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Spatio-temporal analysis of soil erosion in Tokoro river watershed in eastern Hokkaido, Japan

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Introduction

Accelerated erosion by human activities leads to degradation of soil ecosystem services and aquatic environment. It is unavoidable issue in Japan because it holds many sloped agricultural lands. Tokoro river watershed, TRW, in eastern Hokkaido, Japan has unique climate characterized with the least precipitation in Japan and cold winter with little snow which induces soil freezing. Frozen subsoil forms impermeable layers to increase surface runoff in early spring. The objectives of this study were i) to understand the spatial and seasonal variation of water and sediment movement in TRW using Soil and Water Assessment Tool, SWAT which is a process-based hydrological model and ii) to evaluate the impact of agricultural activities, topography of agricultural lands, and runoff characteristics on soil erosion through identification of highly erosive areas and seasons based on the simulation output.

Materials and methods

Water and sediment movement in TRW was simulated from 2011/1/1 to 2015/12/31. SWAT calculates water and sediment movement processes using spatial and temporal information of topography, land use, soil, weather, and land management in watershed. TRW was delineated into 17 subbasins based on topographic information and further divided into 764 HRUs which had homogenous combination of slope class, soil type, and land use in each subbasin. On-land processes were calculated in each HRU. After water and sediment yield from HRUs were summed in each subbasin, stream routing processes were calculated. Model parameters were calibrated so that the estimated stream flow and sediment load at the outlet would fit the measurements. From the simulation by the calibrated model, outputs were extracted as follows: 1) Contribution to the gross sediment yield and erosion rate of each land use; 2) Erosion rate of each subbasin; 3) Erosion rate of whole watershed on each month; and 4) Surface runoff and percentage of surface runoff in water yield in each month.

Results and Discussions

Calibrated SWAT reproduced well the fluctuation of stream flow and sediment load at the outlet of TRW. Although the model underestimated sediment load during large flood events with the average estimation error of -16.1±5.4% on peak-discharge months, it showed satisfactory

performance with coefficient of determination: R^2=0.88, Nash-Sutcliffe efficiency coefficient: Ens=0.86, and percentage of bias: PBIAS=0.34% for monthly sediment load estimation. Agricultural lands which covered 17.6% of the watershed were considered as the primary sediment sources contributing to 68.5% of estimated gross sediment yield of the watershed. Spatial variation of estimated erosion rate showed high sediment yield in the middle- and down-stream area of TRW where agricultural activities were intensive, and higher sediment yield particularly in the area where more agricultural lands had steep slopes (more than 51 t km^{-2} yr^{-1}). Monthly erosion rate estimation indicated that the most severe erosion occurred on March and April (6.9±1.4 and 7.3±1.9 t km^{-2} mon^{-1} respectively). On March, average percentage of surface runoff was estimated as 90.5±6.5%. Therefore, surface runoff in early snowmelt season when the frozen subsoil prevented infiltration was considered as an important driver of soil erosion.