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SEDIMENT YIELD AND TRANSPORTATION ANALYSIS: CASE STUDY ON MANAGAWA RIVER BASIN

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Sediment system in watershed is not only sediment yield but also including sediment transportation along the rivers. In this study, the Geographic Information System (GIS) combined with sediment yield model can be enhancing the evaluation of soil erosion estimation. Surface erosion on Managawa river basin is computed with the Modified Universal Soil Loss Equation (MUSLE) and it is verified to reflect the hydrological processes be able to estimate soil losses. In the sediment transport routing module, total load equation is applied to carry sediment from soil surface erosion to deposit in Managawa dam. According to annual accumulation sediment volume data in Managawa reservoir during 1981 – 2003, the establish model and simulation results are satisfy. The efficiency of the Modified Universal Equation with sediment routing in rivers is more than the simple Modified Universal Equation.

Key Words **:** *Sediment Yield, Sediment Transportation, Soil Erosion, MUSLE, Managawa Dam*

1. INTRODUCTION

Managawa Dam is located on the high rainfall density and steep slope area caused sediment problems. Every year the bottom levels of reservoir are observed then we can know annual sediment depositing volume. There exist many kinds of soil erosion models, both physical models and empirical models and also there are many useful numerical formulas to predict annual sediment yield. The most popular soil erosion equation is Universal Soil Loss Equation (USLE). Simple empirical methods such as Universal Soil Loss Equation (USLE) (Musgrave, 1947; Wishchmeier and Smith, 1965), Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1991) or Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975) are frequently used for estimation of surface erosion and sediment yield from catchment areas. In Modified Universal Soil Loss Equation (MUSLE), the rainfall energy factor is replaced with a runoff factor and optimizes hydrologic process of sediment yield thus these improve the sediment yield prediction. The main objective of this study is computing annual depositing sediment volume in Managawa dam by using soil erosion model and sediment transportation model. Erosion on sub-basin caused by rainfall and surface runoff is computed with Modified Universal Soil Loss Equation (MUSLE), which time interval is day continuously from 1983 to 2004. After outlets of each sub-basin, sediment will be transported by main channel. This study shows the results of these combined systems.

2. STUDY AREA

Managawa Dam constructed during 1965-1977 in Fukui prefecture is located at latitude 35º 55' 50" N and longitude 136º 32' 31" E. Managawa Dam is a concrete arch dam with 127.5 m height, 357 m width and 115 MCM capacity designed for irrigation, water supply and power generation where Managawa river is a tributary of Kuzurui river. Catchment area above the dam is about 223.7 km^2 that the mean elevation is 830 m above mean sea level and land slope is about 0.45. Since there are

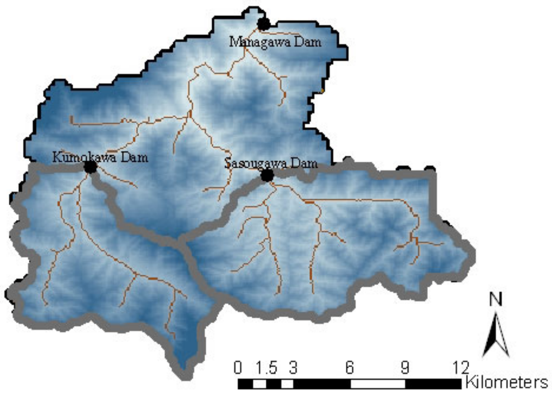

Fig.1 Managawa river basin

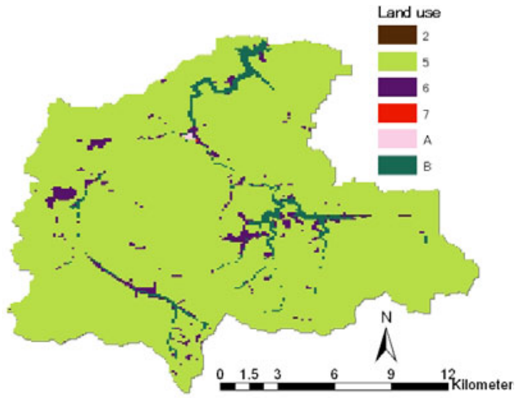

Fig.2 Land use 1997, 2 = Agricultures, 5= Forest, 6=Waste Land, 7=Building, A= Small Building, B=Water Body

Kumokawa Dam and Sasougawa Dam situated on up stream of Managawa Dam as shown in **Fig.1,** sediment will be captured by those dams but Kumokawa Dam has been filled full by sediment. Therefore sediment supply to Managawa Dam is also generated from watershed above Kumokawa Dam. During the study period, 1981-2004, the average annual rainfall is 2391 mm. The area is covered by forest where accounts for 94% area of total watershed. The major soil types in the study area are sandstone, mudstone and conglomerate (Managawa Dam office, 2005)

3. METHODOLOGY

In this study, the computing an annual sediment volume depositing in dam by mathematical model is necessary to input the models; soil erosion model, hydraulic model and sediment transport model, with hydrology data, hydrodynamic data, sediment data, geographic data and topographic data.

(1) Data collection and data analysis

Hourly rainfall data from 1981-2004 were collected by 8 rain gauges located on Managawa river basin and the results from plotting double mass curve of each rainfall stations are reliable. Distribution of rainfall could be affected by topographical data such as elevation and so on, the Thiessen method was used to estimate rainfall within the entire catchment.

Discharge and water level data are available in hourly to input as boundary condition in hydraulic model which outflows from Kumokawa Dam and Sasougawa Dam are the upper boundaries and water level at Managawa Dam is the lower boundary.

Geographic Information System (GIS) data used for finding out parameters in soil erosion model are Digital Elevation Model (DEM) 50m x 50m, land use and soil type. For land use information, there are available in 1976, 1987, 1991 and 1997 however the most of land use of the study area is forest and it does not so much change by time as shown in **Fig.2**.

Calculating soil erosion, Modified Universal Soil Loss Equation (MUSLE), in this study apply with the Soil and Water Assessment Tool (SWAT) that the watershed modeling framework is delineated starting from the digital description of the landscape as Digital Elevation Map (DEM), land use and soil data sets using ArcView interface, Spatial Analyst, with geomorphologic assessment procedures to obtain soil erosion from each sub-basin. Managawa river basin was divided in to 9 sub-basins which one sub-basin on upper Sasougawa Dam is neglected because that dam will capture all sediment from upper part. After that the calculated daily sediment supply from each sub-basin will be taken to input as lateral sediment inflow to Managawa River model which hydrodynamic (HD) and sediment transport (ST) models are calculated by MIKE 11 developed by DHI Water and Environment. Flow chart of this study is shown in **Fig.3**.

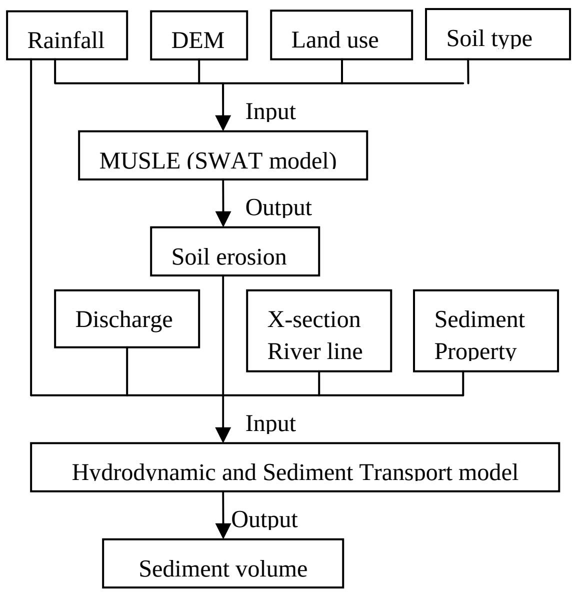

Fig.3 Scope of this study

(2) Modified Universal Soil Loss Equation (MUSLE)

The Soil and Water Assessment Tool (SWAT) is a long term distributed parameter model, designed to predict the impact of land management practice in a watershed (Arnold et al., 1998). In this study, the SWAT ArcView interface (DiLuzio et al., 2001) was used to write SWAT input files from GIS data layers. SWAT model calculates soil erosion caused by rainfall-runoff process using MUSLE. The model is a modified form of the USLE. The difference between the two approaches that in MUSLE rainfall energy factor is replaced with a runoff factor which represents energy used in detaching and transporting sediment. SWAT model requires a Digital Elevation Model (DEM) from which it determines the drainage network and divides the basin into sub-basins defined by grid cells, spatially related one to another, that each has geographic position in the watershed defined by surface topography.

This study applies SWAT model only to find out the soil erosion of each sub-basin at each outlet point. The MUSLE is used in this study which is given as Eq.(1). From MUSLE, the shortest time interval of output is daily and this study need daily sediment yield data to input in sediment transport model.

$$Y = 11.8(Q_s q_p A_{area})^{0.56} K \cdot C \cdot P \cdot LS \cdot CFRG \quad (1)$$

Where Y is the sediment yield on a given day (ton), Q_s is the surface runoff (mm), q_p is the peak runoff rate (m^3/s), A_{area} is area (km^2), K is the USLE soil erodibility factor, C is the USLE cover and management factor, P is the USLE support practice factor, LS is the USLE topographic factor and $CFRG$ is the coarse fragment factor. SWAT estimates the surface runoff (Q_s) with the SCS curve number method and the peak runoff rate is calculated with the rational method:

$$q_p = \frac{c \cdot i \cdot A_{area}}{3.6} \quad (2)$$

Where q_p is the peak runoff rate (m^3/s), A_{area} is area (km^2), c is the runoff coefficient, i is the rainfall intensity (mm/hr) and 3.6 is a unit conversion factor.

There are 8 sub-basins which sub-basin no.1, 2 and 3 are on the dam area so those sub-basins will directly supply sediment into dam. The soil erosion of those areas from MUSLE will be directly sum up to total sediment volume as shown in **Fig.4** and **Fig.5** and the sub-basin No.9 is not supplying sediment to Managawa Dam.

Fig.4 Sub-basins in this study

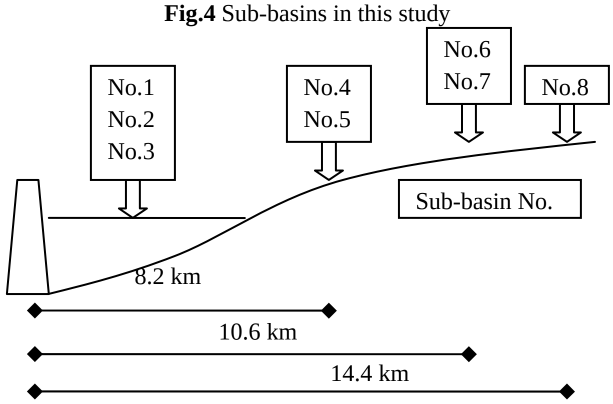

Fig.5 Location that sediment yield of each sub-basin from MUSLE supplied to the main river system

(3) Hydrodynamic and Sediment Transport models

The hydrodynamic module (HD) contains an implicit, finite difference computation of unsteady flows in rivers. The non-linear equations of open channel flow (Saint Venant Equation) can be solved numerical between all grid points at specified time intervals for given boundary conditions.

The basic equation is governed by the continuity and momentum equations:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q \quad (3)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial\left(\alpha \frac{Q^2}{A}\right)}{\partial x} + gA\left(\frac{\partial h}{\partial x} + S_0\right) + \frac{n^2 gA|Q|Q}{A^2 R^{4/3}} = 0 \quad (4)$$

Where Q is discharge (m^3/s), A is cross section area (m^2), q is lateral inflow (m^2/s), α is momentum distribution coefficient, h is water level (m), S_0 is bed slope, n is Manning's roughness coefficient (s/m$^{1/3}$) and R is hydraulic radius (m)

The sediment transport computations are made in parallel with the hydrodynamic computations. The sediment transport equations are solved in time and space as an implicit function of the corresponding values of the hydraulic parameters. In this study, total load model Acker and White (1973) presented a semi-empirical sediment transport mode is used for computation.

a) Boundary conditions, calibration and verification for Hydrodynamic model

Outflows from Kumokawa Dam and Sasougawa Dam are set to upstream hydrodynamic boundaries and water level at Managawa Dam is set to down stream boundary as shown in **Fig.6**.

To calibrate Hydrodynamic model by changing roughness coefficient which this study select year 1995 and 2004 for calibration and year 1998, 2002 and 2003 are for verification. The efficiency index (EI) for calibration is 94 % and for verification is 88% while roughness coefficients, Manning M, are 20, 20 and 15 for branch 1, 2 and 3 in sequence.

b) Sensitivity analysis of sediment transport model

Daily sediment yield from MUSLE computation will be supplied to the main river system at outlet points of each sub-basin. Acker and White equation need to input grain size diameter (D50). The distributed grain size diagram of 4 sediment samplings in Managawa Dam in 1998 is shown in **Fig.7.** Sample 1, 2 and 3 were taken near dam body and sample 4 was taken around upstream delta deposits. Based on these data, the sediment transportation model will apply the approximate value for D50 as 0.005 m in this study.

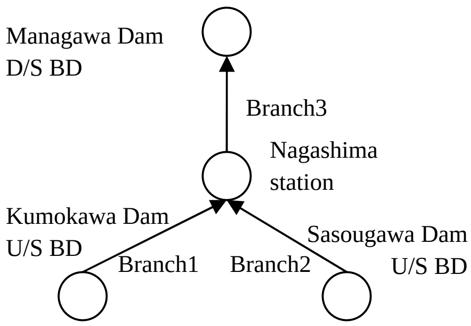

Fig.6 Hydrodynamic boundary conditions

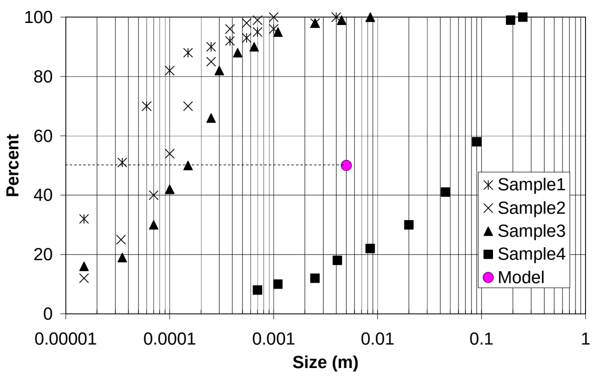

Fig.7 Sediment distribution curve of 4 samplings in Managawa Dam, 1998

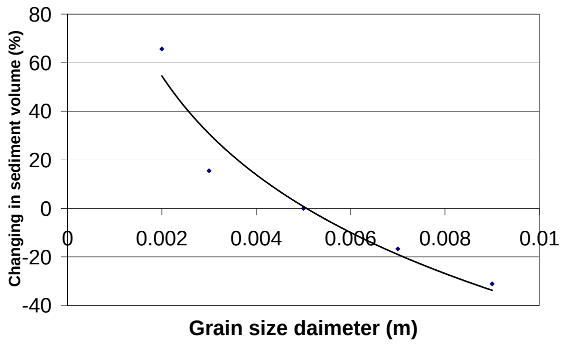

Fig.8 Sensitivity analysis of grain size diameter effect to accumulation sediment volume in 1995

For reference, sensitivity analysis of grain size diameter is shown in **Fig.8.** When grain size becomes finer, sediment accumulation volume becomes larger.

4. RESULTS

(1) Topographic results

This study has generated a watershed to 8 sub-basins as shown in **Fig.4** excluding Sasougawa dam basin. From 50m x 50m grid, we can obtain topographic information as area, average slope and average elevation in **Table 1**.

(2) Soil surface erosion results

Average annual sediment yields (t/ha) for each sub-basin during 1981 to 2004 were computed by MUSLE with SWAT model as shown in **Table 2.**

Table 1 Topographic information of each sub-basin

Sub basin	Area (km^2)	Slope (%)	Elevation (m)	Manning's n
1	9.39	0.44	546	0.035
2	12.76	0.52	363	0.035
3	11.54	0.52	546	0.035
4	9.84	0.45	704	0.035
5	27.35	0.45	557	0.035
6	8.01	0.49	1089	0.035
7	17.64	0.42	705	0.035
8	53.81	0.44	629	0.035

Table 2 Annual average soil surface erosion from MUSLE

Sub-basin	Average Erosion (t/ha/year)
1	9.66
2	12.04
3	12.08
4	9.86
5	10.39
6	10.94
7	9.26
8	10.58

Sub-basin No. 2 and 3 show high erosion rate because these slopes are so steep. The average sediment yield from the whole watershed calculated from Eq.(5) is about 60,161 m^3/year.

$$S_y = \frac{\sum Y_a \cdot Area \cdot 100}{\sigma} \tag{5}$$

Where S_y is the average sediment yield (m^3), Y_a is the sediment yield (t/ha), *Area* is sub-basin area (km^2) and σ is soil density about 2.65 t/m^3.

(3) Sediment volume in dam

The volume of sediment depositing in the large dams are measured every year in Japan. Sediment volume data of Managawa Dam is also available from starting operation until recently year but some data was disappear because of technical error as shown in **Table 3**.

After sediment yield from each sub-basin was computed by MUSLE, those data were used to input in total load transport model, Acker and White (1973). And then sediment will be routed along the river and deposited in the dam reservoir. Computed results are shown with observed ones in **Table 3**. Observed data in 2004 was extremely large mainly because of the Fukui heavy rainfall in July 18, 2004.

Table 3 Observed and computed sediment volume, 1981-2004, in Managawa Dam

Year	Observed Volume (m^3)	Computed Volume (m^3)
1981	-	42,304
1982	-	75,108
1983	78,664	77,730
1984	15,768	66,523
1985	166,907	53,337
1986	16,726	73,660
1987	23,477	75,525
1988	59,272	54,324
1989	79,652	93,670
1990	353,591	106,494
1991	-	58,157
1992	-	41,525
1993	175,980	66,901
1994	-	52,652
1995	106,271	60,281
1996	-	52,339
1997	4,812	42,950
1998	249,132	121,724
1999	41,822	66,315
2000	-	50,654
2001	101,227	81,551
2002	237,574	83,042
2003	36,322	63,617
2004	1,078,341	145,913

(-) data is not available

5. DISCUSSION

The computed sediment volumes in this study show large differences with the observed data because the observed data have some errors in some year. Therefore, total accumulated sediment volumes were compared between them. Observed and computed total sediment volumes until year 2003 were 1,747,197 m^3 and 1,560,381 m^3 respectively, which error is about 10%. In some year, the accumulative data are not much difference as shown in **Fig.9**. Therefore, the sediment yield and sediment transport model in this study can be used to estimate the sediment accumulation volume in Managawa Dam.

In order to determine efficiencies of the MUSLE model, a logarithmic form of Nash-Sutchliffe model is adopted, which is given by:

$$Z_{\ln} = 1 - \frac{\sum_{e=1}^{n} (\ln(A_{eo}) - \ln(A_{ep}))^2}{\sum_{e=1}^{n} (\ln(A_{eo}) - A_{\ln m})^2} \tag{6}$$

Where A_{eo} is the observed soil loss for event *e*, A_{ep} is the predicted soil loss and $A_{\ln m}$ is the mean value of $\ln(A_{eo})$ for all the events selected.

The Nash-Sutchliffe efficiency for this combined MUSLE and sediment transport model is about 0.30 where a model efficiency of 1.0 represents a perfect fit of the model to observed values. Negative values indicate that use of the average is a better predictor than the model (Nash-Sutchliffe, 1970). The Nash-Sutchliffe efficiency for the simple MUSLE is -0.84 and then the present model of MUSLE with the river routing system is increasing the efficiency.

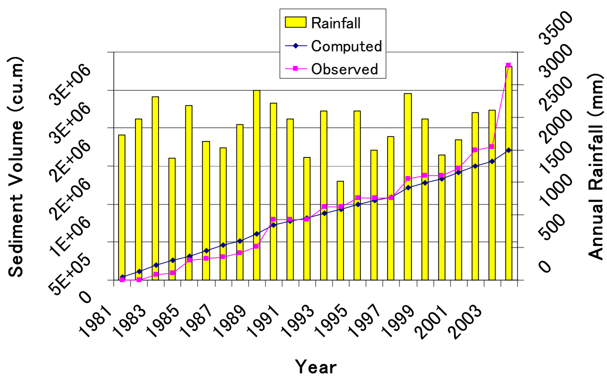

Fig.9 Annual rainfall, observed and computed accumulation sediment volume

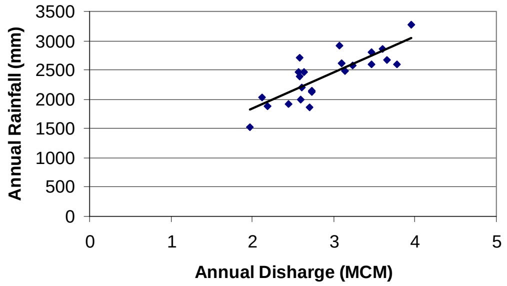

Fig.10 Relationship between Annual Discharge and Annual Rainfall, 1981-2004

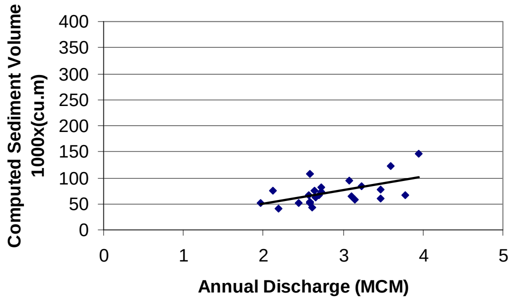

Fig.11 Relationship between Annual Discharge and Computed Sediment Volume

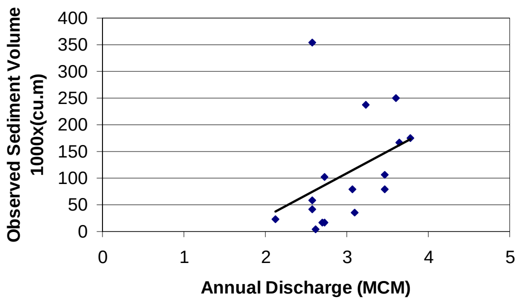

Fig.12 Relationship between Annual Discharge and Observed Sediment Volume

In order to improve the model, the relationship among annual rainfall, annual discharge, and observed and computed sediment volumes are analyzed. The annual runoff flowed into Managawa Dam has good correlation with annual rainfall as plotted in **Fig.10**. The annual sediment volume in dam is not only depended on the soil surface properties and rainfall but depended on discharge also. **Fig.11** and **Fig.12** show that the computed sediment volume from the model has moderately correlation with annual discharge but the observed one is varying more widely. R-square of computed sediment volume and annual discharge is 0.34, whereas the one of observed sediment volume and annual discharge is 0.16. Correlation may be dropped by the large rainfall events and other modifications are needed to compute sediment yield and transport process in such high flood periods. However, this study shows that this MUSLE with sediment transport model can be used to estimate reservoir sedimentation volumes and its tendency if basic characteristics of each catchment such as topographical, geological, meteorological conditions may change.

6. CONCLUSION

This study is an attempt to estimate the yearly volume of sediment deposition in Managawa Dam using the Modified Universal Soil Loss Equation (MUSLE) with sediment transport model. The MUSLE was developed for simulating the impact of land management practices on eco-hydrologic system (Arnold et al., 1995). The results of annual sediment accumulating volume for this study area show large differences with the observed data but total volumes almost coincided very well. In order to improve the model, other modifications may be needed to compute sediment yield and transport process in high flood periods. However, this model can be used to estimate reservoir sedimentation volumes and its tendency if catchment's conditions may change.

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