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Application of Web ERosivity Module (WERM) for estimation of annual and monthly R factor in Korea

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ABSTRACT

Soil erosion is a very serious problem from agricultural as well as environmental point of view. Various computer models have been used to estimate soil erosion and assess erosion control practice. Universal Soil Loss Equation (USLE) is one of the most frequently used soil loss estimation models which have been used in many countries around the world. Erosivity (USLE R-factor) is one of the USLE input parameters to reflect impacts of rainfall in computing soil loss. R factor for a specific rainfall event depends upon maximum rainfall intensity of specific period and kinetic energy of that event. Annual R factor is calculated as the sum of erosivities of such rainfall events that occurred. It is usually calculated from rainfall data having higher temporal resolution but the process of calculation is very tedious and also the higher temporal resolution data are not readily available in many parts of the world. Various regression models have been developed to estimate monthly R factor as well as annual R factor using monthly/yearly rainfall amount. However, it is rarely allowed to estimate R factor with higher accuracy using these models since they were developed from obsolete dataset and also only the rainfall amount was used for an input parameter without rainfall intensity. In this study, a web-based Erosivity estimation system (Web ERosivity Module-WERM) was developed to compute R factor using 10 min interval rainfall data. The model was then tested for 75 different cities in Korea using the rainfall data of 15 to 18 years from 1997 to 2014 obtained from Korea Meteorological Administration (KMA). Using the monthly rainfall data and R factor values obtained from the model, regression equation for 25 cities was developed to estimate monthly R factor from the monthly rainfall with amount and intensity of rainfall considered. The coefficient of determination (R^2) of the regression equation ranged from 0.75 to 0.92. This indicated that these regression equations can be used to estimate the value of R-factor from the monthly rainfall data with more than 75% accuracy. The WERM is very simple to use and it can be a very effective tool to compute R factor using higher temporal resolution rainfall data. Along with this, it is possible to calculate R factor using local daily rainfall with the help of regression equations which are available for 25 cities in South Korea till now.

1. Introduction

Global warming and climate change are the matter of concerns for climatologists and hydrologists. The hydrologic change is anticipated to be more aggressive as a result of rise in global air temperature, which consequently leads to change in current rainfall pattern (Christensen et al., 2015). Rainfall events with greater rainfall amount and rainfall intensity are anticipated to occur as per Intergovernmental Panel on climate change IPCC report report of IPCC (2013). As a result of frequent occurrence of greater intensity rainfall events, erosivity increases and top soil becomes more susceptible to soil erosion. Seven to 49% increase in annual rainfall erosivity was observed for East Tennessee, USA from 2010 to 2099 based on different greenhouse gas emission scenarios (Hoomehr et al., 2016). Soil erosion by water is one of the major problems all over the world from agricultural as well as environmental point of view. Soil erosion leads to a decrease in sustainability and productive capacity of agricultural land (Mullan, 2013). Many problems, such as increase in landslide phenomena, disturbance of ecosystem, loss of cultivable land, diffusion of toxic contaminant by the sediment inflow to rivers etc., arise due to soil erosion which consequently decrease agricultural productivity (Lee and Heo, 2011). Moreover, the quality of fertile soil is being deteriorated as a result of detachment and removal of top soil particles, which has led to decline in agricultural productivity in various places of the world. Likewise, soil erosion has affected ecosystem such as water quality and quantity, biodiversity, recreational activities etc. (Panagos et al., 2015). Thus, the

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world community has recognized soil erosion as a major problem and is giving more and more importance on protection and restoration of soil resources (Lal, 2003). Some effective best management practice should be implemented for the better sustainable management of soil erosion. Implementation of site-specific practice is not possible without estimation of accurate soil loss (Jeong et al., 2004). For this purpose, three different groups of models categorized as empirical, conceptual and physically-based models have been developed during the last few decades (De Vente and Poesen, 2005). These models are being used in order to assess current erosion condition and control practice implemented. One of such empirical models is Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978). Similarly Agricultural Non-Point Source pollution Model (AGNPS) (Young et al., 1989) and Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998) are the few examples of conceptual models. Likewise, CREAMS: A field scale model for Chemicals, Runoff and Erosion from Agricultural Management System (Knisel, 1980), Water Erosion Prediction Project (WEPP) (Flanagan and Nearing, 1995) and European Soil Erosion Model (EUROSEM) (Morgan et al., 1998) are some of the examples of physically based models that have been developed and are being used. Empirical equations are still used to estimate soil erosion because of their simple structures and ease of application (Kim and Yun, 2008) with reasonable accuracy.

USLE is one of the most popular and widely used empirical erosion models to predict soil erosion. It is being used in many countries around the world especially at regional and national levels because of its simplicity and robustness (Park et al., 2010; Gitas et al., 2009). Despite its some drawbacks such as that it is not available to estimate gully and stream channel erosion since it considers only sheet and rill erosion and it considers single slope length for entire field (Wischmeier and Smith, 1978), the USLE model has been used around the world with six input parameters to calculate soil loss at a field scale (Gitas et al., 2009). The USLE input parameters can be enriched using recent technologies like detailed digital elevation model (DEM), satellite image data, management practices, soil layer depth survey, detailed soil information etc. Since the model performance relies entirely on the six input parameters, we need to evaluate them carefully and accurately (Eisazadeh et al., 2012). In South Korea, the USLE has been extensively used to predict soil erosion. The reason behind this is that the USLE parameters have already been well established over the years (Lim et al., 2005; Park et al., 2010). The USLE has been further improved with the help of additional research, experiments, data and newer resources to develop Revised Universal Soil Loss Equation (RUSLE) which has the same formula as USLE but has some improvements in determining factors (Renard et al., 1997).

Among these six USLE/RUSLE input parameters, the rainfall erosivity or R factor is a parameter to explain rainfall impacts on soil surface. It is the erosive capacity of rainfall to cause soil loss. When the other five factors are held to be constant, soil loss is seen to be directly proportional to total storm energy times maximum 30 min intensity (Renard et al., 1997). The product of total storm energy and maximum 30 min intensity is termed as R factor. In real, the factors that are affected by rainfall erosivity are amount, intensity, terminal velocity, drop size, and drop size distribution of rain (Blanco-Canqui and Lal, 2008). It is calculated as sum of product of Kinetic Energy and its maximum 30 min intensity of each rainfall storm in a year (Wischmeier and Smith, 1978; Renard and Freimund, 1994; Brown and Foster, 1987).

Specific kinetic energy of rainfall event can be expressed as volume-specific kinetic energy and time-specific kinetic energy (Kinnell, 1981; Rosewell, 1986). Time-specific kinetic energy can be obtained from volume-specific kinetic energy by multiplying it by rainfall intensity and some constant (Salles et al., 2002). Different kind of mathematical relations have been developed and proposed to describe relationship between kinetic energy and intensity of rainfall (Rosewell, 1986). Among which logarithmic model (Eq. (1)) proposed by Wischmeier and Smith (1978) and an exponential model (Eq. (2)) proposed by Kinnell (1981) are commonly used models.

$$KE = a + b \log I \tag{1}$$

$$KE = KE_{max}[1 - c. \exp(-d.I)] \tag{2}$$

Where KE is Kinetic energy, I is intensity of rainfall, a, b, c, and d are empirical constants and KE_{max} is a maximum unit energy (intensity approaching infinity) (Lim et al., 2005).

R factor is usually calculated from rainfall data having high temporal resolution but the process of calculation is very tedious. With the bulk amount of high temporal resolution rainfall data, it is not easy to calculate R factor manually using these empirical equations individually for each rainfall event and sum up. A web-based platform could be an effective tool in this case in order to save time and energy and get the accurate R factor value using these data within a couple of minutes. Moreover, measured higher temporal resolution data are not always readily available in many regions of the world (Blanco-Canqui and Lal, 2008). Therefore, R factor has been related with precipitation for quick and easy determination of its value for the sake of its accuracy. A long-term R factor was related to average annual precipitation for Switzerland by Meusburger et al. (2012) which explained the spatial variation of 53.4%. Monthly erosivity maps were developed along with seasonal erosivity density assessment and development of monthly R factor regression function for Greece based on high temporal resolution rainfall data by Panagos et al. (2016a) which showed that erosivity per precipitation amount were higher during the period of June to December. Likewise, monthly R factor for 1568 stations was recently calculated to update rainfall erosivity database at European scale (REDS) where July and August were found to be the month with highest number of intense erosive events in Europe (Panagos et al., 2016b).

Different researches have been conducted to estimate R factors in South Korea. Jung et al. (1983) estimated R factors from the rainfall data from 1964 to 1980 and derived a relationship between monthly/yearly R factor and monthly/annual precipitation for the city of Suwon, Korea. Eqs. (3) and (4) show monthly and yearly R factor equations by Jung et al. (1983).

$$\text{USLE annual R factor}: R = 0.0115X^{1.4947} \tag{3}$$

Where X is yearly rainfall amount (mm) and R is the yearly erosivity (MJ mm ha^{-1} h^{-1} $year^{-1}$)

$$\text{USLE monthly R factor}: R = 0.0378Y^{1.4190} \tag{4}$$

where Y is monthly rainfall amount (mm) and R is the monthly erosivity (MJ mm ha^{-1} h^{-1} $month^{-1}$).

Since these equations could not calculate variations of annual and monthly R factor values correctly for all the geographic regions of Korea, Jung et al. (1999) suggested correction coefficient of 0.595 for mountainous region and 1 or less for other non-mountainous regions (Park et al., 2010). However, these correction coefficient values could not explain variations in R factor values nationwide in Korea. Park et al. (2000) estimated R factor from the rainfall data of 53 stations from 1973 to 1996. For this estimation, hourly rainfall data were used, from which 30 min rainfall intensity cannot be estimated (Park et al., 2000). The average R-factor value of 158 locations in Korea was compiled and published by Jeong et al. (2004) which is suggested by Korean Ministry of Environment (2012). These values are calculated using inverse distance weight method based on one kilometer spatial unit from research of Jung et al. (1983) and Park et al. (2000) using the rainfall data of 24 years from 1973 to 1996 (Jeong et al., 2004). The USLE R factors based on 60-min-interval precipitation data from 60 meteorological sites covering entire Korea for 30 years from 1981 to 2010 was calculated by Park et al. (2011). Lee and Heo (2011) introduced a