discharge from the river basin to the coastal environment is estimated in this study. The comparison between the observed and simulated results shows a reasonable good fit between the two. From the analysis of the effects of land use change, in which the land use data for the year 1976 and 1997 were used, it is observed that within the period of 21 years sediment discharge to the coastal environment increased. This can be attributed to decrease in forest cover from 69.9% in year 1976 to 68.3% in year 1997; increase in agricultural areas from 2.5% to 6.1% and also increase in residential areas from 0.6% to 7.0%. Analysis of future climate scenarios shows the high total sediment discharge for the year 2050, however for the rest of the years there is no clear trend which can be observed between the present and future climate scenarios. The average annual sediment discharge for the present period, 1990-2000 is about 7.88×10^5ton/year; and for the future climate scenario, 2040-2050, the average sediment discharge to the coastal environment is about 7.07×10^5ton/year. The decrease in sediment discharge to the coastal environment for the future climate scenario is probably due to decrease in the amount of precipitation. However, in the calculation of future sediment discharge to the coastal environment, the current land cover is used; no attempt is done to predict future land cover.

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