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Research article

GIS based optimal impervious surface map generation using various spatial data for urban nonpoint source management

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ABSTRACT

Impervious surfaces are mainly artificial structures such as rooftops, roads, and parking lots that are covered by impenetrable materials. These surfaces are becoming the major causes of nonpoint source (NPS) pollution in urban areas. The rapid progress of urban development is increasing the total amount of impervious surfaces and NPS pollution. Therefore, many cities worldwide have adopted a stormwater utility fee (SUF) that generates funds needed to manage NPS pollution. The amount of SUF is estimated based on the impervious ratio, which is calculated by dividing the total impervious surface area by the net area of an individual land parcel. Hence, in order to identify the exact impervious ratio, large-scale impervious surface maps (ISMs) are necessary. This study proposes and assesses various methods for generating large-scale ISMs for urban areas by using existing GIS data. Bupyeong-gu, a district in the city of Incheon, South Korea, was selected as the study area. Spatial data that were freely offered by national/local governments in S. Korea were collected. First, three types of ISMs were generated by using the land-cover map, digital topographic map, and orthophotographs, to validate three methods that had been proposed conceptually by Korea Environment Corporation. Then, to generate an ISM of higher accuracy, an integration method using all data was proposed. Error matrices were made and Kappa statistics were calculated to evaluate the accuracy. Overlay analyses were performed to examine the distribution of misclassified areas. From the results, the integration method delivered the highest accuracy (Kappa statistic of 0.99) compared to the three methods that use a single type of spatial data. However, a longer production time and higher cost were limiting factors. Among the three methods using a single type of data, the land-cover map showed the highest accuracy with a Kappa statistic of 0.91. Thus, it was judged that the mapping method using the land-cover map is more appropriate than the others. In conclusion, it is desirable to apply the integration method when generating the ISM with the highest accuracy. However, if time and cost are constrained, it would be effective to primarily use the land-cover map.

1. Introduction

The rapid progress of urban development and expansion is causing various environmental problems. In particular, the increase of impervious surfaces such as concrete buildings and asphalt roads enables nonpoint source (NPS) pollutants on the ground surface to flow directly into rivers when it rains, aggravating water pollution (Arnold and Gibbons, 1996; Barnes et al., 2001; Booth et al., 2002). Therefore, in an effort to reduce the NPS pollution due to increased impervious surfaces, technology developments such as low impact development (LID), green stormwater infrastructure (GSI), and the construction of related facilities are on the increase (Dietz, 2007; Che et al., 2014). To obtain the financial resources required to pursue such projects, advanced nations such as the United States, Germany, and Canada are implementing a stormwater utility fee (SUF); South Korea is now also considering a similar system (Parikh et al., 2005; Roy et al., 2008; Crockett, 2010; US EPA, 2010; Bonnaffon, 2011; Graham et al., 2011; KECO, 2012). The details of each country vary, but the SUF is generally imposed on each land parcel's owner. The SUF is estimated based on the impervious surface ratio that is calculated by dividing the total area of impervious surfaces within a land parcel by the total area of the land parcel. Therefore, there is an inevitable need to deliver impervious

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surface area data that are accurate to the point of identifying even small areas of impervious surface on a land parcel.

In this regard, various methods of generating impervious surface maps (ISMs) have been proposed in previous studies such as image classification of remotely sensed data, mapping by location surveys, merging of building design drawings, and fusion of various existing thematic maps (Bauer et al., 2004; Yuan et al., 2008; Weng, 2012). In order to generate the ISMs in high spatial resolution, Cablk and Minor (2003) suggested a combination of image processing methods based on principal component analysis and spatial morphological operators using IKONOS imagery. Mohapatra and Wu (2007) and Lu and Weng (2009) also tried to generate ISMs by using IKONOS imagery, though the details of each method were different. On the other hand, Hodgson et al. (2003) and Linden and Hostert (2009) used airborne data to produce ISMs with high spatial resolution. However, the methods applied in previous studies have limitations in generating large-scale ISMs for urban areas, because urban areas that require impervious surface management are usually crowded with narrow roads and high-rise buildings. The mapping method using only optical images has innate problems, including: limitations in managing shadows; occlusion problems due to high-rise buildings; and issues of poor classification of very small objects such as narrow roads and small flower gardens, caused by limitations in spatial resolution. Although a large-scale map with high location accuracy and high spatial resolution is absolutely needed to support an SUF, a mapping method using only remotely sensed data cannot satisfy these conditions. Therefore, when only spatial accuracy is considered, such maps should be produced by a location survey. Yet, in the practical sense, such location surveys are also difficult to accomplish because they require a tremendous budget for a complex urban area. Therefore, as an alternative, a method of map generation that uses various large-scale spatial data that are already established could be considered.

Recently, in South Korea, three mapping methods using already produced spatial data were suggested as effective ways of generating an ISM to support an SUF (KECO, 2012). The three methods are: map generation through attribute reclassification of a land-cover map, map generation through layer extraction and conversion of a digital topographic map, and map generation through screen digitization based on ortho photographs. As these methods use only spatial data that are already produced and regularly updated, they were expected to result in economical and efficient map generation. However, these methods were only conceptually presented. Since there was not a practical application of the map generation method, accuracy and validity were not verified, and it was impossible to reveal the limitations of each method. The determination of which method might be optimal for the generation of ISM and whether it could be adopted in the urban area were not conducted. Therefore, this study applies various mapping methods to large-scale ISM generation by using various spatial data focused on the urban area and suggests an optimal method for map generation through comparison and contemplation of the accuracy of the maps produced.

2. Material and methods

2.1. Study area

Bupyeong-gu, Incheon, South Korea, was selected as the study area (Fig. 1). Bupyeong-gu, with an area of 32 km^2 and an estimated population of 557,000 people, is located about 10 km west of the

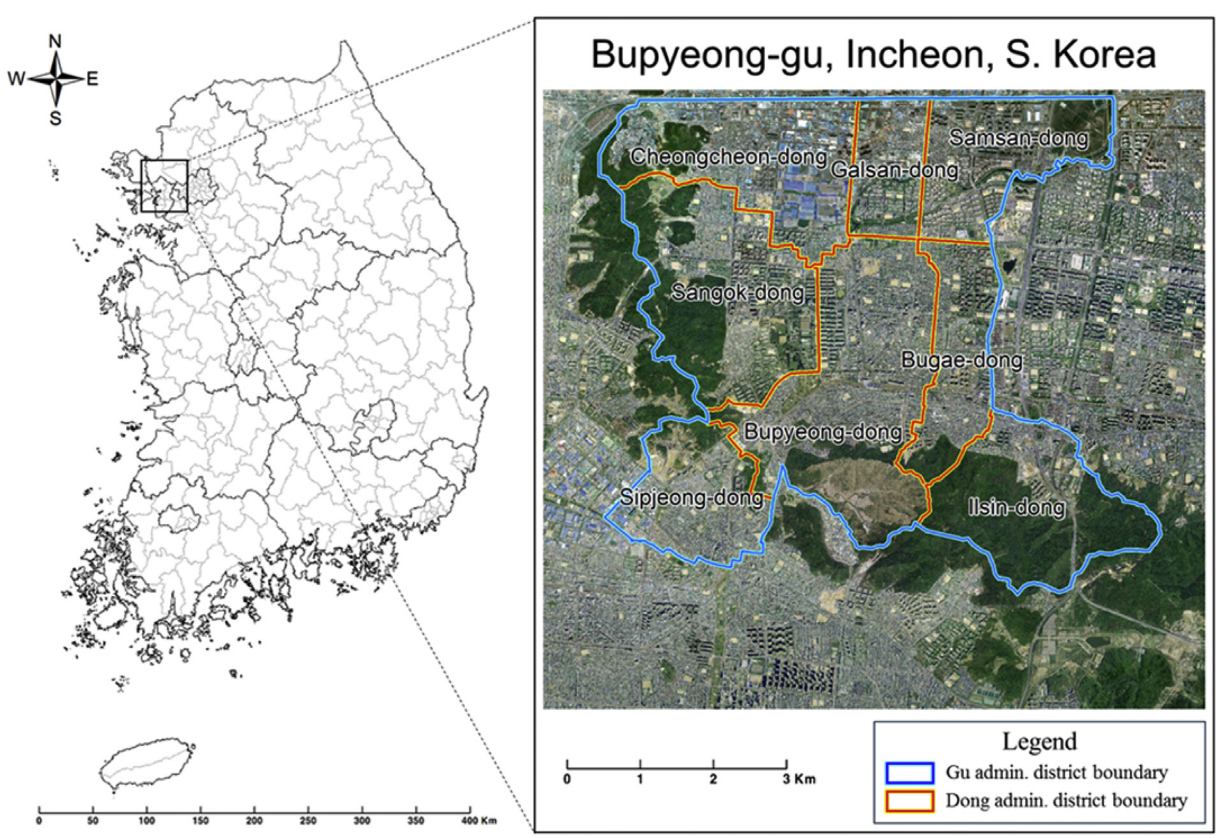

Fig. 1. Study area (Bupyeong-gu, Incheon, South Korea).