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Accuracy assessment of NLCD 2011 impervious cover data for the Chesapeake Bay region, USA

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ABSTRACT

The National Land Cover Database (NLCD) contains three eras (2001, 2006, 2011) of percentage urban impervious cover (%IC) at the native pixel size (30 m-×-30 m) of the Landsat Thematic Mapper satellite. These data are potentially valuable to environmental managers and stakeholders because of the utility of %IC as an indicator of watershed and aquatic condition, but lack an accuracy assessment because of the absence of suitable reference data. Recently developed 1 m^2 land cover data for the Chesapeake Bay region makes it possible to assess NLCD %IC accuracy for a 262,000 km^2 region based on a census rather than a sample of reference data. We report agreement between the two %IC datasets for watersheds and the riparian zones within watersheds and four additional square units. The areas of the six assessment units were 40 ha cell, 433 ha (riparian mean), 2756 ha cell, 5626 ha cell, 8569 ha (watershed mean) and 22,500 ha cell. Mean Absolute Deviation (MAD) and Mean Deviation (MD) were about 1.5% and -1.5%, respectively, for each of the assessment units except for the riparian unit, for which MAD and MD were 0.88 and 0.62, respectively. NLCD reliably reproduced %IC from the 1 m^2 data with a small, consistent tendency for underestimation. Results were sensitive to assessment unit choice. The results for the four largest assessment units had very similar regression parameters, R^2 values, and bias patterns. Results for the riparian assessment were different from those for the watershed unit and the other three larger units. MAD was about 50% less for the riparian zones than it was for the watersheds, the direction of bias was less consistent, and NLCD %IC was uniformly higher than 1 m^2 %IC in urbanized riparian zones. For the smallest unit, bias patterns were more similar to the riparian unit and regression results were more similar to the four larger units. MAD and MD were also sensitive to the amount of urbanization, increasing as NLCD %IC increased. The low overall bias and positive relationship between bias and urbanization suggest that the benefits of obtaining 1 m^2 IC data outside of urban areas may not outweigh the costs of obtaining such data.

1. Introduction

Impervious cover (IC) is an environmental indicator that is used to establish policy (Brabec, 2009). The states of Connecticut (Bellucci, 2007) and Maine (Maine, 2012) use IC to help identify impaired waters as part of their reporting for the Clean Water Act (33 U.S.C. §1251 et. seq. (1972)). Perhaps first examined as an indicator of watershed and aquatic condition in the 1970s (Hammer, 1972), IC emerged as an important indicator two decades later (Arnold and Gibbons, 1996; Schueler, 1994), and is now widely used to assess watershed and aquatic condition (Brabec et al., 2002; Brabec, 2009; Schueler et al., 2009). Use of IC is widespread because many studies have shown adverse impacts on watershed and aquatic condition (storm flow volume, streambank erosion, biotic integrity, pollutant levels) even at very low levels of IC (e.g., Ourso and Frenzel, 2003; Schiff and Benoit, 2007; Stanfield and Kilgore, 2006). In addition, not unlike its role in assessment of watershed and aquatic condition, IC has also been recognized as an important component of the urban heat island (UHI) effect (Oke,

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1982). IC contributes to several of the factors responsible for altered energy dynamics in urbanized areas, including anthropogenic heat, increased storage of sensible heat, and decreased evapotranspiration (Oke, 1995).

Measurement of percentage impervious cover (%IC) from a variety of remote platforms and using a variety of methods has been an active area of research (Slonecker et al., 2001; Weng, 2012) because it is measured more efficiently from the air than from field campaigns (Brabec et al., 2002; Wickham et al., 2014a, 2014b). The National Land Cover Database (NLCD) (www.mrlc.gov), a product of the Multi-Resolution Land Characteristics Consortium (www.epa.gov/mrlc), provides %IC, land cover, and tree canopy density database elements for the contiguous United States based on Landsat TM data (Homer et al. 2004). NLCD has been produced for the nominal years of 2001, 2006 (%IC and land cover only), and 2011 (www.mrlc.gov) (Fry et al., 2011; Homer et al., 2007, 2015). The NLCD %IC dataset classifies each 30 m-×-30 m Landsat TM pixel as 0% to 100% impervious cover in 1% increments based on modeled relationships to a sample of high resolution data (Yang et al., 2003).

Accuracy assessment is an important aspect of NLCD (Stehman et al., 2003, 2008; Wickham et al., 2017), but it has been focused on the land cover database element because fiscal and labor constraints necessitated prioritization of the numerous accuracy assessment objectives (Stehman et al., 2008) that arose from the database design (Homer et al., 2004) and temporal aspect of NLCD. Greenfield et al. (2009) and Nowak and Greenfield (2010) assessed the accuracy of NLCD 2001 %IC through photointerpretation of Google Earth™ images, and Wickham et al. (2013) reported cursory estimates of NLCD 2006 %IC accuracy as part of the land cover accuracy assessment for that NLCD era. There are no complementary estimates of %IC accuracy for NLCD 2011. The objective of this research is to document the agreement between NLCD 2011 %IC and the recently released high resolution (1 m^2 pixels) land cover data for the Chesapeake Bay watershed (chesapeakeconservancy.org). The Chesapeake Bay data, which extend from New York State through Virginia, provide a suitable reference source (Olofsson et al., 2014) over a broad region for comparison to NLCD 2011.

Availability of census- rather than sample-based reference data for the entirety of the 262,000 km^2 Chesapeake Bay watershed (http://www.chesapeakebay.net) creates the opportunity to assess NLCD 2011 %IC accuracy for each 30 m-×-30 m NLCD pixel by converting the Chesapeake Bay data to a binary format and summing over all 1 m^2 units within each NLCD pixel. This simple approach, however, assumes that the two datasets can be registered to each other precisely. That is, each NLCD pixel is comprised of exactly 900 Chesapeake Bay (1 m^2) pixels. Without requisite geometric precision, some portion of the disagreement will be attributable to misregistration (Dai and Khorram, 1998).

Larger assessment units can be used to mitigate the adverse impact of imperfect spatial registration (Stehman and Wickham, 2011). However, use of assessment units other than a NLCD pixel also necessitates inclusion of a secondary objective, which is to assess the sensitivity of agreement results to assessment unit characteristics. Particularly in geography, it has been recognized for a long time that statistical relationships are often dependent on assessment unit characteristics (Dark and Bram, 2007; Openshaw, 1977). This phenomenon, often referred to as the Modifiable Area Unit Problem (MAUP), has two main aspects: zonation and scale (Dark and Bram, 2007). Zonation refers to how the data are organized. For example, data could be organized by county or a square grid whose cells are the average size of the counties. Scale refers to size of the assessment unit (e.g., large number of small units versus a small number of large units). Because the reference data constitute a census rather than a sample, results can be tested for sensitivity to assessment unit characteristics. We envisioned that testing the sensitivity of agreement results to a range of sizes (see, for example, Jelinski and Wu, 1996) would be useful information for users of NLCD %IC products.

2. Methods

Land cover data with a spatial resolution of 1 m^2 for the Chesapeake Bay region (chesapeakeconservancy.org) were compared to the 30 m-×-30 m %IC data from the NLCD 2011 (www.mrlc.gov). The Chesapeake Bay data were mapped using imagery from the National Argriculture Imagery Program (NAIP) acquired during 2013, and other ancillary data that included LIDAR and orthophotography where available (chesapeakeconservancy.org). We used the Chesapeake Conservancy's data for the entire region. These data included six classes: water, barren, trees and shrubs, herbaceous, impervious (other), and impervious (roads). User's and producer's accuracies for the Chesapeake Bay data exceeded 90% (chesapeakeconservancy.org), except user's accuracies for trees and shrubs (87%) and herbaceous (79%). The %IC from the Chesapeake Bay data will hereafter be referred to as the “reference” classification. The modeled relationships used to develop %IC for NLCD 2001 (Yang et al., 2003) were updated to produce NLCD 2006 and 2011 using spectral-based change detection and Classification and Regression Tree (CART) modeling (Xian and Homer, 2010). Each NLCD era is based on the Landsat TM image acquisition date, which can vary somewhat because of cloud cover and other issues that affect data availability. The NLCD 2011 %IC data are nominally 2 years older than the 1 m^2 data for the Chesapeake Bay.

Assessment of agreement between NLCD %IC and reference %IC data was not conducted on an NLCD pixel-by-pixel basis. The geometric precision of NLCD is ± 15 m (i.e., ± 1/2 Landsat TM pixel), whereas the geometric precision of the NAIP imagery use to develop the Chesapeake Bay (reference) data is ± 6 m (http://www.fsa.usda.gov). These precision estimates quantify the accuracy of geometric registration to their individual map bases. They do not guarantee that the two datasets will align to each other accurately. An assessment based on NLCD pixels as the spatial unit was not undertaken because of the difficulty of spatially registering the two datasets to each other so that the ground area covered by each NLCD pixel exactly matched the ground area covered by the 900 reference data pixels.

The red arrow and the locations labeled “1” in Fig. 1 illustrate the challenges related to spatial registration of the two datasets. The road intersection at the red arrow appears to be shifted about 45 m south and 15 m east in NLCD relative to the reference data, and thus comparison of %IC at the intersection would yield values of 0% for NLCD and perhaps 50% for the reference data. Shifting NLCD north and west would appear to align the two datasets at the road intersection, but also would appear to result in misregistration of roads at the locations labeled “1.”

Differences in %IC between NLCD and the reference data illustrated in Fig. 1 may also be attributable to inconsistencies in the definitions of imperviousness, misclassification, differences in image acquisition dates, or a combination of such factors. The polygons located at “2”, “3”, “4”, and “5” reflect some of these differences. The polygon labeled “2,” based on inspection of Google Earth™ imagery, appears to be a 1 ha cinder storage area for winter road maintenance. The polygon does not appear to be a “sealed” surface, and therefore its classification as impervious in the reference data could be debated. In the NLCD land cover data, the 1 ha polygon is subsumed into a tract of cropland that is immediately north and west of it. Both datasets include a barren class, which would be the more correct classification. The polygons labeled “3” and “4” are mines, which also would be included in the barren class in both datasets. The mines are classified as impervious cover in the reference data. Polygon “3” is classified as barren by NLCD, but NLCD misclassifies polygon “4” as deciduous forest. Accuracy assessment of both data sets indicates confusion between barren and impervious cover (Pallai and Wesson, 2017; Wickham et al., 2017). The road labeled “5” was not detected in NLCD. Map and reference label differences at polygons “2” and “5” may also be attributable to differences in acquisition dates between the two datasets. Inspection of historical Google Earth™ imagery suggests that the road and the polygonal cinder storage

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