

Assessment of soil loss in South Korea based on land-cover type

Chunhwa Jang · Yongchul Shin · Donghyuk Kum · Rogyoung Kim ·
Jay E. Yang · Sung Chul Kim · Sang Il Hwang · Kyoung Jae Lim ·
Jeong-Ki Yoon · Youn Shik Park · Younghun Jung

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Abstract Soil loss poses a significant threat to the long-term sustainability of hydrological systems, the environment, and agriculture. In this regard, efficient soil management relies on accurate quantification of soil loss. To this end, the Organization for Economic Cooperation and Development (OECD) standard of soil erosion, developed for agricultural areas, has been applied in many countries, including South Korea. Due to the lack of standard methods for assessing soil erosion in South Korea, the OECD standard has been applied to non-agricultural regions of Korea despite the possibility that local soil erosion characteristics may differ from those in agricultural areas. Such an approach might give erroneous information on soil loss to policy and decision makers. This study estimated soil

loss for eight different land cover-types in Korea using the universal soil loss equation, and compared the results with those from the unmodified OECD soil erosion standard. Estimated soil loss differed considerably among land-cover types. The results have implications on the limitations in applying the OECD soil erosion standard to soil management in Korea. Thus, this study suggests a modified soil erosion standard for efficient soil management.

Keywords Soil loss · USLE · Land cover · Soil management

1 Introduction

Soil is an important natural resource necessary for the sustainability of agriculture, industry and hydrological and natural systems (Yang et al. 2003; Feng et al. 2010). Furthermore, soil has various influences on crop growth, pollutant purification and control, rainwater retention, and control of floods and of temperature near the soil surface and in the root zone. Generally, topsoil has abundant organic matter that aids crop growth and also provides habitats for microorganisms. The topsoil can be classified into two layers, comprised of organic (O) and leached (A) horizons, within which can be large variations. Yoo (2000) defined topsoil as soil with a depth ranging from 7–25 cm, where the soil at 0–7 cm depth is the organic horizon. In general, accumulation of soil to a depth of 30 cm requires a period of thousands to tens of thousands of years. As a result, recovery of regions where soil has been lost may require an extremely long time period.

KMOE estimated the economic value of soil resources in order to provide a framework for the effective maintenance of soil resources (KMOE 2010). The estimated economic

C. Jang · D. Kum · J. E. Yang · K. J. Lim · Y. S. Park
Regional Infrastructure Engineering, Kangwon National
University, Chuncheon, Gangwon 200-701, Korea

Y. Shin
Department of Biological and Agricultural Engineering, Texas
A&M University, College Station, TX 77843-2117, USA

R. Kim · J.-K. Yoon
Soil and Groundwater Research Division, National Institute of
Environmental Research, Seo-gu, Incheon 404-708, Korea

S. C. Kim
Department of Bio Environmental Chemistry, Chungnam
National University, Yuseong-gu, Taejon 305-764, Korea

S. I. Hwang
Division of Natural Resources Conservation, Korea Environment
Institute, Eunpyeong-gu, Seoul 122-706, Korea

Y. Jung (✉)
Institute of Environmental Research, Kangwon National
University, Chuncheon, Gangwon 200-701, Korea
e-mail: jung.younghun@gmail.com

value of soil resources in South Korea was estimated at KRW 26.4 trillion; comprising KRW 22.5 trillion for pollutant purification capability, KRW 1.0 trillion for water-holding capability, KRW 0.7 for aggregate-providing capability, and KRW 0.5 trillion for carbon dioxide storage.

Soil loss due to rapid industrialization, forest fires, artificial pasturing, agricultural activities, etc. has been on the increase worldwide (Terranova et al. 2009). Consequently, increasing soil loss causes additional issues such as landslides, collapse of banks, habitat destruction, degraded water quality, floods, and droughts. Furthermore, climate change has the potential to accelerate the rate of soil loss by bringing more severe and frequent precipitation events (Nearing et al. 1989; Li et al. 2011; Lee et al. 2013). Thus securing the environmental and economic services provided by soil resources to ecosystems and humanity requires prevention of soil loss. Accurate estimates of soil loss can significantly contribute to establishing efficient and systematic strategic plans for soil conservation. However, generating accurate estimates of soil loss can be difficult due to limitations in the availability of knowledge, technology, finance and human resources. In practice, rates of soil loss are influenced by complex combinations of factors such as soil type, climate, and topography (Park et al. 2011). To tackle this problem, various conceptual and physical approaches which simplify soil loss processes have been applied to estimate soil loss in many parts of the world (Shi et al. 2004; Lu et al. 2004; Albaradevia et al. 2011; Tibebe and Bewket 2011; Prasanakumar et al. 2012; Singh et al. 2014).

With the aim of efficient management and prevention of soil loss from fields, various modeling approaches such as the universal soil loss equation (USLE, Wischmeier and Smith 1978), Areal Non-point Source Watershed Environment Response Simulation (ANSWERS, Beasley et al. 1980), Chemical, Runoff, and Erosion for Agricultural Management System (CREAMS, Knisel 1980), Water Erosion Prediction Project model (WEPP, Nearing et al. 1989), and the European Soil Erosion Model (EuroSEM, Morgan et al. 1990) have been developed/utilized. For accurate soil loss evaluations, the movement and transport of sediment caused by the impact and runoff of precipitation need to be monitored at watershed outlets through long-term monitoring systems. However, such monitoring approaches are expensive, time-consuming, and require substantial human resources, and applying them at the scale of an entire country is practically infeasible. For these reasons, the USLE and Revised USLE (RUSLE, Renard et al. 1997) models have been used worldwide (John et al. 2011; Park et al. 2011; Bagarello et al. 2012; Zhenlan et al. 2012; Shengpan et al. 2013).

South Korea is comprised of mostly mountainous terrain which covers approximately 70 % of the land surface, and has a continental monsoon climate with 60–70 % of total annual rainfall occurring during summer (June to September). Recently, intense, heavy rainfall events have caused massive direct surface

runoff, which could be one of the major causes of severe soil loss in mountainous areas (Shin et al. 2005; Kim et al. 2010; Kum et al. 2011). As a result, many studies have used the USLE and RUSLE models to assess soil losses at larger, watershed-scales in South Korea. For example, Lee (2004) evaluated the risk of soil erosion at Boun, South Korea, using geographic information system (GIS) and remote sensing (RS) data to parameterize USLE models. Jung et al. (2004) evaluated soil loss amounts in South Korea based on the USLE and RUSLE models using finer-scale soil classes and suggested input parameters and appropriate ranges for these to represent the entire country. However, the USLE R and K factors that were suggested in their study represent only local regions, not the entire country. Similarly, Park et al. (2011) evaluated the amounts of soil lost in 1985 (17.1 Mg/ha), 1995 (17.4 Mg/ha), and 2005 (20.0 Mg/ha) based on the USLE model with input data comprising 30 m × 30 m. However, the application of these studies is limited because they still use coarse-scale datasets that could underestimate soil loss amounts and do not suggest any criteria for efficient soil management. Jeong et al. (2012) identified areas at severe risk of soil loss at a small watershed-scale, but not for a larger-scale that could represent the entire country. Thus, we need to explore large-scale soil loss assessments.

Recently, the South Korean government established Soil Conservation Schematic Planning (SCSP) to efficiently manage soil resources and mitigate risks arising from climate change. However, systematic investigations regarding current states and levels of soil loss, and management in light of these, are still in the initial phase. The need for this investigation of soil loss in South Korea was established by Act 6.2 of the Soil Environmental Protection Law (SEPL) (KMOE 2012a, b). However, the SCSP is based on the OECD soil erosion standard for agricultural areas only. The application of the OECD soil erosion standard for agricultural areas across the entire heterogeneous country could produce uncertain results. In this context, this study attempts to statistically quantify soil loss from a range of land-cover types at the national level. The USLE model was used to estimate soil loss from eight different land-cover types (Orchard, Bare land, Paddy, Urban, Upland, Forest, Wetland, and Pasture) across South Korea. Cumulative distribution functions were constructed separately for each land-cover type based on its estimated soil loss, and then soil losses at 5, 50, and 95 % cumulative probabilities were analyzed in accordance with the OECD standard.

2 Materials and methods

2.1 Study area

For our study area, we selected the entire South Korea (33° to 38°N, 126° to 132°W), except the coastal islands

(Fig. 1). In general, the climate of South Korea is dry and cold during winter, and humid and hot during summer, with heavy precipitation originating from the East Asian monsoon from June to September. In addition to seasonal variation in precipitation, there is distinct spatial variation. The central and southern regions have the annual precipitation in the range of 1,100–1,400 and 1,000–1,800 mm, respectively. Lowland areas are mainly located in the central west and southeastern regions, while mountainous terrain is located in the central east and southwestern regions, amounting to 70 % of the total land area (Fig. 2a). The spatial distribution of land-cover types is shown in Fig. 2b.

A land cover map at 5 m resolution was prepared from the Environmental and Geographical Information System (EGIS), composed of Landsat TM and Korea Multi-Purpose Satellite-2 (KOMPSAT 2) images. The total area of the study region is 91,843 km², mostly covered by the forest (66 %) and paddy field (14 %) land-cover types. More than 90 % of agricultural land are located on slopes (>2 %), and 40 % of those are located on slopes of 7–15 %. Soils on steep slopes in South Korea, which

has mountainous terrain with intense rainfall events during summer and frost weathering during winter, can be easily eroded. Consequently, soils in the forested areas usually have a thin topsoil layer, with the eroded soils being deposited in nearby alluvial fans, valleys, streams, etc.

2.2 OECD soil erosion standard

Soil erosion by surface water is one of the major sources of soil degradation across the world (OECD 2013), suggesting that appropriate soil erosion management plans need to be applied to fields at risk of such erosion. To address this issue, the OECD defined five categories indicating the degree of soil loss risk (Table 1, OECD 2008). Soil losses of more than 11 Mg/ha/year (moderate to severe erosion conditions based on the OECD standard) were regarded as at high soil erosion risk. The OECD reported that approximately 23.2 % of agricultural lands in South Korea suffered moderate to severe erosion conditions (OECD 2013). In a OECD assessment of soil erosion risk, South Korea was ranked 9th among 28 nations, in the following order: Slovak Republic (54.8 %, 2004) > Turkey

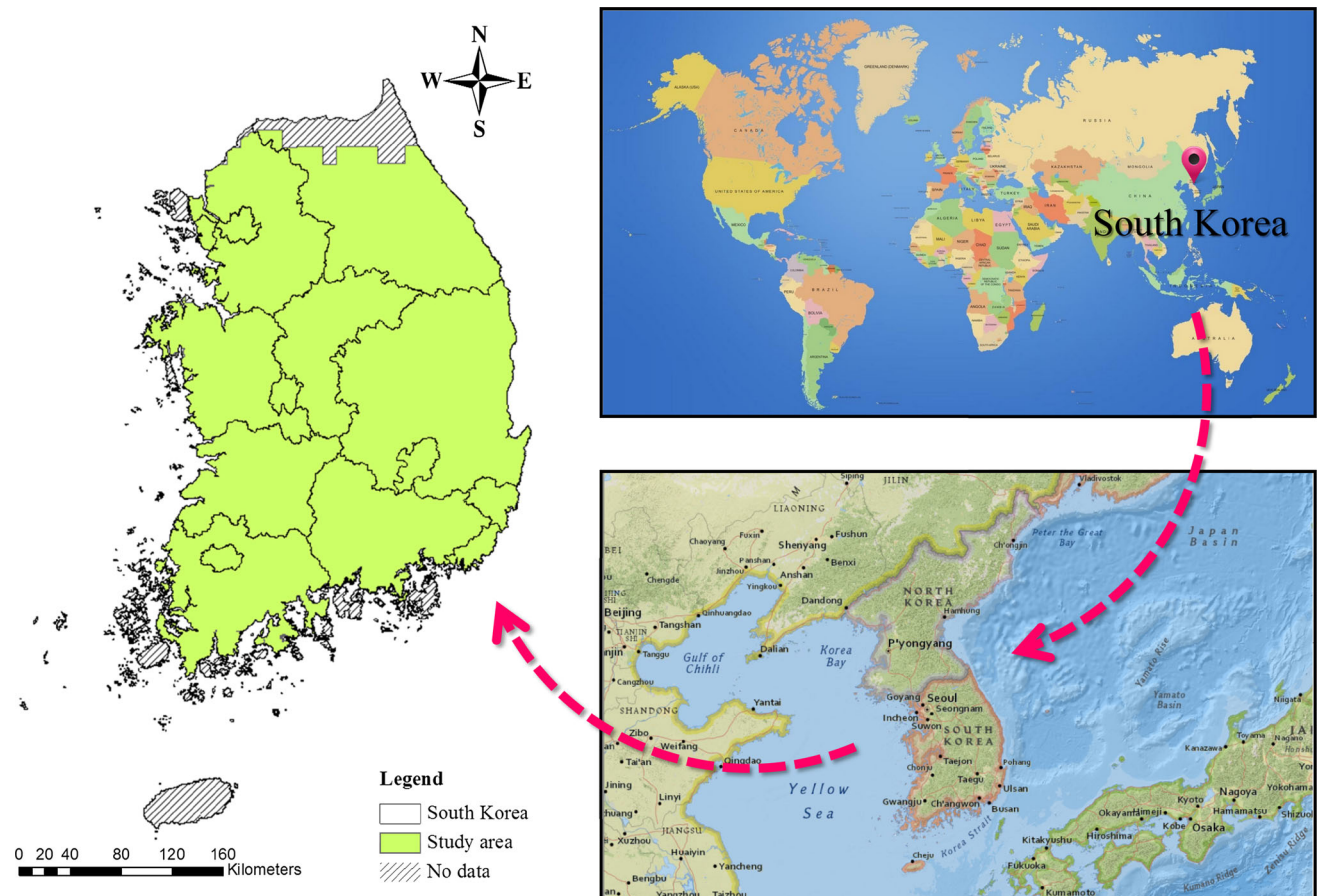


Fig. 1 Location of study area, South Korea

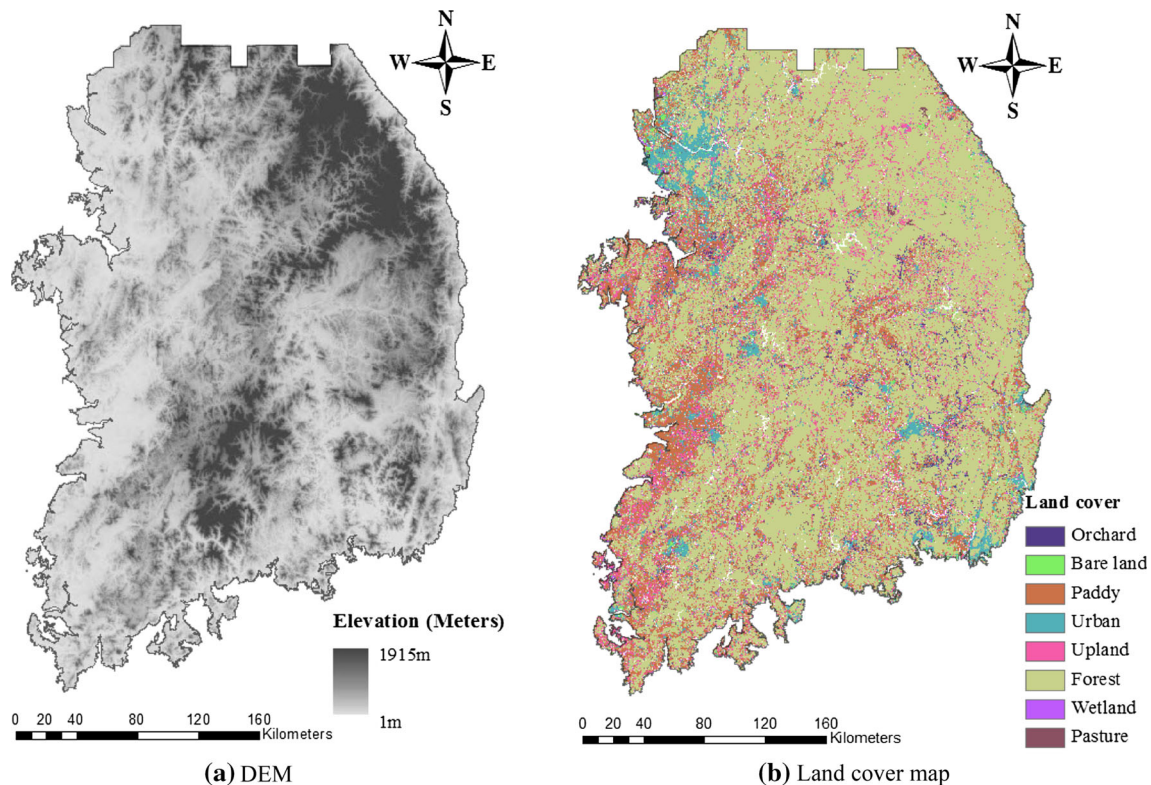


Fig. 2 Digital elevation model and land cover map of South Korea

Table 1 Five categories of soil erosion risk in agricultural land area defined by OECD (2008)

Erosion categories	Tolerable	Low	Moderate	High	Severe
Soil erosion (Mg/ha/year)	<6	6–10.9	11–21.9	22–32.9	<33

(39 %, 1990–1994) > Slovenia (37.5 %, 2007) > Italy (30.4 %, 1999) > Poland (29.1 %, 2010) > Spain (28 %, 2002) > Luxembourg (25 %, 2010) > Hungary (25 %, 2002) > Korea (23.2 %, 2002) > Greece (20 %, from OECD (2008)) > United Kingdom (17 %, 2000–2002) > Mexico (9.4 %, 2001) > Belgium (9.2 %, 2010) (OECD 2013). Generally, soil erosion is influenced by environmental factors such as soil depth and type, and agricultural and climatic conditions. In this study, the OECD soil loss categories, which are based on data collected from agricultural areas worldwide and do not consider the effects of precipitation or local soil loss conditions, were utilized to classify soil loss potentials in South Korea.

3 Methodology

3.1 Overview of methodology

USLE was used to estimate soil loss. Digital elevation model (DEM) is required to prepare USLE LS and P factor maps, and

the available DEM resolution will affect soil loss estimates (Kim et al. 2009; Zhang et al. 2014). The maximum DEM cell size can be determined by that required to accurately reflect the slope and slope-length of fields and watersheds, and previous studies indicate that a DEM with 30-m cells was insufficient accurately reflect the characteristics of watersheds (Kang et al. 2009; Kim et al. 2009). Therefore, high-resolution inputs were required. KMOE provides a high resolution DEM at a cell size of 5 m. However, processing such high-resolution data requires advanced computer processing power since the study area was of 91,843 km². Therefore, a DEM with a 10-m cell size was used to enhance the accuracy of soil loss estimates and to overcome limitations of the computer processing power. USLE LS and P factor maps were prepared from this DEM. In addition, the other inputs (i.e., land use for the USLE C factor map and a soil map for the USLE K factor map) were prepared with a 10-m cell size. Once soil loss was estimated OECD standard, cumulative density function (CDF), and normalization methods were performed. In this study, overview of methodology can be shown in Fig. 3.

3.2 Universal soil loss equation (USLE) model

The USLE has been widely used for estimating soil loss from agricultural land since its initial development 40 years ago. Wischmeier and Smith (1965) proposed modifications to the equations modeling soil desorption and movement by rainfall. The USLE was initially applied to the quantification of soil loss to support decisions on agricultural land management in the USA. Thus, the values of USLE factors were determined for the USA conditions, but have been used to estimate soil loss in many other countries, including the USA (Kinnell 2010). However, the development of GIS and remote sensing (RS) has extended the applicability of the USLE by making available spatio-temporal USLE factors. The USLE model, which comprises rainfall-runoff erosivity (R), soil erodibility (K), slope-length and steepness (LS), cover-management (C), and practice (P) factors, assesses long-term averaged soil loss amounts. The accuracy of USLE-based estimations is dependent on the spatial resolution of input data. The output of a USLE simulation at national-/watershed-scale should not be used to identify soil loss hot spots because this scale-dependency may limit model performance when searching for hotspots and evaluating soil loss with greater accuracy. According to the RUSLE 1.06 Users' manual, the USLE model should not be used to estimate the absolute amount of soil loss. The USLE could be used to evaluate the effects of various soil erosion management practices on soil loss. Given below is the USLE equation:

$$A = R \times K \times LS \times C \times P \tag{1}$$

where, A (Mg/ha/year) is the average annual soil loss amount, R is the rainfall-runoff erosivity factor (MJ mm/ha year hr), K is the soil erodibility factor (Mg hr/MJ mm), LS is the slope-length and gradient factor, C is the cover and management factor, and P is the land management practice factor. This study followed the topsoil preliminary investigation guidance (TPIG) protocol (KMOE 2012a, b) in order to estimate the USLE factors.

3.2.1 Rainfall-runoff erosivity factor (R)

The rainfall-runoff erosivity (R) factor represents the erosivity of rainfall at a geographical location, which is estimated from the annual summation of storm rainfall energy multiplied by the maximum intensity in a 30-min interval (Toy and Foster, 1998). Under the assumption that R for a given region is fixed, we used the R values of Park et al. (2000) for 158 sites across Korea, one for each administrative district, as our starting point (Table 2). We then constructed an R factor map with a resolution of 10 m × 10 m using the inverse distance weighted (IDW) method. Park et al. (2000) did not provide information about the location of R factors in each administrative district, so we assumed they were located at the centroid point of each administrative district R_e was calculated by Eqs. 2 and 3 (Wischmeier and Smith 1978).

$$E = \left(\frac{210 + 89 \log I}{100} \right) \times R_d \tag{2}$$

$$R = \sum E \times I_{\max 30} \tag{3}$$

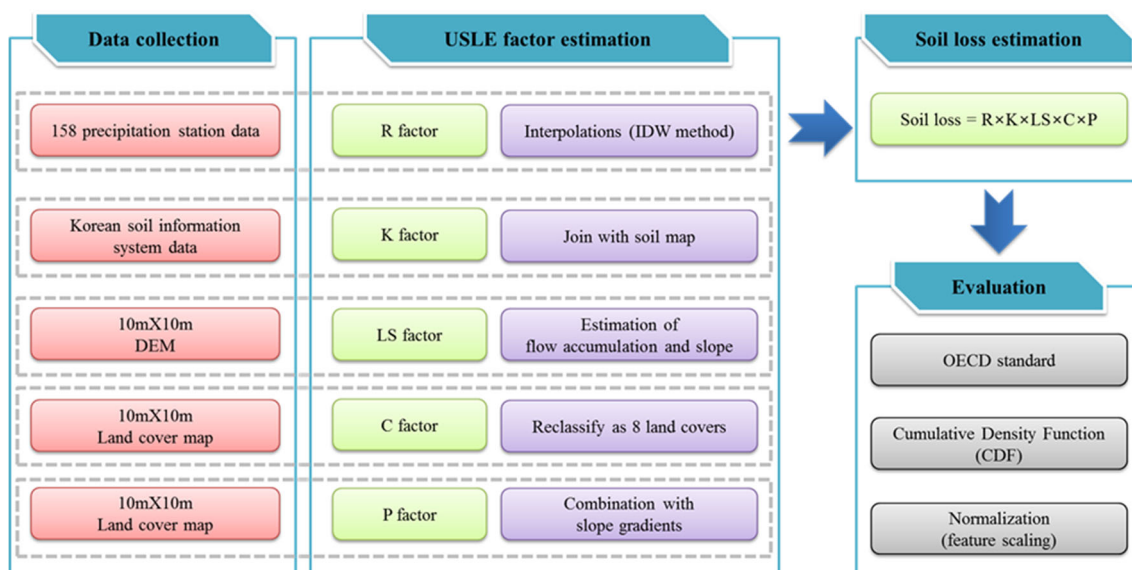


Fig. 3 Overview of methodology

Table 2 R factor of 158 precipitation station in Korea (1973-1996)

City/county	R	City/county	R	City/county	R	City/county	R
Gapyeong	4631	Dongducheon	4976	Yangju	5103	Jecheon	4128
Gangneung	4111	Donghae	3975	Yangpyeong	4956	Jindo	4674
Gangjin	5381	Masan	5417	Yesan	4910	Jinan	3988
Gwacheon	5041	Mogpo	3557	Yeosu	5799	Jinju	5238
Geoje	7076	Muju	3792	Yeosu	4777	Jincheon	4442
Geochang	3807	Mungyeong	3278	Yecheon	3351	Jinhae	5584
Gyeongsan	3020	Milyang	3843	Yeongi	4561	Changnyeong	4090
Gyeongju	3296	Boryeong	5230	Yeoncheon	4923	Changwon	4770
Goryeong	3638	Boseong	5464	Yeonggwang	4422	Cheonan	4646
Goseong	5716	Boeun	3875	Yeongdeog	2668	Cheolwon	4440
Goseong (Kangwon)	4629	Bonghwa	3431	Yeongdong	3401	Cheongdo	3555
Goyang	5236	Busan	5496	Yeongam	4667	Cheongsong	2827
Gochang	4343	Buan	4111	Yeongyang	2918	Cheongyang	5005
Goheung	6076	Buyeo	5104	Yeongwol	4032	Cheongwon	4297
Gogseong	4583	Bucheon	4945	Yeongju	3752	Cheongju	4389
Gongju	4777	Bugjeju	4841	Yeongcheon	2723	Chuncheon	4242
Gwangmyeong	5016	Sacheon	5719	Osan	4906	Chungju	4091
Gwangyang	5540	Sancheong	5106	Ogcheon	3903	Chilgog	2826
Gwangju	4615	Samcheog	3693	Wando	5281	Taebaeg	3662
Gwangju (gyeonggi)	4956	Sangju	3186	Wanju	4186	Taeon	5008
Goisan	3919	Seoguiipo	6035	Yongin	4863	Tongyeong	5527
Gurye	4711	Seosan	4982	Ulreung	3357	Paju	5301
Guri	5089	Seoul	5152	Ulsan	4276	Pyeongchang	4126
Gumi	2728	Seocheon	4525	Uljin	3027	Pyeongtaeg	4891
Gunsan	4190	Seongnam	4975	Wonju	4429	Pocheon	4742
Gunwi	2794	Seongju	3223	Eumseong	4357	Pohang	2778
Gunpo	4939	Sogcho	3784	Euiryeong	4646	Hanam	5011
Geumsan	3934	Muan	4024	Euiseong	2814	Hadong	5411
Gimje	4196	Suwon	4913	Euiwang	4951	Haman	4888
Gimcheon	3088	Sunchang	4245	Euijeongbu	5077	Hamyang	4364
Gimpo	5757	Suncheon	5067	Icheon	4762	Hampyeong	4431
Gimhae	4909	Siheung	4899	Igsan	4439	Habcheon	4145
Naju	4689	Sinan	4213	Inje	3367	Haenam	4785
Namyangju	4973	Andong	3054	Incheon	5557	Hongseong	4970
Namwon	4279	Ansan	4938	Imsil	3861	Hongcheon	4323
Namjeju	5470	Asan	4835	Jangseong	4451	Hwaseong	4928
Nonsan	4562	Anseong	4704	Jangsu	4045	Hwasun	4892
Danyang	3936	Anyang	4996	Jangheung	5691	Hwacheon	4145
Damyang	4487	Namhae	7268	Jeonju	4259	Hoingseong	4442
Dangjin	4953	Yanggu	3509	Jeongseon	3991		
Daegu	3062	Yangsan	4469	Jeongeub	4245		

where, I_{max30} is the maximum 30-min rainfall intensity, E is the total storm kinetic energy (m ton/ha/cm), R is rainfall erosivity (MJ mm/ha year h), R_d is rainfall data (cm) and I is the rainfall intensity (cm/h). The estimated R factors are shown in Fig. 4a.

3.2.2 Soil erodibility factor (K)

The soil erodibility factor (K) provides a measure of the cohesive or binding characteristics of soil or surface materials in fields under standard experimental conditions (Toy

and Foster, 1998). K is a function of the distribution of particle-sizes, organic-matter content, and the structure and permeability of the soil or surface material. We calculated K by using soil series data. Most soil data were obtained from the Korean soil information system (<http://soil.rda.go.kr>),

but a data for a few soils were not available. In these cases, we used data for similar soil from the Korean soil information system. We estimated the gridded data (10 m × 10 m) across the country (Fig. 4b). K was calculated using Eqs. 4 and 5 (Wischmeier and Smith 1978).

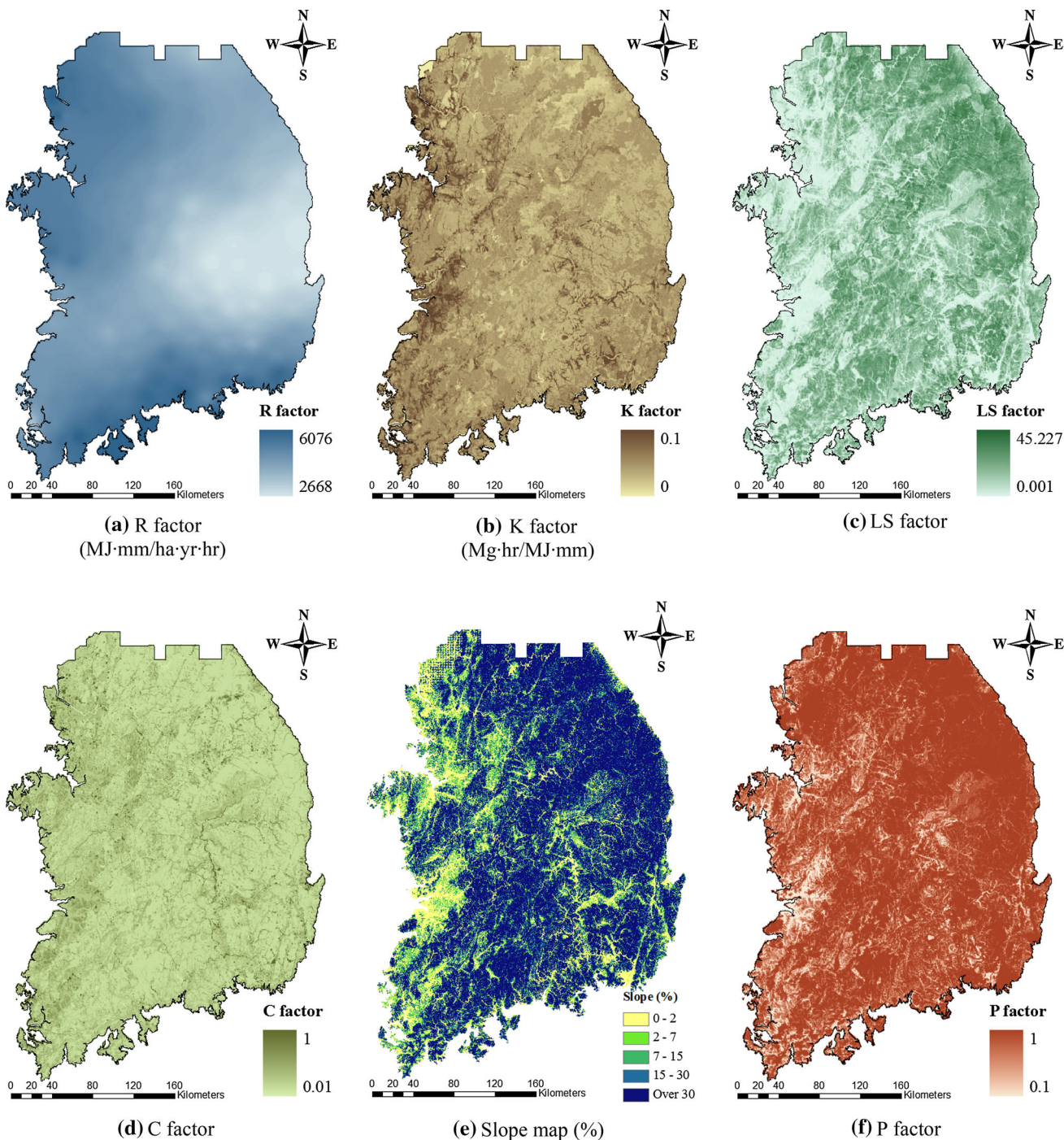


Fig. 4 Distribution of the USLE factors

$$K = \frac{\left[\frac{2.1 \times 10^{-4}(12 - OM) M^{1.4} + 3.25(S_1 - 2) + 2.5(P_1 - 3)}{100} \right]}{9.8} \quad (4)$$

$$M = (MS + VFS) \times (100 - CL) \quad (5)$$

where, K is the soil erodibility factor (Mg hr/MJ mm), OM is the percentage organic matter (%), M is a function describing grain size regarding the soil loss (%), S_1 is the soil structure index (1 to 4), P_1 is the soil permeability class (1 to 6), MS is the percentage silt (%), VFS is the percentage very fine (%), and CL is the percentage clay (%).

3.2.3 Slope-length and steepness factor (LS)

The LS factor represents the effect of topography (hillslope length and steepness) on rates of soil loss in fields (Toy and Foster 1998). LS increases as hillslope length and steepness increase, under the assumption that runoff accumulates and accelerates in the downslope direction. The method uses the ratios of length and slope to the standard length and slope of 22.13 m and 9 %, respectively. LS was calculated using Eq. 6 (Moore and Burch 1986a, b; Shin 1999), and a DEM with a grid size of 10 m provided by the National Geographic Information Institute of Korea was used.

$$LS = \left(\frac{[FlowAccumulation] \times Cellsize}{22.1} \right)^{0.6} \times \left(\frac{\sin \theta \times 0.01745}{0.09} \right)^{1.3} \quad (6)$$

where, LS is the slope-length and steepness factor (no units), θ is the slope angle (°). $FlowAccumulation$ is used to integrate flow direction in the calculation of LS , and can be estimated from DEMs with GIS. $Cellsize$ is the resolution of the DEM used in the calculation of LS . The estimated values of LS are shown in Fig. 4c.

3.2.4 Cover-management factor (C)

The C factor is an expression of the effects of surface vegetation cover on rates of soil loss at a particular site compared to loss under tilled, continuous fallow conditions (Jeong et al. 2012). A high C value indicates that a soil surface covered by vegetation will prevent the soil loss due to rain impact and runoff more than bare soil. In addition, root activity (root depth and distribution) and porosity increase the infiltration rate of rainfall water into the soil (as opposed to flow along the surface), reducing soil loss (Jeong et al. 2012). Thus, we calculated C using KMOE (2012) and the land cover data (i.e., urban, water, and

wetland areas) (Table 3) (Park et al. 2011; Shin 1999). The estimated values of C are shown in Fig. 4d.

3.2.5 Land management practice factor (P factor)

The P factor expresses the effect of various conservation practices (e.g. contouring, terracing, and buffer strips) on soil loss. P decreases with these practices, which reduce the impacts of rainfall-runoff and velocity, and increase the deposition of sediment before it leaves the field boundary (Toy and Foster 1998). The effectiveness of certain erosion-control practices varies substantially with local conditions. Table 4 shows the values of the P factor assigned for each combination of land cover and slope gradients, based on the literature (KMOE 2012a, b; Shin 1999). We calculated slope (%) for each cell using the DEM (Fig. 4e), and then estimated P using the calculated slopes and land-cover type (Fig. 4f).

3.3 Calculation of soil loss across the entire country based on cumulative density functions

Soil loss for the entire South Korea was estimated by the USLE method. The essential USLE factors (R , K , LS , C , and P) were estimated based on KMOE (2012). All USLE factors at the national level were estimated at a spatial resolution of 10 m \times 10 m. The estimated USLE factors were used to individually estimate soil loss for the eight different land-cover types with the aim of assessing whether it is appropriate to apply the OECD standard to soil management in South Korea without accounting for the land-cover type. To do this, first soil loss for the entire country was spatially and quantitatively estimated. Then soil loss for each of the eight land-cover types was estimated, and these were compared with each other. The estimated amount of soil loss for each land-cover type was used to graphically construct a cumulative density function (CDF) under the assumption that all cells of the land cover map have an equal probability of soil loss occurrence.

Table 3 USLE C factors for dominant land covers in Korea

Land cover	C factor	Source
Bare land	1.00	KMOE (2012a, b)
Paddy	0.10	
Upland	0.30	
Pasture	0.15	
Forest	0.05	
Orchard	0.09	
Urban and built-up	0.1	Shin (1999)
Wetland	0.05	
Water	0.01	

Table 4 USLE P factors for dominant land covers in Korea

Land cover	Slope gradient (%)	P factor	Source
Bare land	–	1.00	KMOE (2012a, b)
Paddy	<2 %	0.12	
	2–7 %	0.10	
	7–15 %	0.12	
	15–30 %	0.16	
	>30 %	0.18	
Upland	<2 %	0.60	
	2–7 %	0.50	
	7–15 %	0.60	
	15–30 %	0.90	
	>30 %	1.00	
Pasture	–	1.00	
Forest	–	1.00	
Orchard	–	1.00	
Urban and built-up	–	1.00	Shin (1999)
Wetland	–	1.00	
Water	–	1.00	

Thus, for each land-cover type, the sum of the probability of soil loss for all cells is one. The amount of soil lost were estimated at 5, 50, and 95 % cumulative probabilities, and then compared with the OECD standard.

3.4 Normalization for comparison of the estimated amounts of soil lost among land-cover types

Comparing the distributions of soil loss estimated for each land-cover type is required for efficient soil resource management because different land-cover types can have different soil loss distributions. Thus, the estimates of soil loss for each land-cover type were normalized. Standard score, Student’s *t*-statistic, studentized residual, standardized moment, coefficient of variation, and feature scaling are common methods of normalization. In this study, the feature scaling method was selected for simple comparison among land-cover types (Eq. 7).

$$X' = \frac{X - MIN(X)}{MAX(X) - MIN(X)} \tag{7}$$

where *X'* is the normalized value, and *X* is the original value.

The normalized values (from zero to one) for soil loss from the eight land-cover types were allocated to the ten groups: 0–0.1; 0.1–0.2; 0.2–0.3; 0.3–0.4; 0.4–0.5; 0.5–0.6; 0.6–0.7; 0.7–0.8; 0.8–0.9; and 0.9–1.0.

4 Results and discussion

4.1 Result of the estimated soil loss amounts

Estimates of soil loss and indices of soil loss risk are required for efficient soil managements. This study estimated soil loss using consisting parameterization of USLE. Figure 5 shows the spatial distribution of estimated soil losses in South Korea at a resolution of 10 m × 10 m. It should be noted that the USLE method used in this study has a limited ability to account for gully erosion. The total estimated amount of soil loss in South Korea was 320,994.990 Mg/year (Table 6). Across the country, the average and maximum amounts of soil loss were 34.56 Mg/ha/year and 14,996.66 Mg/ha/year, respectively (Fig. 5). These values rank as ‘Severe’ (greater than 33 Mg/ha/year, the highest risk of soil erosion), out of the five OECD standard categories. Based on this result, South Korea seems to potentially have a serious soil loss problem. Figure 6 and Table 5 show the spatial distribution of the estimated amounts of soil loss, classified by the OECD standard and soil loss risk based on the OECD standard for land-cover types. More soil loss occurred in forests, compared to other land-cover types. Approximately 70 % of the total land area in South Korea is forest (Fig. 2b). Since most forest is in mountainous regions, soil loss in forests can be affected by steep slopes as well as land cover (Fig. 2a). In this regard, approximately 30 % of the entire country (27,500 km²/91,843 km²) belongs to the “Severe”

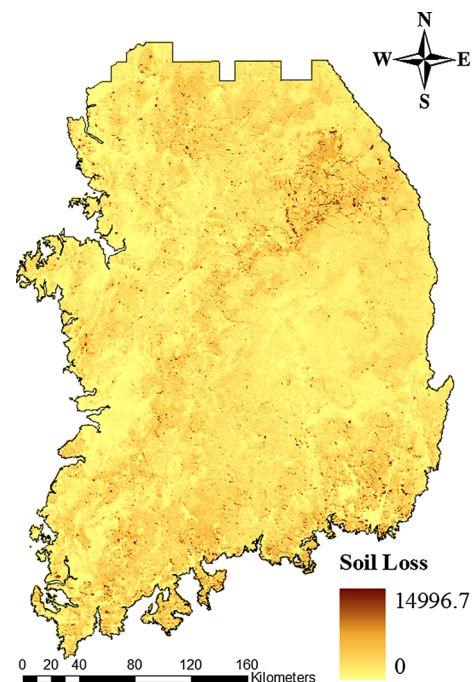


Fig. 5 Spatial distribution of the estimated soil loss rate (Mg/ha/year)

category, indicating a need to implement strict soil management plans and policies. However, applying these in practice may be difficult due to the limitations of knowledge, human and financial resources, and policy. From these results, the application of the OECD standard may result in pressure to improve soil management in South Korea. Thus, these findings may provide a basis for efficient surface soil layer management strategies appropriate for the Korean topography. However, a limitation of this study was that the USLE equations used are based on the conditions in the United States. Further studies are required to find appropriate equations for the estimation of the USLE factors in the Korean context.

4.2 Comparison of the estimated amounts of soil loss among the land-cover types

The amounts of soil loss were separately estimated for the eight different land-cover types in South Korea. Figure 7 shows the spatial distributions of the estimated amounts of soil loss for each land-cover type at the national scale. Of the total estimated soil loss amount of $320,995 \times 10^3$ Mg/year, forests and wetlands were estimated to contribute amounts of $171,820 \times 10^3$ Mg/year (54 % of the total amount) and 828×10^3 Mg/year (0.3 % of the total amount) respectively. Based on these figures, it would seem to be most urgent to prevent soil loss in forests. However, this does not account for the areas of each land-cover type, and direct comparison may be misleading for

decision makers aiming to manage soil resources effectively. For example, among the eight land-cover types, the estimated soil loss amount was largest in forests, which occupy 66 % of the total area. Accordingly, the prevention of soil loss in forests may be one method for protecting soil resource in South Korea. However, such a method may be an inefficient allocation of limited time, financial, and human resources. Similarly, paddy fields occupy 9.5-fold greater area than bare land, but the estimated soil loss amounts are 4-fold lower (Table 6). Management of bare land is likely to be more efficient than management of paddy fields. Estimated soil loss amounts for each land-cover type are in the 4th column of Table 6. The largest and the smallest differences between the maximum and minimum values of estimated soil loss amounts were for bare land (0–14,996.7 Mg/ha/year) and paddy fields (0–265.28 Mg/ha/year) respectively. Moreover, the average soil loss amounts range from 4 Mg/ha/year (paddy) to 319 Mg/ha/year (bare land). In other words, on an average, bare land has 80-fold greater soil loss than paddy fields. These results show that there are significant differences in the estimated soil loss amounts among land-cover types, and thus, distinct standards for each land-cover type will enhance the efficiency of soil management.

4.3 Application of OECD standards using estimated soil loss amounts for each land-cover type

In this study, the estimated soil loss amounts for the eight land-cover types were minutely compared by constructing CDFs along a gradient of soil loss (Fig. 8). Table 7 shows the estimated the soil loss amounts at the 5, 50, and 95 % cumulative probabilities. At 5 % cumulative probability, the estimated soil loss amounts were highest in forests (0.5873 Mg/ha/year) and lowest in wetlands (0.0024 Mg/ha/year). However, the estimated soil loss amounts at 5 % were <1 Mg/ha/year for all land-cover types, and belong to the ‘Moderate’ category of the OECD standard (Table 1). At 50 % cumulative probability, the highest and lowest values were estimated in bland (45.36 Mg/ha/year) and paddy fields (0.0053 Mg/ha/year). In particular, bare land and upland were in the ‘Severe’ category of the OECD standard, indicating the highest soil loss risk. Based on estimated soil loss amounts at 95 % cumulative probability, all land-cover types fell into the ‘Severe’ category, except paddy fields. In common with 50 % cumulative probability, the estimated soil loss amount in bare land was higher than that for the other land-cover types. Soil loss was estimated at 1,407 Mg/ha/year for bare land, which is 73-fold greater than the estimate for paddy fields (19.23 Mg/ha/year). Based on these results, bare land and uplands potentially have a high soil loss risk.

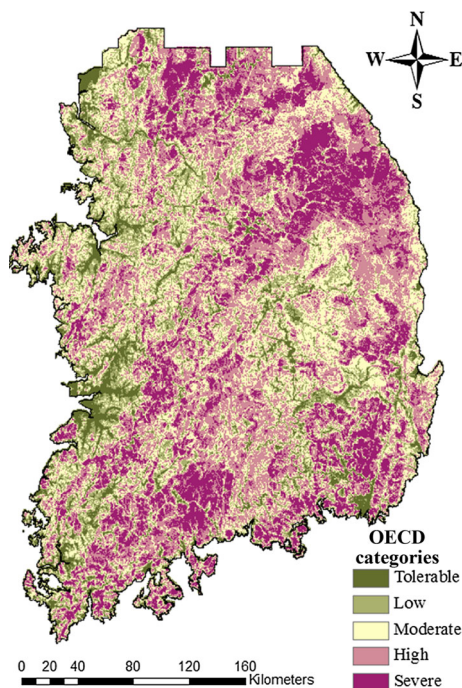


Fig. 6 Soil erosion risk classified by the OECD standard

Table 5 Soil loss risk classified by the OECD standard for types of land covers

Land cover	Tolerable		Low		Moderate		High		Severe		Area (km ²)
	<6		6–10.9		11–21.9		22–32.9		>33		
	Area (km ²)	%	Area (km ²)	%	Area (km ²)	%	Area (km ²)	%	Area (km ²)	%	
Orchard	489.69	0.53	66.06	0.07	111.78	0.12	81.06	0.09	288.47	0.31	1,037.06
Bare land	615.08	0.67	3.38	0.00	12.70	0.01	14.29	0.02	678.47	0.74	1,323.92
Paddy	9,767.23	10.63	1,197.96	1.30	1,100.43	1.20	314.59	0.34	150.77	0.16	12,530.98
Urban	3,204.85	3.49	314.24	0.34	509.49	0.55	316.32	0.34	1,276.16	1.39	5,621.06
Upland	3,205.51	3.49	141.38	0.15	302.01	0.33	311.11	0.34	3,973.87	4.33	7,933.88
Forest	22,474.53	24.47	2,890.78	3.15	7,852.31	8.55	7,634.42	8.31	20,185.34	21.98	61,037.38
Wetland	439.25	0.48	34.01	0.04	50.19	0.05	36.37	0.04	90.43	0.10	650.25
Pasture	689.77	0.75	45.21	0.05	97.79	0.11	82.96	0.09	792.99	0.86	1,708.72
Total	40,885.92	44.52	4,693.02	5.11	10,036.69	10.93	8,791.11	9.57	27,436.50	29.87	91,843.25

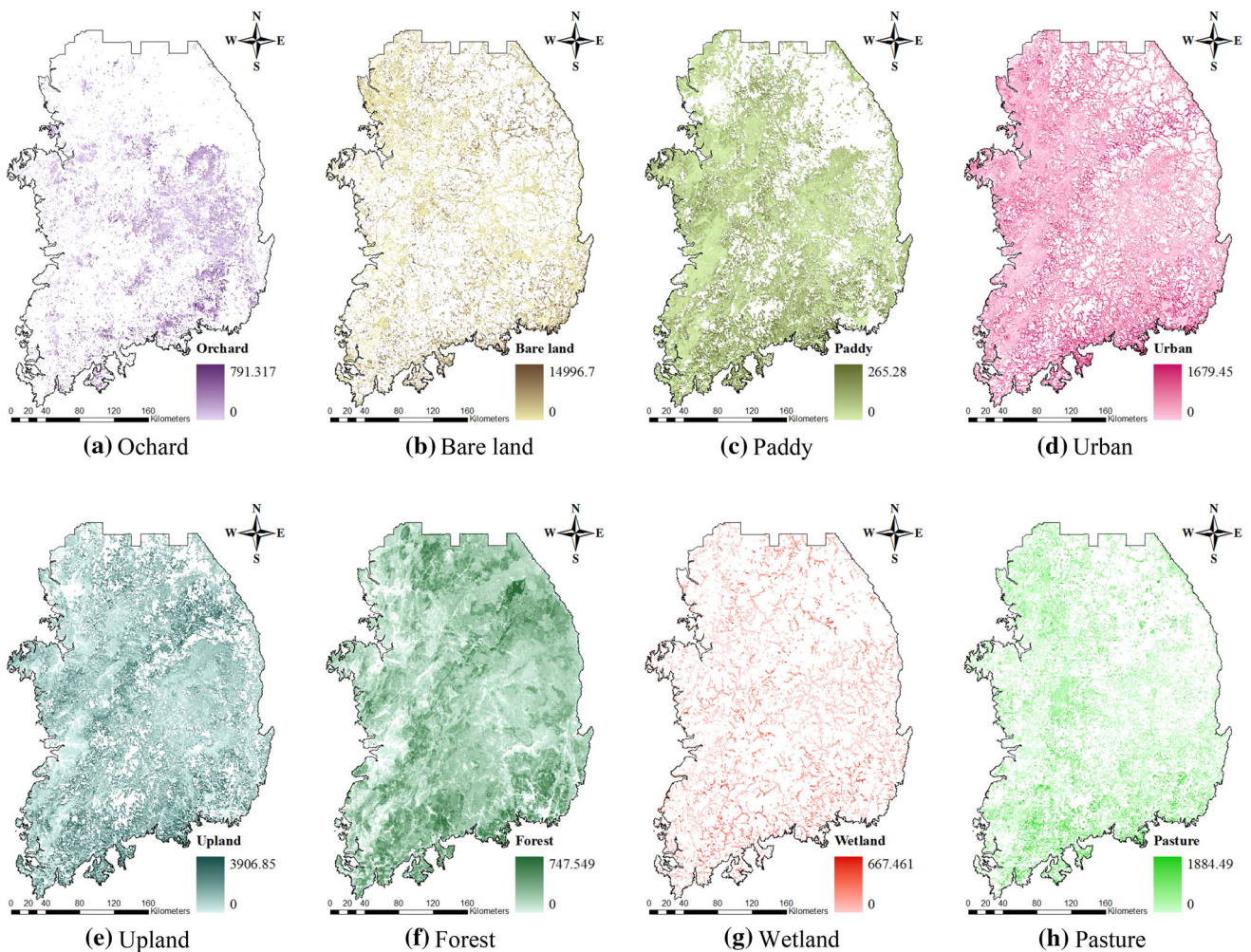


Fig. 7 Spatial distribution of the estimated soil erosion by land covers (Mg/ha/year)

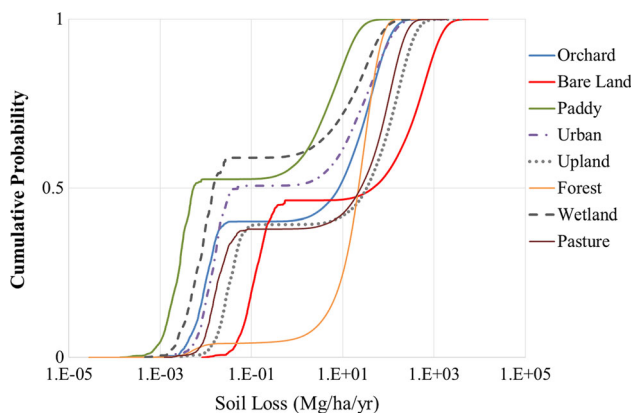
Initials stages of developing soil management strategies in South Korea were directed toward prevention of soil loss without following any clear standards. Specifically, the

OECD standard for agricultural land has been uniformly applied to all land-cover types when identifying locations with high soil loss risk in South Korea. However, the

Table 6 Quantitative results of the estimated soil loss amount

Land cover	Area		SL amounts		SL rate	
	(km ²)	(%)	(10 ³ Mg/year)	(%)	Maximum (Mg/ha/year)	Average (Mg/ha/year)
Orchard	1,037.06	1.13	2,733.69	0.85	791.32	26.36
Bare land	1,323.92	1.44	42,177.44	13.14	14,996.66	318.58
Paddy	12,530.98	13.64	5,024.92	1.57	265.28	4.01
Urban	5,621.06	6.12	13,473.68	4.20	1,679.45	23.97
Upland	7,933.88	8.64	74,491.20	23.21	3,906.85	93.89
Forest	61,037.38	66.46	171,820.22	53.53	577.34	28.15
Wetland	650.25	0.71	828.42	0.26	667.46	12.74
Pasture	1,708.72	1.86	10,445.41	3.25	1,884.50	61.13
Total	91,843.25	100	320,994.99	100	14,996.66	34.95

SL soil loss

**Fig. 8** Cumulative probability of the estimated soil erosion by land covers in South Korea where, x-axis is logarithmic scale

results from this study show that estimated soil loss amounts vary significantly among land-cover types. Thus, uniform application of the OECD standard to all land-cover types can exacerbate concerns about the depletion of the limited national budget and resources for soil management.

Effective soil erosion control requires appropriate BMPs and regulations for land-cover types. Various BMPs have

been developed and applied not only in South-Korea but also worldwide. BMP plans need to be established with appropriate strategies. For instance, a strategy to control the area of Korea with more than 33 mg/ha/year of soil loss, in the ‘severe soil erosion’ category by OECD standards, may be challenging because it represents 30 % of South Korea (Table 5). Therefore, areas with high soil erosion potential were identified to aid practical prioritization of soil erosion control.

4.4 Normalization using the estimated soil loss amounts based on land-cover type

The normalized soil loss estimates for the eight land-cover types are in Fig. 9 and Table 8. Normalized scores for soil loss from each type were put into ten categories (Table 8); 90 % of the scores ranged from 0.0 to 0.1, and 97 % of the scores ranged from 0.0 to 0.1 in urban areas and paddy fields. These results indicate that only a few areas have a possibility of severe soil loss. Thus, there is a need to identify these areas of severe soil loss, and then to establish a BMP plan to reduce soil loss in these areas, thereby improving cost efficiency. Compared to the other land-

Table 7 Estimated soil loss amounts at 5, 50, and 95 % cumulative probabilities

Land cover	5 %		50 %		95 %	
	SL (Mg/ha/year)	Area (km ²)	SL (Mg/ha/year)	Area (km ²)	SL (Mg/ha/year)	Area (km ²)
Orchard	0.0041	951.62	8.16	518.53	109.91	85.44
Bare land	0.0491	1,257.72	45.36	661.96	1,407.05	66.20
Paddy	0.0010	11,904.43	0.0053	6,265.49	19.23	626.55
Urban	0.0059	5,340.01	0.0497	2,810.53	117.36	281.05
Upland	0.0157	7,537.19	33.25	3,966.94	374.26	396.69
Forest	0.5873	57,985.51	22.08	30,518.69	76.40	3,051.87
Wetland	0.0024	617.74	0.0145	325.12	65.79	32.51
Pasture	0.0089	1,623.28	24.69	854.36	231.23	85.44

SL soil loss

Fig. 9 Comparison of the normalized soil loss by land cover types

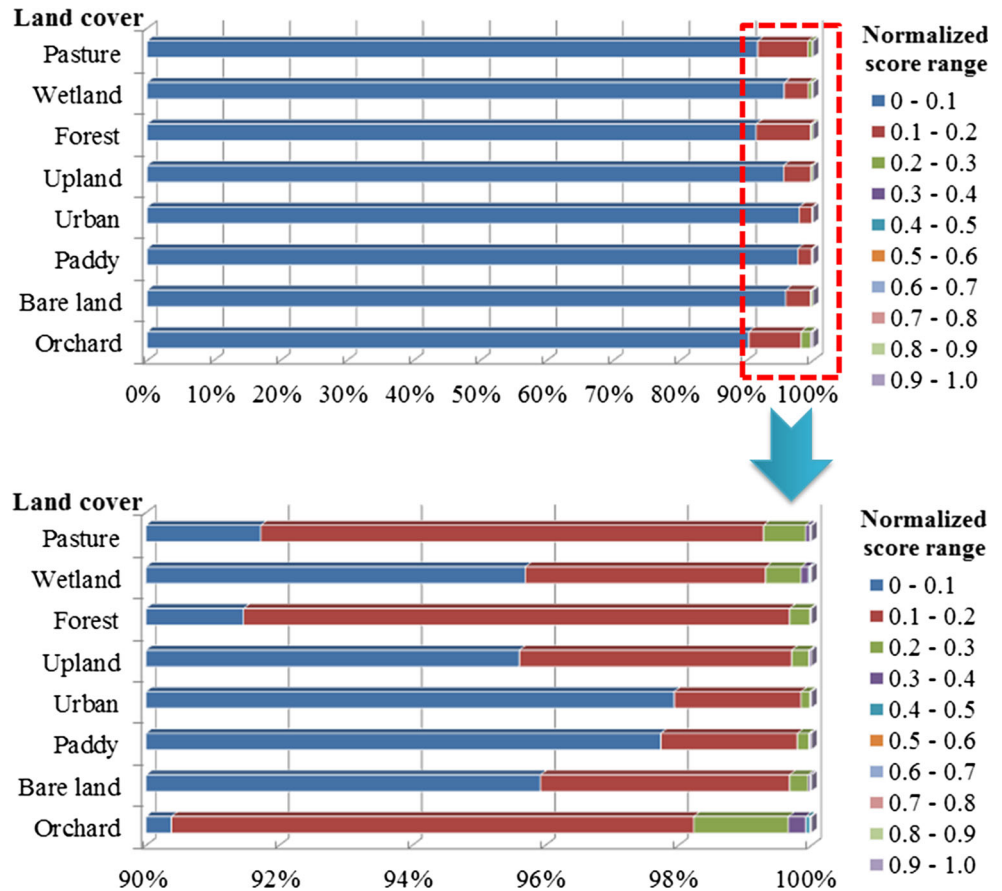


Table 8 Distribution of the normalized soil loss by land covers (%)

Land cover	Normalized values										Total
	0–0.1	0.1–0.2	0.2–0.3	0.3–0.4	0.4–0.5	0.5–0.6	0.6–0.7	0.7–0.8	0.8–0.9	0.9–1.0	
Orchard	90.39	7.85	1.42	0.2623	0.0593	0.0156	0.0042	0.0008	0.0001	0.00001	1
Bare land	95.93	3.74	0.2796	0.0345	0.0081	0.0019	0.0004	0.0002	0.00003	0.00001	1
Paddy	97.74	2.05	0.1758	0.0256	0.0047	0.0009	0.0006	0.0001	0.00003	0.00002	1
Urban	97.94	1.91	0.1306	0.0165	0.0024	0.0007	0.0003	0.0001	0.00002	0.00001	1
Upland	95.62	4.09	0.2603	0.0284	0.0037	0.0005	0.0001	0.0001	0.00003	0.00001	1
Forest	91.47	8.20	0.3080	0.0144	0.0015	0.0002	0.0001	0.00003	0.00001	0.000003	1
Wetland	95.70	3.61	0.5302	0.1152	0.0263	0.0062	0.0021	0.0009	0.0026	0.0001	1
Pasture	91.73	7.55	0.6331	0.0659	0.0124	0.0026	0.0009	0.0003	0.0001	0.0002	1

cover types, pasture had higher normalized scores, ranging from 0.9 to 1.0; therefore, a BMP plan to reduce soil loss in pastures is a priority.

5 Conclusion

Soils are recognized as a limited resource and asset. Soil loss can occur rapidly, for example due to intense rainfall,

steep slopes, and erodible soil types, but the recovery of damaged regions may require an extremely long time period. Thus preventing soil loss is almost certainly a more efficient management strategy than attempting to recover lost soils. However, to date in South Korea, soil loss has been managed only for non-point sources (NPS) without considering economic value of the soil loss itself. Furthermore, OECD standards for assessing soil erosion have been applied to identify of soil erosion hot spots at the

national level without accounting for land cover characteristics. These limitations may give rise to large uncertainties in estimates of soil loss amounts, and lead to inappropriate soil management. In this study, we estimated soil loss amounts for eight land-cover types using USLE for entire South Korea (excluding coastal islands). Our findings indicate that identifying regions potentially at risk of excessive soil loss by including data on land use and watershed could be more a more realistic approach than the use of the OECD (33 Mg/ha/year) standard, which identified approximately 30 % of South Korea as high risk.

The average soil loss amounts for each land use (26.36, 318.58, 4.01, 23.97, 93.89, 28.73, 12.74, and 61.13 Mg/ha/year for orchards, bare land, paddy fields, urban areas, uplands forests, wetlands, and pastures) showed marked differences (Fig. 9). Based on the OECD standard (more than 33 Mg/ha/year), bare land, uplands, and pastures need to be managed as soil erosion hot spots. However, such identification of soil erosion hot spots based on the average values for each land-cover-type across the entire country has not been conducted to date. It may not only be inefficient, but also may also pose difficulty in implement management strategies in the fields. For these reasons, we estimated and classified the risk of soil loss amounts at 5, 50, and 95 % cumulative probabilities for each land use at the national level. These estimated soil loss amounts showed significant differences at 5, 50, and 95 % cumulative probabilities. Specifically, bare land has the potential for serious soil loss, and needs a countermeasure for prevention or mitigation. However, paddy fields, which cover the second largest area of the eight land-cover types in South Korea (13.6 % of the total area), did not show severe soil loss at 95 % cumulative probability. The decreasing area occupied by paddy fields in South Korea may increase the overall risk of soil loss in South Korea. These results suggest that our approach of considering local characteristics could be reasonable and practical for identifying regions at high risk of soil loss. Furthermore, these findings highlight the need for identifying region specific standards of soil loss risk, and show that prioritization of soil management accounting for land-cover type is a valuable approach that may lead to the efficient use of time, finance, and effort.

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