Estimation of soil erosion rate in the Democratic People’s Republic of Korea using the RUSLE model

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ABSTRACT
Forests are well known to control soil erosion and severe flooding. In the Democratic People’s Republic of Korea (North Korea), deforestation was estimated at 20% between 1997 and 2014. This decline was mainly reflective of improper land use practices on steep slopes. Intensive deforestation and inappropriate land management can lead to severe soil erosion. The objective of this study was to describe the regional soil erosion severity in North Korea using the Revised Universal Soil Loss Equation (RUSLE) model coupled with a GIS technique. This model is widely being used to assess the potential mean annual soil erosion under different rainfall, soil characteristics, slope, and land use conditions. The results showed that the average annual rate of soil loss was estimated to be 15.8 tonnes ha⁻¹ yr⁻¹. Regionally, Nampo city is the most vulnerable region to soil erosion (55.1 tonnes ha⁻¹ yr⁻¹), followed by Hwanghaebuk-do (30.5 tonnes ha⁻¹ yr⁻¹), due to rapid land development. Denuded lands, which are estimated at around 65% of the total area, are predicted to have contributed 192.1 million tonnes yr⁻¹ to the country’s soil erosion. Participatory agroforestry and reforestation were found to be practical solutions to reduce soil erosion, particularly on degraded landscapes, and improve people’s farm-based livelihoods.

Introduction

Soil erosion is a natural process on all land that relocates top-soil by the exogenous forces of water or wind (Eswaran et al. 2001; Li et al. 2010). Agricultural expansion and deforestation, which in turn can lead to changes in land cover, are the key drivers to accelerating soil erosion in developing countries (Millward and Mersey 1999). Excessive erosion has been recognized as a major global environmental problem, causing the removal of nutrient-rich topsoil, degradation of stream competence, and depletion of suitable arable land (Oldeman 2000; Lal 2001).

The Democratic People’s Republic of Korea (hereafter North Korea) is a country that suffers heavily from land degradation due to increasing anthropogenic pressures. These mainly include uncontrolled land conversion and unplanned logging, especially on sloping lands (Stone 2012; Engler et al. 2014). In North Korea, continuous efforts have been made to increase arable land area. Since 1976 the North Korean government has encouraged terrace field cultivation on steep mountainous regions. Under this nationwide policy, forest lands were observed to have continuously deforested. Due to serious food shortages, private plot cultivation became an inevitable choice for local people. As of 2004, c. 1670 km² of sloping lands have been reclaimed by the terrace field cultivation movement (Ahn 2005). Since the country’s economic collapse in the early 1990s, and the resulting severe energy shortage, uncontrolled tree cutting for fuelwood by local people has further accelerated deforestation in rural areas (Engler et al. 2014).

Over the last decade, however, a participatory agroforestry project was been established in North Korea in conjunction with the Swiss Development Cooperation Office. This project, which began in 2002, was aimed at restoring heavily degraded landscapes and providing much-needed food for local communities on sloping lands (Itty 2010). Given this intervention, it is necessary to estimate the effect of agroforestry on denuded lands, in comparison with erosion rates of areas without proper land management.

Few studies have attempted to account for the nationwide soil erosion potential in North Korea. The estimates from these studies largely varied depending on the applied techniques, vis-à-vis accuracy and availability of data. The North Korean government officially reported that soil erosion was estimated to be 40 to 60 tonnes ha⁻¹ yr⁻¹ on sloping lands, but a recent study has estimated that it can exceed 100 tonnes ha⁻¹ yr⁻¹ in severe cases (MoLEP 2012). It was also reported that 15 tonnes ha⁻¹ of soils have been eroded annually throughout North Korea (Tenenbaum 2005). Lvovich et al. (1991) suggested that 2 to 10 tonnes ha⁻¹ of sediments can be annually transported into the ocean from North Korea.

The Revised Universal Soil Loss Equation (RUSLE) is a widely used equation that updates the Universal Soil Loss Equation (USLE) for predicting soil loss from interrill (sheet) and rill erosion that is caused by rainfall and associated overland flow (Renard et al. 1991). RUSLE uses the equation structure of USLE, but the empirical relationships for representing erosion processes have been updated with recent data, and new relationships have been derived based on modern erosion theory and data (Renard et al. 1994). However, this model is limited to different climatic condition and terrain, land cover, and soil factors (Park et al. 2012). Thus,
validation of simulation results is generally conducted by comparing the prediction with measured soil loss yield.

There have been a few Korean studies published that attempt to apply RUSLE to North Korea using methodologies specifically developed for limited data availability. Jung et al. (2002) reported the rainfall erosivity factor from monthly precipitation data of North Korea by modifying a methodology developed for the use of yearly precipitation data of South Korea (Jung et al. 1983), and adding a weight for the winter season considering the effect of snow melt. Lee and Heo (2011) modified the Institute of Agricultural Sciences (IAS) index to improve the methodology of Jung et al. (2002). Lee and Heo (2015) compared four different calculation methods to estimate the erosivity factor and concluded that Jung et al. (2002)’s calculation provided the lowest standard deviation of the estimates for the condition of North Korea. Lee et al. (2008) has estimated the soil loss for Imjingang watershed, simplifying the estimation of the cover-management factor.

One limitation of those studies is that the estimates were not validated with actual measurements due to lack of field data on soil loss in North Korea. As a result, none of the studies on North Korea mentioned in the previous paragraph have been validated. An indirect way to validate the estimates is to use data from adjacent regions, where actual measurements of soil loss are available. A general issue of application of RUSLE to the Korean peninsula is that the large portion of forest lands is located in mountainous areas, which often leads to overestimation of the total soil loss due to the high topographic factor (LS) of the steep slopes. Conversely, forest lands on steep hills are known to have relatively lower soil loss than agricultural lands due to the surface protection provided by litter cover and natural barriers such as dead trees or branches scattered on the slopes (Elliot et al. 1999). Therefore, it is necessary to adjust these forest land factors to enhance the accuracy of the estimation.

This study aims to quantitatively estimate the soil erosion rates of each administrative region in North Korea using the GIS-based RUSLE approach as a modeling tool. It also aims to evaluate the effects of agroforestry and reforestation in terms of their effect on mitigating soil erosion risk in comparison with the current status. Currently available data for North Korea on rainfall, soil, topography, and land cover and use were utilized to derive the inputs of RUSLE under the GIS framework. Each input factor was estimated using selected methodologies that have been developed specifically for either South or North Korea. In addition, we took steps to test the model’s performance targeting subwatersheds of the Bukhan River, which is located very near to the border between South and North Korea. The results of this study will provide valuable information on soil erosion study in North Korea.

Material and methods

Description of study area

North Korea is located in the far east of Asia, lying at latitudes 37°–43°N and longitudes 124°–131°E (Figure 1). The land area of North Korea is 123,140 km² in size, about 42% (51,580 km²) of which is covered with forest lands (Korea Forest Service 2016). It has a continental climate with four distinct seasons that are influenced by the continental landmass of Asia and the surrounding oceans. The weather is characterized by hot and humid summers and cold and dry winters. The annual average temperature is 9–10 °C, with averages of 24 °C in the summer and –6 °C in the winter, respectively. The annual precipitation varies by region throughout the country, ranging from 1000 mm to 2200 mm (Korea Meteorological Administration 2015). As the country’s climate is strongly influenced by seasonal East Asian monsoons, 34%–54% of the annual precipitation is concentrated in July and August (Jung et al. 2002).

Most of the land in North Korea is topographically located in either mountainous terrain or upland slopes, where only 17% of the total area is suitable for crop cultivation (MoLEP 2012). The total agricultural land of North Korea was estimated to be 20,421 km² in 2005, most of which is used in dry field farming (55%), followed by rice paddy fields (32%), orchards, and mulberry farms (MoLEP 2012). Dry field farming is a common agricultural technique in which crops are cultivated on slopes of less than 15°. However, steep slope agriculture, situated on slopes greater than 15°, is also widespread in North Korea.

RUSLE model structure and parameter estimation

USLE was developed in 1958 by the Soil Conservation Service in the US as a field scale tool to estimate soil loss on agricultural lands (Wischmeier and Smith 1978). USLE was designed to simulate sheet and rill erosion, but it has several intrinsic defects in its model structure (Sonneveld and

Figure 1. Location of the study site.
Nearing (2003). RUSLE was developed as an update to USLE to enhance its prediction performance (Renard et al. 1991, 1997).

RUSLE uses the same factorial approach employed in USLE as follows:

\[ A = R \times K \times LS \times CP \]

where A represents the soil erosion rate, commonly expressed in tonnes ha\(^{-1}\) yr\(^{-1}\); R refers to the rainfall erosivity factor, in MJ mm ha\(^{-1}\) hr\(^{-1}\) per year, a climatic index that describes the potential ability of rainfall to cause soil erosion; K is soil erodibility factor reflecting the susceptibility of a specific soil to erosion, in tonnes hr ha MJ\(^{-1}\) ha\(^{-1}\) mm\(^{-2}\); LS is a topographic factor that includes slope length (L) and slope steepness (S); C is an index for the protective coverage of vegetation and organic materials in direct contact with the ground surface; and the conservation practice factor P considers soil conservation practices and other measures that control the erosion.

The soil erosion rate is dependent on climatic conditions, soil, vegetation, and topographic characteristics. In order to reflect the high spatial variation of these characteristics, the study area is discretized into homogeneous units for soil loss computation. In the present study, the layers of controlling factors in RUSLE were all created in grid cells of 100 m \(\times\) 100 m. Data used for R, K, LS, and CP were encoded into the respective units and then integrated under GIS spatial analysis to quantify, evaluate, and generate a soil erosion risk map of North Korea.

Rainfall erosivity factor (R)

The rainfall erosivity factor, R, represents the impacts of rainfall geometry and rainfall amount on soil erosion development (Renard et al. 1991). It is calculated by the summation of the erosion index EI\(_{ij}\) over the period of evaluation.

As long-term rainfall intensity data of high temporal resolution are not often available in most developing countries, Jung et al. (2002) developed a simple method relating the monthly rainfall amount in North Korea to the monthly R value:

\[ RM_j = 0.0378 \times X_j^{0.419} \]

where RM represents the monthly R value (MJ mm ha\(^{-1}\) hr\(^{-1}\) per month) of a particular month (labeled as number j), and X is the total amount of rainfall in the month (mm month\(^{-1}\)).

In the winter or early spring, a small amount of runoff by snowmelt or light rain on frozen soil can cause soil erosion (Wischmeier and Smith 1978). Therefore, monthly R values for the winter season (December–March) were adjusted by using 1.5 times the RM value.

Also, there are significant irregularities in the rainfall amount and pattern in Korea. The high spatial and temporal variability in the monthly rainfall, caused by a change in the frequency of rainfall events or in the rainfall amount per event, is represented by the regional adjustment factor U\(_{adj}\).

The regional adjustment factor was empirically derived from the rainfall concentration (%) for a specific period by Jung et al. (2002). The derived regional factors for 27 meteorological stations of North Korea ranged from 0.53 to 1.33, with the lower values for the highland and eastern coastal region, and the higher values for the mountainous inland and western plain regions.

With the modifications outlined above, the annual R value for the stations was calculated by Jung et al. (2002) as:

\[ R = \left( \frac{1}{N} \sum_{i=1}^{N} \sum_{j=1}^{12} RM_j \right) \times U_{adj} \]

The monthly rainfall data used to estimate the rainfall erosivity factor by Jung et al. (2002) was for the 25- or 30-year periods 1981–1994 or 1973–1994 obtained from 27 weather stations throughout the country (Korea Meteorological Administration 2010). Estimated R values ranged from 1053.32 MJ mm ha\(^{-1}\) hr\(^{-1}\) yr\(^{-1}\) (Chongjin station) to 4837.31 MJ mm ha\(^{-1}\) hr\(^{-1}\) yr\(^{-1}\) (Kusong station). The R value was highest in Pyeonganbuk-do and Gangwon-do, and lowest in Hamkyeongbuk-do, depending on the rainfall characteristics.

With the R values obtained above, a raster map of the R factor was generated using the inverse distance weighted (IDW) interpolation method (ArcGIS version 10.1, ERSI) (Figure 2).

Soil erodibility factor (K)

The soil erodibility factor, K, is a quantitative indicator that measures the erosion susceptibility of a particular soil by rainfall and runoff (Renard et al. 1997). Soil texture is the main factor affecting the erodibility of soils, and their structure, organic matter content, and permeability also contribute to the soil erosion rate.

Soil types over the entire area were identified from a soil map (scale 1:25,000), which was published in 2009 by the National Institute of Agricultural Sciences (NAS-Korea). In accordance with the grouping method of Rivas (2006), all types of soils were grouped into their United States Department of Agriculture (USDA) soil textures, and then the associated K values were assigned (Table 1) based on Stewart et al. (1975)’s K values, which were obtained using the nomograph method and averaged for broad ranges of specific soils. The values of 2% organic matter content (Stewart et al. 1975) were used after being converted to the metric unit (tonnes hr ha MJ\(^{-1}\) ha\(^{-1}\) mm\(^{-1}\)). The spatial distribution of K values in North Korea is presented in Figure 2.

Topographic factor (LS)

The effect of topography on soil erosion is accounted for by the LS factor, in which L is the slope length factor and S represents the influence of the slope gradient on erosion. Both the slope length and steepness substantially affect development of sheet and rill erosion. As the amount of runoff increases with the slope length, and the velocity of runoff increases with the slope steepness, soil erosion increases with slope length and steepness.

The slope length factor has been expressed by Wischmeier and Smith (1978) as:

\[ L = \left( \frac{\lambda}{22.13} \right)^m \]

where \( \lambda \) is the slope length (Table 2), and m is a dimensionless exponent.

The slope length is defined as the horizontal distance from the origin of the overland flow to the depositional area
Slope length is one of the topographic parameters that are relatively difficult to decide. Regarding the inaccuracy problem of slope length, $\lambda$, for the areas of different land uses, Foster et al. (1996) suggested values of slope length matched the land use by considering the hydrologic condition of the ground surface (Table 2).

The slope contingent variable, $m$, is a continuous function of the slope gradient to represent the expected ratio of rill to interrill erosion, ranging from 0.01 to 0.56 (McCool et al. 1997). The value of $m$ in RUSLE is computed by the following equations (Renard et al. 1997):

$$m = \frac{\beta}{(1 + \beta)}$$

and

$$\beta = \frac{(\sin\theta/0.0896)}{\left\{3.0(\sin\theta)^{0.8} + 0.56\right\}}$$

where $\beta$ is the ratio of rill erosion to interrill erosion, and $\theta$ is the angle of the slope.

The slope steepness factor was calculated as:

$$S = 16.8\sin\theta - 0.50 \quad \theta \geq 9\%$$

$$S = 10.8\sin\theta + 0.03 \quad \theta < 9\%$$

Topographic analysis was performed to produce the slope gradient in the direction of flow accumulation using 100 m DEM achieved from Shuttle Radar Topography Mission (SRTM). The estimated LS values range between 0.0 to 40.0, being highest in the mountainous regions of the north and lowest in the flat areas of the southeast, as shown in Figure 2.

The cropping management factor, $C$, is a measure of the relative effectiveness of crop and soil management practices on

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soil erosion prevention (Morgan 1995). The C factor is a numerical descriptor to compare the soil erosion rates from a specified crop land to the corresponding loss from continuously fallow and tilled land (Renard et al. 1997). This factor represents the interrelated effects of crop type, cropping sequence, cultural practices, and growing period (Wischmeier and Smith 1978). RUSLE provides guidelines for selecting an appropriate C value for crop type and tillage practice based on field measurements from the US.

The supporting conservation factor, P, reflects the effects of practices on the reduction of water runoff and soil erosion. Soil erosion with different conservation and farming practices are compared to those with straight row cropping on an up-and-down slope to determine the observation deviation (Morgan 1995).

Korea has a large proportion of forest in mountainous areas, and paddy fields in crop lands. When forest is located in mountainous areas there is a high possibility of overestimation of soil loss due to the steepness of the slopes. In general, however, the surface of the forest floor is well protected with leaves and branches, and the soil often has high permeability. As a result, soil loss from forest land might not follow the general tendency of crop lands.

The C and P factors provided by USDA do not include these typical types of land use in Korea. Therefore, in order to avoid overestimation for forest lands, C and P values for various supporting practices were adapted from those defined for agricultural practices in northeast Asian countries published by Yoshikawa et al. (2004) and the results of Kumar and Kushiwaha (2013), and Kim (2006) (Table 2). The spatial distribution of the C and P values is presented in Figure 2. In this study, the land cover classification map with a resolution of 30 m provided by NAS was used to derive the C and P factors.

**Classification of the soil erosion risk and accuracy**

The soil erosion rate, A, was spatially calculated as a product of all factors using ArcGIS (version 10.1, ERSI). The soil erosion risk was classified by the erosion rate as: very slight (< 5 tonnes ha\(^{-1}\) yr\(^{-1}\)); slight (5–10 tonnes ha\(^{-1}\) yr\(^{-1}\)); moderate (10–20 tonnes ha\(^{-1}\) yr\(^{-1}\)); severe (20–40 tonnes ha\(^{-1}\) yr\(^{-1}\)); and extremely severe (>40 tonnes ha\(^{-1}\) yr\(^{-1}\)) following Singh et al.’s (1992) classification.

RUSLE model and GIS technique have been widely used for spatial evaluation of soil erosion risk, providing an inexpensive, quick, and simple tool (Kim 2006; Kumar and Kushiwaha 2013; Kim et al. 2014). However, it is not easy to evaluate how well the observations represent the real data. For this study we chose three subwatersheds of the Bukhan River in South Korea to test-run the model. The soil loss yields measured in the field by turbidity of streams were obtained from Ministry of Environment data (Ministry of Environment 2003).

**Effect of agroforestry and reforestation**

In order to estimate the effect of agroforestry and reforestation on soil erosion rate, the soil loss was estimated for the scenarios that the total area of denuded land is turned into agroforestry or forest land. The parameters affected by the land use (i.e. C, P, and the slope length [\(\lambda\)] of LS) were adjusted to represent the characteristics of each land management: (i) agroforestry: each parameter of denuded land was replaced by the average of the parameters from forest plantation and upland field; and (ii) reforestation: the parameters of denuded land were replaced by those forest plantation value. The forest plantation’s C (0.02) and P (0.8) values were assigned based on Kumar and Kushiwaha (2013).

**Results and discussion**

The average annual soil erosion rate over North Korea was estimated to be 15.8 tonnes ha\(^{-1}\) yr\(^{-1}\), which is equivalent to the removal of approximately 1.9 mm per year of topsoil over the entire area. This erosion rate is classified as “moderate” risk level by the classification of Singh et al. (1992). Morgan (1995) has suggested that 10.0 tonnes ha\(^{-1}\) of annual soil loss is the threshold for the sustainable use of agricultural lands. Considering this threshold, North Korea seems to have an unsustainably high soil erosion risk at a national scale.

As shown in Table 3, however, approximately 83% of the total land area was in a low erosion risk category, primarily in the northern part of the country, which means reasonably high sustainability at the country scale. These low risk areas are mostly located in mountainous regions that are far from populated areas, where direct impact of soil degradation might not be significant.

The greatest contribution to the total soil erosion risk was from the small areas of very high soil erosion risk. As shown in Table 3, approximately 9% of the land area was estimated to suffer from severe or extreme erosion risk, which indicates that the affected land is in critical condition. In particular, the areas of high and extreme erosion risks were concentrated in the southern most highly populated part of the country where there is the greatest demand for highly productive soil to supply food and fuel. Therefore, an urgent action plan for sustainable land management seems to be needed in these areas.

**Table 2. Land use classification of North Korea and the associated slope length (\(\lambda\)) and C and P factors.**

| Land use         | Slope length (\(\lambda\), m) (Kim et al. 2014) | C    | P     |
|------------------|-----------------------------------------------|------|-------|
| Paddy rice       | 70                                            | 0.020| 0.500 |
| Upland field     | 50                                            | 0.400| 0.160 |
| Mowing grass     | 15                                            | 0.020| 1.000 |
| Forest           | 10                                            | 0.004| 1.000 |
| Denuded land     | 85                                            | 0.800| 1.000 |
| House/business   | 70                                            | 0.010| 1.000 |

**Table 3. Classification of soil erosion risk using the soil erosion rate in North Korea.**

| Soil erosion rate (tonnes ha\(^{-1}\) yr\(^{-1}\)) | Soil erosion risk | Total area |
|-----------------------------------------------|-------------------|------------|
| < 5                                          | Very slight       | 83%        |
| 5–10                                         | Slight            | 4%         |
| 10–20                                        | Moderate          | 4%         |
| 20–40                                        | Severe            | 3%         |
| < 40                                         | Extremely severe  | 6%         |
| Total                                        |                   | 100%       |

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| Total                                        |                   | 100%       |
A regional evaluation of soil erosion risk is shown in Table 4. Nampo city was noted to be the most susceptible to soil erosion, producing 55.1 tonnes ha\(^{-1}\) yr\(^{-1}\) of average soil erosion rate. It was also classified at the "extremely severe" level with more denuded areas compared with other regions. This observation is possibly due to the rapid development and improper land use practice of commercial and residential areas near to, and inside, forest lands (Piccarreta et al. 2006; Feng et al. 2010). Pyeongyang and Hwanghaebuk-do are also vulnerable to soil erosion mainly due to urbanization and resulting unprotected land cover, and the topography. In contrast, well-conserved areas such as Hamkyeongbuk-do and Hamkyeongnam-do were estimated to have "slight" to "very slight" erosion risk. This reflects the effect of land use on soil erosion rates; in other words C and P factors were the main independent variables, which was also observed by Zhao et al. (2012).

In order to understand soil erosion risk at a regional scale, it is important to determine which land uses or practices mitigate soil erosion. As shown in Figure 3, an absolute majority of the total soil loss can be attributed to the denuded soil along hilly and sloping lands. The average soil erosion rate from denuded lands is 192.1 tonnes ha\(^{-1}\) yr\(^{-1}\), which is extremely high compared to 16.7 tonnes ha\(^{-1}\) yr\(^{-1}\) from upland fields, 1.4 tonnes ha\(^{-1}\) yr\(^{-1}\) from forests, and 0.9 tonnes ha\(^{-1}\) yr\(^{-1}\) from paddy rice fields. As a result, denuded lands, which occupy less than 6.5% of the total land area, constitute approximately 76.2% of the total soil loss (Figure 4). Therefore, an urgent, effective implementation is needed to control soil erosion.

The estimates by RUSLE seem to under- and over-estimate the erosion rate of North Korea. The RUSLE model from three watersheds in South Korea under- and over-estimate within 2%–20% error compared with actual measurement (Figure 5), which was also observed in the studies of Risse et al. (1993), Rapp et al. (2001), Park and Shin (2011), and Soms (2015). The differences in soil loss estimates were due to these reasons. First, this model did not estimate rill and gully erosion induced by extreme rainfall (Soms 2015). Second, the soil and land use maps do not reflect reality and the amount of turbulence caused by human activity (Kinnell 2003). Lastly, the soil erosion comes from two different sources: (i) from the catchment surface; and (ii) from channel banks. Therefore, the actual measurement of soil erosion is

| Denuded land area (% of total region area) | Soil erosion rate (tonnes ha\(^{-1}\) yr\(^{-1}\)) | Soil erosion risk |
|------------------------------------------|-----------------------------------------------|------------------|
| Gaeseong                                  | 10                                           | 17.2             | Moderate       |
| Gangwon-do                                | 6                                            | 22.0             | Severe         |
| Hamkyeongbuk-do                           | 4                                            | 5.0              | Slight         |
| Hamkyeongnam-do                           | 3                                            | 6.5              | Slight         |
| Hwanghaebuk-do                            | 10                                           | 30.5             | Severe         |
| Hwanghaenam-do                            | 17                                           | 24.5             | Severe         |
| Jagang-do                                 | 5                                            | 18.5             | Moderate       |
| Nampo                                     | 23                                           | 55.1             | Extremely severe |
| Pyeonganbuk-do                            | 9                                            | 20.6             | Severe         |
| Pyeongannam-do                            | 8                                            | 17.9             | Moderate       |
| Yanggang-do                               | 14                                           | 30.0             | Severe         |
| Yanggang-do                               | 3                                            | 8.4              | Slight         |

Table 4. Estimated average soil erosion rate and the classification of soil erosion risk on the regional scale in North Korea.

Figure 3. Spatial distribution of estimated annual soil erosion rates in North Korea.
possibly higher than the RUSLE model (Soms 2015). Nevertheless, the RUSLE model with GIS seems to reasonably estimate the erosion rate of North Korea and to identify potential soil erosion risk hotspots referenced in Soms’s study (2015).

The effects of agroforestry and reforestation on soil erosion were most significant in Nampo and Hwanghaebuk-do, which are the nearest areas to Pyeongyang. The average soil erosion rate in Nampo declined from 55.1 tonnes ha$^{-1}$ yr$^{-1}$ to 31.8 tonnes ha$^{-1}$ yr$^{-1}$ by agroforestry and to 21.6 tonnes ha$^{-1}$ yr$^{-1}$ by reforestation (Figure 6). Hwanghaebuk-do was estimated to have 41% lower erosion rate by applying agroforestry and 60% lower rate by reforestation (Figure 6). The dramatic impact of reforestation and agroforestry in these areas might be due to the large proportion of denuded lands near to the populated areas (Table 4; Figure 7). These areas can directly affect the agricultural productivity and water quality of adjacent watersheds.

Figure 6 shows the comparison of soil erosion rates with future projections in-line with reforestation and agroforestry interventions. The annual soil erosion rate can be reduced up to 41% by implementing agroforestry and by over 60% by reforestation of denuded lands. This result agrees with a general expectation that reforestation is more efficient to control soil loss than agroforestry. Nevertheless, the difference generated by the two practices can be negligible in most of the low risk provinces (Figure 6) where the proportion of denuded land is small (Figure 4). Even with the more significant difference for the higher risk provinces (Figure 6), and considering the economic benefits, participatory agroforestry might be a
more practical intervention than reforestation, not only for restoration of degraded lands but also for food supply to local communities in rural areas. Therefore, the application of agroforestry projects seems to be more appropriate to achieve multipurpose benefits in North Korea.

**Conclusions**

Soil erosion is a naturally occurring process on all lands, but it may lead to an excessive loss of topsoil from degraded sloping areas. Uncontrolled deforestation and sloping land cultivation are known to be the major causes of severe soil erosion in North Korea.

The average annual soil loss throughout the country, estimated using GIS-based RUSLE, was approximately 15.8 tonnes ha\(^{-1}\) yr\(^{-1}\), a level considered to be unsustainable. Regionally, Nampo city showed the highest soil loss of approximately 55.1 tonnes ha\(^{-1}\) yr\(^{-1}\), followed by Hwanghaebuk-do of 30.5 tonnes ha\(^{-1}\) yr\(^{-1}\). This vulnerability seems to be mainly due to heavy land development for residential and commercial uses. In the national scale, only 6.5% of total land area has degraded, but erosion from the denuded soil comprises approximately 76.2% of the total soil erosion rate.

The actual measurements of sediment yield from a few adjacent watersheds near to the North Korean border in South Korea showed a good agreement with the model’s estimates of soil erosion risk.

Both agroforestry and reforestation seem to be very effective interventions to control soil erosion on denuded land. Agroforestry was estimated to be almost as effective as reforestation in the low risk provinces, and slightly less effective than reforestation in the high risk provinces. Considering the economic use of the lands, agroforestry seems to be more practical than reforestation, because it allows crop cultivation for food supply with reasonably similar effects on land conservation.

This study was somewhat limited due to the limited availability and topicality of the input data from North Korea. Also, it was impossible to directly validate the estimates from RUSLE with field observations. Nevertheless, the estimates from three watersheds in South Korea showed a good agreement with the measurement of annual soil loss. Therefore, the national map of soil erosion risk generated in this study seems to provide...
reasonable estimations of annual soil loss in North Korea, which is useful for implementing more efficient and effective soil conservation practices to reduce soil erosion in North Korea.

**Disclosure statement**

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