A comparative analysis of forest area differences between statistics information and spatial thematic maps

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1. Introduction

Global warming caused by GHG emissions has led to an unprecedented level of environmental and social changes, including climate change (Sisay et al., 2017). Specific details on the obligation to reduce GHG emissions are described in the Kyoto Protocol in 1997, and the Paris Agreement in 2015 was adopted as an agreement between the Parties at the 21st Conference of the Parties (COP) held in Paris, France in 2015, signifying the beginning of a new climate regime. In the Paris Agreement, the parties took measures to reduce GHG emissions and mitigate climate change, such as pursuing efforts to reduce GHG emissions to hold the increase in the global average temperature to well below 2°C above pre-industrial levels (UNFCCC, 2015).

Forests perform a variety of positive functions, including carbon storage, acting as biodiversity repositories, and urban heat island mitigation. Forest administration plays a pivotal role in climate change mitigation, sustainable ecosystem management, and provision of ecosystem services (Lal, 2005; Brockerhoff et al., 2017).

In particular, forests that are not affected by land use changes absorb about 8.8 GtCO₂e of carbon dioxide per year, so, increasing the importance of the carbon sink function among forests (Xu et al., 2018). Accordingly, to accurately calculate the amount of carbon dioxide absorbed by forests and to manage forests based on it, international organizations including FAO and international conventions such as United Nations Framework Convention on Climate Change (UNFCCC) mandate the creation and update of national forest resource statistics (National Institute of Forest Science, 2011). Forests play an essential role in the implementation of various strategies including climate change mitigation, and the establishment of reliable data and information about forests is imperative (Magdon and Kleinn, 2013). The data and information about forests in Korea are constructed through statisticses and spatial data such as Forest Basic Statistics (FBS), Cadastral Statistical Annual Report (CSAR), digital forest type maps, land cover maps, and continuous cadastral maps (Park et al., 2006; Jeong et al., 2011; Korea Forest Service, 2015; Ministry of Land, Infrastructure and Transport, 2015; Oh et al., 2016).
The analysis of forest areas. Hwang et al (2018) reported and such differences need to be taken into account for are different depending on the institution of production, and production methods for statistics and spatial data between each type of information. Investigate the cause of differences in the forest area and the purpose of production described in the statistics minimum partitioning criteria, the production method, type of information and data, as well as the method of including domestic forest area, the limitations of each the differences between forest statistics calculation data, land use category, leading to differences in the calculated purposes and different classification criteria for each land use category, leading to differences in the calculated forest area. However, there has been limited research on the differences between forest statistics calculation data, including domestic forest area, the limitations of each type of information and data, as well as the method of utilization considering these differences. Therefore, this study analyzed the different definitions of forest, the minimum partitioning criteria, the production method, and the purpose of production described in the statistics and spatial data, and then calculated the forest area to investigate the cause of differences in the forest area between each type of information.

2. Materials and methods
2.1. Study area
The study site is Wonju city, Gangwon-do, located at a longitude of 127° 54′–128° 03′ E and latitude 37° 17′–37° 24′ N. The land area was 86,782 ha, of which forests accounted for approximately 70%. According to the classification by forest ownership in Wonju, Gangwon-do, national/public forests and private forests account for approximately 35% and 65%, respectively, of the forested area; and in terms of the distribution of forest physiognomy, coniferous forest, deciduous forest, mixed forest, and unstocked forest accounted for approximately 27%, 40%, 28%, and 5%, respectively. In Wonju city, the forest area decreased by approximately 2% in 2015 compared to 2005, and the city was one of the areas with a high rate of decrease in forest area compared to the nation-wide decrease rate (Korea Forest Service, 2005; 2015) (Figure 1).

2.2. Study data
The data used in this study was divided into two main categories. First, the data for comparison and analysis of forests, minimum partitioning criteria, and research methods of forest area defined in the statistics information by different organizations for presenting forest statistics and spatial data, creation and management of the Forest Resources Act, Land Cover Map Drawing Guidelines, Act on The Establishment, Management, and etc. of Spatial Data, and existing research such as the FBS Statistical Information Report (Korea Forest Service, 2019) and Cadastral Statistical Information Report (Ministry of Land, Infrastructure and Transport, 2019) were used as references. Second, for areas calculated by different organizations presenting forest statistics, the FBS (2020) and Cadastral Statistical Annual Report (CSAR) (2020) were used for statistics information, and the digital forest type map (2020) provided by KFS, the subdivided land cover map (2020) provided by the Ministry of Environment, and the continuous cadastral map (2020) were used for spatial data. Spatial data were analyzed using Arcmap 10.1, Esri (Table 1).

2.3. Methods
This study performed a qualitative analysis which included comparing the definition of forest, minimum partitioning criteria, and methods of production using the relevant laws, guidelines, and manuals by different organizations for the production of statistics and spatial data. In addition, the forest area of the statistics and spatial data were calculated for a quantitative comparative analysis (Figure 2).

1) Forest definition and methods of production specified in the statistics and spatial data

A) The difference in definition and criteria for forests in the statistics and spatial data

Forest statistics in Korea are produced in the form of statistics and spatial data by KFS, the Ministry of Environment, and MOLIT. The statistics information includes the FBS of KFS and CSAR of MOLIT, and spatial data includes a digital forest type map of KFS, a land cover map of the Ministry of Environment, and a continuous cadastral map of MOLIT. FBS defines the forest as a concept including “standing timber and bamboo that are growing collectively and the land on which they are growing, land that has temporarily lost the standing timber and bamboo that had been growing there, forest roads, rocky formations, and marshlands within the lands of items” according to Article 2(1) of the Creation and Management of the Forest Resources Act. The digital forest type map was created using the same set of criteria used by the FBS. The land cover map was categorized into a high-level land cover map, a middle-level land cover map, and a sub-divided land cover map based on spatial resolution according to the Land Cover Map Drawing Guidelines. The high-level land cover map defines forest as “land with collective growth of trees, and the middle-level land cover map and sub-divided land cover map define the forest by categorizing it into coniferous forest,
deciduous forest, and mixed forest categories. The definition of forest by CSAR includes land registered area, forestry registered area, cadastral map, and forestry map area in accordance with the provisions of the Act on the Establishment, Management, etc. of Spatial Data, and the term “forestry” is used instead of “forest”. The definition of the forestry by CSAR includes grove land, bamboo thicket land, rocky ground, gravelly ground, damp ground and wasteland, etc., which form the forest and wilderness.

From the statistics and spatial data, forest area was calculated based on the definition and criteria of the forest defined for each type of data. Therefore, the difference in definition and criteria of forests were analyzed for each type of statistics and spatial data.

Table 1. Used data in analysis.

| Category     | Data                                      | Organization                                      |
|--------------|-------------------------------------------|---------------------------------------------------|
| Statistics data | Forest Basic Statistics (FBS)             | Korea Forest Service                               |
|              | Cadastral Statistical Annual Report (CSAR)| Ministry of Land, Infrastructure and Transport    |
| Spatial data | Digital Forest Type Map                   | Korea Forest Service                               |
|              | Sub-divided Land Cover Map                | Ministry of Environment                            |
|              | Continuous Cadastral Map                  | Ministry of Land, Infrastructure and Transport    |

Figure 1. Location of the study area.

Figure 2. Study method.

B) method of production and period of the update according to the purpose

Since the statistics and spatial data were produced with different purposes of production in KFS, ME,
and MOLIT, the format and production timing of the data is different. In terms of the purpose of production of the statistics and spatial data related to forest statistics calculation, data are produced for the purpose of providing basic reference data for forest policy establishment in accordance with Article 32 of the Creation and Management of Forest Resources Act. The FBS calculated and provided information on forest area/growing stock in units of si/gun/gu(city/county/district). The digital forest type map is produced for efficient management and administration of forests in accordance with Article 8(2) of the Creation and Management of Forest Resources Act, and the status of forests, including forest type, forest physiognomy, and age class, is provided in the form of spatial data. The land cover map classifies the topographical features on the Earth’s surface according to scientific standards and is produced for the purpose of establishing environmental policies by the central and local governments in accordance with the Land Cover Map Drawing Guidelines. CSAR and continuous cadastral maps were produced for analysis of the actual land use status in accordance with the act on the Establishment, Management, etc. of Spatial Data, and the map provides the calculation of the area and number of parcels by land category. Therefore, in this study, the difference in production method and period according to the purpose was investigated using relevant laws and guidelines for statistics information and spatial data.

2) Analysis of forest area of statistics and spatial data

The forest area was extracted from the FBS, CSAR, digital forest type map, land cover map, and a continuous cadastral map for comparison between different types of statistics and spatial data, and the differences were analyzed for each type of data. When spatial data was used for forest area calculation, to analyze the area differences according to the overlapping area and the gap area between polygons constituting spatial data, topology rules were applied. In the topology rules, rules to finding errors for the overlapping area and gap area were added to analyze the overlapping area and gap area for each type of spatial data.

3. Results and discussion

3.1. Definition and criteria of Forest for statistics and spatial data

3) The difference in definition and criteria for forests in the statistics and spatial data

The definition of forest in the land cover map and CSAR is similar to the definition used by FBS. On the other hand, the definition of the forest by FBS and digital forest type map includes forest roads, rocky formations, and marshlands, whereas the land cover map categorizes forest roads as bare land, and the land covered with bamboo thickets as grasslands. In addition, because wilderness, included in forestry under CSAR, are defined as “uncultivated plains and fields without authorization,” the term forestry may be judged as a concept encompassing both forest and grassland. Kim and Lee (2007) conducted an analysis by classifying grassland as forest to unify the classification items of a land cover map and CSAR. This classification was performed because the definition of forestry under CSAR includes both categories of forest and grassland. Regarding the minimum partitioning area of the forest, FBS specifies the minimum area as 0.1 hectares(ha) for artificial forest and 0.5 hectares(hectares) for natural forest, and the digital forest type map specifies the minimum area constituting the forest at 0.1 ha with the minimum width at 20 m. As for the minimum area for identification of forest physiognomy, 0.1 ha and 0.5 ha were identified for the artificial and natural forests, respectively, similar to that specified by the FBS(National Institute of Forest Science, 2012). The sub-divided land cover map defines the criteria for all categories as 3 m in width for linear elements and 10 × 10 m for planar elements. In addition, the minimum classification criteria for items such as grassland, graveyard, bare land, and rock walls/boulders in the forest are specified as 20 × 50 m areas. In the case of the subdivided land cover map, the CSAR does not define the minimum partitioning area of the forest, but the units of parcels and areas are used for classification (Ministry of Land, Infrastructure and Transport, 2019). In FBS, the forest area is partitioned and read under the same criteria as the digital forest type map, but the land cover map differs depending on the forest area and the categories and sub-categories. It is judged that different forest areas will be calculated for each partitioning criterion because of the disparities in the criteria of the partitioning of the forest area. Since the CSAR and continuous cadastral map divide the land into parcels and areas, the standard for partitioning forest area may be different for FBS, digital forest type maps, and land cover maps, leading to differences in the calculated forest area (Table 2).

4) Analysis of purpose, method of production, and period of update

Due to the differences in the purpose of production of the statistics and spatial data related to forest statistics calculation, the production methods were also different. The FBS data are produced by compiling administrative survey data built on the basis of the previously established CSAR and KFS survey results and the data of local governments. For the production of a digital forest type map, aerial photographs, local forest physiognomy surveys, and reference land surveys were used as bases for comparison, and the map was produced by the zoning of forest
physiognomy followed by modification and editing of it. For the production of a sub-divided land cover map, the land cover boundaries and properties were obtained and classified based on the image data. In addition, field surveys were conducted only in areas where it was difficult to obtain information, such as unclassified items. CSAR is produced by aggregating nationwide land and forestry register area items registered in the cadastral book.

In addition, statistics and spatial data have different update periods. Since FBS and digital forest type maps are currently published over a 5-year period, annual changes in the forest area cannot be identified with this information. In particular, in the case of FBS, statistics are prepared without a related budget; if the project budget can be secured, FBS will be provided on a yearly basis per city/province/county/district, which is expected to be useful in terms of utilization of FBS in research and checking of forest area information (Korea Forest Service, 2019). However, because the sub-divided land cover map and CSAR are updated every year, information on changes in the forest area is provided every year in terms of land cover and land use. The continuous cadastral map updates the information on the area with changes on a monthly basis, which enables the analysis of changes in forests on the cadastral map.

FBS, digital forest type maps, sub-divided land cover maps, CSAR, and continuous cadastral maps were different in terms of following various aspects depending on the institution: legal basis and definition of forest, minimum partitioning criteria for forest area, the purpose of production and production methods, and period of production and update. Therefore, appropriate data should be used when considering the purposes of forest management and administration. For forest management and administration, FBS should be used when utilizing data on forest area and growing stock by city/county/district, and for the acquisition of spatial data for age class, diameter class, and crown density for subdivided areas such as city/county/district and eup/myeon/dong, a digital forest type map should be used. In addition, the sub-divided land cover map should be used in forest management planning with a focus on the status of forest cover, and CSAR and the continuous cadastral maps are thought to be appropriate for forest management planning with a focus on the status of mountain land use. Therefore, in the future, for forest management planning and forest area analysis, the plans should be established according to the characteristics of data to be used and the purpose of production, and the forest area should be calculated accordingly. In addition, the construction period for the statistics information and production period of spatial data prepared for each institution should be unified so that each type of data can be linked and utilized for research and identification of the current status (Table 3).

### 3.2. Comparison of Forest area in statistics and spatial data

Forest area in 2020 was calculated to be the highest in the order of CSAR (area: 61,406 ha, ratio: 70.7%), Continuous Cadastral Map (area: 61,272 ha, ratio: 70.6%), FBS (area: 60,704 ha, ratio: 69.9%), Digital Forest Type Map (area: 59,928 ha, ratio: 69.0%), Sub-divided Land Cover Map (area: 57,818 ha, ratio: 66.6%) (Figure 3). For the digital forest type map and subdivided land cover map, there was no overlap between polygons (Must Not Overlap) and no gaps between polygons (Must Not Have Gaps); however, overlap and gaps occurred between polygons in the case of the continuous cadastral map. Therefore, the forest area of the continuous cadastral map was calculated to be larger than that of the digital forest type map and the subdivided land cover map (Figure 4).

In the case of the digital forest type map and the subdivided land cover map, the same area of approximately 57,805 ha was classified as forest, whereas the approximate areas of grassland and bare land in the sub-divided land cover map were 2,499 ha and 489 ha, respectively, both of which were classified as forest in the digital forest type map. As for grassland, because it was located within the forest, it was classified as forest in the digital forest type map, but in the sub-divided land cover map, the area was designated as a graveyard according to the land cover, and thus, it was classified
Table 3. Production standard in statistics and spatial data.

| Data                     | Forest Basic Statistics                                                                 | Digital Forest Type Map                                                                 | Sub-divided Land Cover Map                                                                 | Cadastral Statistical Annual Report/Continuous Cadastral Map |
|--------------------------|----------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|----------------------------------------------------------------|
| Purpose                  | Provide basic data for forest policy establishment by preparing Forest Basic Statistics by investigating and evaluating forests across the country in a scientific method. | A comprehensive analysis of the status of forests, such as species of trees, diameter class, and age class, for forests across the country for efficient management and administration of forests. | Using basic data for efficient management of land-related data, policy establishment, administrative improvement, and tax imposition. | The actual patterns of land use. |
| Methods of production    | Put together administrative survey data and Cadastral Statistical Annual Report and Local governments data. | Aerial images reading and field survey. | The land cover boundaries and properties are read and classified based on image data and field survey. | Cadastral book and Continuous Cadastral Map update. |
| Period of update         | 5 years                                                                                | 5 years                                                                                | 1 year                                                                                  | 1 year/1 month                                                    |

Figure 3. The comparison of forest area between statistic and spatial data in 2020.

Figure 4. Topology error in Continuous Cadastral Map.
as grassland. In the case of bare land, as it was located within the forest in the digital forest type map, it was classified as forest, but in the sub-divided land cover map, the area was classified as bare land. This difference may have occurred because, in the case of the land cover map, the images were classified in terms of land cover, unlike in the case of the digital forest type map (Figure 5).

In the case of the digital forest type map and the continuous cadastral map, the land with an area of approximately 57,539 hectares was classified as forest, and the areas of approximately 1,511 hectares and 1,389 hectares were classified as forest in the digital forest type map, but these same areas were classified as settlement and cropland, respectively, in the continuous cadastral map. In the case of the settlement areas, it was also classified as forest in the digital forest type map, because the area included the forest and forest road near housing sites. However, in the continuous cadastral map, it was classified as a building site and road, thus, it was included in the settlement category. In the case of cropland, in the digital forest type map, the land was the adjacent area near the forest and cropland and new agricultural land in the forest, and it was, therefore, classified as forest, but in the continuous cadastral map, as the land was used as cropland, it was classified as cropland from the perspective of land use (Figure 6).

In the case of the subdivided land cover map and the continuous cadastral map, an area of approximately 55,333 ha was classified as forest, and the areas of approximately 1,634 ha and 1,365 ha were classified as forest in the subdivided land cover map, but in the continuous cadastral map, the areas were classified as settlement and cropland, respectively. In the case of settlement, it was classified as forest because it was forest according to the land cover on the subdivided land cover map, but in the continuous cadastral map, it was classified as a building site, and thus, it was included in the settlement. In the case of cropland, it was classified as forest in the subdivided land cover map according to the land cover classification, but in the continuous cadastral map, it was classified as cropland in terms of land use because it was used as cropland (Figure 7).

As the purpose of production for each type of spatial data was different, the forest area was classified into different categories according to the type of spatial data, even in the same region; therefore, the calculated forest area was different for each type of spatial data. Therefore, it is unreasonable to use existing forestry data for climate change mitigation. In the future, the forest area calculation for climate change mitigation can be calculated accurately and efficiently if the review is conducted focusing on the areas of inconsistency between each data.

### 3.3. Cause of discrepancies of Forest area and improvement plan

Statistics and spatial data have limitations according to production methods for each type of information, and improvements are needed in the future. For statistics information, there may be cadastral incongruence in
Figure 6. Areas classified as forest in the digital forest type map but classified as settlement (a) and cropland (b) in the Continuous Cadastral Map.

Figure 7. Areas classified as forest in the Sub-divided Land Cover Map but classified as settlement (a) and cropland (b) in the Continuous Cadastral Map.
which the real status of land use and the information on the cadastral book are different, which may lead to differences in the actual area and the area of the cadastral book (Hong, 2009).

In the case of spatial data, because the digital forest type map classifies forest physiognomy through the visual reading of pre-photographed aerial images, reading errors may occur depending on the subjective opinion of the person reading the images. In addition, in the case of a field survey data errors may occur as the check is conducted with only visual observation instead of a forest survey, which may vary depending on the surveyor’s judgment (Do, 2019). For the subdivided land cover map, as in the case of the middle-level land cover map, the map is produced by visually reading and classifying the boundaries and properties of land cover, based on the image data; therefore, there may be errors due to the subjective opinions of the person reading the data (Jeon et al., 2015). In the continuous cadastral map, there may be problems such as the error between the area registered in the land register or forestry register and the corresponding area of the parcel on the map may exceed the allowable range and cadastral incongruence with overlap and gap between the adjacent parcels (Hong, 2007).

Therefore, it is necessary to prepare and establish countermeasures for these limitations in the future, and the data should be used appropriately while considering the characteristics and purposes of each type of data. When it is necessary to use forest area and forest statistics in policy establishment and decision-making about forests in Korea, an analysis should be performed using FBS and digital forest type maps. In addition, the land cover map, including the sub-divided land cover map and the digital forest type map should be used to a forest area on the calculate for land cover side. on the other hand, CSAR and the continuous cadastral map should be used to a forest area on the calculate for land use side. Therefore, when calculating the forest area, it is necessary to select statistics and spatial data considering land use or land cover, and it is expected to be useful in policy establishment and decision-making in the future.

4. Conclusion

In this study, we analyzed differences in qualitative aspects such as the definition of forest, minimum partitioning criteria, map production methods and purposes, the timing of construction and update of information/data specified in the statistics and spatial data, as well as the differences in quantitative aspects by calculating the forest area for each type of information. In terms of the definition of forest and minimum partitioning criteria, FBS and digital forest type maps were similar, but sub-divided land cover maps, CSAR, and continuous cadastral map were different in these aspects. In the case of the subdivided land cover maps, the partitioning criteria of all categories are specified at $10 \times 10$ m, but in the case of CSAR and continuous cadastral maps, the minimum partitioning area of the forest was not specified, but the classification was made using parcel and area, which is clearly different from the case of FBS and digital forest type maps. With regard to the purposes of map production and methods for each type of data, FBS and digital forest type maps are utilized as basic reference data for forest policy establishment and as data for efficient management and administration of forests, which is different from the purpose of the land cover map with which environmental policy is established based on the topographic features of the earth surface, as well as from the purpose of CSAR and a continuous cadastral map, which aims to analyze the actual patterns of land use based on the current status. As a result of calculating the forest area was highest in the order by CSAR, Continuous Cadastral Map, FBS, Digital Forest Type Map, and Sub-divided Land Cover Map. The forest in the digital forest type map was classified by cropland, grassland, settlement, and bare land in the subdivided land cover map and continuous cadastral map. And we found that the Continuous Cadastral Map has overlap and gap between polygons occurred through the topology analysis. For statistics information and spatial data, with the difference in the definition of forest, minimum partitioning criteria, purpose, and methods of production, the calculated forest area differs accordingly, and there are clear limitations depending on the characteristics of each type of data. In the future, when analyzing the forest area using statistics and spatial data, the type of data should be selected considering the purpose of use, and the analysis should be carried out by considering the characteristics of each type of data. In the future, this study will be useful in research using statistics and spatial data related to forests in Korea, and if the different types of data can be linked, it will augment their effective utilization.

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Disclosure statement

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References

Brockerhoff EG, Barbaro L, Castagnerol B, Forrester DI, Gardiner B, Gonzalez-Olabarria JR, Lyver PO, Meurisse N, Oxbrough A, Talo H, et al. 2017. Forest biodiversity, ecosystem functioning and the provision of ecosystem services. Biodivers Conserv. 26(13):3005–3035.

Do MR. 2019. Building work manual to increase accuracy in digital forest type map. [Masters dissertation]. Kangwon University. Chuncheon.

Ham BY, Lee CY, Byun HK, Min BK. 2013. A study on detection of deforested land using aerial photographs. J Korean Soc Geospatial Inform Sci. 21(3):11–17.

Hong SE, Lee HJ, Kim YK. 2007. The estimation of the cadastral digital map’s accuracy for the KLIS’s effective operation. J GIS Assoc Korea. 15(1):81–94.
Hong SE. 2009. An analysis on the cadastral non-coincidence of a forest area. Geographical J Korea. 43(1):103–113.

Hwang JH, Jang RI, Jeon SW. 2018. Analysis of spatial information characteristics for establishing land use, land-use change and forestry matrix. J KAGIS. 21(2):44–55.

Hwang SH, Kim KH, Lee GH, Lee MR. 2016. A study on the development of landslide area priority estimation process using high resolution satellite imagery. Korean Spatial Information Society Conference. p. 85–88.

Jeon SW, Kim JU, Kim YH, Jung HC, Lee WK, Kim JS. 2015. Improvement of forest boundary in landcover classification map(Level-II) for functional assessment of ecosystem services. J Korean Env Res Tech. 18(1):127–133.

Jeong DJ, Kang KH, Heo J, Son MS, Kim HS. 2011. Valuation of biodiversity and ecosystem services using national forest inventory data. J Eia. 20(5):615–625.

Kim DM, Lee WK. 2015. Estimate of climate change impact on future carbon budget in korea peninsula: focused on forest cover change. Korean Spatial Information Society Conference. p. 246–249.

Kim GH, Kim OS, Jung HC. 2016. Method of construction of land cover map(Level-II) in inaccessible terrain. J Korean Cartogr Assoc. 16(3):49–61.

Kim SH, Jang DH. 2014. Analysis of forest types and estimation of the forest carbon stocks using landsat satellite images in Chungcheongnam-do, South Korea. J KARG. 20(2):206–216.

Kim SJ, Lee YJ. 2007. The effect of spatial scale and resolution in the prediction of future land use using CA-Markov technique. J KAGIS. 10(2):58–70.

Korea Forest Service 2005. Forest basic statistics. Daejeon, Korea.

Korea Forest Service 2015. Forest basic statistics. Daejeon, Korea.

Korea Forest Service 2019. Forest basic statistics statistical information report. Daejeon, Korea.

Lal R. 2005. Forest soils and carbon sequestration. For Ecol Manage. 220(1-3):242–258.

Lee GS, Cho GS. 2019. Improvement of evaluation method of soil loss in connection with GIS-based cadastral map. JKCl. 21(3):29–41.

Lee JS, Park DH. 2011. Analysis of spatial patterns and estimation of carbon emissions in deforestation using GIS and administrative data. IFES. 27(1):39–46.

Magdon P, Klein C. 2013. Uncertainties of forest area estimates caused by the minimum crown cover criterion-a scale issue relevant to forest cover monitoring. Environ Monit Assess. 185(6):5345–5360.

Ministry of Land, Infrastructure and Transport 2015. Cadastral statistics annual report. Sejong, Korea.

Ministry of Land, Infrastructure and Transport. 2019. Cadastral Statistics Annual Report statistical information report. Sejong, Korea.

National Institute of Forest Science. 2011. 6th national forest inventory survey of forest health monitoring. Seoul, Korea.

National Institute of Forest Science. 2012. Development of large scale forest type maps and renewal methods using digital aerial image. Seoul, Korea.

Oh KY, Lee MJ, No WY. 2016. A study on the improvement of sub-divided land cover map classification system - based on the land cover map by ministry of environment. Korean J. Remote Sens. 32(2):105–118.

Park YK, Kwon SD, Song CC, Kwon DS, Lee JH, Kim HH. 2006. A study on the GIS-based method of building digital forest land-use map. J KAGIS. 9(3):46–57.

Sisay K, Thurnher C, Belay B, Lindner G, Hasenauer H. 2017. Volume and carbon estimates for the forest area of the amhara region in northwestern ethiopia. Forests. 8(4):122.

UNFCCC 2015. Adoption of the Paris agreement. Report No. FCCC/CP/2015/L.9/Rev.1. http:// unfccc.int/resource/docs/2015/cop21/eng/lo9r01.pdf

Xu Z, Smyth CE, Lempière TC, Rampley GJ, Kurz WA. 2018. Climate change mitigation strategies in the forest sector: biophysical impacts and economic implications in British Columbia, Canada. Mitig Adapt Strateg Glob Chang. 23(2):257–290.