QUANTIFYING IMPACT OF DEFORESTATION USING MULTI-SATELLITE AND MULTI-SPATIAL MODEL IN THE NORTH KOREA

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ABSTRACT: Deforestation in North Korea has been covered in many studies, but the exact amount of its impact and geographical area is still very different depending on the research and literature. In this study, we used Sentinel-2, the latest multi-spectral satellite image in Europe, and Landsat satellite image, which can detect forest cover before deforestation, to find out where to restore not only the degraded area. Forest area was identified in 1970-1980s using Landsat satellite images and focused on changes in the area. Monthly Sentinel-2 images are calculated as NDVI to identify forest-related covers through phenological change of vegetation. Random forest machine learning classification is used to classify each cover. And for the impact of deforestation also quantified in terms of agriculture and water by multi-spatial model. Agro-environmental variables, agricultural water demand and forest water supply were estimated using the EPIC and InVEST-WY models, respectively. Analysis of deforestation showed that area under forests decreased by 25%, whereas that under cropland increased by 63%, and that the conversion from forest to cropland was the largest for the study period. As a result, agricultural water demand increased and forest water supply decreased, significantly. Analysis of the net impact of deforestation on water budgets using recent climate and two land covers showed that forest water supply decreased by 43% and agricultural water demand increased by 62%. In terms of agro-environment, the negative changes in organic carbon loss, water erosion, and runoff were observed, regardless of the crop type. On newly-converted agricultural lands, runoff is 1.5 times higher and water-driven erosion and soil organic loss are more than twice as high compared to older croplands. The North Korea has declined many benefits from ecosystem attributable to deforestation in recent three decades. In contrast, South Korea has experienced success in national-scale afforestation in recent decades, and North Korea can emulate this. The restoration of forests in North Korea promises more than environmental benefits; it will provide a new growth engine for the prosperity of the Korean Peninsula as a whole.

1. INTRODUCTION

Deforestation destroys forest ecosystems and impoverishes their functions. All the functions provided by forests, including carbon sink activity for mitigating greenhouse gas emissions, reducing air pollution, and water storage and supply, are diminished at regional and global scales by deforestation This in turn has negative repercussions on the global environment in terms of climate change response, air quality, and water security (Kim et al., 2017; Lee et al., 2018; Lim et al., 2018). In particular, the numerous ecosystem services provided by forests are lost when converted into urban land, cropland, or degraded areas (Song et al., 2016; Lee et al., 2017).

Unlike the case of tropical rainforests, which typically make way for urban development, deforestation in North Korea has been characterized in terms of economic hardship, food shortages, and very rapid progress (Choi et al., 2017).These rapid changes and degradation characteristics may have aggravated the reduction in the functions of forest ecosystems Although there have been a number of studies of forest carbon, ecosystems, and agriculture that have sought to investigate the impact of drastic deforestation in North Korea (Cui et al., 2014; Kim et al., 2016; Lim et al., 2017a), no study has focused on the water sector. It has been suggested that degraded forests in North Korea have been mostly converted to cropland (Lim et al., 2017a). Thus, both water supply and demand are likely to have undergone considerable changes.

Deforestation in North Korea has been covered in many studies, but the exact amount of its impact and geographical area is still very different depending on the research and literature. In this study, we used Sentinel-2, the latest multi-spectral satellite image in Europe, and Landsat satellite image, which can detect forest cover before deforestation, to find out where to restore not only the degraded area. And for the impact of deforestation also quantified in terms of agriculture and water by multi-spatial model. Agro-environmental variables, agricultural water demand and forest water supply were estimated using the EPIC and InVEST-WY models, respectively.

2. DATA AND METHOD

2.1 Study Area

North Korea is located in the northeastern hemisphere at 37.41°N–43.01°N and 128.17°E–130.41°E. The country's land area is 123,135 km^2, accounting for approximately 55% of the entire Korean Peninsula (Lim et al., 2017a). Annual average temperature and precipitation are 10 °C and 1000 mm, respectively (Lim et al., 2017b). Mountains and uplands account for approximately 80% of North Korea's land area. The Taebaek Mountains are located along the eastern coast of the Korean Peninsula. The Gaema Plateau, the highest region in the Korean Peninsula, is located in the northern part of the country. A deciduous broadleaf forest covers 60.0% and evergreen needleleaf forest occupies 25.2% of the total forested area of North Korea (Kim et al., 2016). About 70 years have elapsed since South Korea and North Korea separated. While the natural environments of the two regions are similar, the division has resulted in great socioeconomic differences between the two countries.

2.2 Spatial Model and Data

The EPIC (Environmental Policy Integrated Climate) crop model is a widely used global crop model developed in the United States (Williams et al., 1989). The EPIC crop model has the advantage of estimating not only crop yield but also other variables corresponding to an agricultural environment including crop water use, the hydrological cycle, and soil carbon and nitrogen contents (Lim et al., 2015; Folberth et al., 2016). This study used the most recent version of the EPIC model (EPIC 0810). The EPIC crop model required daily and monthly statistical weather data as inputs. Three parameters are necessary for these two sets of daily weather data: minimum temperature (T_{min}), maximum temperature (T_{max}), and precipitation. Other physical variables also need to be prepared such as solar radiation, wind speed, and relative humidity. The EPIC model requires various soil-related parameters such as OC (%), pH, cation exchange capacity (cmol kg^{-1}), sand (%), silt (%), bulk density (t m^{-3}), and electrical conductivity (mS cm^{-1}). These data were accessed from the Digital Soil Map of the World and spatially modified using the ISRIC-WISE database (Food and Agriculture Organization, 2007). We estimated four (wind erosion, water erosion, organic carbon loss, runoff) agro-environmental variables and agricultural water demand using EPIC model.

The InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) model is a suitable tool for spatially quantifying ecosystem functions and services. It has been applied in many countries around the world, including South Korea (Kim et al., 2017), since its development in the United States (Sharp et al., 2015). The InVEST model incorporates many ecosystem functions, and includes dozens of sub-models, including water yield, carbon storage and sequestration, habitat quality, timber production, and marine water quality. This study utilized the water yield sub-model of InVEST (hereafter InVEST-WY) to estimate forest water supply in North Korea. Through the InVEST-WY sub-model, annual water yield was calculated for each grid in the study area. In this study, the annual water yield from a forest was defined as "forest water supply." The InVEST-WY model requires six input data and two components as follows: annual precipitation, potential evapotranspiration, depth-to-root restricting layer (see below), plant available water content (AWC), land use, watersheds, biophysical table (see below), and seasonality factor. These data represent meteorological characteristics, physical conditions, and spatial attributes in each pixel.

2.3 Satellite Data and Classification Method

We used Sentinel-2, the latest multi-spectral satellite image in Europe, and Landsat satellite image, which can detect forest cover before deforestation, to find out where to restore not only the degraded area. Especially in this classification process, we apply the latest intelligent technology. In this study, forest area was identified in 1970-1980s using Landsat satellite images and focused on changes in the area. Evaluate whether the previously forested area has been transformed into the current stocked forest, non-stock forest, hillside cropland, or hillside bareland. Monthly Sentinel-2 images are calculated as Normalized Difference Vegetation Index (NDVI) to identify these four covers through phenological change of vegetation. Random forest (RF) machine learning classification is used to classify each cover. The learning item use 500 points of information from North Korean main literature and visually read through high-resolution images.

3. RESULT AND DISCUSSION

3.1 Deforestation Area in North Korea in the past three decades

A significant decline in forested areas, a significant increase in cropland areas, and a rise in other land covers, such as grassland and bare ground, has occurred over the past 3 decades in North Korea. In 1988 forests accounted for about 97,000 km^2, or approximately 80% of the total land area of North Korea. However, by 2010, forests had shrunk to approximately 60%. During this period, 27,680 km^2 of forests were converted to other land covers. Approximately 65% of this deforested area (17,740 km^2), was converted to cropland, and the remaining 35% to other covers, including grassland and bare ground. Newly forested areas could not make up for this diversion; the difference between the total forested areas in the two periods was 23,876 km^2. Croplands accounted for 21,339 km2 in 1988, and increased by approximately 63% to 34,703 km^2 by 2010. New croplands in recent land years cover an area of 19,549 km^2, which is approximately 92% of the area of existing cropland in 1988. When the area of land converted to urban or forest from cropland was included, the difference between both periods was 13,363 km^2. Thus, forest degradation in North Korea over the past 30 years is closely related to the changes in the area of cropland, and a similar trend has been reported in previous studies (Lim et al., 2017a). In addition to the western plains, coastal regions, and large riverside area, which have traditionally contained cropland, the area of cropland has expanded inland and to the northeast mountainous areas. Changes in land cover in the central mountainous areas have become prominent, and a large area of the Gaema Plateau, the region with the highest altitude in the Korean Peninsula, has been converted from forests to cropland. Thus, most regions have experienced cropland expansion, and forest degradation has become a nationwide phenomenon.

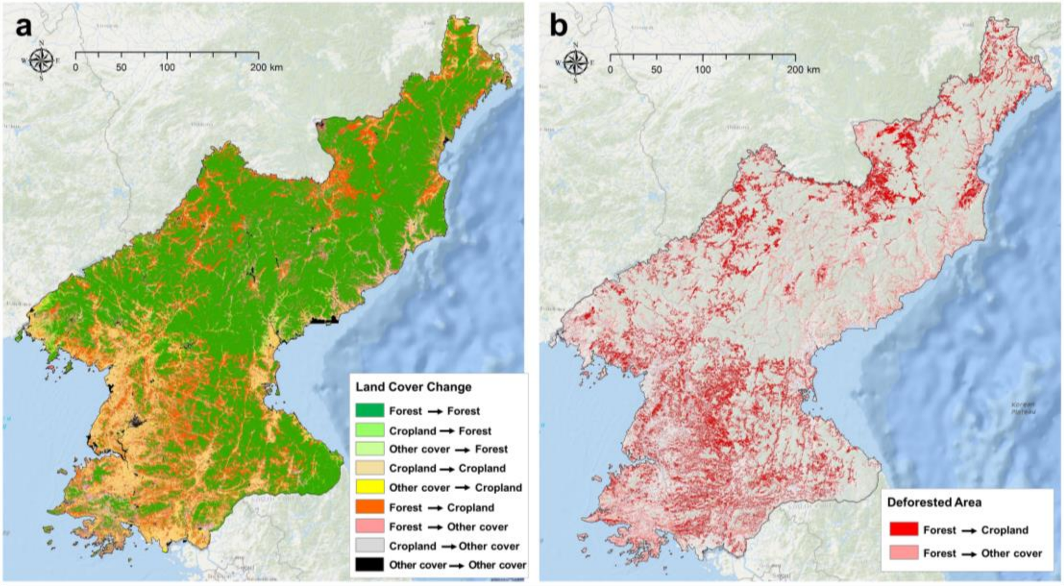


Figure 1. Deforestation status of North Korea using multi-temporal satellite data (a: Land cover change map, b: Deforestation map)

3.2 Impact of Deforestation on Agro-environment

To thoroughly confirm the impact of deforestation on agro-environmental variables, the differences in the variables were compared by dividing the estimated results of agro-environmental variables in the 2000s into the original cropland area. These original croplands remained as croplands in the 1980s and the converted croplands were newly expanded after the 1980s until the 2000s (as defined). The comparison of the original croplands using the four agro-environmental variables confirmed that after conversion from forests to croplands, three variables were negative and one variable appeared to differ by crop. Water erosion largely increased in converted croplands, although the difference between the crops was not significant. The average water erosion amount of original cropland was 4.03 t ha^{-1} (rice paddies) and 4.72 t ha^{-1} (maize cropland). The water erosion of converted cropland was 9.3 t ha^{-1} (rice paddies) and 10.94 t ha^{-1} (maize cropland), more than twice the values of original cropland. The value of water erosion was higher in maize croplands and the difference was greater in converted croplands. Furthermore, the deviation was also higher in maize croplands and largely increased in converted croplands.

Organic carbon loss showed a similar pattern as the water erosion and no significant differences between crops were observed. The average organic carbon loss amount in converted cropland was more than twice that in original cropland: 40.65 kg ha^{-1} (rice paddies) and 40.87 kg ha^{-1} (maize) in original cropland, and 98.23 kg ha^{-1} (rice paddies) and 101.2 kg ha^{-1} (maize) in converted cropland. The organic carbon loss of converted croplands also confirmed the drastic increase in deviation compared to the original croplands. Both crops showed high average runoff, with values three times higher in converted croplands. The average values in original cropland were 62.89 mm (rice paddies) and 65.37 mm (maize) and in converted cropland were 94.75 mm (rice paddies) and 93.6 mm (maize). Therefore, regardless of the crop type, the loss of soil, organic matter, and water resources remarkably increased in converted croplands, implying the impacts of deforestation on agriculture. Regarding wind erosion, the results for rice paddies and maize croplands were found to be uniquely contrary. For example, the erosion of forests converted to rice paddies was much lower (original cropland: 0.14 t ha^{-1}, converted cropland: 0.12 t ha^{-1}), whereas the erosion rates of forests converted to maize croplands were considerably higher (original cropland: 0.28 t ha^{-1}, converted cropland: 0.36 t ha^{-1}), caused by the changes in wind erosion according to the cropland type.

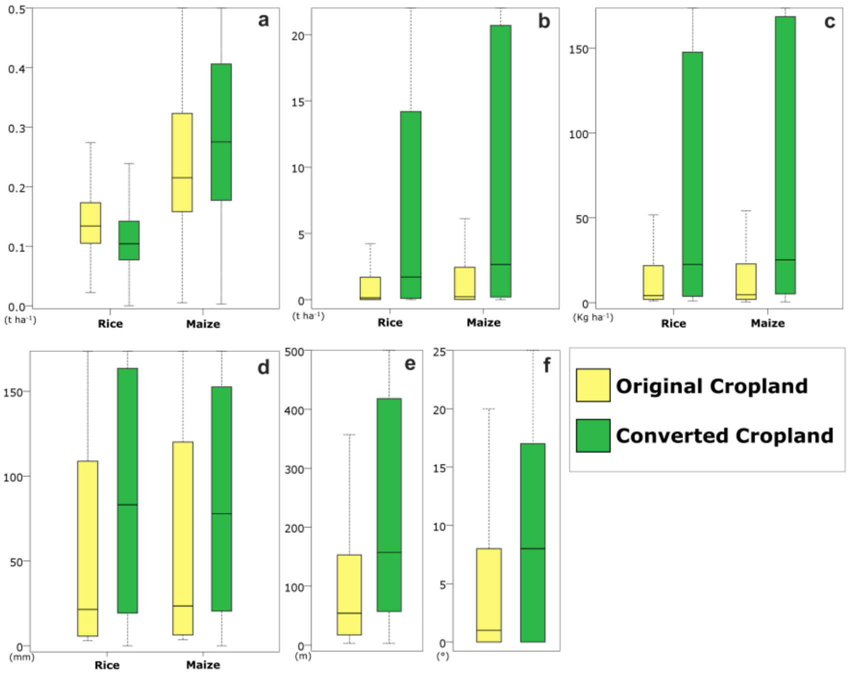


Figure 2. Comparison of agro-environmental variables with original cropland and converted cropland in each crop: (a) Wind erosion; (b) Water erosion; (c) Organic carbon loss; (d) Runoff; (e) DEM; and (f) Slope.

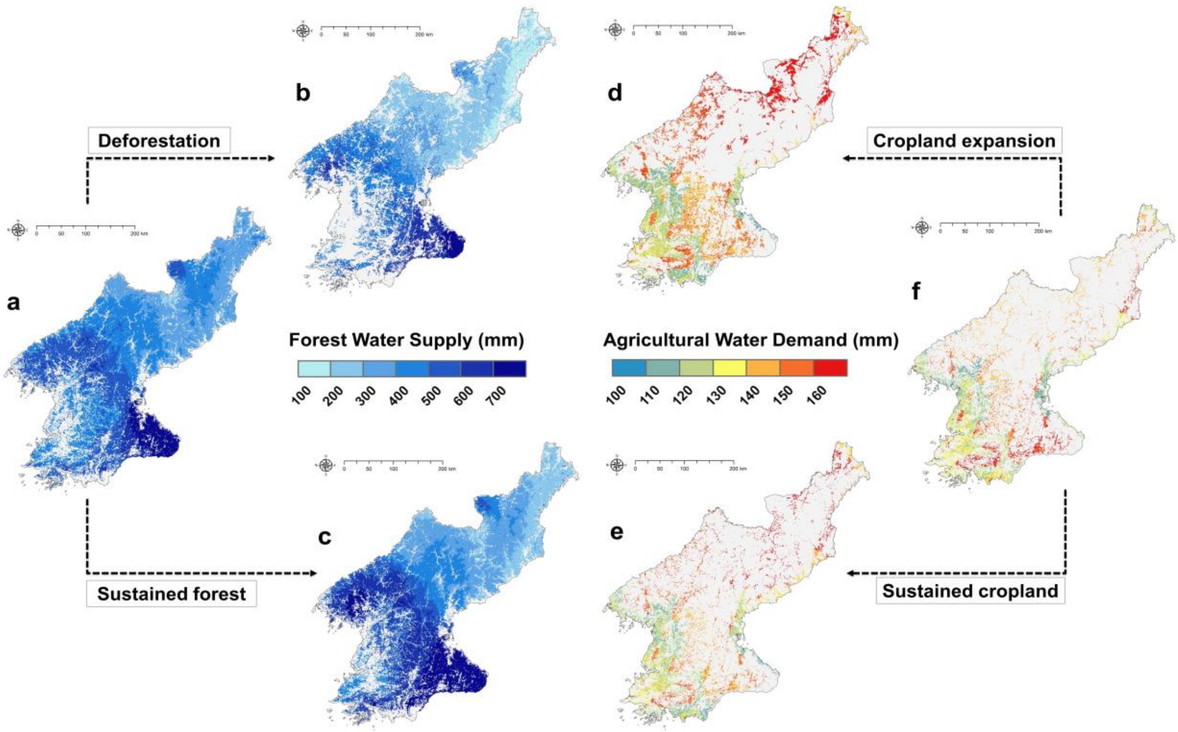
3.3 Impact of Deforestation on Water Supply and Demand

The estimation results of forest water supply before and after deforestation were significantly different. In the 1980s, before deforestation, a relatively abundant water supply (higher than the current value) existed throughout North Korea. Each grid demonstrated an average water supply of 368 mm yr^{-1}, with forests supplying a total of 34,840 million m^3 y^{-1} of water for the entire country. Estimates of agricultural water demand before and after North Korea's deforestation were significantly different. In the 1980s, before deforestation, water demand was moderate, except for the western plains and the southern inland area. Each grid demonstrated an average water demand of 128 mm y^{1}, and a total of 2,851 million m^3 y^{-1} of water was required for agriculture throughout North Korea.

A comparison of the results of the two simulations, namely before and after deforestation, demonstrated that the amount of water supplied by forests after deforestation declined by about 40% in North Korea, whereas agricultural water demand increased by about 60% in the same period (Table 2). Notably, the study period experienced a change in climate as well as change in land cover. Thus, it is necessary to simulate the current climate with fixed land cover to confirm the net impact of deforestation. Water supply and demand quantities were re-simulated by applying the land cover in the 1980s to the climate of the 2000s.

Assuming that the forests of the 1980s were completely sustained, the estimated average water supplied by the forests was 381 mm y^{-1} in each grid, and forests supplied a total of 36,058 million m^3 y^{-1} of water for all of North Korea (Table 2). This was an increase of about 3.5% compared with the result of the 1980s, suggesting that if the forests were sustained, their water supply function could be improved. The net impact of deforestation on forest water supply was a supply loss amounting to 15,581 million m^3 y^{-1} (43.2% of the total).

Based on the assumption that the area of cropland of the 1980s has not changed, the average demand for agricultural water was 129 mm y^{-1} in each grid, and total agricultural water demand amounted to 2,882 million m^3 y^{-1} for all of North Korea. This is almost the same as that in the 1980s, suggesting that water demand would not have increased without the change in cropland distribution. The net impact of deforestation on agricultural water demand was an increase of 1,796 million m^3 y^{-1} (62.3% of the total).



Figgure 6. Spatial distributions of the change in forest water supply and agricultural water demand attributable to deforestation in North Korea: (a) forest water supply in the 1980s; (b) forest water supply in the 2000s; (c) forest water supply assuming forest area of the 1980s and climate of the 2000s; (d) agricultural water demand in the 2000s; (e) agricultural water demand of cropland area of the 1980s and climate of the 2000s; (f) agricultural water demand in the 1980s.

4. CONCULSION AND FUTURE RESEACH

A thorough assessment of the impact of deforestation has significant implications for forest restoration, and can facilitate implementation of afforestation policies. Analysis of the land cover change in North Korea before and after deforestation showed that forested area decreased by 25% and total cropland area increased by 63%, both being primarily attributable to the transformation from forest to cropland. Changes in forest water supply and agricultural water demand before and after deforestation were estimated through the InVEST-WY and EPIC models, respectively. The results showed that agro-environmental variables changed negatively and agricultural water demand increased significantly, while water supplied by forests decreased considerably. The accurate spatial information on forest restoration should be used to study how to develop the forest restoration pathways through what purpose and method. The results of this study indicated a decoupling between water demand and supply for North Korea on account of deforestation during the study period. Therefore, North Korea should attempt to reproduce South Korea's experiences on reforestation, and restore the environmental functions (including water balance) of its forests.

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