Prediction of sediment production in the Abukuma River basin due to rainfall sensitivity

Edea Loa Graduate School of Symbiotic Systems Science and Technology, Fukushima University
Seiki Kawagoe Faculty of Symbiotic Systems Science, Fukushima University

1. Introduction

Japan's economic activities and population growth since the mid 19th century have contributed to significant developments that have resulted in land cover and land-use changes. The country is also prone to several natural disasters, which also significantly impact land cover and land-use changes. Two of the recent disasters are the Great East Japanese Earth Quake on March 11, 2011 (GEJE2011) and the Typhoon-Hagibis on October 2019 (Typhoon 201919). These ongoing land-use changes due to natural disasters and other human-made activities have led to land degradation and massive soil erosion, which may have significant environmental concerns especially in vulnerable areas such as hilly terrain areas and the flood plain areas. Evaluating the soil erosion within the basin environment is an important task that would assist decision-makers in the land and water resource management and planning areas for predicting future disasters, proposing countermeasures and monitoring of basin outlets. The average annual soil loss of the basin, together with a large impact event of the year 2019, was analysed using the USLE equation. The USLE is an erosion model designed to predict the average rate of soil erosion for each feasible alternative combination of crop system and management practice in association with a specified soil type, rainfall pattern, and topography (Wischmeier and Smith 1978) [1]. The main objective of this paper is to analyse the Abukuma Basin average yearly soil loss for the year 2019, together with a large impact rainfall event and map out an impact map with based on sub-basins and evaluate the soil production factors and make projections for future soil losses within the impacted sub-basins.

2. Study area

The study area is approximately 5390 km2 of watershed area and a total river length of 234km which runs from Fukushima prefecture to Miyagi prefecture (Fig.1). Abukuma River Basin is the second-longest river in the Tohoku region and sixth in the whole of Japan which consists of a mixture of steep and flat conditions with irregular changes in surface water runoffs and soil erosion. It collects its water from the affluent in the high mountains and discharges into the Pacific Ocean. The basin has some small to medium-sized metropolitan areas which are scattered across the study basin.

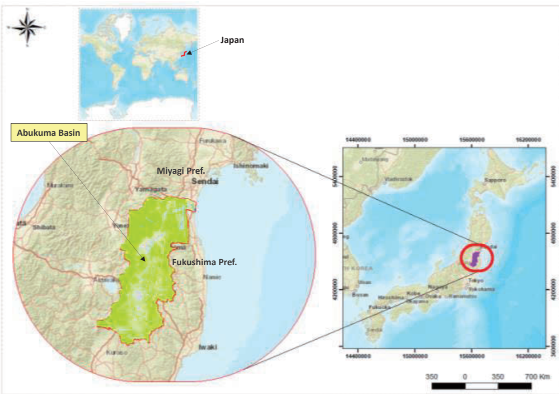

Fig.1: Study area

Keyword：USLE, vegetation, landcover, rainfall sensitivity, soil production.
Kanayagawa1, Fukushima city, Fukushima. Fukushima University
Tel and Fax 024-548-5261

3. Methodology

The widely used model for estimating soil loss referred to as the Universal Soil Loss Equation (USLE) was used to analyse the mean annual soil loss in the study area. The equation uses the product of five (5) different factors as follows;

$$A = R \text{ x } K \text{ x } LS \text{ x } C \text{ x } P \quad (1)$$

Where, *A* is the mean annual soil loss per unit area, *R* is the rainfall erosovity factor, *K* is the soil erodibility factor, LS is slope length and steepness factors respectively, *C* is the land cover management factor and the support practice factor denoted by *P*. The rainfall erosivity factor *(R)*is the rainfall erosive force specifically for all the rainfall events in a year. The R-factor derived from 60 minutes rainfall intensity developed for Japan conditions by Hosoyamada & Fujiwara, (1984 a) [3] was adopted to (Eq. (2)).

$$R = KE \text{ x } I_{60} \quad (2)$$

$$KE = (916 + 331) \text{ x } log_{10}\, I) \text{ x } 0.753 \quad (3)$$

The soil erodibility factor *(K)* is the measure of the susceptibility of soil particles to detach and transport due to the impact of the raindrop and surface runoff. The K-factor for this study is the average value from the standard experimental results of sediment model user guide. From Clay to very fine sandy loam with the average K value of 0.78. The LS-factor *(LS)* or topographic factor is the combined outcome of the slope length and slope steepness represented by L and S, respectively. The LS-factor for each land cell may be evaluated using the equation derived from Moore and Burch (1986) [4] was adopted (Eq. (4)):

$$LS = \left(\frac{Flow\ Acc.+Cell\ size}{22.13}\right)^{0.4} \text{ x } \left(0.0896\frac{Sin\ Slope}{0.0896}\right)^{1.3} \text{ x } 1.4 \quad (4)$$

The C-factor *(C)* is the crop or vegetation management factor. It represents the ratio comparing the soil loss from the land under a specific crop and vegetation to the corresponding loss from the standard soil plot. The C-factor was determined from remote sensing data. The Normalised Difference Vegetation Index (NDVI) (Eq.(5)) was used to produce the C -factor map:

$$NDVI = \frac{(NIR-Red)}{(NIR+Red)} \quad (5)$$

The method proposed by Durigon et al. (2014) [5] was used to estimate the C-Factor map (Eq.(6)).

$$C = \left(\frac{-NDVI+1}{2}\right) \quad (6)$$

The support factor denoted by P is the effect and impact of support practices that reduce the amount of erosion. In the study basin case with huge natural forest catchments, urban centres where these practices are not done; hence, P's value is kept as 1.0.

4. Results and discussions

From the analysis of each of the USLE factors, the average value for the R-factor in the year 2019 was 3,639 ton/ha/hr/yr (Fig. 5). The R-factor value from the impact of typhoon192019 was obtained as 2354 ton/ha/hr/yr. The K-factor value was obtained as the average value from the standard experimental results of sediment model user guide with the value of 0.78. The LS-factor in the study area ranged from 0 to 115, with the average values of 0.26. The C-factor values for the study area ranged from 0.16 to 0.62.

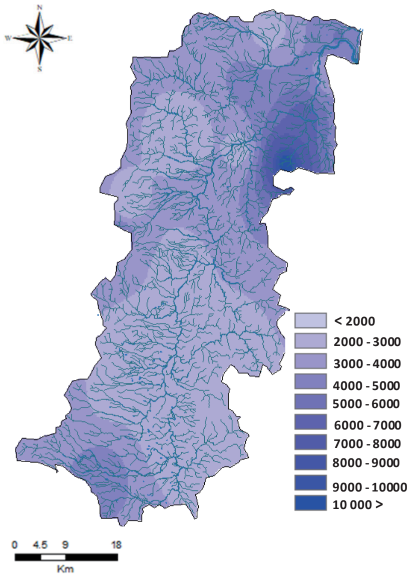

Fig.2: R-factor Map (2019)

From the soil loss analysis, the average soil loss volume for the year 2019 was estimated to be around $5.6x10^7m^3$. The impact from Typhoon 201919 alone on October 12, 2019 is estimated to an average of $3.7x10^7m^3$. The average soil loss based on the annual soil loss and the impact of the Typhoon 201919 indicate that Shirashikawa (78,775 ha) towards the northern and downstream end of the basin produced the highest soil followed by Yashirogawa (43,563 ha) and Abukumagawajōryū (30,954 ha) sub basin towards the southern end or the upstream sub-basins (Fig.3-Map A and B). The main factor contributing to the high volumes of soil losses in these three basins is due to the larger catchment areas compared to the smaller catchment. The soil loss impact map Fig.3-Map C was produced from dividing the soil losses of each of the sub basins from the Typhoon201919 impact and the potential average impact. The results indicate that Uchigawa (10,703 ha), Nigorikawa (3,479 ha), Omorikawa (1,933 ha) and Hirosegawa (23,968 ha) were the highly impacted sub basins from the Typhoon 201919. These impacted sub-basins are located towards the mid to downstream end of the Abukuma basin (Fig. 3-Map C). The average soil loss projection shows that by year 2050 Uchikawa will have produced an average of $4.7x10^5m^3$ by year 2050 (Fig.4). One of the major causes of which has caused the more significant impacts are due to the low NDVI and land use changes, and the geographical steepness of the sub-basins observed from these four sub-basins.

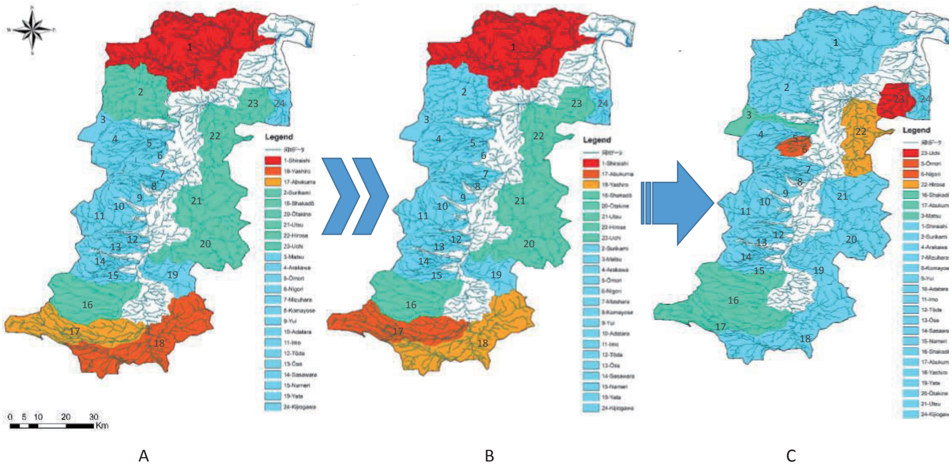

Fig.3: Abukuma – Sub basin soil loss distribution Maps. (A) Typical Potential Average Soil Loss, (B) Large Impact Event (C) Impact Map

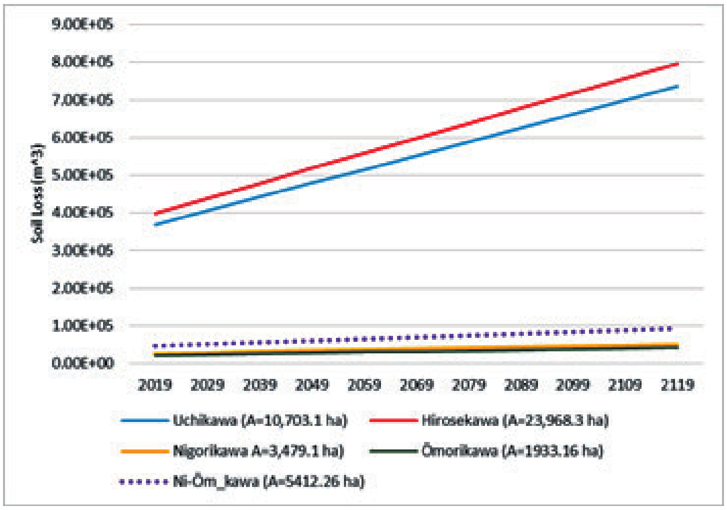

Fig.4: Impacted Sub-basin Avg Soil Loss estimated projection.

5. Conclusion

The USLE model was carried out in the GIS environment to estimate the soil loss in the Abukuma River basin, Fukushima Prefecture, Japan, for 2019. The results of the estimates of a potential rainfall erosivity impact and the impact of the large impact event (typhoon 201919) erosivity impact were analysed to identify the impact of the typhoon on each of the sub-basins. The soil loss production is generally caused by the naturally occurring agents such as the climate, topographical and land use characteristics in the impacted sub-basins were studied. Apart from the naturally occurring force behind the soil loss processes, human activities also contribute extensively to accelerating the process. The outputs of this study were based on historical and with limited data inputs. Further studies should be carried out to verify the model in terms of site survey and confirmation of the land surface changes.

Acknowledgment: This research was supported by the Environment Research and Technology Development Fund (2-1907) of the Environmental Restoration and Conservation Agency of Japan, and Pacific Leads Program, JICA.

References

[1] Wischmeier, W.H., Smith, D.D.: Predicting rainfall erosion losses – a guide to conservation planning. U.S. Department of Agriculture, Agriculture handbook No. 537 (1978)

[2] Dhakal, A. TSUCHIYA, S. OHSAKA, O. (2006): Application of the USLE and sediment delivery models in a mountainous catchment, p 44

[3] Hosoyamada, K., and Fujiwara, T. (1984 b): Application of the USLE for predicting the amount of soil erosion (II): Soil erodibility factor, slope length factor and support practice factor of the LISLE, Journal of the Japanese Society of Irrigation Drainage and Reclamation Engineering, Vol. 52, p. 497-502. (in Japanese)

[4] Moore, I.D., Burch, F.J., 1986. Physical basic of the length–slope factor in the Universal Soil Loss Equation. Soil Sci. Soc. Am. J. 50, 1294–1298.

[5] Durigon, V. L., Carvalho, D. F., Antunes, M. a H., Oliveira, P. T. S., & Fernandes, M. M.(2014). NDVI time series for monitoring RUSLE cover management factor in a tropical watershed. International Journal of Remote Sensing, 35, 441e453. https://doi.org/10.1080/01431161.2013.871081.