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Research papers

Soil erosion and transport simulation and critical erosion area identification in a headwater catchment contaminated by the Fukushima nuclear accident

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ABSTRACT

Radiocesium released by the accident at the Fukushima Dai-ichi Nuclear Power Plant in 2011 contaminated a large land surface area. Due to the strong and size-dependent adsorption capability of soil particles to radionuclides, a better understanding of erosion and transport of soil particles and identification of erosion prone areas within watersheds are significant for contaminant management. For this purpose, we simulated soil erosion and transport in a partially forested catchment for multiple particle size classes. Critical erosion areas were identified by the spatial distribution of net soil erosion. Comparisons between simulated and measured suspended solids concentration at multiple locations throughout the catchment demonstrated successful model performance. For the period Mar. 12, 2011 through Dec. 31, 2014, model results indicated that 5500 tonnes of clay, 52000 tonnes of silt, and 22000 tonnes of sand are transported from the catchment. The results showed that soil erosion in the middle part of the catchment is greater mainly because of steep slopes and large fraction of agricultural lands. These simulations suggest that soil decontamination of erosion-prone agricultural lands in the mid- catchment areas would be effective in reducing radiocesium migration with soil particles.

1. Introduction

The Tohoku earthquake in Japan occurred on March 11, 2011. Subsequent explosions at the Fukushima Dai-ichi Nuclear Power Plant (FDNPP) released an estimated 153 PBq ^{131}I and 13 PBq ^{137}Cs to the atmosphere between March 21 and April 5, 2011 (Chino et al., 2011). Radionuclides were deposited onto the land surface and incorporated into surface soils. Among all kinds of radionuclides emitted during the accident, ^{137}Cs will persist for the longest time because of its long half-life. Airborne monitoring surveys show radiocesium was widely distributed across forested, agricultural, and residential areas of a large portion of the Abukuma watershed near the FDNPP (MEXT, 2013). Soil erosion generated by localized rainfall events and frequent typhoons is a driving force for radiocesium transport across the landscape. Soil particles to which radionuclides have sorbed are the transmission media of primary concern (Yamashiki et al., 2014). Thus, soil erosion and transport must be quantified to better understand the behavior and fate of radiocesium at the watershed scale.

Process-based watershed soil erosion models can represent fluvial transport associated with the detachment, transport, and deposition of soil particles caused by rainfall and surface flow throughout a catchment (Lee et al., 2013). In recent decades, a number of soil erosion modeling tools have been developed, including models such as EUROSEM (Morgan et al., 1998), WEPP (Flanagan and Nearing 1995), KINEROS (Woolhiser et al., 1990), SWAT (Srinivasan and Arnold, 1994), and DYRIM (Wang et al., 2007, 2015). Such models can be used to identify critical erosion areas that deliver disproportionately high amounts of sediments and associated contaminants relative to other locations. Identification of those areas most susceptible to erosion can aid development of mitigation strategies and evaluate the effectiveness of best management practices to control nonpoint source pollution, thereby providing a means to prioritize decontamination efforts and evaluate future radiocesium transport (Kumar and Mishra, 2015; Sardar et al., 2014; Tripathi et al. 2003; White et al. 2009; Wu and Chen, 2012, 2013).

Although modeling studies of soil erosion and radiocesium transport for the Fukushima area were conducted after the nuclear accident, earlier studies were limited because they either did not consider the size distribution and differential transport of soil particles associated with radiocesium transport (Tanaka et al. 2013; Kinouchi et al. 2015) or

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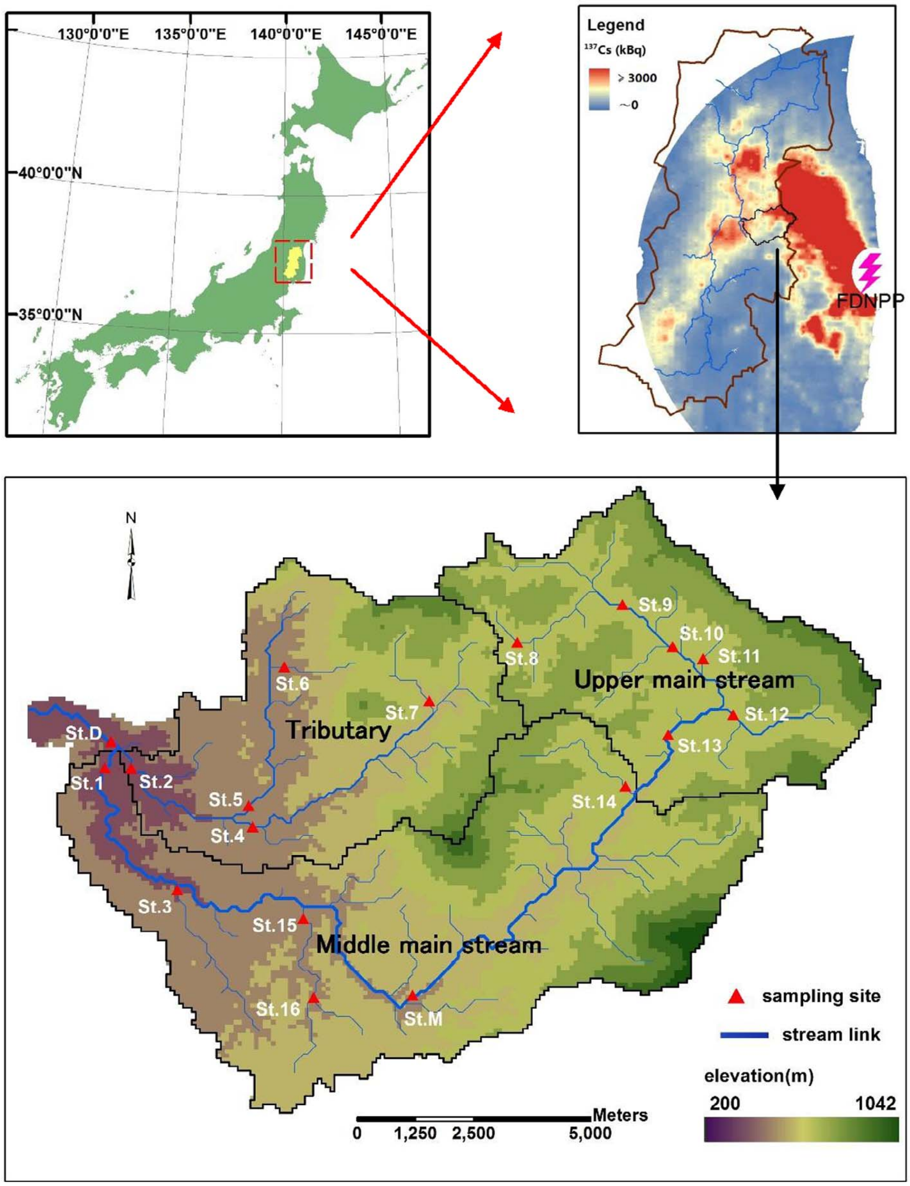

Fig. 1. Outline of the Kuchibuto River catchment (The inventory of ^{137}Cs was obtained from the 3rd airborne monitoring survey by MEXT (2013)).

simulated sediment-radiocesium transport at annual time-scales (Yamaguchi et al. 2013, 2014). Transport by different particle sizes is important because radionuclides sorption to soils is size-dependent, with preferential sorption to finer particles that have higher specific surface areas (He and Walling, 1996; Tanaka et al., 2014). Moreover, soil erosion and transport through fluvial systems is episodic and varies widely over time such that analyses on fine temporal scales are needed to trace water-sediment-radiocesium dynamics for each event. In contrast, sediment measurements in prior studies were limited to a few events or other relatively short timeframes.

Given limitations of prior studies, the objectives of this study were to: (1) simulate soil erosion and transport processes for multiple particle size classes; (2) calibrate and validate the model using nearly 4-year measurements in the study catchment; and (3) identify critical erosion areas within the catchment based on simulated spatial distributions of soil erosion.

2. Study area

The study area is the Kuchibuto River catchment, which is a headwater catchment in the Abukuma River watershed (Fig. 1). High ^{137}Cs activities have been monitored in this catchment. A consequence of soil erosion and fluvial transport, radioactive substances have been delivered to the more populated downstream regions that lead to the Pacific Ocean. The catchment area is 137 km^2 with elevations that range from 200 m above sea level at the catchment outlet to 1000 m in the parts of the catchment and an average slope of approximately 9°. The predominant land use is forest, followed by agriculture (i.e. paddy fields and farm land), and a very small portion of urban area (Fig. 2). Four soil types, evolved mainly from granitic parent materials, cover the catchment: kuroboku soil, granitic forest soil, lowland soil, and gley soil.

3. Data collection

Spatial data includes topographic, land use, and soil properties data. A Shuttle Radar Topography Mission (SRTM) based 90-meter Digital Elevation Model (DEM) data was downloaded (http://glcf.umd.edu/data/srtm/) and used to generate slope, flow direction, flow accumulation, river links and sub catchment boundaries (Fig. 1). Stream channel geometry (width, bank height, etc.) was defined as measured by a field survey in 2013. A sandy bed was assumed for the initial condition of stream bed materials since steep bed slopes are dominant