Land use and land cover changes in the Haean Basin of Korea: Impacts on soil erosion

by Jin-Yong Lee1,2, Maimoona Raza1,2*, and Kideok D. Kwon1,2

1 Department of Geology, College of Natural Sciences, Kangwon National University, Chuncheon 24341, Republic of Korea
2 Critical Zone Frontier Research Laboratory, Kangwon National University, Chuncheon 24341, Republic of Korea; *Corresponding author, E-mail: maimoona.raza@yahoo.com

(Received: January 9, 2019; Revised accepted: February 11, 2019)

https://doi.org/10.18814/epiiugs/2019/0190003

This study examined the relationship between the land-use and land-cover changes in the mountainous Haean Basin of the Republic of Korea, a water source area, and the muddy water in the downgradient. The water flowing out from the basin is highly turbid having value of 650.1 Nephelometric Turbidity Unit (NTU), while that from the upper Inbuk Stream lacking major crop fields is very clean (less than 1 NTU), indicating agricultural activities as the origin of the turbid water. Among the six major crops in the cultivated area, rice prevails the maximum area (31.5–51.5%, mean = 38.7%), followed by radish (0.2–32.4%, mean = 20.1%) and potato (9.4–32.2%, mean = 19.4%). The mean annual soil erosion (t ha−1 yr−1) from major crops; radish (55.6), potato (53.0), cabbage (47.9), soybean (40.3), ginseng (23.6), orchard (18.7), and rice (13.5) contributed to water turbidity, differently. Avoiding the cultivation of radish crop can help to reduce overall rate of soil erosion from the basin. Proper maintenance of mitigation measures would result in minimal soil erosion and reduced water turbidity.

Introduction

Soil supports the human life, feeding people in the world by maintaining the growth of a variety of crops (Pimentel, 2006; Schwilch et al., 2016; Nigussie et al., 2017). Soil eco-services, such as biomass production, storage and filtration of water, provision of genetic biodiversity, and carbon storage, have recently attracted more worldwide attention because of the economic development and changing climate (Keesstra et al., 2012; Coyle et al., 2016; Stavi et al., 2016; Zhong et al., 2016). All these benefits are based on healthy and clean soils (Doran and Zeiss, 2000; Dominati et al., 2010). However, the soil has been overused and exploited for various purposes in recent centuries and thus has been degraded (Pimentel et al., 1995; Lal, 2001; García-Ruiz, 2010; Panagos et al., 2016; Belmont and Foufoula-Georgiou, 2017).

Soil erosion is a worldwide environmental problem, causing the reduction of the crop productivity and thus economic profits, deterioration of the downgradient stream and river water qualities and their benthic ecosystems, and the reduction of landscape amenities (Jack et al., 2009; Kettering et al., 2012; Pimentel and Burgess, 2013; Zhao et al., 2013; Jung et al., 2015; Molla and Sisheber, 2017). Soil erosion is a natural phenomenon. The primary triggering agents of soil erosion are water and wind; water erosion generally prevails in arid and semi-arid regions with strong and varying winds (Oldeman, 1992; Blanco-Canqui and Lal, 2010). The amount and intensity of rainfall is the main climatic factor controlling soil erosion by water (Renard et al., 1997; Ni et al., 2008; Ochoa et al., 2016; Saedi et al., 2016; Zhang et al., 2017). Its increasing amount, duration, and intensity greatly increase soil detachment and erosion (Vaezi et al., 2017). Anthropogenic activities such as tillage, especially in agricultural regions, can aggravate the erosion (Oost et al., 2000; Montgomery, 2007; Vanacker et al., 2014; Reusser et al., 2015; Sobral et al., 2015; West et al., 2015; Ochoa et al., 2016). The land slope gradient and length also influence the sediment transport and soil erosion (Zhang and Wang, 2017), in addition to important factors such as the soil texture and organic matter (Keesstra et al., 2016).

Land use and cover (LULC) changes are considered the primary factors dominating soil erosion (Yang et al., 2003; Symeonakis et al., 2007; Alkharabsheh et al., 2013). Because of the developing economy and increasing population, land has been increasingly utilized to meet various demands and agricultural land is being severely exploited worldwide for food and crop production. Therefore, overexploited arable land is degraded; soil erosion aggravates this situation. Furthermore, the changing climate is driving farmers to change their land use and crops (Lambin et al., 2001; Olesen and Bindi, 2002). The changing market price of crops induces the voluntary change in agricultural land use (Searchinger et al., 2008; Lambin and Meyfroidt, 2011). All these natural and human factors complicate the mitigation measures for soil erosion, especially in agricultural areas.

Over twenty-five million people in the Seoul Metropolitan Area, a downgradient area from the Haean Basin, depend on the water supply from this basin’s rivers. This basin in the Republic of Korea (Korea hereafter) is a mountainous area with heavy agriculture in which various crops are cultivated including rice, cabbage, radish, potato, pepper, and ginseng. The objective of this study is to elucidate the origin and causes of the severe muddy (turbid) water in the downgradient.
watershed. The LULC changes and the effects of crop types on soil erosion were examined in detail. We also evaluated the effectiveness of several mitigation measures performed by the Korean government to reduce the soil erosion and muddy water in the basin. This study provides useful insights to reduce turbid water through sustainable agriculture methods.

Materials and Methods

Study Area

The studied watershed (Soyanggang Watershed) is located at the northern boundary of Korea in northeastern Asia, bordering North Korea (Fig. 1a; 37°00’ to 38°32’N, 127°41’ to 128°17’ E), 80 km northeast of Seoul, the capital city of the country. The total area is ~2,700 km$^2$ and its topographic elevation ranges between 180 and 1,708 m (Fig. 1b; Jo et al., 2010; Jung et al., 2015). The average annual precipitation of the past five decades (1961–2010) is 1,092 mm (measured at the Inje Weather Station, Fig. 1b) and over 60% of the total annual precipitation occurs in the wet season, that is, June to August, due to the Asian monsoon (Lee and Lee, 2000). The average annual air temperature of the same period is 9.9°C; it shows a distinctive increase of 0.06°C per decade due to the warming climate (Lee, 2008; Lee and Han, 2013). Approximately 87% of the watershed is covered with forests and 6% and 7% account for agricultural and residential land, respectively (Lee et al., 2013). The mean annual air temperature from 2000–2010 ranged between 8.1°C and 9.3°C, with an increasing rate of 0.016°C per year, and the annual precipitation from 1973–2010 varied between 667 and 1,740 mm, with a mean of 1,168 mm (Lee and Han, 2013). Many dendritically distributed streams flow to converge at Lake Soyang (surface area: 70 km$^2$; storage capacity: 2.9 billion m$^3$). The water drains to the west and enters the Han River in Seoul. The Han River supplies water to twenty-five million citizens of the metropolitan city area. Thus, the water quality of the upper watershed greatly affects the urban water supply system (Lee, 2008; Shin et al., 2016). The Central Korean government has therefore banned a variety of land development activities in the upper watershed to preserve the river quality (Choi et al., 2016).

The watershed and hence the Han River have suffered from high-turbidity water since 1997, especially in the monsoon season (June to August). This is one of the main public and governmental grievances because it causes the dramatic increase of the water treatment costs (sometimes the shutdown of the water supply systems) and deterioration of the river ecosystems (Kim and Jung, 2007; Lee, 2008). The Korean government and researchers have conjectured that the turbid (muddy) water originates from soil (suspended solids) eroded from upgradient highland agricultural areas in the watershed. Three regions were determined to be the hot spots of soil erosion (three grey shaded regions in Fig. 1b; Kim and Kim, 2006; Kim and Jung, 2007; Lee, 2008; Gangwon Province, 2010; Choi et al., 2012; Lee and Han, 2013; Ministry of Environment of Korea, 2014). The three hot spots are heavily cultivated agricultural areas (highland vegetable); the uppermost region is considered to be the area with the greatest soil loss (57.6% of total annual loss) in this watershed (Lee, 2008; Gangwon Province, 2010; Kim et al., 2015). The situation is aggravated by repeated replenish-

![Figure 1. Locations of (a) the Soyanggang Watershed and (b) the Haean Basin (the main interest of this study), three heavy agricultural areas (grey shaded), two water quality monitoring points (IJ and SY), and the weather station. The maps were created using Adobe Illustrator CS4 (Ver. 14.0.0; https://www.adobe.com). [Colour figure can be viewed at wileyonlinelibrary.com].](https://www.wileyonlinelibrary.com)
ment with soil from nearby mountains to compensate for the soil loss due to the erosion of cropland (Park et al., 2010; Arnhold et al., 2014; Ministry of Environment of Korea, 2016).

The uppermost prominent soil erosion area is the Haean Basin (Fig. 2a), which is the focus area for this study. It directly borders with Demilitarized Zone between North Korea and South Korea, and has been a severe battle field between the UN troops (mainly South Korea and US) and North Korea (plus China) from 1950–1953. The basin has also been called “Punch Bowl” by US soldiers due to its elliptical bowl shape and is one of the most popular sites for national security tours (Lee, 2009; Jo and Park, 2010). The total area of the basin is 62 km², with a length of 10.5 km north–south, a width of 6.7 km east–west, and an outer circumference of 32 km (Lee, 2009). The topographic elevation ranges from 340 m at the flat bottom of the basin to 1,304 m in the surrounding mountains. Dendritically distributed small streams flow to the center of the basin and a converged stream (Mandae Stream, Fig. 1b) exits in the east.

The basin was formed by differential weathering of relatively harder metamorphic rocks and weaker granites (Won et al., 1988). The geology of the basin is comprised of Precambrian metamorphic rocks, Jurassic granites, and Quaternary alluvial deposits (Fig. 2b). Metamorphic rocks, including gneiss, schist, and quartzite, are observed at the outer rims and in areas with elevations above 600–700 m in which the topographic gradients are steeper (over 20°; Fig. 2b and c). Jurassic granites widely occur in low-elevation areas and are highly weathered; saprolites can be found in the basin at a thickness of 20–45 m (Fig. 2d). Alluvial deposits are only found near the streams.

The basin is a heavily cultivated area including a variety of crops such as rice, radish, potato, cabbage, pepper, and ginseng. Because of the cool conditions in summer, which are unlike that of other agricultural areas, this basin is famous for cultivating highland cool vegetables at elevations ranging from 450–600 m (Lee, 2009; Lee and Han, 2013). All crops, except for rice, are cultivated in sloping land using a ridge and furrow system with plastic mulches. The mean annual air temperature from 2000–2010 ranged between 8.1°C and 9.3°C, with an increasing rate of 0.016°C per year, and the annual precipitation from 1973–2010 varied between 667 and 1,740 mm, with a mean of 1,168 mm (Lee and Han, 2013). In addition to the forests (50%–60%), almost all land is used for crop production (35%–40%; Yun et al., 2015). Because of these intensive agricultural activities, this basin experiences high rates of soil erosion (Ruidisch et al., 2013; Arnhold et al., 2014; Meusburger et al., 2016). To supply agricultural irrigation water, ~600 groundwater wells have been developed in this basin; the number is continuously increasing. The groundwater levels are generally between 2 and 20 m below the ground surface in flat areas and decrease substantially in the crop-growing season (Choi and Lee, 2010). Therefore, groundwater pumping will soon become another environmental problem in this basin (Lee and Han, 2013; Kim et al., 2015).

Data Collection

We collected various data including the turbidity and related water quality, precipitation, land use, crop type, and crop production. The turbidity data (only maximum values) for the water at the outlet of the Soyanggang Dam (SY in Fig. 1b) from 1991–1999 were taken from Kim and Jung (2007), those (daily data) for 2000–2008 were obtained from Kim and Jung (2007), those (daily data) for 2000–2008 were obtained.

Figure 2. (a) Elevation map of the Haean Basin (the main interest of this study), (b) Geologic cross section A–A’, (c) Biotite gneiss found at outer rims of the basin, and (d) highly weathered granite (saprolite) at the center of the basin. The maps were created using Adobe Illustrator CS4 (Ver. 14.0.0; https://www.adobe.com). [Colour figure can be viewed at wileyonlinelibrary.com].
from Lee (2008), those for 2009–2011 were taken from Choi et al. (2012), and the remaining data (incomplete data, 2012–2013) were obtained from the Water Resources Management Information System (WAMIS: http://www.wamis.go.kr) of the Ministry of Land, Infrastructure and Transport (MOLIT) of Korea. Based on Choi et al. (2012), the turbidity values are highly indicative ($r = 0.79$–0.95) of suspended solids in the water of this watershed. The stream water quality, including the turbidity, temperature, electrical conductivity (EC), dissolved oxygen (DO), total organic carbon (TOC), total nitrogen (T-N), and total phosphorus (T-P), was measured at one more location, approximately 30 km downgradient from the basin (IJ in Figure 1b). In addition, we used data for the period 2012–2016 collected by the Ministry of Environment (ME) of Korea (http://www.koreawqi.go.kr). However, some data are missing due to malfunctions of measurement devices, especially for the period of 2013–2014.

The precipitation data were collected at two locations: near the center of the watershed (Inje Weather Station, Fig. 1b) and in the center of the basin (Haean automatic weather station). The two stations are operated by the Korea Meteorological Administration (KMA). Measured atmospheric data can be obtained from the KMA website (http://www.kma.go.kr/weather/). The land cover data for 1989, 1999, and 2009 (only available every ten years) were obtained from the Environmental Geographic Information Service (EGIS) of the ME (https://egis.me.go.kr/main.do). Earlier data are not available due to military security problems. The data for each land use type (e.g., forest, residential, rice paddy, and upland fields), cultivation area for each crop (e.g., rice, radish, potato, and cabbage), and the annual production in the basin for 1990–2014 were obtained from the Yanggugun Statistical Yearbook (http://www.yanggu.go.kr/ebook/). However, data for 1996–1997 are missing.

Field Survey

In addition to the data collection from many reliable sources (official government websites and peer-reviewed literature), we have conducted multiple field surveys (at least two times per year) since 2007 to investigate and confirm the LULC changes and to examine the occurrence of the turbid water in the basin (Lee, 2008, 2009). The detailed field campaigns using fourteen research members equipped with portable GPS devices (Model GPS 72H, Garmin, USA), a topographic map (scale 1:5000), and a clinocompass (Model CM-B, NaRIKa Corp., Japan) were conducted from 2016–2017 (April and October of each year, seven days per campaign) to confirm the land use and crop changes. The turbidity values were measured at necessary points using a portable turbidimeter (Orion AQUAfast AQ4500, Thermo Electron Corporation).

To collected the particle size distribution of soil from each crop field, we collected 14 topsoil (0–10 cm) samples (two samples from each crop field located at elevations ranging from 400–600 m) from the basin in May 2017. The soil samples were oven-dried at 40°C and the grain sizes were determined by mechanical sieves (<2 mm); those of finer materials were determined by a laser particle size analyzer (Model Mastersizer 2000, Malvern Ins., UK) at the Central Laboratory of Kangwon National University in Chuncheon, Korea. The bulk density of 28 topsoil samples (four from each crop field; two in April and two in May before and after the tillage, respectively) was also determined. In addition to collecting soil loss rate data for this basin from the literature, we monitored the soil loss of fourteen experimental, open plots with areas ranging from 200–450 m² (two for each crop; similar slopes and elevations: 450–500 m) for two years (April 2015–April 2017). Each plot was hydraulically divided by constructed trenches and the runoff and sediments were measured by a water channel and a large steel bucket.

Results

Occurrence and Progress of Turbid Water

Fig. 3a shows the turbidity values measured at the outlet (effluent) of the Soyanggang Watershed (Soyanggang Dam: SY in Fig. 1a) from 1991–2013. The turbidities were relatively low until 2005, although several peak values exceeded the permissible limit (30 NTU) of the dam effluent set by the Korean government (Ministry of Environment of Korea, 2014). In general, a relatively high turbidity occurs in this watershed during the monsoon season (July–September) when the rainfall is concentrated over a short timespan (Lee and Lee, 2000; Kim et al., 2016). However, the situation started to change in 1997 with peaks going above the permissible limit and showed an exceptional sharp increase of water turbidity in 2006 (Fig. 3a). After heavy rainfall events (176.5 mm on July 12, 202 mm on July 15, and 130.5 mm on July 16), the water turbidity rapidly increased and reached peak values (311 NTU on July 27 and 328 NTU on August 7). High levels of turbidity exceeding the permissible value are representing the most severe turbidity recorded to date. The severe turbidity in 2006 seems abnormal because similar rainfall phenomena have repeatedly occurred before and after this year, but similar levels of turbidity have not been observed.

In the monsoon season (July–September) of 2007, the turbidity increased to 93.4 NTU (August 18) and these high values (~30 NTU) were sustained for 44 days (August 12 to September 24). The reduced turbidity peak in comparison to previous year 2006 is mainly due to smaller rainfall in the monsoon season of the year (821 mm for the season in 2007) and the reduced intensity (peak daily rainfall of 103 mm on August 9) compared with those of the previous year (1,029 mm for the monsoon season in 2006). The reduced turbidity might also result from several mitigation measures, including vegetative buffers, and water retention reservoirs, which were implemented in this area by local and central governments (~40 million USD from 2007–2015; Ministry of Environment of Korea, 2014, 2015). After 2007, the turbidity levels gradually decreased (peak values: 52 NTU in 2008, 50 NTU in 2009, 18 NTU in 2010, 18 NTU in 2011, and 5 NTU in 2012), although the monsoon rainfall and its intensity did not decrease (see Fig. 3a).

However, the decreasing turbidity values were reversed in year 2013. The turbidity values increased up to 100 NTU and these high values were sustained for 104 days, although the rainfall amount and intensity in the monsoon season were not higher than that of the previous years (2008–2011, except for 2012). The situation did not improve much in 2014–2016 (peak values: 75 NTU in 2014, 95 NTU in 2015, and 104 NTU in 2016; Ministry of Environment of Korea, 2016). Some studies questioned the effectiveness of the mitigation facilities, attributing the elevated turbidities to the improper maintenance of mitigation facilities such as vegetative buffers and water retention res-
The wet season scene (June 2007) observed at the merging point (location P1 in Fig. 1b) of the Mandae and Inbuk streams reveals an interesting phenomenon (Fig. 3b). The water flowing out from the Haean Basin was highly turbid (650.1 NTU), while that from the upper Inbuk Stream lacking major crop fields was clear (less than 1 NTU). This turbidity difference indicates that the turbid water mainly originates from agricultural activities and influenced by increased precipitation rates during monsoon season (Lee, 2008). The highly turbid water persisted down to the lower Inbuk Stream (location P2 in Fig. 1b; see Fig. 3c) and finally reached Lake Soyang, where severe problems arise with respect to the water treatment and water supply systems downstream (Kim et al., 2016; Choi et al., 2016).

Fig. 4 shows that the turbid water is still occurring despite installation of mitigation measures in the basin for 2012–2016. The turbidity ranges between 0.0 and 559.9 NTU, with a mean of 9.7 NTU; high turbidities over 30 NTU were concentrated in the monsoon season (Fig. 4a). The water temperature showed periodic seasonal variations (Fig. 4b) depending on the air temperature; it was high in summer (up to 28.6°C) and low in winter (down to 0.0°C). The stream water pH were varying the least (range = 6.4–8.0, mean = 7.1, coefficient of variation = 0.04) and showed no substantial correlations with other parameters (Fig. 4c). The ECs of the stream water ranged between 38 and 136 µS/cm (mean = 81 µS/cm). This EC values are lower than the upper basin stream water (Kim and Lee, 2016), which is due to mixing with clean water from other nonagricultural areas (Jo et al., 2010).

The DO of the stream water was highly variable (CV = 1.81) ranging between 7.3 and 14.5 mg/L (mean = 10.9 mg/L) with a strong negative correlation with the water temperature (r = -0.905, p < 0.0001). The DO was at a seasonal low in summer, while it was at a seasonal high in winter because the oxygen solubility decreased with the increasing water temperature (Lee et al., 2015; Dick et al., 2016). Based only on the dissolved oxygen, the stream water was under very good conditions, irrespective of the turbidities. The TOC ranged between 0.4 and 5.4 mg/L (mean = 1.1 mg/L) and showed an intermediate positive correlation with the turbidity (r = 0.48, p < 0.001). A substantial portion of the TOC in the water originated from eroded soil containing particulate organic carbon (Jeong et al., 2012; Jung et al., 2014).

Fig. 4g and h show the nutrient (N and P) concentrations of the stream water. The T-N ranged between 0.675 and 5.691 mg/L (mean = 1.936 mg/L), showing moderate correlations with the water temperature (r = 0.57, p < 0.001) and dissolved oxygen (r = -0.54, p < 0.001). This is indicative of a high N flux in the water during the summer monsoon season (Kettering et al., 2012) when turbid water prevailed. The P behavior was similar to that of N, although the concentration was not very high (range = 0.006–0.153 mg/L, mean = 0.022 mg/L).
To examine soil erosion and the turbid water in the watershed, we examined the LULC changes in the basin. Fig. 5 shows the LULC of the basin in 1989, 1999, and 2009. After cessation of the Korean war (not a civil war) in 1953, the basin was restricted to a military security area until 1972. In 1989, a major portion of the basin was covered by forest (~65%) and much of the basin area was used for agriculture (~18%). The agricultural land (paddy and upland fields) was mostly distributed at elevations below 500 m. Ten years later (in 1999), the land was increasingly developed with respect to agricultural fields (35.9%), residential and building sites (2.1%), and roads (1.5%; see the central map in Fig. 5). The expansion of the cropland was distinct during this period (Kim et al., 2014). Nearly all lowland (below an elevation of 500 m) was occupied by agricultural fields, which were expanded to intermediate (650 m) and even high-elevation lands (>800 m). During the next decade (2000–2009), however, a large change was not observed in the land cover (change rate of crop fields, forest, and residential = +0.5%, -1.2%, and -6.5%, respectively). Fig. 6 shows the detailed land use changes in the basin from 1990–2014 based on the yearbook of the county. Forests occupied the dominant portion (57.9%–75.1%) of the area (unidentified area for 1990–1992 can be considered to be forest based on the satel-

Figure 5. Land cover maps of the study area in 1989, 1999 and 2009. The maps were obtained from the Ministry of Environment (https://egis.me.go.kr/main.do). [Colour figure can be viewed at wileyonlinelibrary.com].

Figure 4. Stream water qualities measured at downstream (IJ in Figure 1b) of the Haean Basin for 2012–2016. Some data are missing due to malfunction of the measurement devices especially in 2013–2014. The data were obtained from the Ministry of Environment of Korea (http://www.koreawqi.go.kr).
lite land cover map in Fig. 5) but decreased with the expansion of croplands until 1995. In recent years, the forest has been slightly reduced (from 3,634.3 ha in 1998 to 3,580 ha in 2014; Fig. 6a). Coniferous forest composed of red pine, nut pine, and white birch trees accounts for ~26%, deciduous forest (oak, royal azalea, and dwarf small-leaf birch trees) account for 29%, and the remainder is mixed forest (Lee et al., 2015). The paddy field area did not significantly change during that period, but a slight decrease has been recorded recently due to the expansion of roads and buildings.

Fig. 6b shows the detailed change in the cultivation area according to the crop types (six major crops in the basin). Among the six crops, rice prevails (31.5%–51.5%, mean = 38.7%), followed by radish (0.2%–32.4%, mean = 20.1%) and potato (9.4%–32.2%, mean = 19.4%). The cultivation area of the six crops gradually increased until 1998; however, it has declined since 2003, coincident with the expansion of the ginseng field and orchard (Fig. 6c). Thus, we can infer that major parts of the six crop fields were largely converted for those usages (Tenhunen et al., 2011). The rapid increase in orchard and ginseng fields is attributed to the higher economical profits and increased air temperature of Korea due to climate change. The change in the land use (crop type) has been promoted by governmental subsidies. Interestingly, the total area of the six crops fields was the largest during 2003–2007, with highly enlarged soybean and radish fields.

Figure 6. Changes in (a) land use in the study area (Haean basin), (b) and (c) cultivation area by crops for 1990–2014. The data were obtained from Yanggugun Statistical Year-Book (http://www.yanggu.go.kr/ebook/www/index.php) but missing for 1996–1997.
Mitigation Measures of Soil Erosion and Turbid Water

Local and central governments have made various efforts to reduce the soil erosion and resulting turbid water in the basin (Fig. 7). They have purchased private cropland, especially highlands with a topographic slope above 30° since 2007 and have planted trees e.g., pine trees instead of crops cultivation (Fig. 7a). Cultivated croplands at higher elevations were banned for further cultivation, which faced significant resistance from landowners.

Changes of crop types can reduce the soil erosion. The cropland used for the cultivation of radish, potato, and cabbage is the main source for soil erosion in the basin (Jeon and Kang, 2010). Orchard can reduce the soil erosion and thus turbid water (see Fig. 6b and c). Some farmers voluntarily converted their crops fields (sometimes paddy fields) into orchards or ginseng fields using governmental subsidies (Fig. 7b).

Other engineering measures, including vegetative buffers, water retention reservoirs, mesh gabion walls, ditch construction, and road pavement have also been adopted (Ministry of Environment of Korea, 2015). When applicable, vegetation buffers with a strip width of 2–2.5 m were applied, especially in high upland fields (Fig. 7c). However, these buffers exhibited long-term maintenance and management issues. A total of 27 small retention reservoirs were constructed in the basin along the streams to retain high-turbidity water and settle down transported sediments (Fig. 7d). However, some of the reservoirs have not been working properly because of thick sediments that accumulated over the years. Mesh gabion walls were also constructed to reduce the soil erosion of cropland wall during rainfall (Fig. 7e). Pavement of dirt roads has
been undergoing; >50% of the dirt roads are now paved (Fig. 7f).

Discussion

Impacts of the Land Use on Soil Erosion

In the past few years, an increase of water turbidity was observed in the basin, even after the implementation of mitigation measures to reduce the soil erosion and water turbidity. Various land use, soil characteristics, and slope of the cultivated area are the main factors related to the soil erodibility (Descroix et al., 2001; Asadi et al., 2012; Panagos et al., 2014; Sun et al., 2014; Li et al., 2015). Table 1 shows the slope angle increasing from 5.5° to 18.6° with increasing topographic elevation from 473 to 528 m in the Haean Basin. Among the main crops in the basin, field surveyed in 2015–2017 (mean ± standard deviation). The soil erosion and water turbidity. Various land use, soil characteristics, and slope of the cultivated area are the main factors related to the soil erosion and water turbidity. Various land use, soil characteristics, and slope of the cultivated area are the main factors related to the soil erodibility (Descroix et al., 2001; Asadi et al., 2012; Panagos et al., 2014; Sun et al., 2014; Li et al., 2015). Table 1 shows the slope angle increasing from 5.5° to 18.6° with increasing topographic elevation from 473 to 528 m in the Haean Basin. Among the main crops in the field, rice paddy, soybean, and cabbage are observed at a relatively lower elevation and less steep slope, while potato, radish, ginseng, and orchards are found at a relatively higher elevation and steep slope. Sun et al. (2014) reported a similar impact of the increase in the soil erosion with the increasing slope for the same land use. Soil erosion is also related to the characteristics of the soil and type of cultivated crop.

Soil erosion strongly depends on the land use and characteristics of the cultivated soil. Table 2 shows that the soil under rice paddy fields in the Haean Basin has the highest bulk density (1.14 g m⁻³) with a clay content above 10%, while potato fields have the lowest bulk density (0.82 g m⁻³) with a clay content <10%. Studies showed that soils with lower clay and silt contents and bulk density experience more soil erosion (Silvestri et al., 2017; Ouyang et al., 2018). One of the main factors controlling the soil erosion is related to the land use (Sharma et al., 2011). Crop fields that provide more than 50% of the ground cover are less prone to soil loss than crops with less ground cover (Lieskovsky and Kenderessy, 2014). The response of the soil erosion to different land uses is important when considering vegetation structure adjustment, development of sustainable agriculture, and the reduction of erosion-related water turbidity (Fu et al., 2011; Sun et al., 2014).

Table 3 indicates a lower mean annual soil loss (t ha⁻¹ yr⁻¹) from rice paddy (1.3), orchard (18.7), ginseng (23.6), and soybean fields (40.3) and a high soil loss from cabbage (47.9), potato (53.0), and radish (55.6) fields in the studied area. Vegetation cover is the key factor to estimate the rate of soil erosion (Nunes et al., 2011). The paddy rice fields located at a lower elevation with a high bulk density and high clay and silt contents exhibit a small amount of soil erosion and less water turbidity. Radish and potato fields at a high elevation with low bulk densities and low clay and silt contents exhibit more soil loss and a higher water turbidity. Ginseng, radish, and potato are similar with respect to the high elevation and being seeds. Ginseng has more fibrous roots that can maintain a high bulk density which can help to reduce soil erosion (Gyssels et al., 2005). A common practice of polyvinyl or straw mulching of ginseng fields in order to maintain the soil moisture, represent the main factor that reduces the soil loss from ginseng

Table 1. Elevation and slope characteristics of crop fields in the Haean basin, field surveyed in 2015–2017 (mean ± standard deviation). The elevation is for the center of each crop field and the slope angle was measured using a clinometer and confirmed using the data from the Institute of Agricultural Sciences (http://soil.rda.go.kr)

| Field type | No. of data | Elevation (m) | Slope angle (°) |
|------------|-------------|---------------|-----------------|
| Rice paddy | 17          | 473(±44)      | 5.5(±1.9)       |
| Soybean    | 17          | 474(±48)      | 6.5(±2.2)       |
| Potato     | 14          | 506(±30)      | 12.1(±3.1)      |
| Radish     | 20          | 528(±57)      | 18.6(±3.6)      |
| Cabbage    | 19          | 475(±56)      | 7.3(±3.1)       |
| Ginseng    | 19          | 513(±69)      | 8.9(±4.6)       |
| Orchard    | 13          | 504(±41)      | 7.1(±4.5)       |

Table 2. Physical characteristics of the top soils obtained from the Haean basin (mean ± standard deviation)

| Field type | No. of data | Elevation (m) | Sand (%) | Silt (%) | Clay (%) | Bulk density (g cm⁻³) | Reference |
|------------|-------------|---------------|----------|----------|----------|-----------------------|-----------|
| Rice paddies | 4–7        | n.a (a)      | 51.4(±6.5) | 38.9(±4.4) | 10.6(±2.1) | 1.14(±0.02) | Kettering et al. (2012) |
| Upland fields | 2          | 429(±5)      | 21.9(±2.5) | 55.7(±6.2) | 22.4(±8.6) | 1.06(±0.11);1.49(±0.14) (b) | This study |
| Soybean    | 5           | 502(±78)     | 69.2(±18.2) | 23.2(±12.4) | 7.6(±5.9) | n.a                  | Arnhold et al. (2014) |
| Potato     | 2           | 458(±12)     | 19.6(±2.2) | 52.5(±2.3) | 27.9(±4.5) | 0.91(±0.05);1.62(±0.08) (b) | This study |
| Radish     | 6           | 501(±59)     | 77.5(±6.1) | 18.2(±4.2) | 4.3(±1.9) | n.a                  | Arnhold et al. (2014) |
| Cabbage    | 2           | 500(±22)     | 69.1(±8.5) | 28.2(±6.2) | 2.7(±2.4) | 0.82(±0.03);1.61(±0.03) (b) | This study |
| Ginseng    | 9           | 527(±75)     | 76.4(±4.9) | 18.9(±3.6) | 4.7(±1.5) | n.a                  | Arnhold et al. (2014) |
| Pepper     | 2           | 475(±32)     | 39.2(±2.2) | 47.9(±2.8) | 12.9(±4.9) | 1.06(±0.02);1.43(±0.20) (b) | This study |

(a) n.a.: not available.  
(b) before tillage in April.
fields due to covered surface. Prosdocimi et al. (2016) observed a valuable reduction in the soil loss and runoff from fields with slight straw mulching compared with fields without mulching. The rate of soil erosion significantly varies depending on the different type of land use and results in the turbidity of water. Appropriate agricultural strategies including the conversion of fields to environment-friendly cultivation are necessary to reduce the soil loss.

Precipitation Trend and Impact on the Water Turbidity

The soil erosion rate and water turbidity is related to the precipitation along with land use and topography (Ochoa et al., 2015). The annual mean precipitation in the Haean Basin from 1991 to 2016 was 1,212 mm/yr (Fig. 8a). The annual precipitation is highly influenced by the rate of the annual monsoon rainfall. From 1991 to 2016, a huge variation in the annual and monsoon rainfall was observed, with sharp peaks in observed in years 1995, 2001, 2006, and 2011. The monsoon period in the studied area was recorded to last from June to August. The decreasing number of days with >0 mm/day precipitation, increasing for >10, 20, and 50 mm/day after 2014, indicates an overall increase in the annual precipitation (Fig. 8b). Such an increase in the precipitation can influence the rate of the annual soil erosion.

Water turbidity strongly depends on the precipitation rate, which results in erosion runoff (Huang et al., 2014; Li et al., 2015; Hashim et al., 2018) and disparities in the runoff and soil loss (Ziadat and Taimeh, 2013). Fig. 9 shows the daily precipitation (in mm) and water turbidity (in NTU) from January 2016 to January 2017 for different crop types in the studied area. The growing season of the major five crops coincides with the monsoon period or is longer than the monsoon period with heavy rainfall. The water turbidity crosses the guideline value of 30 NTU, specifically during the period of monsoon rainfall due to heavy runoff. In contrast to this study, a study of a plain area in India revealed an increase in the soil erosion with the decline of the monsoon rainfall (Giosan et al., 2017). The elevation and mountain slope in the Haean Basin increases the soil erosion and runoff during the monsoon season.

The change in the land use will respond differently to the soil erosion due to monsoon rainfall (Santos et al., 2017; Zare et al., 2017). Radish, potato, and cabbage crop fields are more vulnerable to soil runoff during the heavy rainfall period than the rice paddy and ginseng.

Table 3. Annual soil erosion (loss) rates (t ha⁻¹ yr⁻¹) estimated for selected major crops with growing characteristics in the Haean basin. The loss rates data are from Arnhold et al. (2014) otherwise are not noted

| Crop | Min. | Mean | Max. | Growing period | Planting |
|------|------|------|------|----------------|----------|
| Soybean | 0.4 | 32.8 | 99.6 | End May–end Oct | Seedling |
| | 35.5<sup>a</sup> | | | | |
| | 0.4<sup>b</sup> | 40.3<sup>c</sup> | 101.3<sup>d</sup> | | |
| Potato | 0.4 | 30.6 | 93.0 | End Apr–end Aug | Seed |
| | 53<sup>e</sup> | | | | |
| Radish | 0.7 | 54.8 | 166.4 | Beg Jun–end Aug | Seed |
| | 52.4<sup>f</sup> | | | | |
| Cabbage | 0.4 | 34.7 | 105.4 | Mid May-end July | Seedling |
| | 47.9<sup>g</sup> | | | | |
| Rice | 0.0<sup>h</sup> | 1.3<sup>i</sup> | 4.3<sup>j</sup> | Mid May–Mid Oct | Seedling |
| Ginseng | 0.6<sup>k</sup> | 23.6<sup<l</sup> | 45.4<sup>m</sup> | Beg May–end Oct | Seed (multi-year growing) |
| Orchard | 0.3<sup>n</sup> | 18.7<sup>o</sup> | 35.3<sup>p</sup> | End Apr–end Oct | Seedling (multi-year growing) |

<sup>a</sup>Data are from Maharjan et al. (2016).
<sup>b</sup>Data are from Choi et al. (2005) for the same province but not the same basin.
<sup>c</sup>Data are from Kim et al. (2011) and units are in t ha⁻¹ day⁻¹.
<sup>d</sup>Data are from Lim (2007) for the same province but not the same basin.
<sup>e</sup>This study.
seng fields in the basin. Sustainable agriculture method is required considering the elevation, slope steepness, soil type, roots of the crop, and straw mulching practice in order to uphold the water quality and to avoid soil erosion in the Haean Basin and mixing with the Inbuk stream.

**Management Practice to Reduce the Soil Erosion and Water Turbidity**

Land use changes and increased rainfall are the sources of soil loss, causing the water turbidity in the Inbuk downstream in Lake Soyang. Conventional agriculture systems lead to environmental degradation, social conflict, and economic problems. A modified and sustainable agriculture system can reduce the soil loss in upstream agricultural areas and prevent its runoff as turbid stream water. Despite executing various engineering-based efforts to control the soil loss, the adoption of those sustainable practices is not prevalent at the farmer’s level. Government support programs often fail to stimulate the farmer’s adoption due to low funds, inappropriate strategies, and ineffective incentives. Based on a downstream consumer survey, residents in the metropolitan area are willing to pay for water quality improvement based on the adoption of sustainable agriculture practices (Lee et al.,

---

*Figure 8. Precipitation in the Soyanggang watershed for 1991–2016: (a) annual precipitation and proportion of the monsoonal (Jun–Aug) rainfall, (b) number of days of precipitation over 0, 10, 20, 50 mm/day, and (c) skewness, kurtosis, and CV of the daily precipitation. The precipitation data were from Korea Meteorological Administration (//www.kma.go.kr).*
The benefits of the water quality improvement of Lake Soyang resulting from sustainable agriculture practices are comparable with the conversion expenses which upstream farmers would pay for (Lee et al., 2016). The adoption of sustainable agriculture practices is only possible with continuous effort that convince farmers about the water quality and the property right.

Engineering-based practices to control the soil erosion in upstream areas are common, but the results with respect to the water quality have not been evident in the past few years. Erosion control practices in the Haean Basin include vegetative buffers, conversion to orchards at high ele-

Figure 9. Monsoon period (June to August) of Korea and precipitation and turbidity in 2016 with growing seasons of five main crops in the basin and their photos at different times.
vation, artificial water ways, mesh gobin walls, and ditches to store sediments from runoff. These are the best management practices to control the soil erosion and are adopted worldwide (Fernholz et al., 2018). The regular maintenance and monitoring of the implemented practices is required for their proper functioning and good water quality in the stream. Changes in the conventional land use of upstream areas might help to reduce soil erosion. The conversion of all fields at 528 m elevation to orchards and ginseng fields at slopes ranging from 15° to 20° may reduce the soil loss due to other land uses. Both orchards and ginseng showed the minimum soil losses at a high slope in this study. The use of polyvinyl or straw mulching has proven to be effective in reducing the soil erosion (Prosdocimi et al., 2016; Cerda et al., 2017). The use of polyvinyl and straw mulching in ginseng fields of the Haean Basin to maintain the moisture content of the soil and suppress undesirable weeds has reduced the soil erosion from the fields. Such a practice is also effective for the reduction of the soil erosion related to other crops. The cultivation of highest erosion causing crop (radish) should be avoided to reduce turbid stream water. Along with the application of sustainable approaches to reduce the soil erosion and water turbidity in upstream areas, the Soyang Lake water treatment is necessary before provision to the metropolitan area to follow guidelines associated with all water quality parameters.

Conclusions

Our study of the Haean Basin suggests that a change in the land use of the upstream area be effective to reduce the soil loss at high elevation. Orchards and ginseng (with mulching) at high elevations can reduce the soil erosion, while the cultivation of radish that has shown maximum contribution to soil erosion among the major crops in the Haean Basin. The government measures to reduce the soil erosion appear effective but proper maintenance and farmer’s voluntary participation will maximize the efficiency and longevity of these benefits. For water supply to Seoul Metropolitan, appropriate water treatment facility is necessary to maintain acceptable values of all water quality parameters, in addition to the water turbidity.

Acknowledgements

This work was supported by the National Research Foundation of Korea (NRF) grant, funded by the Korean government (MSIT) (No. NRF-2015R1A4A1041105), Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2018R1D1A1B07047200), and 2018 Research Grant from Kangwon National University. The authors thank Woo-Hyun Jeon, Gyeong Seon Shin, Sang Woong Yun, Jeong Jik Kim, Han-Seon Ryu, Ho Geon Lee for their field assistance.

References

Alkharabsheh, M.M., Alexandridis, T.K., Bilas, G., Misopolinos, N. and Silleos, N., 2013, Impact of land cover change on soil erosion hazard in northern Jordan using remote sensing and GIS. Procedia Environmental Sciences, v. 19, pp. 912–921, doi:10.1016/j.proenv.2013.06.101.

Arnhold, S., Lindner, S., Lee, B., Martin, E., Kettering, J., Nguyen, T.T., Koellner, T., Ok, Y.S., and Huwe, B., 2014, Conventional and organic farming: Soil erosion and conservation potential for row crop cultivation. Geoderma, v. 219, pp. 89–105, doi:10.1016/j.geoderma.2013.12.023.

Asadi, H., Raeisvandi, A., Rabiei, B., and Ghafrir, H., 2012, Effect of land use and topography on soil properties and agronomic productivity on calcareous soils of a semiarid region, Iran. Land Degradation and Development, v. 23, pp. 496–504, doi: 10.1002/ldr.1081.

Belmont, P., and Foufoula-Georgiou, E., 2017, Solving water quality problems in agricultural landscapes: New approaches for these nonlinear, multiprocess, multiscale systems. Water Resources Research, v. 53, pp. 2585–2590, doi: 10.1002/2017WR020839.

Blanco-Canqui, H., and Lal, R., 2010, Principles of Soil Conservation (1st edition). Springer, Netherlands, 617 p., doi:10.1007/978-1-4020-8709-7.

Cerda, A., Garcia-Diaz, A., Comino, J.R., Pereira, P., Novara, A., Jordan, A., and Brevik, E., 2017, The use of straw in vineyards and orchards to reduce the soil and water losses in Eastern Spain. 19th EGU General Assembly, EGU2017, proceedings from the conference held 23–28 April, 2017 in Vienna, Austria. Abstract no. 2017EGUGA199C, p. 9.

 Choi, H.M., Lee, and J.Y., 2010, Groundwater level distribution and rainfall response characteristics in Haean Basin of Yangu. Journal of Soil and Groundwater Environment, v. 15, pp. 1–8 (in Korean with English abstract).

Choi, I.C., Kim, H.N., Shin, H.J., Tenhunen, J., and Nguyen, T.T., 2016, Willingness to pay for a highland agricultural restriction policy to improve water quality in South Korea: Correcting anomalous preference in contingent valuation method. Water, v. 8, pp. 547, doi:10.3390/w8110547.

Choi, J., Choi, Y.H., Lim, K.J., and Shin, Y.C., 2005, Soil erosion measurement and control techniques. Food and Fertilizer Technology Center. Retrieved from http://www.fftc.agnet.org/htmlarea_file/library/20110808174828/eb568.pdf.

Choi, J.W., Kang, M.J., Kim, D.I., Moon, S.I., Shin, D.S., Kim, H.T., Park, B.K., Park, C.H., Lee, J.K., Ryu, D.H., Kim, B.C., and Shin, M.S., 2012, Assessing the Action Plans in the Control Area of Non-point Source Pollution (2): Soyang Lake. National Institute of Environmental Research: Seoul, Korea (in Korean).

Coyle, C., Creame, R.E., Schulte, R.P., O’Sullivan, L., and Jordan, P., 2016, A functional land management conceptual framework under soil drainage and land use scenarios. Environmental Science and Policy Journal, v. 56, pp. 39–48, doi:10.1016/j.envsci.2015.10.012.

Descroix, L., Viramontes, D., Vuclinic, M., Barrios, J.G., and Esteves, M., 2001, Influence of soil surface features and vegetation on runoff and erosion in the Western Sierra Madre (Durango, Northwest Mexico). Catena, v. 43, pp. 115–135, doi:10.1016/S0009-2541(00)00134-7.

Dick, J.J., Soulsby, C., Birkele, C., Malcolm, I., and Tetralaff, D., 2016, Continuous dissolved oxygen measurements and modelling metabolism in peatland streams. PLoS one, v. 11, e0161363, doi: 10.1371/journal.pone.0161363.

Dominati, E., Patterson, M., and Mackay, A., 2010, A framework for classifying and quantifying the natural capital and ecosystem services of soils. Ecological Economics, v. 69, pp. 1858–1868, doi:10.1016/j.ecolecon.2010.05.002.

Doran, J.W., and Zeiss, M.R., 2000, Soil health and sustainability: managing the biotic component of soil quality. Applied Soil Ecology, v. 15, pp. 3–11, doi:10.1016/S0929-1393(00)00067-6.

Fernholz, K., Feeney, W., Groot, H., Pepeke, E., Henderson, C., and Erickson, G., 2018, Water quality best management practices in US Midwestern agricultural landscapes: what can be learned from the experience of the forest sector. http://www.dovetailline.org/report_pdf/2018/dovetaillnps0418.pdf.

Fu, B., Liu, Y., Lu, Y., He, C., Zeng, Y., and Wu, B., 2011, Assessing the soil erosion control service of ecosystems change in the Loess Plateau of China. Ecological Complexity, v. 8, pp. 284–293, doi:10.1016/j.ecocom.2011.07.003.

Gangwon Province., 2010, Management Plan of Non-Point Source in Soy-
ang Lake Watershed. Gangwon Province: Chuncheon, Korea (in Korean).

García-Ruiz, J.M., 2010, The effects of land uses on soil erosion in Spain: a review. Catena, v. 81, pp. 1–11, doi: 10.1016/j.catena.2010.01.001.

Giovan, L., Ponton, C., Usman, M., Bluezat, J., Fuller, D.G., Galy, V., Nogar, H., Joel, J.E., Cameron, M., Lukas, W., and Eglinton, T.J., 2017. Massive erosion in monsoon central India linked to late Holocene land cover degradation. Earth Surface Dynamics, v. 5, pp. 781–789, doi: 10.3929/ethz-b-00021370.

Gyselis, G., Poesen, J., Bochet, E., and Li, Y., 2005. Impact of plant roots on the resistance of soils to erosion by water: a review. Progress in Geophysical Geography, v. 29, pp. 189–217, doi: 10.1191/0309133305pp443a.

Hashim, S.I.N.S., Talib, S.H.A., Abustan, M.S., and Tajuddin, S.A.M., 2018. Water quality and trophic status study in Sembrong reservoir during Monsoon Season. IOP Conference Series: Earth and Environmental Science, v. 146, conference No. 1, 012079p.

Huang, T., Li, X., Rijnaarts, H., Grotenshuis, T., Ma, W., Sun, X., and Xu, J., 2014. Effects of storm runoff on the thermal regime and water quality of a deep, stratified reservoir in a temperate monsoon zone, in northwest China. Science of the Total Environment, v. 485, pp. 820–827, doi: 10.1016/j.scitotenv.2014.01.008.

Jack, B.K., Leimona, B., and Ferraro, P.J., 2009, A revealed preference approach to estimating supply curves for ecosystem services: Use of auctions to set payments for soil erosion control in Indonesia. Conservation Biology, v. 23, pp. 359–367, doi: 10.1111/j.1523-1739.2008.01086.x.

Jeon, M.S., and Kang, J.W., 2010, Muddy water management and agricultural development measures in the watershed of Soyang Dam: Focused on Haean-myeon, Yanggu-gun. Research Institute for Gangwon: Chuncheon, Korea (in Korean).

Jeong, J.J., Bartsch, S., Fleckenstein, J.H., Matzner, E., Tenhunen, J.D., Lee, S.D., Park, S.K., and Park, J.H., 2012: Differential storm responses of dissolved and particulate organic carbon in a mountainous headwater stream, investigated by high-frequency, in situ optical measurements. Journal of Geophysical Research. Biogeoscience, v. 117, G03013, doi: 10.1029/2012JG001999.

Jo, K.W., Lee, H.J., Park, J.H., and Owen, J.S., 2010, Effects of monsoon rainfalls on surface water quality in a mountainous watershed under mixed land use. Korean Journal of Agricultural and Forest Meteorology, v. 12, pp. 197–206, doi: 10.5532/KJAFM.2010.12.197.

Jo, K.W., and Park, J.H., 2010, Rapid release and changing sources of Pb in a mountainous watershed during extreme rainfall events. Environmental Science and Technology, v. 44, pp. 9324–9329, doi: 10.1021/es102109a.

Jung, B.J., Lee, J.K., Kim, H., and Park, J.H., 2014, Export, biodegradation, and disinfection byproduct formation of dissolved and particulate organic carbon in a forested headwater stream during extreme rainfall events. Biogeoscience, v. 11, pp. 6119–6129, doi: 10.5194/bg-11-6119-2014.

Jung, B.J., Jeanneau, L., Alewell, C., Kim, B., and Park, J.H., 2015, Downstream alteration of the composition and biodegradability of particulate organic carbon in a mountainous, mixed land-use watershed. Biogeochemistry, v. 122, pp. 79–99, doi: 10.1007/s10533-014-0032-9.

Kcestra, S.D., Geissen, V., van Schaik, L., Mosse, K., and Pirainen, S., 2012, Soil as a filter for groundwater quality. Current Opinion in Environmental Sustainability, v. 4, pp. 507–516, doi: 10.1016/j.cosust.2012.10.007.

Kcestra, S., Pereira, P., Novara, A., Brevik, E.C., Azorin-Molina, C., Parra-Alcantara, I., Jordan, A., and Cerda, A., 2016. Effects of soil management techniques on soil water erosion in apricot orchards. Science of the Total Environment, v. 551, pp. 357–366, doi: 10.1016/j.scitotenv.2016.01.182.

Kettering, J., Park, J.H., Lindner, S., Lee, B., Tenhunen, J., and Kuyzyakov, Y., 2012, N fluxes in an agricultural catchment under monsoon climate: a budget approach at different scales. Agriculture Ecosystem and Environment, v. 161, pp. 101–111, doi: 10.1016/j.agee.2012.07.027.

Kim, B., and Jung, S., 2007, Turbid storm runoffs in Lake Soyang and their environmental effect. Journal of Korean Society of Environmenta...
areas have a WTP for water quality protection in upstream areas?. Water, v. 9, 511p. doi: 10.3390/w9070511.

Li, X., Huang, T., Ma, W., Sun, X., and Zhang, H., 2015, Effects of rainfall patterns on water quality in a stratified reservoir subject to eutrophication: Implications for management. Science of the Total Environment, v. 521, pp. 27–36, doi: 10.1016/j.scitotenv.2015.03.062.

Li, Z.W., Zhang, G.H., Geng, R., Wang, H., and Zhang, X.C., 2015, Land use impacts on soil detachment capacity by overland flow in the Loess Plateau, China. Catena, v. 124, pp. 9–17, doi: 10.1016/j.catena.2014.08.019.

Lieskovsky, J., and Kenderessy, P., 2014, Modelling the effect of vegetation cover and different tillage practices on soil erosion in vineyards: a case study in Vrable (Slovakia) using WATEM/SEDEM. Land Degradation and Development, v. 25, pp. 288–296, doi: 10.1002/ldr.2162.

Lim, K.J., 2007, Mitigation analysis of soil loss with changes in soil addition and crops in highland agriculture. Research Institute for Gangwon: Chuncheon, Korea (in Korean).

Mahajan, G.R., Ruidisch, M., Shope, C.L., Choi, K., Huwe, B., Kim, S.J., Tenhunen, J., and Armhold, S., 2016, Assessing the effectiveness of split fertilization and cover crop cultivation in order to conserve soil and water resources and improve crop productivity. Agriculture Water Management, v. 163, pp. 305–318, doi: 10.1016/j.agwat.2015.10.005.

Meusburger, K., Mabit, L., Ketterer, M., Park, J.H., Sandor, T., Porto, P., and Alevess, C., 2016, A multi-radiuncile approach to evaluate the suitability of 239+ 240Pu as soil erosion tracer. Science of the Total Environment, v. 566, pp. 1489–1499, doi: 10.1016/j.scitotenv.2016.06.035.

Ministry of Environment of Korea (MEK), 2014, Monitoring and evaluation of non-point source management area in Soyang Lake (Final Report). Wonju Regional Office of MEK: Wonju, Korea.

Ministry of Environment of Korea (MEK), 2014, Monitoring and evaluation of non-point source management area in Mandae, Giaa, and Juun Regions. Wonju Regional Office of MEK: Wonju, Korea.

Molla, T., and Sisheber, B., 2017, Estimating soil erosion risk and evaluating erosion control measures for soil conservation planning at Koga watershed in the highlands of Ethiopia. Solid Earth, v. 8, 13p, doi: 10.5194/se-8-13-2017.

Montgomery, D.R., 2007, Soil erosion and agricultural sustainability. Proc. Natl. Acad. Sci, v. 104, pp. 13268–13272, doi: 10.1073/pnas.0611508104.

Ni, J.R., Li, X.X., and Borthwick, A.G.L., 2008, Soil erosion assessment based on minimum polygons in the Yellow River basin, China. Geomorphology, v. 93, pp. 233–252, doi: 10.1016/j.geomorph.2007.02.015.

Nigussie, Z., Tsemekare, A., Haregeweyn, N., Adgo, E., Nohmi, M., Tso, M., Aklhog, D., Mesheha, D.T., and Abele, S., 2017, Farmers' perception about soil erosion in Ethiopia. Land Degradation and Development, v. 28, pp. 401–411, doi: 10.1002/ldr.2647.

Nunes, A.N., De Almeida, A.C., and Coelho, C.O., 2011, Impacts of land use and cover type on runoff and soil erosion in a marginal area of Portugal. Applied Geography, v. 31, pp. 678–699, doi: 10.1016/j.apgeog.2010.12.006.

Ochoa, C.P., Fries, A., Montesinos, P., Rodriguez-Diaz, J.A., and Boll, J., 2015, Spatial estimation of soil erosion risk by land-cover change in the Andes of southern Ecuador. Land Degradation and Development, v. 26, pp. 565–573, doi: 10.1002/ldr.2219.

Ochoa, P.A., Fries, A., Mejia, D., Burneo, J.L., Ruiz-Sinoga, J.D., and Cerda, A., 2016, Effects of climate, land cover and topography on soil erosion risk in a semiarid basin of the Andes. Catena, v. 140, pp. 31–42, doi: 10.1016/j.catena.2016.01.011.

Oldeman, L.R., 1992, Global extent of soil degradation. ISRIC: Wageningen, The Netherlands.

Olesen, J.E., and Bindi, M., 2002, Consequences of climate change for European agricultural productivity, land use and policy. European Journal of Agronomy, v. 16, pp. 239–262, doi: 10.1016/S1161-0301(02)00004-7.

Oost, K.V., Govers, G., and Desmet, P., 2000, Evaluating the effects of changes in landscape structure on soil erosion by water and tillage. Landscape Ecology, v. 15, pp. 577–589, doi: 10.1023/A:10008198215674.

Ouyang, W., Wu, Y., Hao, Z., Zhang, Q., Bu, Q., and Hao, X., 2018, Com-
Silvestri, N., Pistocchi, C., and Antichi, D., 2017, Soil and nutrient losses in a flat land/reclamation district of Central Italy. Land Degradation and Development, v. 28, pp. 638–647, doi: 10.1002/ldr.2549.

Sobral, A.C., Peixoto, A.S.P., Nascimento, V.F., Rodrigues, J., and da Silva, A.M., 2015, Natural and anthropogenic influence on soil erosion in a rural watershed in the Brazilian southeastern region. Regional Environmental Change, v. 15, pp. 709–720, doi: 10.1007/s10113-014-0667-z.

Stavi, I., Bel, G., and Zadaya, E., 2016, Soil functions and ecosystem services in conventional, conservation, and integrated agricultural systems. A review. Agronomy for Sustainable Development, v. 36, 32p. doi: 10.1007/s13752-016-0368-8.

Sun, W., Shao, Q., Liu, J., and Zhai, J., 2014, Assessing the effects of land use and topography on soil erosion on the Loess Plateau in China. Catena, v. 121, pp. 151–163, doi: 10.1016/j.catena.2014.05.009.

Symeonakis, E., Calvo-Cases, A., and Arnau-Rosalen, E., 2007, Land use change and land degradation in southeastern Mediterranean Spain. Environmental Management, v. 40, pp. 80–94, doi: 10.1007/s00267-004-0059-0.

Tenhunen, J., Seo, B., Kim, I., Arnhold, S., Shope, C., and Park, S., 2011, Spatial Setting of the TERRECO Project in the Soyang Lake Watershed of Gangwon-do and the Haean Catchment of Yanggu-gun. In TERRECO Science Conference, Karlsruhe Institute of Technology, Garmisch-Partenkirchen, Germany.

Vaezi, A.R., Ahmadi, M., and Cerda, A., 2017, Contribution of raindrop impact to the change of soil physical properties and water erosion under semi-arid rainfalls. Science of the Total Environment, v. 583, pp. 382–392, doi: 10.1016/j.scitotenv.2017.01.078.

Vanacker, V., Bellin, N., Molina, A., and Kubik, P.W., 2014, Erosion regulation as a function of human disturbances to vegetation cover: a conceptual model. Landscape Ecology, v. 29, pp. 293–309, doi: 10.1007/s10980-013-9956-z.

West, A.J., Arnold, M., Aumaitre, G., Bourles, D.L., Keddadouche, K., Bickle, M., and Ojha, T., 2015, High natural erosion rates are the backdrop for present-day soil erosion in the agricultural Middle Hills of Nepal. Earth Surface Dynamics, v. 3, pp. 363–387, doi: 10.5194/esurf-3-363-2015.

Won, J.K., Na, K.C., and Lee, M.W., 1988, Geology in Northern area of Demilitarized Zone. Cultural heritage administration of Korea: Seoul, Korea (in Korean).

Yang, D., Kanae, S., Oki, T., Koike, T., and Musiake, K., 2003, Global potential soil erosion with reference to land use and climate changes. Hydrological Processes, v. 17, pp. 2913–2928, doi: 10.1002/hyp.1441.

Yun, S.W., Lee, J.Y., and Lee, H.G., 2015, Variation of stream water quality and baseflow contribution from groundwater during rainfall event in the Haean basin. Journal of Geological Society of Korea, v. 51, pp. 611–621 (in Korean with English abstract).

Zare, M., Samani, A.N., Mohammady, M., Salmani, H., and Bazarfshah, J., 2017, Investigating effects of land use change scenarios on soil erosion using CLUE-s and RUSLE models. International Journal of Environmental Science and Technology, v. 14, pp. 1905–1918, doi: 10.1007/s13762-017-1288-0.

Zhang, S., Fan, W., Li, Y., and Yi, Y., 2017, The influence of changes in land use and landscape patterns on soil erosion in a watershed. Science of the Total environment, v. 574, pp. 34–45, doi: 10.1016/j.scitotenv.2016.09.024.

Zhang, X.J., Wang, and Z.L., 2017, Interrill soil erosion processes on steep slopes. Journal of Hydrology, v. 548, pp. 652–664, doi: 10.1016/j.jhydrol.2017.03.046.

Zhao, G., Mu, X., Wen, Z., Wang, F., and Gao, P., 2013, Soil erosion, conservation, and eco-environment changes in the Loess Plateau of China. Land Degradation and Development, v. 24, pp. 499–510, doi: 10.1002/ldr.2246.

Zhong, Z., Boqi, W.E.N.G., Yixiang, W.A.N.G., Luo, X., and Jing, Y. E., 2016, Adopting a pintoil as live mulch for peach orchards in China: Benefits of soil and water conservation and comprehensive Eco-service. Agriculture Science and Technology, v. 17, pp. 1702–1708.

Ziadat, F.M., and Taimeh, A.Y., 2013, Effect of rainfall intensity, slope, land use and antecedent soil moisture on soil erosion in an arid environment. Land Degradation and Development, v. 24, pp. 582–590, doi: 10.1002/ldr.2239.

Jin-Yong Lee is a Professor at Kangwon National University. He has published over 200 research papers in international and Korean journals. He was awarded the Young Geologist Award, the Commendation Award from Environment Minister, an Academic Award and Best Paper Award from The Geological Society of Korea, an Academic Award from Korea Federation of Water Science and Engineering Societies, and Academic and Contribution Awards from the Korean Society of Soil and Groundwater Environment. He has served as Editor in Chief for the Journal of the Geological Society of Korea and Editor for Geosciences Journal and Episodes.

Maimoona Raza is a Ph.D. candidate in the Department of Geology at Kangwon National University. Her research has been concerned with groundwater and the soil environment, with keen interest in identification of groundwater quantity and quality for better management practices. She won the award of best student poster in Hydrological Science section during AOGS-2018 held in Hawaii, the United States of America. She has published five papers in international journals.

Kideok D. Kwon is an Associate Professor in the Department of Geology at Kangwon National University. His main research focuses on the molecular level understanding of water-rock interactions including trace- and heavy-metal contamination in soil and groundwater. His research extends to the Critical Zone Science connecting the past and present climate change.

March 2019