METHOD FOR PREDICTING THE SEDIMENT RUNOFF PROCESS DUE TO HEAVY RAINFALL IN THE YAZAGYO RESERVOIR BASIN, MYANMAR

Aye Mon Khaing*
MEE20718

Supervisor: Assoc. Prof. HARADA Daisuke**
Prof. Atsuhiro Yorozuya***
Prof. OSANAI Nobutomo ****
Dr. Menglu Qin*****

ABSTRACT

In July 2015, the Yazagyo Dam reservoir experienced a huge amount of sediment deposition due to the heavy rainfall caused by cyclone Komen. The reservoir lost 49.4% of its storage capacity from its initial state (64 million m^3) to (32.4 million m^3) within that year due to sediment deposition in the reservoir. This study predicted and evaluated sediment inflow rate along the river course and at the reservoir using a rainfall-runoff-inundation-based sediment transport model to manage reservoir sedimentation to last the long-life span of the dam. As a result of evaluating three cases of modeling with different sediment size distributions, the dam sedimentation due to the cyclone was reproduced when we employed the finest sediment size distribution. In addition, we found that 70% of sediment comes from Tributary-1, which implies an efficiency of countermeasures as the building of a check dam or other proper methods for this tributary and could expect 5 to 10 million m^3 sediment deposition into the reservoir annually.

Keywords: Sediment Runoff, Dam sedimentation, Landslide, Yazagyo Dam, Heavy rainfall

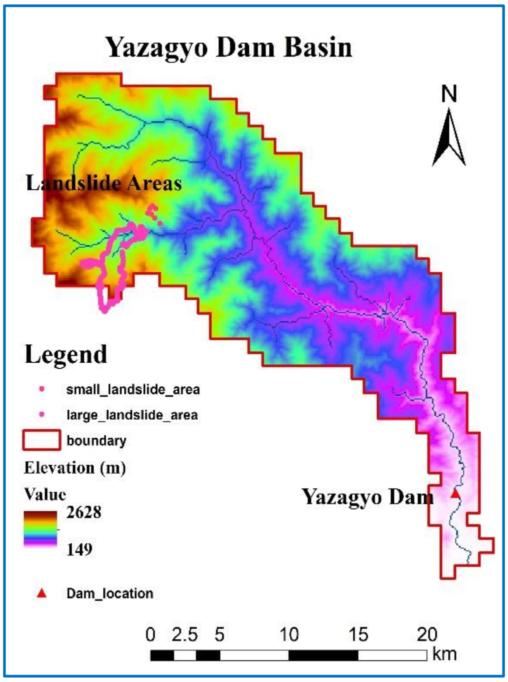

Figure 1. Map of the Yazagyo Basin

INTRODUCTION

This study targeted the Yazagyo Dam as the large and multipurpose dam in Myanmar a country that included more than 200 large dams. This dam project started in 2003 for the development of the Myittha River Basin, a tributary of the Chindwin River, and this project was completed in 2014-2015. During July 2015, a large monsoon rain began, and the country experienced heavy rain continuously for nearly three weeks, from mid-July to August 2015. Heavy rainfall (480 mm) on July 16, 2015, triggered a massive landslide approximately 53 km upstream of the Yazagyo Dam near the village of Hangken, Falam District in the Upper Chin Hill region of northwestern Myanmar. The impact of the landslides and vegetation uprooted from the upstream forest areas, and the debris flow hazards seriously affected not only the Chin Hills area and region along the river course but also the Yazagyo Dam. This dam was inundated with timber and sediment transported along the river course after the cyclone Komen on August 1, 2015.

Finally, fine sediment was transported into the Yazagyo reservoir. The sediment reduced the reservoir's storage capacity, and hampered operations for supplying irrigation water and hydropower generation for years. The Yazagyo Dam is a multipurpose dam built with a 3.96 MSM (million square meters) water

* Assistant Engineer, Department of Irrigation and Water Utilization Management, MOALI, Myanmar
** Associate Professor, GRIPS, Tokyo and Research Specialist, ICHARM, Tsukuba, Japan
*** Professor, GRIPS, Tokyo and Senior Researcher, ICHARM, Tsukuba, Japan
**** Professor, GRIPS, Tokyo, Japan
***** Doctor, GRIPS, Tokyo and Research Specialist, ICHARM, Tsukuba, Japan

spread area, and 64 MCM (million cubic meters) storage capacity at the 195 m full-supply level, the designed level before Komen. In 2016, according to a topographic survey of the reservoir, the estimated storage capacity was only 32.4 MCM, and 31.6 MCM of inflow capacity lost due to the sedimentation. Hence the reservoir capacity was 49.4% smaller it was at the initial state. In 2018, according to another topographic survey, the storage capacity was only 11.9 MCM, and the sediment inflow volume was 20.5 MCM which means that the storage capacity was 63.27% lower than the 2016 storage capacity and 81.4% lower than the capacity at the initial state. Therefore, this sediment value 20.5MCM intend to about 10MCM coming sediment into the reservoir annually and the storage capacity of the Yazagyo Dam is decreasing progressively, and the Yazagyo reservoir is gradually losing its functionality. This study attempted to predict and evaluate the sediment transport rate along the river course and to the reservoir in the future, to develop a plan to reduce the sedimentation rate by using countermeasures such as structures and proper methods, and analyze the reservoir operation for the long life span of the dam.

METHODOLOGY

The overall methodology is illustrated in Figure 2, which defines the basic concept of this research. This methodology was used to predict the sediment inflow rate in the reservoir, which was the main target of this research. This study focused on the sediment grain size distribution and location of the sediment supply using the RRIS (RRI based sediment transport model), which was computed for all river cells.

The RRIS Model combines three models: drainage model, rainfall-runoff model, and sediment transport model. Among these, the sediment transport model considers both bed-load and suspended load sediment. In this model, the formulae of Egashira et al. for bed-load and Harada et al. (density stratified flow model) for suspended load transport are available.

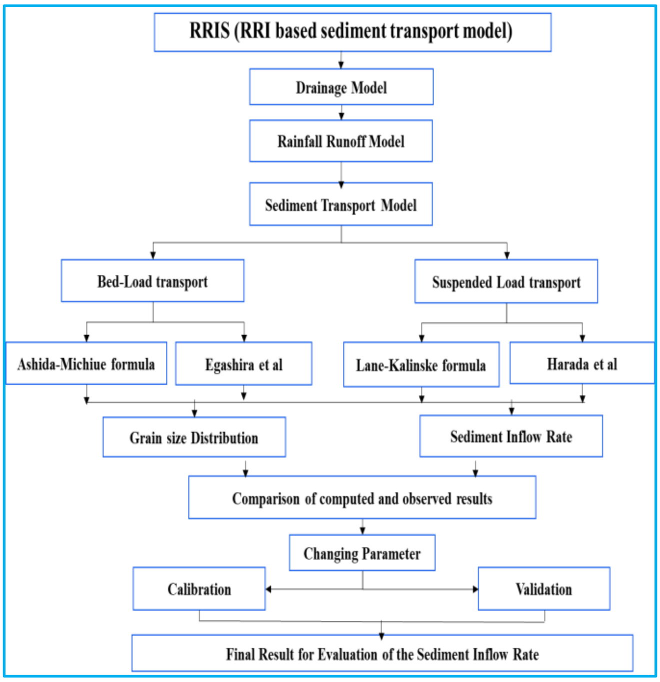

Figure 2. Flow chart of research methodology

After running the RRIS model, we obtained grain size distribution and sediment inflow rate result that included bed-load and suspended load sediment, changing river bed elevation, and shear stress friction of sediment grains. Then, the computed result was adjusted to the real conditions to change the parameters, such as the sediment grain size distribution and supply pattern of sediment sources. That, the model was calibrated and validated. Finally, the RRIS model was used to evaluate the sediment inflow rate in the reservoir.

The RRI model obtains the following mass balance equations which are based on the governing equation for water flow. The bed-load transport rate is defined as the quantity of absolute sediment volume discharging in unit time and unit length, and the equation to evaluate its transport rate is formulated in a non-dimensional form.

Governing equations for sediment

The mass conservation of bed sediment is defined as below (equation of bed elevation);

$$\frac{\partial Z_b}{\partial t} + \frac{1}{1-\lambda} + \left(\frac{\partial q_{bx}}{\partial y} + \frac{\partial q_{by}}{\partial y} + E - D\right) = 0 \qquad (1)$$

where, Z_b is the bed elevation, E and D are the erosion and deposition rates, q_b is the bed-load transport rate for the grain size and λ is the porosity of the bed sediment.

Bed-load inflow rate by the formula of Egashira et al. (1997)

The bed-load transport rate can be determined by the equation

$$q_{b^*} = \frac{4}{15}\frac{K_1K_2}{\sqrt{f_d+f_f}}\tau_*^{\frac{5}{2}} \tag{2}$$

Where; $qb*$ is the non-dimensional bed load transport rate, $\tau_*$is the non-dimensional bed shear stress, and K_1, K_2, f_d, and f_f are specified by theory

The non-dimensional bed shear stress τ_* can be estimated by the following equation

$$\tau_* = \frac{u_*^2}{\left(\sigma/_\rho - 1\right)gd} = \frac{h_t \sin\theta}{\left(\sigma/_\rho - 1\right)d} \tag{3}$$

$$d = \frac{u_*^2}{\left(\sigma/_\rho - 1\right)g\tau_*} \tag{4}$$

Where the shear velocity u_* can be computed as shown below

$$\mathrm{u}_* = \sqrt{\mathrm{gh}\ \sin\theta} \tag{5}$$

$$K_1 = \frac{1}{cos\theta}\frac{1}{tan\emptyset - tan\theta} \tag{6}$$

$$K_2 = \frac{1}{C_s}\left[1 - \frac{h_s}{h_t}\right]^{0.5} \tag{7}$$

$$\mathrm{f_d} = k_d\ (1-e^2)\left(\frac{\sigma}{\rho}\right)\ \bar{c_s}^{\ \frac{1}{3}} \tag{8}$$

$$\mathrm{f_f} = k_f\ (1-\bar{c_s})^{\frac{5}{3}}\ \bar{c_s}^{\ -\frac{2}{3}} \tag{9}$$

The thickness of the bed-load layer equation was obtained by Egashira et al.'s formula

$$\frac{h_s}{h_t} = \frac{1}{\left(\sigma/_\rho - 10\right)\overline{Cs}}\ \frac{\tan\theta}{\tan\emptyset\mathrm{s} - \tan\emptyset} \tag{10}$$

Where $\overline{Cs}$ is the average sediment concentration of the bed load layer obtained using the formula;

$$\overline{Cs} = \frac{1}{\left(\sigma/_\rho - 1\right)}\ \frac{\tan\theta}{(\tan\emptyset\mathrm{s} - \tan\emptyset)} \tag{11}$$

Mass conservation of suspended sediment for grain size d*i*

The equation can be written as follows;

$$\frac{\partial\bar{c}h}{\partial t} + \frac{\partial r_1\bar{u}\bar{c}h}{\partial x} + \frac{\partial r_1\bar{v}\bar{c}h}{\partial y} = \frac{\partial}{\partial x}\left(h \in_x \frac{\partial\bar{c}}{\partial x}\right) + \frac{\partial}{\partial y}\ \left(h \in_y \frac{\partial\bar{c}}{\partial y}\ \right) + E - D \tag{12}$$

where, $\bar{c}$ is the depth-averaged value for sediment concentration, $\bar{u}$, and $\bar{v}$ are the velocities of the x, and y components, $\in_x$, and $\in_y$ are the dispersion coefficients of the x, and y components, r_1 is the correction factor, E is the erosion rate of sediment, and D is the deposition rate of sediment, respectively. The erosion rate can be determined form by the flow characteristics (turbulence characteristics) near the bed.

The suspended sediment concentration is evaluated by

$$\frac{\partial \mathrm{c}}{\partial t} + \mathrm{u}\frac{\partial c}{\partial x} = \frac{1}{h}\frac{\partial}{\partial x}\left(\varepsilon h\frac{\partial\bar{c}}{\partial x}\right) + \frac{1}{h}\ \left(1 - \frac{\mathrm{c}}{c_s}\ \right)(\ w_e c_{s-}\ w_o c_s) \tag{13}$$

Finally, according to Harada et al.; (2019)

$$\frac{W_e}{u} = \frac{\mathrm{K}}{R_{i*}} \left(R_{i*} = \frac{\frac{\Delta\rho}{\rho} g\mathrm{h}}{u^2} \; and \;\; K = 1.5 \times 10^{-3} \right) \tag{14}$$

DATA

The Yazagyo Basin has only one rainfall station and only daily rainfall data. Therefore, we employed GSMaP rainfall data from July 1, 2015 to August 31, 2015 which includes the cyclone Komen period. For grain size distribution data, we considered three cases based on the field-observed data.

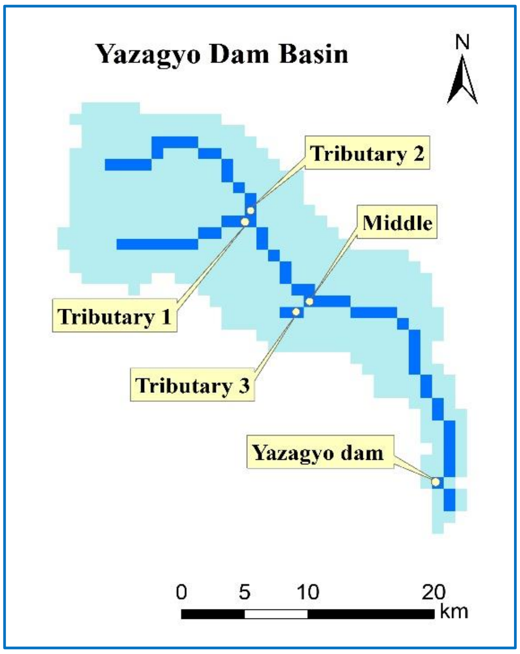

Figure 3. Result target locations

Case 1: The grain size distribution data for fine grains (13%) and coarse grains (87%) got from the ICIMOD Investigation of Landslide Dam in Chin Hill, Myanmar Field Report which is close to the 2016 survey result in the village of the Hangken.

Case 2: The grain size distribution data for fine-grains (47%) and coarse grains (53%) were assumed from the entire landslide area in Chin Hills region, with the condition of the area supplying equilibrium sediment continuously without any change of grain size distribution from the upper site of the river confluence.

Case 3: Grain size distribution data for fine-grains (80%) and coarse grain (20%) were assumed from landslide areas supplying equilibrium sediment from the upper site of the river confluence. These results focused on the five target locations such as tributary 1,2 and 3, the middle of the river course, and the dam reservoir shown in Figure 3.

RESULTS AND DISCUSSION

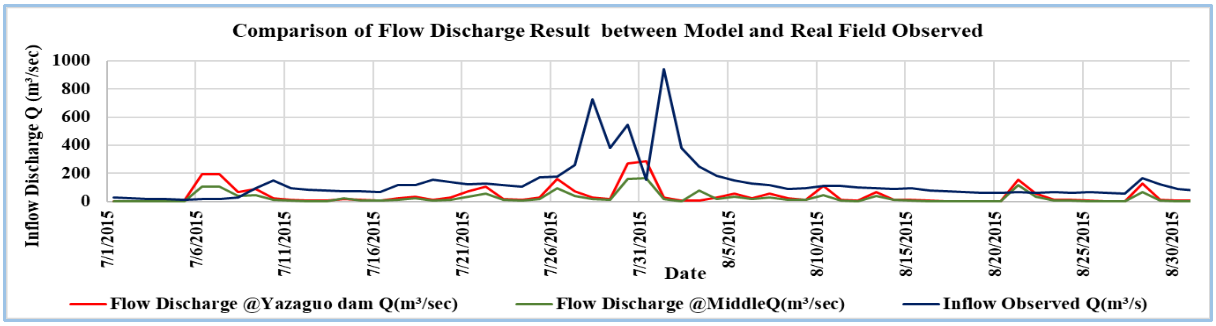

Figure 4. Comparison of flow discharge results between model and real field observed

Figure 4 compares the observed water discharge at the dam, the discharge in the middle of the river course, and the simulated results. Although the simulated peak discharge during cyclone Komen may underestimate the observed discharge, the discharged influence sedimentation, as the dam lost almost 49.4% of its the reservoir capacity within the year. The estimating of dam volume depends on the water level relation with time interval. The higher the water level, the more the dam volume is, and also the more the flow discharge of the dam.

The results of the sediment inflow volume for the three cases are shown for five representative locations.

Case 1: Sediment grain size distribution –fine grains 13% and coarse grains 87% (sediment size from ICIMOD field report published after the cyclone Komen in 2016).

Table 1. Results for Case 1

Fine grain 13%	Location				
Coarse grain 87%	Tri-1	Tri-2	Tri-3	Middle	Reservoir
	MCM	MCM	MCM	MCM	MCM
Bed-load sediment	1.607	0.019	0.000	1.372	0.927
Suspended load sediment	1.777	0.877	0.615	2.070	2.038
Sediment inflow rate	**5.641**	**1.494**	**1.025**	**5.737**	**4.941**

Table 1 the results for the five target locations, i.e., tributaries 1, 2, and 3, the middle of the river course, and the reservoir. As shown, the suspended load was greater than the bed load along the waterway. The sediment inflow rate transported a volume of (4.941MCM) containing a 60% bed-load and suspended load sediment volume into the reservoir that implies about (5MCM) deposited into the reservoir.

Case 2: Sediment grain size distribution –fine grains 47% and coarse grains 53%

Table 2. Results for Case 2

Fine grain 47%	Location				
Coarse grain 53%	Tri-1	Tri-2	Tri-3	Middle	Reservoir
	MCM	MCM	MCM	MCM	MCM
Bed-load sediment	6.320	2.035	0.000	4.353	3.330
Suspended load sediment	3.978	2.947	1.238	6.766	7.023
Sediment inflow rate	**17.164**	**8.303**	**2.063**	**18.53**	**17.255**

The results for Case 2 shown in Table 2. After changing the sediment grain size percentages as shown in the table and assuming a continuous supply of equilibrium sediment from the upper reach; inflow deposits of (17.255MCM) contained a 60% bed-load and suspended load sediment volume. As a result, the bed-load sediment exceeded the suspended load only at the tributary 1.

Case 3, Sediment grain size distribution –fine grains 80% and coarse grains 20%

Table 3. Results for case 3

Fine grain 80%	Location				
Coarse grain 20%	Tri-1	Tri-2	Tri-3	Middle	Reservoir
	MCM	MCM	MCM	MCM	MCM
Bed-load sediment	13.761	0.106	0.000	5.747	4.570
Suspended load sediment	4.782	4.658	1.514	8.435	9.024
Sediment inflow rate	**30.905**	**7.940**	**2.524**	**23.636**	**22.660**

The results for Case 3 are shown in Table 3. With sediment percentages of 80% fine grains and 20% of coarse grains supplied constantly from the upper reach, the sediment inflow rate was (22.66 MCM) and it contained a 60% of bed-load and suspended load sediment volume into the reservoir. The observed field data at this location according to the 2016 topographic survey revealed a value of (31.6 MCM).

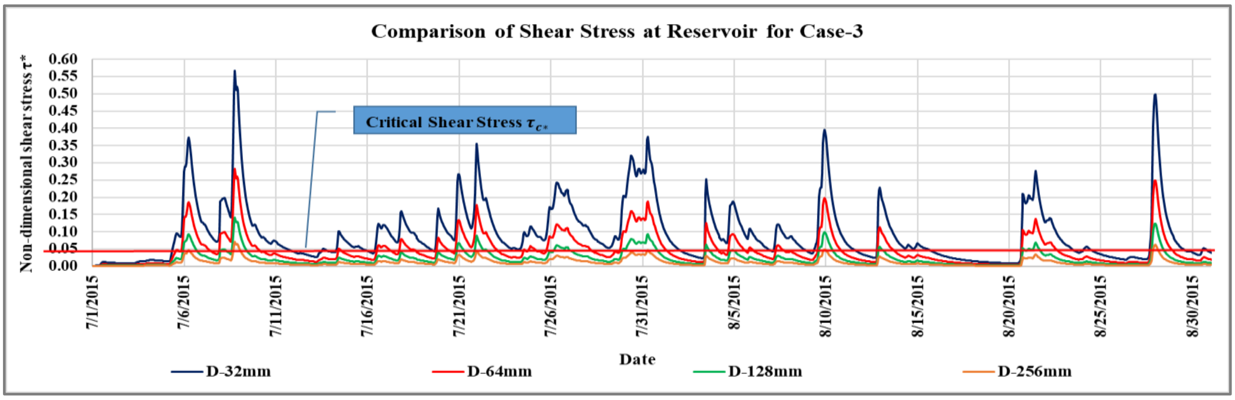

Figure 4. Comparison of shear stress at the reservoir

Figure 4 shows a comparison of shear stress for a Case 3 results. The critical shear stress τ_{c*} is governed by the shear velocity and the sediment size along the river course. In this result, fine-grained sizes less than 2 mm and coarse grained sizes less than 256mm move to the reservoir due to ($\tau_{c*} > 0.05$) depending on riverbed slope, shear velocity, friction between sediment and river bed, and flood level. In this result, we can determine which sediment sizes move to various locations along the river course.

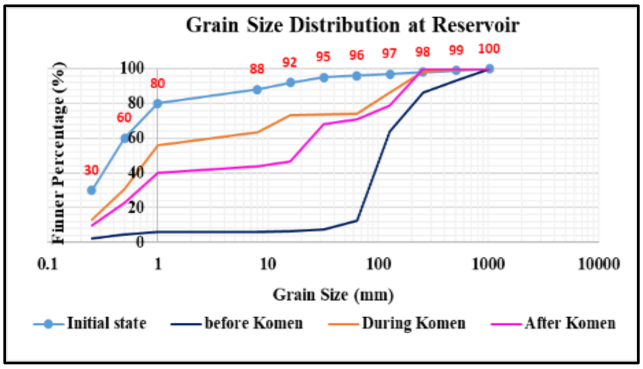

Figure 5 shows the grain size distribution results at the reservoir for Case 3. In this case, we consider the large amount of fine-grain 80% and coarse grain 20% as input data, and the blue line is the initial state of sediment grain size distribution. We can see all of the fine-grain sediment results are smaller than the initial state. On the other hand, coarse sediment % is greater than the initial state into the reservoir location depending on sediment supply rate and high flood level.

Figure 5. Sediment grain size distribution result

According to the RRIS model results, 70% of all of the sediment rates from the tributary-1, 20% from tributary-2, and 10% from tributary-3 supplied into the reservoir. Tributary-1 is the major sediment source located in the landslide areas. When comparing tributary-1 and tributary-2 results, the suspended load volume is similar but the bed-load sediment of tributary-1 is larger than that of tributary-2. When considering in bed-load sediment transports with Egashira et al., formula, the bed slope of Tributary-1 is the mild slope of the waterway, so the depth of water level h_t is high, the thickness of bed-load layer $\frac{h_s}{h_t}$ value is small means that the $\frac{h_s}{h_t}$ value of tributary-2 is larger than that of tributary-1. Therefore, the K_2 value of tributary-1 that contained the bed-load formula is large, and also bed-load sediment rate is high. Similarly, the K_2 value of tributary-2 is small, and the bed-load sediment rate is a small result. Therefore, tributary-1 is more sediment supply than tributary-2 according to the bed-load layer equation, K_2 equation, and sediment bed-load equation by using step by step according to equation numbers as (10), (7), and (2).

Although the computation results revealed that countermeasures would be effective in Tributary 1, it is unrealistic to construct a check dam (erosion control dam) to reduce the sediment yield from the area, because the area is far from the dam. Therefore, hillside erosion controls, such as vegetation, would be an effective way to reduce sediment yield from Tributary 1. In addition, the model results show that even with the current sediment size distribution such as that of Case 1, we have to expect approximately 5 MCM of sedimentation annually in the dam reservoir, and the observed field results show 10MCM of sediment annually into the dam. Constructing a check dam just upstream of the dam, assuming a 60% reduction of dam sedimentation will contribute to maintaining the dam functions. The purpose construction of check dams is to reduce the sediment rate, erosion, and slow water flows into the reservoir, in that way, reducing river bed and river banks erosion downstream.

CONCLUSION AND RECOMMENDATION

This study evaluated the sediment runoff process due to heavy rainfall in the Yazagyo Reservoir Basin. As a result of considering three modeling cases (1-3) with different sediment size distributions, we obtained results for Case 1 of (4.941MCM), Case 2 of (17.255MCM), and Case 3 of (22.66MCM) that each contained a 60% bed-load and suspended load sediment volume (see Table 1,2 and 3). Among the cases, Case-3 well reproduces the sedimentation within the Komen cyclone time, which implies a huge amount of fine sediment supply from the landslide area, its transportation along the river, and deposition in the dam reservoir. To reduce the dam sedimentation, Tributary-1 that is a major source of sediment supplying to the dam should be controlled by hillside erosion management such as vegetation plants. Among the ways, keeping the dam function, the check dam construction just upstream of the reservoir would also be more effective. In that case, according to the computational results, we should expect 5 to 10 MCM sediment deposition into the Yazagyo dam reservoir annually. As a recommendation, we need to cope with sediment inflow to build check dams urgently in the proper places and by appropriate methods to manage the sedimentation such as flushing, sluicing, dredging, and dry excavation into the reservoir.

ACKNOWLEDGEMENTS

I express my gratitude to Assoc. Prof. Daisuke Harada, my supervisor, Prof. Atsuhiro Yorozuya, Prof. Shinji Egashira, Dr. Menglu Qin, and ICHARM for their helpful suggestions, support, and kindness during my master's course of study. I appreciate the support of all ICHARM members, who encouraged me to pursue the accomplishments of this study.

REFERENCE

Bajracharya, S. R., Maharjan, S. B. and Dangol, V. (2017). 'Investigation of the landslide dam in Chin Hill, Myanmar, 15 July 2016'. Available at: http://lib.icimod.org/record/32575

Bajracharya, Samjwal. Ratna; Sudan Bikash. Maharjan; Vishnu. Dangol. (2017) 'Landslide Dam Outburst Flood in Chin Hill, Myanmar', p. 15

Egashira, S., Miyamoto, K. and Itoh, T. (1997). Constitutive equations of debris flow and their applicability. Proceedings of 1st International Conference on Debris Flow Hazards Mitigation, Chen CL (ed.), ASCE: New York, pp. 340-349

Harada, D., Egashira, S., Ahmad, T. and Katayama, N. (2019). Erosion rate of bed sediment by means of entrainment velocity. Proceedings of Hydraulic Engineering. Volume 64, pp. 967-972. JSCE

Sayama, T. and Iwami, Y. (2016) Rainfall–runoff and flood inundation predictions using RRI model.