博士論文要約

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学位論文題名

Modelling hydrological processes and ^{137}Cs load responses to climate and land use changes in Hiso River watershed, Fukushima, Japan

（福島県比曽川流域における気候と土地利用の変化に対する水文過程と^{137}Cs負荷応答のモデル化）

Introduction

Hiso River watershed (HRW) is within the radiocesium contaminated area caused by the accident in Fukushima Daiichi nuclear power plant (FDNPP). Lots of Cesium-137 (^{137}Cs) released from the FDNPP were considered as the most serious risk to ecosystems and human health. Deposited ^{137}Cs was bound to soil particles and transported with rainfall-runoff. The subsequent decontamination work (removing the topsoil) after the FDNPP accident resulted in an enormous land use change in HRW. Changes in climate and land use could bring remarkable influences on hydrological processes further involving the transport of ^{137}Cs. The key objectives of this study are: (1) to downscale future climatic variables in HRW using the statistical downscaling methods (SD) from three General circulation models (GCMs) and evaluate the effect of temperature and precipitation on hydrological processes. (2) to simulate streamflow, sediment and ^{137}Cs load using the Soil and Water Assessment Tool (SWAT) model in HRW. (3) to evaluate components of water cycle in different scenarios based on changes of future climate and land use in HRW.

Materials and methods

The study site, HRW, is located in the upper Hiso River (37°37′19″ N, 140°41′45″ E) in Iitate, Fukushima, Japan, and covers an area of 426 ha. The annual average of the daily average/maximum/minimum temperature is 10.09 °C /15.04 °C /5.19 °C. The annual precipitation is 1,318 mm. The elevation of HRW ranges from 606 to 790 m.a.s.l. Soil types in the HRW comprise Brown Forest soils and Dry Brown Forest soils (63.62%), Gray Lowland soils (0.94%), Gley Lowland soils (11.27%), and Ordinary Andosols (24.18%).

Stream water samples were collected from watershed outlet of the HRW (140.6957 E, 37.6219 N). The stream water level (H, m) and stream flow velocity (V, m/s) (2013-

2017) were measured every 10 minutes by using the water level sensor (UIZ-WL500, UIZIN Co., LTD, Tokyo) and flow velocity sensor (UIZ-RI, UIZIN Co., LTD), respectively, then the streamflow (Q, m^3/s) was calculated using the Manning equation. The turbidity (Formazin Turbidity Unit, FTU) was measured every 10 minutes' intervals by using a turbidity sensor (UIZ-TC3000-DN, UIZIN Co., LTD). To measure the suspended sediment and dissolved/suspended ^{137}Cs concentrations, the 96 water samples were collected through manual and automatic sampling (ISCO 3700 Automatic Water Sampler, Teledyne ISCO, Lincoln) during the period of 2013 to 2017. The dissolved/suspended ^{137}Cs concentrations were determined by a Ge semiconductor detector (BE5035, CANBERRA, USA) for 5,000 s. As input dataset for SWAT, 30 m mesh digital elevation model (DEM), soil map and land use map were downloaded from the Japanese Geographical Survey Institute (JGSI). Weather data (like daily temperature, daily rainfall, relative humidity, solar radiation, and wind velocity) in Iitate weather station were obtained from the Japan Meteorological Agency.

There were two phases (calibration and validation) divided for the streamflow/sediment/^{137}Cs load simulation in SWAT model. The simulation ran from Jan. 2007 to Dec. 2017 with a six years warm-up period (2007-2012), including two periods of calibration (2013-2015) and validation (2016-2017). The SWAT model was first calibrated using SWAT CUP with the SUFI-2 calibration and uncertainty analysis routine. The calibration of flow and sediment was performed manually to obtain a good match between the observed and simulated values. Then the total ^{137}Cs load in the river was simulated using the well-calibrated SWAT model and the equations among suspended sediment concentration, turbidity and dissolved/ suspended ^{137}Cs concentrations. The accuracy of SWAT simulation results was determined by examining the coefficient of determination (R^2), the Nash and Sutcliffe efficiency (E_{NS}) and *Pbias*.

Land use change scenarios were established based on influences of the FDNPP accident (2011) and decontamination work (2015) in HRW. Scenario 1 (S1) assumed no agriculture abandon (before FDNPP accident in 2011), scenario 2 (S2) assumed agricultural land changed to be wild grass (between the accident and decontamination work, 2011-2014), and scenario 3 (S3) assumed agricultural/wild grass land turned to be bare land (After decontamination work in 2015).

Climate change scenarios (2010-2099) were driven from three GCMs, comprising the Canadian Earth System Model version 2 (CanESM2: Representative Concentration Pathway (RCP) 2.6, 4.5 and 8.5), Hadley Centre Coupled Model version 3 (HadCM3: A2 and B2) and the fifth version of the Model for Interdisciplinary Research on Climate (MIROC5: RCP2.6, 4.5 and 8.5).

Temperature and precipitation projection

This study strived to construct future daily rainfall and maximum and minimum temperature (Tmax and Tmin) from three GCMs in HRW by SD. Projections in three periods (2030s: 2010-2039, 2060s: 2040-2069, and 2090s: 2070-2099) were compared to observations in the baseline (1980-2009). Tmax and Tmin were predicted to increase by -0.6-4.2 °C and -0.1-3.9 °C under all climate scenarios. Conversely, there were several discrepancies in the projections of precipitation under different GCMs scenarios. MIROC5 was projected a range of 11.6-13.3% increasing in rainfall, but CanESM2 and HadCM3 showed the decline trends by 17.4% and 0.2%, respectively. The generated outcomes from three GCMs exhibited an increase (4.5%) in temperature, while a decrease (-2.0%) in precipitation, which was expected that there would be warmer and dryer weather in HRW.

Modelling ^{137}Cs load and evaluating impacts of land use change on hy drological processes

SWAT model successfully simulated streamflow (R^2 > 0.69 and E_{NS} > 0.47) and sediment yield (R^2 > 0.82 and E_{NS} > 0.68) from 2013 to 2017. The daily streamflow was separated into direct runoff (0.70 mm/day) and baseflow (2.02 mm/day), and SWAT simulated direct runoff (0.72 mm/day) and baseflow (1.74 mm/day) showed a similar magnitude as the observed value during 2013-2017. Steep areas were identified as the critical source area of soil erosion. Deposition dominated channel sediment routing during 2013-2017. Besides, three land use scenarios were assumed under climate conditions of 2011-2017 in SWAT. Results showed that conversion from agricultural lands to wild grass showed a relatively small decrease of streamflow (-0.8%) while a more evident decrease of sediment yield (-21%). When the land with plant cover was changed to the bare land, streamflow and sediment yield obviously increased 3.8-4.6% and 28-63%, respectively. The monthly total ^{137}Cs load in the stream was basically well simulated (R^2 > 0.50). The simulated monthly total ^{137}Cs load was underestimated in normal flow regimes, while overestimated in rainstorm events. The simulated total ^{137}Cs load of 3263.02 MBq/yr was close to the observed of 3573.36 MBq/yr.

Response of hydrological processes to climate and land use changes

Three land-use change scenarios under future climate scenarios from three GCMs were established and input into SWAT model during 2010-2099, compared to baseline of 1980-2009. Smallest increased temperature and greatest decreased rainfall derived from CanESM2 led to the greatest decreased (4.8-94.0%) in all water balance components. Highest temperatures and more rainfall from MIROC5 resulted that water yield (WY), surface runoff (SURQ), groundwater flow (GWQ) and lateral flow (LATQ) increased 19.1%, 29.8%, 18.0%, and 17.3%, respectively. In comparison, decreased in evapotranspiration (ET) by 2.4-9.5%. MIROC5-RCP8.5 scenario always generated larger magnitudes for climatic variables and water balance components compared with other climate scenarios. Land use changes will bring a minor influence on simulated mean annual WY, LATQ and ET in the future. However, it will have strong impacts on SURQ and GWQ when agricultural and wild grass land changed to bare land, which obviously increases SURQ, with rates of 160% and 83%, respectively.

Conclusions

Since our modeling results limited by some factors and uncertainties, further work should be required to improve the SWAT (using sub-daily time-step and developing the module of flooded irrigation, drainage, and puddling practices), combine the ^{137}Cs decay model into transfer of ^{137}Cs, and reduce the uncertainties of climate change projection (Like employing more GCMs and selecting the most suitable GCMs by accessing GCMs adaptability). In conclusion, SWAT model was well applied to investigate the hydrology, sediment, ^{137}Cs load in HRW. There is likely a warmer and dryer weather condition in HRW. Future climate change and land use change will bring different responses to water balance components across the watershed.