SEDIMENT RUNOFF IN IRRAWADDY (AYEYARWADY) RIVER BASIN AND THE SEDIMENT MANAGEMENT

MYO THANDAR
School of Industrial Training and Education (SITE), Myanmar, myomyo.gtc@gmail.com

KAZUKI YAMANOI
Disaster Prevention Research Institute, Kyoto University, Kyoto, Japan, yamanoi.kazuki.6s@kyoto-u.ac.jp

MASAHARU FUJITA
Disaster Prevention Research Institute, Kyoto University, Kyoto, Japan, fujita.masaharu.5x@kyoto-u.ac.jp

ABSTRACT

The Ayeyarwady River, located in the center of Myanmar, is an important commercial waterway for citizens, but at the same time, it is a large river that transports a huge amount of sediment. In recent years, human impacts such as deforestation have led to changes in the transport process of this sediment. Under this background, basin-scale sediment management plays an important role in both disaster mitigation and environmental conservation. Therefore, it is very important to evaluate the sediment transport process and the effects of human impacts by using numerical simulation for maintaining the waterway. In this study, a water and sediment discharge model was applied to the upstream area of Ayeyarwady River to make the sediment transport process in this basin clear. Since there is no sufficient rainfall data, the satellite-based rainfall data was employed for this simulation. The effects of human impacts on the sediment transport process were evaluated by scenario-based simulations, assuming that the sediment production changed due to deforestation and forest conservation. Although there is still a problem related to the quality of results due to the limitation of the data availability, the simulation was successfully conducted and found out where the deposition and erosion take place along the river.

Keywords: Ayeyarwady river, natural disasters, sediment runoff model, GSMaP, sediment management

1. INTRODUCTION

Ayeyarwady river has 2,210km lengths from the Northern highest mountainous area to the Southern plain area through the Ayeyarwady delta and the Bay of Bengal, and it ends into the Andaman Sea of the Indian Ocean. The river basin is generally divided into three parts, Upper, Middle, and Lower basin, as shown in (Figure 1). The areas of interest in this study are the upper and middle part of the river basin as shown in Figure 2, and the basin area is 173,411 km^2. In this figure, unit channels and unit slopes for an employed model described in Section 3 are also shown.

The delta area is the fertilization region with rich alluvial soil, and so agriculture is the main activity of almost residents. Not less than three million people are living in the delta region. It is the most densely populated area, and the annual population rate also has been increasing almost every year. The annual rainfall amount in the delta area is ranging from 2,000mm to 3,000mm. Much rainfall runoff and the active movement of soil in the basin result in extendings of the delta to the Andaman Sea every year. For the research on sediment runoff at the basin scale, the topography, geology, geography, climate condition and other conditions should be surveyed to know the current situation and to understand how the river management system should be improved.

The climate condition of Myanmar is tropical monsoon, and the specific climate conditions of the upper basin and the lower basin are a warm and humid subtropical climate and a humid tropical climate, respectively, according to the Department of Meteorology and Hydrology (Myanmar). Those climate zones are dominated by the South Asia summer monsoon, and it causes heavy rainfalls.

Annual precipitation varies from 1,500 to 2,500 mm throughout the basin. Myanmar is one of the countries vulnerable to climate change, where the monsoon weather pattern is changing every year. The water discharge ranges from 2,300 m^3/s to 32,600 m^3/s around the snowmelt season in the mountainous areas, the average discharge is 13,000 m^3/s, and the average annual water discharge is 410 km^2/year.

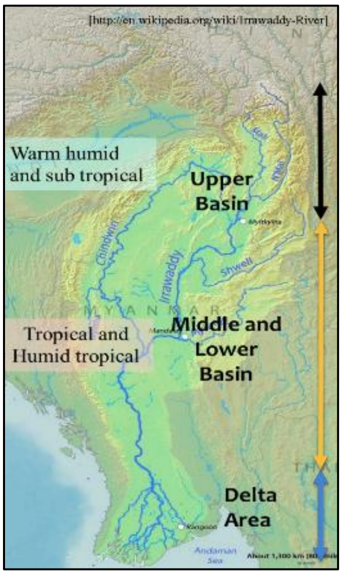

Figure 1. Location of the Ayeyarwady River Basin
Sources: https://en.wikipedia.org/wiki/Irrawaddy_River

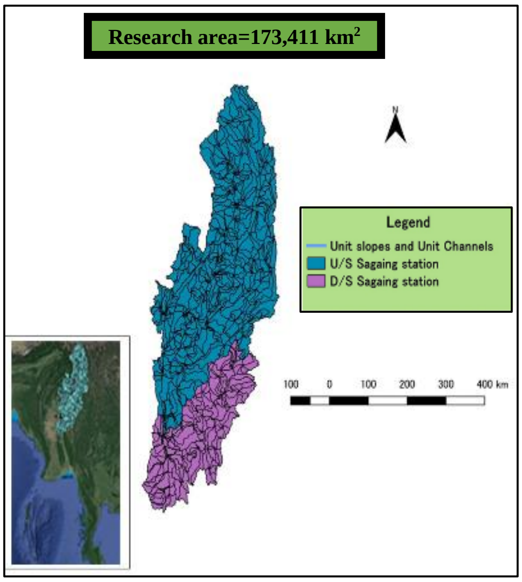

Figure 2. Research area

1.1 Navigation system

The commercial transportation system by ships has run in the Ayeyarwady River Basin since the early sixth century as it belongs to the huge area of the country, and it is crucial for Myanmar. According to a report by the Directorate of Water Resources and Improvement of River Systems (DWIR), navigable lengths in the main Ayeyarwady river and the delta area are 1,534km. Fishery products, petrol, and others are carried by ships from the lower to the upper regions, and timber and cement are transported from the upper to the lower regions. The various products are transported not only throughout the country but also to other foreign countries. Unfortunately, the navigation route cannot be used widely in dry weather conditions because of the two main factors. One reason is the river water depth becomes shallower than usual as the amount of rainfall is very low in the dry season. Another reason is the formation of sandbars due to high sediment transportation. Sand bar formation makes waterways limited (Figure 3). Depending upon these circumstances, the cargo vessels have been undergoing difficulties to move smoothly to their directions because of the large amount of sediment deposition in the river waterway. Nowadays, it has been encountering many problems along with the navigable waterway system, and therefore it is very important to preserve the navigation route. To diminish such kind of problems, some countermeasures are performed to fix the navigation route in the river. Control of bed variation by dykes is one of the typical methods in the river. In the mountainous areas, the construction of check dams in the tributaries is a basic countermeasure to reduce sediment supply from the tributaries. Also, the trapped sediment by the check dams can be used as sediment resources such as construction materials. Some projects have been running to maintain the ship transportation system that is one of the most important transportation systems in Myanmar. Analysis of the feature of the basin-scale sediment runoff is very fundamental and important to find effective countermeasures in the projects.

Figure 3. Commercial waterway system and sandbars formation in the Ayeyarwady River Basin, Myanmar
Source: https://www.mmtimes.com/news/ayeyarwady-river-navigation-project-start-february.html

1.2 Natural disasters

Myanmar is one of the most countries which have been suffering from natural disasters such as flooding in the lowland regions, soil erosion along the river system, earthquakes (mainly occurred in the Sagaing region), and landslides. As a background of natural disasters, human impacts cannot be ignored. Particularly, deforestation in the mountainous regions is very serious as a factor in sediment disasters. Local people are logging natural forests to export woods to other foreign countries and make charcoal for the demand of fuel, without renewal plantation. The widespread of the law of forest area strongly affect the shallow landslides and soil erosion and consequently gives an impact on bed variation in the downstream. Forest degradation and deforestation possibly cause environmental deterioration such as landslides, floods, water loss, low-intensity rainfall, and drought. Those are threatening to the ecological and hydrological conditions of the Ayeyarwady river basin. Such processes are progressing along the central Ayeyarwady and the delta area.

1.3 Impacts, response, and issues related to the sediment

Figure 4 shows an impact-response structure disturbing the Ayeyarwady river basin. From a socio-economic point of view, urbanization and agricultural expansion leading to deforestation are very important impacts. Also, the government has progressed the dam construction projects. These human impacts strongly affect the sediment runoff system. Climate change acts directly on the river basin under this socioeconomic condition. Flood disasters and sediment disasters could be much more severe. The influence on the environment condition could also be much larger. Considering that the annual suspended load in the Ayeyarwady basin has been currently ranked fifth-largest in the world, and the total dissolved has been ranked fourth-highest in the world, climate change seems to be a threat for the ship transportation system that already has several problems. In order to find the scenarios for the maintenance of the ship transportation system, it is very important to identify the sources of sediment production mainly caused by heavy rainfalls and to simulate the sediment runoff.

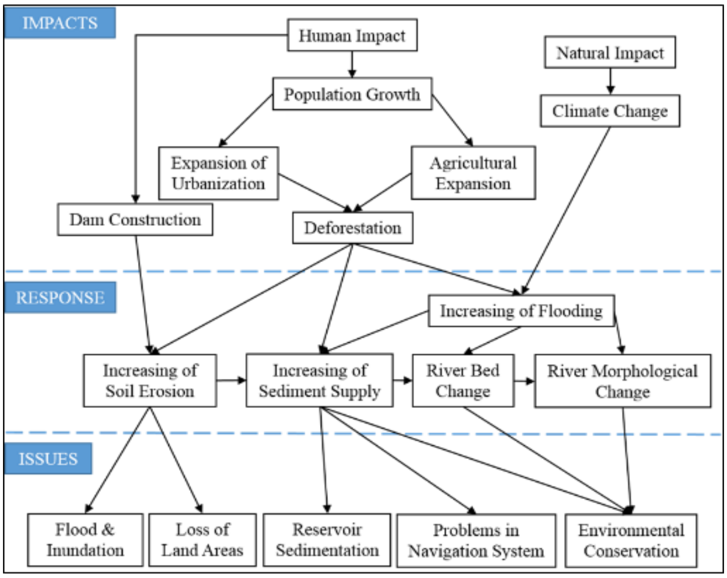

Figure 4. The impacts and issues of sediment runoff and transport

2. OBJECTIVES

Under the current conditions on sediment production and sediment runoff, riverbed variation causes some problems in the utilization of ship transportation. In some locations, the water depth is not enough for navigation because of too much sediment deposition. To find the countermeasures out, "Ayeyarwady River Basin Research Organization (ARBRO), Integrated River Basin Management, Hydro-power Development (Ministry of Electrical Power), Ministry of Environment and Forestry, and Civil Society Organizations, etc are performing team research works and field analysis in the Ayeyarwady river using various kinds of numerical simulation models and field investigation. However, any numerical simulation of sediment runoff at a basin-scale has not still carried out. In this paper, we employ a simulation model (Yamanoi and Fujita, 2014) and investigate the applicability of the model to the sediment runoff in the Ayeyarwady River.

Data sets of precipitation, sediment production rate, bed material, and slope condition are necessary for the simulation. The accuracy and reliability of the calculation result are dependent on the quality and quantity of the data. However, as the available data are limited in Myanmar, the problem is how we can get a reasonable result even with less data. Particularly, rainfall data based on rain gauges is not enough for the simulation. Considering above background, the following problems are tried to be cleared in this paper;

1. Applicability of satellite-based rainfall data to the spatial and temporal distribution of rainfall data all over the basin
2. Applicability of the simulation model by Yamanoi and Fujita to the Ayeyarwady river basin

3. Reliability of the simulation without enough data on precipitation.

3. METHODOLOGY

3.1 Overview of the simulation model for rainfall and sediment runoff

In this paper, we employ Yamanoi and Fujita model (2014) as a rainfall and sediment runoff model. Regarding the detail, refer the Yamanoi and Fujita (2014). In this section, the main basic equations are introduced. First of all, they are employed for the analysis of sediment-related problems and consideration of other scenarios related to the Ayeyarwady river basin. This basin model can identify by dividing it into two parts such as (1) unit slope and (2) unit channel to estimate the runoff of the slope on a basin-scale (Figure 5).

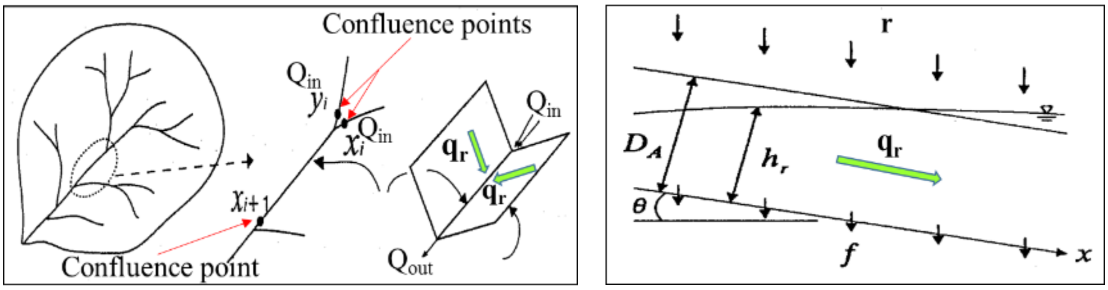

Figure 5. Unit channels and unit slopes as a watershed model (left). Overview of the rainfall runoff model in unit channels (right)

In this model, rainfall runoff in unit slopes is calculated by kinematic wave model. The unit slope is divided into 10 parts in x-direction. The conservation law of water is described by

$$\alpha\frac{\partial h_r}{\partial t}+\frac{\partial q_r}{\partial x}=(r-f)cos\theta \qquad (1)$$

where, h_r is the water depth from the bed rock, r is the rainfall intensity, f is the infiltration ratio, and θ is the gradient of the unit slope. α is described by

$$\alpha=\begin{cases}\lambda_s & (h_r<D_A)\\ 1 & (h_r\geq D_A)\end{cases} \qquad (2)$$

where D_A is the soil thickness of the unit slope, and λ_s is the effective porosity of the soil on the unit slope suface. q_r is the unit water discharge which is obtained by

$$q_r=\begin{cases} kh_r\sin\theta & (h_r<D_A)\\ kD_A\sin\theta+\dfrac{1}{N}\sqrt{\sin\theta}\,(h_r-D_A)^{5/3} & (h_r\geq D_A)\end{cases} \qquad (3)$$

where k is the coefficient of permeability, N is the Manning's roughness coefficient on the surface of the soil layer. The conservation law of water in unit channels is shown as

$$\frac{\partial h}{\partial t}=\frac{1}{BL}\{Q(x_i)+Q(y_i)-Q(x_{i+1})\}+\frac{1}{B}\{q_{r\mathrm{left}}+q_{r\mathrm{right}}\} \qquad (4)$$

where B and L are the width and length of the unit channel, respectively, and Q is the water discharge at the downstream end of the unit channel. x_i and y_i are the two unit-channels which flow into the unit channel x_{i+1}. $q_{r\mathrm{left}}$ and $q_{r\mathrm{right}}$ are the water discharges at the ends of both unit slopes connecting to the unit channel x_{i+1} and these flow into the unit channel x_{i+1}.

The conservation law of sediment in the unit channel x_{i+1} are described by

$$\frac{\partial z}{\partial t}=\frac{1}{(1-\lambda)BL}\{Q_s(x_i)+Q_s(y_i)-Q_s(x_{i+1})+V_{pro}\} \qquad (5)$$

where z is the river bed elevation, λ is the porosity of the river bed material, Q_s is the sediment discharge which is obtained by the summation of bed load and suspended load discharge, Q_b and Q_{sus}, respectively. V_{pro} is the sediment production ratio in the two unit-slopes connecting to the unit channel x_{i+1}. To treat not only river bed deformation but also the change of grain size distribution, the bed load and suspended load discharge is calculated for each grain size step. The conservation law of sediment for each grain size step j is described by

$$\frac{\partial p_j}{\partial t} = \frac{1}{\Delta BL}\{Q_{sj}(x_i) + Q_{sj}(y_i) - Q_{sj}(x_{i+1})\} - \frac{\partial z}{\partial t}\frac{f_j}{\Delta} \tag{6}$$

where, Q_{sj} is the sediment discharge in grain size step j and p_j is the grain content whose size is d_j in the surface layer of the riverbed. f_j is obtained by

$$f_j = \begin{cases} p_{j0} & \left(\frac{\partial z}{\partial t} \leq 0\right) \\ p_j & \left(\frac{\partial z}{\partial t} > 0\right) \end{cases} \tag{7}$$

where p_{j0} is the grain content in a lower layer of the surface layer.

3.2 Rainfall distribution and application

Unit slopes and unit channels are extracted from the ASTER GDEM, which has 30 m resolution using tools of GRASS GIS. The unit channels in the calculation domain are shown in Figure 6. The location of rain gauges installed by the Department of Meteorology and Hydrology (DMH) Myanmar is also shown in this map. Since the number of rain gauges is not enough to calculate the rainfall runoff, we employed the satellite-oriented precipitation data obtained by GSMaP. However, the satellite-oriented precipitation showed a smaller value than the gauge-observed one. Therefore, we modified the satellite-oriented data by the method described below.

Firstly, we introduced the modification coefficient α, which is defined by the ratio of the gauge-observed precipitation and satellite-oriented precipitation. Figure 7 shows the relationship in annual precipitation at six observation stations shown in Figure 6. Since the trend of the relationship changes in around 2008 to 2009, we introduced two different alpha values. By using this value, the satellite-oriented rainfall R_{sat} is modified to R_m by $R_m = \alpha R_{sat}$.

Additionally, the precipitation data is modified to the effective precipitation R_e by introducing runoff ratio β because the target catchment is too large to neglect the evaporation. Figure 8 shows the comparison of the annual total volume of modified precipitation in the target drainage basin V_m, annual discharge V_{dis} and its ratio β. In this study, we used the different β year by year.

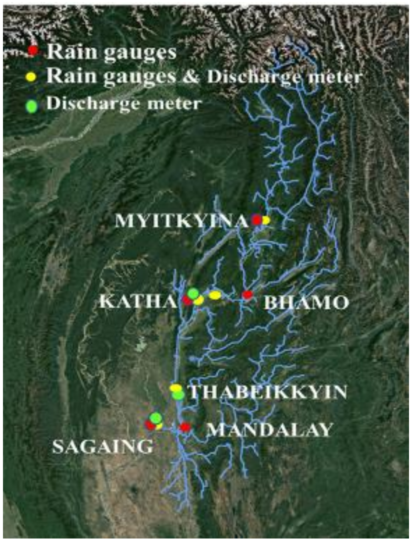

Figure 6. Unit channels in the target watershed and the location of the observation points.

3.3 Simulation scenarios

In this study, to consider the effect of the change of sediment production ratio due to the impacts such as deforestation and forest conservation, we conducted the three simulation cases changing the sediment production ratio. Scenario 1 is the basic scenario to reproduce the sediment runoff and sediment deposition /riverbed erosion over ten years. In this scenario, we set the sediment production ratio as the value, which is estimated by the average sediment discharge at the downstream end (Sagaing). As rainfall condition, the hourly precipitation from 2004 to 2013 are given based on a method explained in 3.2. To evaluate the effect of the decrease of sediment production due to forest conservation, scenario 2 employs the half sediment production ratio as scenario 1. On the contrary, scenario 3 assumes the increase in sediment production due to deforestation. In this scenario, we employed the double value of sediment production ratio as the scenario 1.

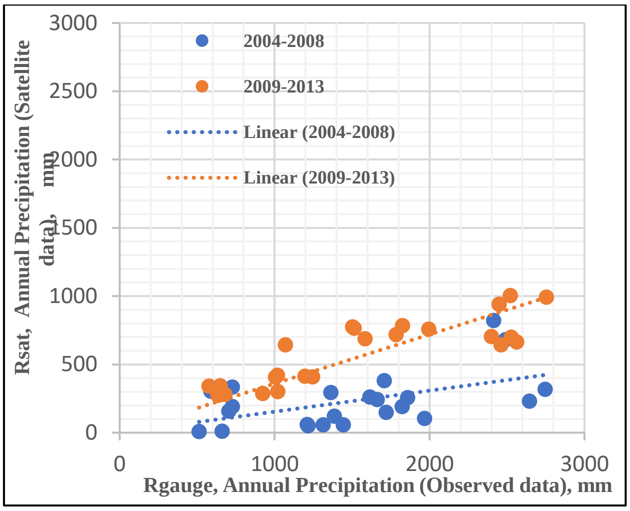

Figure 7. Comparison of the gauge-observed and satellite-oriented annual precipitationat five observation points.

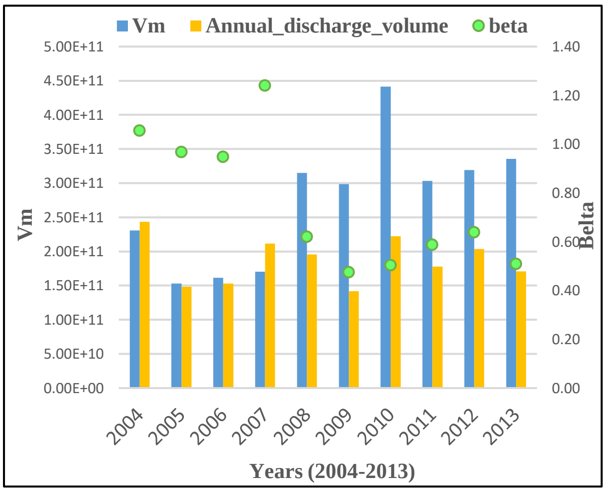

Figure 8. Comparison of the annual total precipitation in the whole catchment V_m, annual total discharge at the downstream end and its ratio β.

4. RESULTS AND DISCUSSION

Many of the parameters given in this simulation cannot be set in detail in the study. The upstream boundary conditions on sediment discharge affect the calculation results, however the reach with the large influence will be limited to the upmost reach because it is a 10-years simulation. Simulation results for the middle and downstream reaches will not include the influence of the boundary condition.

Figure 9 shows the simulation result for scenario 1. In this scenario, the amount of sediment equal to the annual sediment discharge at Sagaing station is given as the production sediment of this basin. In this case, the change in bed elevation in the middle and lower reaches ranges between -0.1 and 1.0m. This shows the current sediment supply condition is providing an almost equilibrium bed condition. Although the accuracy of the simulation cannot be evaluated clearly because there is no data of actual riverbed variation, it is thought that the simulation almost represents the actual situation because any problems on bed degradation and aggradation are still not found. So, it can be said that the current situation of the sediment runoff is almost in equilibrium. Under the equilibrium condition, the local trouble spots for the navigation system could appear due to the sand bar movement. Local maintenance of waterway at the trouble spot is required. Also, Figure 9 shows that the sediment deposition occurs in some parts of the lower and middle reaches. The risk of local flood inundation rises more than usual. Figure 10 shows the case of the sediment production is half the current rate. The change in bed elevation is about -0.1m in 5-years. Little sediment supply condition is causing bed degradation which is gradually developing, and the active streams could be fixed and become much deeper. The waterway condition seems to be much better, but the irrigation system may have some troubles, and also local scouring near bridge piers must be very serious in the future. Figure 11 shows that the change in bed elevation is more than 0.1 m, and too much sediment supply condition is causing bed aggradation in the lower reach. These situations create many problems in the river waterways and navigation system because the waterway could be unstable, and consequently, the flood inundation rich becomes rise very much.

As described above, to increase the sediment production than the current situation, the problem is large in terms of river use and flood control, it is required to be the current state or less sediment production.

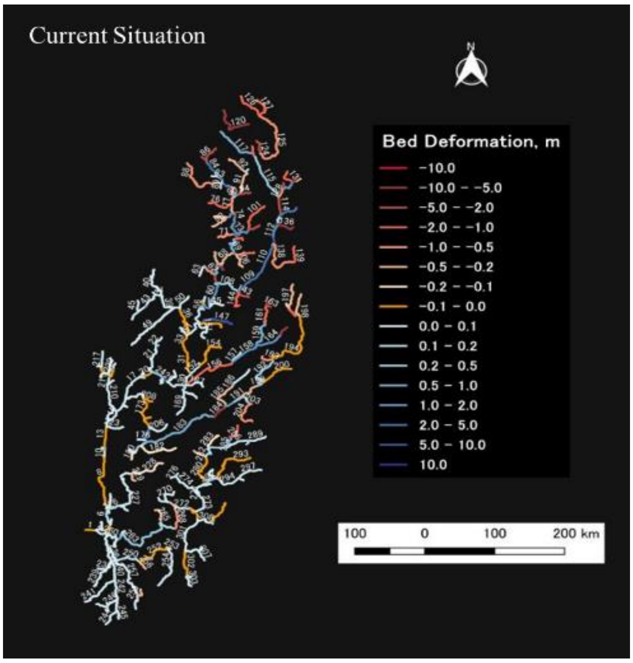

Figure 9. Bed deformation results by scenario 1

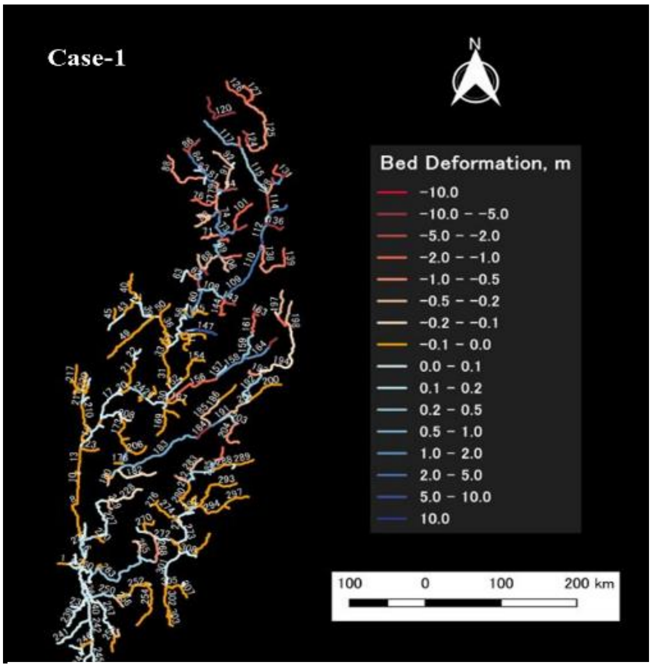

Figure 10. Bed deformation results by scenario 2

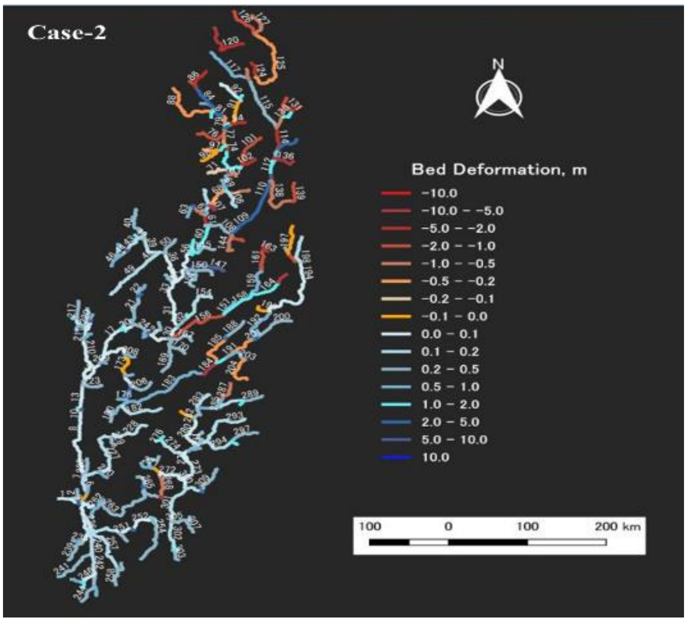

Figure 11. Bed deformation results by scenario 3

5. CONCLUSIONS

A simulation model of sediment runoff is necessary to find the countermeasures for the problems related to the sediment runoff at a basin scale. However, only few data for the simulation are available for the numerical simulations in the developing countries such as Myanmar. In particular, the radar system for rainfall monitoring is not working in those countries. Even if they have the ground rain gauge system, the working sites are very limited. Moreover, it cannot be said that the basic data such as the water discharge, the sediment discharge and the sediment production for the simulation are sufficient even in Japan.

In this study, for the analysis of the characteristics on the sediment runoff in the Ayeyarwady River in Myanmar, we tried to apply the GSMaP (Global Satellite Mapping of Precipitation). Also, as the other data such as the sediment production rate, the grain size distributions of bed materials, and slope conditions are not sufficient, the simulation results are thought not to have good accuracy. However, information on sediment management could be obtained by analysis commensurate with this calculation accuracy.

Regarding the problems on sediment management, it often takes many years from the beginning of the causes to the appearance of the phenomenon. Therefore, it is essential to take the countermeasures before the problem becomes apparent, and it is important to perform the predictions by numerical simulation of sediment runoff early. However, the data for the analysis is not enough in many countries. However, it is important for such countries to use the data available to discuss solutions according to the accuracy of their calculations. Through this study, we could show an example.

ACKNOWLEDGMENTS

We would like to thank JAXA/EORC for the provision of GSMaP product as precipitation data.

REFERENCES

Kazuki YAMANOI, Masaharu FUJITA: Development of a Combined Model of Sediment Production, Supply and Transport and its Applicationto a Mountainous Basin, Journal of JSCE, Ser.B1(Hydraulic Engineering), Vol.70, No.4, p.l_925-1_930,2014.

Fujita, M., Yamanoi, K. and Izumiyama, H. (2014) A Combined Model of Sediment Production, Supply and Transport, Sediment Dynamics; form the summit to the sea, ICCE/IAHS International Symposium (Accepted).

Swe Hlaing Win, (2011), Sediment Dynamics in Irrawaddy River, Myanmar; A thesis submitted for the Degree of Master of Social Science, Department of Geography, National University of Singapore.

K.Okamoto, T.Iguchi, N.Takahashi, K.Iwanami and T.Ushio; The Global Satellite Mapping of Precipitation (GSMaP) project, 25th IGARSS Proceedings, pp. 3414-3416, 2005.

Robinson, R.A.J. et al.: The Irrawaddy river sediment flux to the Indian Ocean: the original nineteenth-century data revised, The Journal of Geography., Vol.115, pp.629-640, 2007.