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Development of web-based WERM-S module for estimating spatially distributed rainfall erosivity index (EI30) using RADAR rainfall data

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ABSTRACT

Despite technological advances, soil erosion modeling is a very complicated process as the amount and rate of soil erosion vary considerably over space and time. Universal Soil Loss Equation (USLE) is one of the oldest and popular models used for soil loss estimation worldwide. USLE R-factor is one of the six input parameters accounting for the impact of rainfall amount and intensity on soil erosion in USLE. The USLE R factor is calculated by averaging annual long time rainfall erosivity index (EI30) values, computed by multiplying maximum rainfall intensity during 30 min periods and the kinetic energy of the rainfall. The gage rainfall data are used for the determination of such EI30 index, and one representative value is given for the entire area. Due to the spatial and temporal variability of rainfall pattern, the value may vary considerably over space and time. It is required to obtain the rainfall data over a surface (heterogeneous) rather than at a point (homogeneous) so that spatially distributed erosivity index values can be calculated. Even though RADAR can provide spatially and temporally distributed rainfall data, the process of manual erosivity index calculation for each raster pixel is very tedious, time-consuming and practically not feasible. To overcome these limitations, the web-based WERM-S module was developed to compute a spatial EI30 index from the 10-min interval spatial rainfall data. The WERM-S consists of three different Fortran modules (Convert Module, R-factor calculation module, and R-factor ASCII module). The Jaun-ri watershed was selected as the study area to test the module since the RADAR rainfall data was available for 2015. June, July, and August were found to be the months receiving the maximum amount of rainfall and the average erosivity indices for June, July and August were found to be 2096, 1002, and 993 MJ·mm/ha-hr-month, respectively. The maximum erosivity index for a pixel within the study area was observed to be 9821 MJ·mm/ha-hr-month for June 4382 MJ·mm/ha-hr-month for July and 6093 MJ·mm/ha-hr-month for August respectively. The higher value of standard deviations of 1850, 950 and 1115 MJ·mm/ha-hr-month for June, July, and August were observed respectively representing that the erosivity index of individual space widely deviated from the mean monthly erosivity index. Thus spatial erosivity index is suggested to be used over average annual R factor values to calculate soil loss using USLE. Furthermore, the WERM-S module can be a very useful tool to automatically calculate the spatially distributed rainfall erosivity index from 10-min interval RADAR rainfall data.

1. Introduction

Soil erosion modeling is considerably complicated process since erosion occurs diversely over space and time. There is a need of local and regional estimate of soil loss since erosion rate should be quantified for proper decision-making regarding appropriate control practice to be implemented (de Vente et al., 2008; Jeong et al., 2004). Various empirical, conceptual and physically-based computer models such as Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978), Agricultural Non-Point Source Pollution Model (AGNPS) (Young et al., 1989), Soil and Water Assessment Tool (SWAT)(Arnold et al., 1998), Water Erosion Prediction Project (WEPP) (Flanagan and Nearing, 1995), and European Soil Erosion Model (EUROSEM) (Morgan et al., 1998) have been developed over the last few decades and are in

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practice for the soil erosion estimation and erosion control assessment (De Vente and Poesen, 2005). USLE is one of the oldest and widely used empirical models, which has been applied in many countries around the world. It is extensively used in Korea since the input parameters have been well-established over the years (Lim et al., 2005; Park et al., 2010). USLE uses six input parameters namely erosivity (R) factor, erodibility (K) factor, topographic (LS) factor, cover management (C) factor and conservation practice (P) factor for the estimation of soil loss. Erosivity or R-factor is one of the six input parameters, which accounts for impacts of rainfall amount and intensity on soil erosion. Rainfall erosivity index (EI30) is one of important parameter required for calculation of the R-factor which is computed by multiplying maximum rainfall intensity during 30 min periods with the kinetic energy of the rainfall. A minimum of 20 years average value of such erosivity indices summed up for a year is termed as USLE/RUSLE R factor (Renard et al., 1997). Because of the spatial and temporal variability of rainfall pattern, such erosivity index also varies considerably over space and time which consequently affects the value of R factor and thus soil erosion amount. Besides, such event based erosivity indices summed up for a month to obtain monthly erosivity can be multiplied with other monthly USLE parameters to obtain the amount of monthly soil erosion for a watershed or field (Diodato, 2006).

The gage rainfall data have been used to determine yearly, monthly and event-based erosivity indices and such erosivity index values have been published for various weather stations in South Korea (Risal et al., 2016). Though the quality and source of error in rainfall data from rain gage can be determined easily, the rain gage provides a measure of rainfall at a point (Einfalt et al., 2004). Since soil erosion is the phenomena occurring over a particular area rather than at a point, soil loss amount needs to be calculated over the area. As USLE is used to estimate soil erosion, actual R-factor over the area rather than at a point is required. The R-factor derived from the gage rainfall data cannot accurately represent the spatial distribution of R-factor since rainfall distribution over the surface is not always uniform. The desirable spatially distributed R-factor can be determined using the spatial rainfall data and applied in USLE for the accurate estimation of soil loss amount. A case study was performed on prediction and uncertainty of soil loss using RUSLE by Wang et al. (2002) and found that R-factor had a considerable spatial and temporal variability even over a relatively smaller area.

For the determination of such spatially distributed R factor using rainfall erosivity index, spatial and temporal rainfall data are needed. RAdio Detection And Ranging (RADAR) is one of the possible sources for finer scale (spatial and temporal) rainfall data. In the areas where rain gages are sparsely distributed, the RADAR data are more suitable to estimate rainfall compared to the gaged data (Yang et al., 2004). The RADAR technology has been utilized in the field of hydrology for the last four decades for weather prediction. The basic principle of this technology is the measurement of the backscattered electromagnetic wave from rain particles in the direction of the RADAR station (Skolnik, 1962). The reflectivity (Z) of the backscattered radiation is proportional to the summation of sixth power of particle diameter (Wilson and Brandes, 1979). Rainfall is related to reflectivity by the following empirical relationship as given in Eq. 1 (Battan, 1973).

$$z = a \bullet R^b \tag{1}$$

where z is reflectivity in $mm^6\ m^{-3}$, R is rainfall amount in $mm\ hr^{-1}$, a and b are constants which depend on rain type and geographic locations (Austin, 1987). The widely used values of constants a and b in Eq. 1 are 200 and 1.6 respectively (Marshall and Palmer, 1948).

The rainfall data obtained from RADAR has been used in various hydrologic and meteorological studies by various researchers around the world (Lo Conti et al., 2015; Peleg et al., 2016; Noh et al., 2016). The RADAR rainfall was compared with actual rain gage data for two short storm events in Southern California in the USA and it was concluded that RADAR rainfall estimate could be used for storm event analysis with consideration of possible topographic interference (Espinosa et al., 2015). In a study by Fabry et al. (1994), rainfall with high spatial and temporal resolution was measured by RADAR for a small basin and it was reported that rainfall map at greater time resolution could capture the temporal evolution essential for optimal rainfall estimation with sufficient accuracy. These findings indicate that RADAR data can be used for deriving the spatial rainfall amount for small area for small time interval. Even though those desired rainfall data exists, the process of manual USLE R-factor calculation from rainfall erosivity index for each raster pixel (small area) is very tedious, time-consuming and practically impossible. There is a necessity of development of a module which can automatically compute spatial erosivity indices from the bulk of spatial rainfall data for the given period. The web-based tool is one of the effective ways for the calculation of such spatially distributed erosivity index from a number of rainfall (ASCII) data files for short time interval since users can access and use the web tool easily from anywhere.

The objectives of this study are to (a) develop the Web ERosivity Module-Spatial (WERM-S) module to calculate spatial rainfall erosivity index of each raster pixel (500 × 500 m resolution) from raw RADAR rainfall data (ASCII files for each 10 min interval) and (b) analyze the difference in rainfall erosivity indices derived from spatial RADAR rainfall data and rain gage data of three nearest stations.

2. Materials and methods

2.1. Study area

The Jaun-ri, a rural hilly watershed located in the Gangwon Province in South Korea, was selected as a study area to test our newly developed WERM-S module and thus estimate spatially distributed R-factor from spatial rainfall data. The watershed is located at the coordinate of 39°42′17″N latitude and 128°24′08″E longitude. The selected watershed is very vulnerable to soil erosion and has been designated as a nonpoint source pollutant hotspot area by the government of South Korea (Park et al., 2011). The R-factor with high spatial resolution is needed to estimate soil erosion accurately and introduce various best management practices in the study watershed. Moreover, the topography of the basin is very steep with a mean slope of 33.5%. The average annual temperature of the watershed is 8.35 °C with maximum and minimum annual precipitation of 2173 and 739 mm respectively for the period from 2010 to 2015 with an annual average precipitation of 1442 mm (KMA, 2016). The study watershed receives maximum rainfall in July and August with more than 50% of total annual precipitation concentrating during the period of these two months. The mean monthly precipitation was measured to be 424 and 212 mm in July and August respectively whereas the mean monthly precipitation of just 11 mm was observed in January. The maximum daily precipitation of 144 mm was observed on 27th July 2011. Similarly, the high amount of rainfall of 111 mm on 15th July 2013 and 95 mm on 15th August 2012 were observed to have occurred in our study area.

The watershed has two dominant land uses, namely forest and agricultural land. Out of total area of 24.89 ha, 23.83 ha (96.17%) is covered by forest, and the remaining 1.06 ha (3.83%) is covered by agricultural land (Park et al., 2011). The soil in the watershed is mostly sandy that is composed of 63% of sand, 28.2% of silt and 7.8% of clay. Extensive highland agricultural farming is performed in the downstream areas of the study watershed. The location of the study area is shown in Fig. 1.

2.2. Data

2.2.1. RADAR rainfall data

The rainfall data (ASCII files) with 10 min interval for 2015 were obtained using RADAR installed in Gwanak Mountain (located at