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Running title: Accuracy Assessment of the 2006 NLCD Percent Impervious Dataset

Abstract

An impervious surface is any surface that prevents water from infiltrating the ground. As impervious surface area increases within watersheds, stream networks and water quality are negatively impacted. The Multi-Resolution Land Characteristic Consortium developed a percent impervious dataset using Landsat imagery as part of the 2006 National Land Cover Database. This percent impervious dataset estimates imperviousness for each 30-meter cell in the land cover database. The percent impervious dataset permits study of impervious surfaces, can be used to identify impacted or critical areas, and allows for development of impact mitigation plans; however, the accuracy of this dataset is unknown. To determine the accuracy of the 2006 percent impervious dataset, reference data were digitized from one-foot digital aerial imagery for three study areas in Arkansas, USA. Digitized reference data were compared to percent impervious dataset estimates of imperviousness at multiple 900m^2, 8,100m^2, and 22,500m^2 sample grids to determine if accuracy varied by ground area. Analyses showed percent impervious estimates and digitized reference data differ modestly; however, as ground area increases, percent impervious estimates and reference data match more closely. These findings suggest that the percent impervious dataset is useful for planning purposes for ground areas of at least 2.25ha.

Introduction

An impervious surface is any surface, natural or manmade, that prevents water from infiltrating the ground and includes rock outcrops, highly compacted soils, paved roads, parking lots, sidewalks, and buildings. Increased overland flow from rain events has been associated with manmade impervious surfaces, which leads to riparian habitat degradation and decreased water quality (Slonecker et al. 2001, Brabec et al. 2002, Shuster et al. 2005). Impervious surface area (ISA) is a measure of imperviousness and is used as an indicator of development and urban sprawl. Degradation of watersheds can occur with ISA as low as 10 to 15 percent (Schueler 1994, Arnold and Gibbons 1996).

Spatial and temporal changes in impervious surfaces are monitored because of the negative impacts that significant levels of imperviousness can have on water quality and riparian habitat. The Multi-Resolution Land Characteristics Consortium (MRLC), which was formed in 1993, provides public domain land cover and other spatial data at landscape scales (Homer et al. 2004). The MRLC created the first National Land Cover Database (NLCD) from Landsat imagery obtained in 1992. This edition of the NLCD consisted of a land cover dataset. Subsequently, the NLCD was updated with Landsat imagery obtained in 2001 and 2006 (Homer et al. 2004, Homer et al. 2007, Fry et al. 2011, Homer et al. 2012). The 2001 NLCD included land cover, tree canopy, and percent impervious datasets, while the 2006 NLCD included land cover, land cover change, and percent impervious datasets (Homer et al. 2012).

NLCD data were derived from remotely sensed satellite imagery. Satellite images contain systematic and random errors, and derived data contain classification errors; therefore, accuracy assessments are needed. The MRLC conducted accuracy assessments of the 2001 and 2006 NLCD land cover datasets and found accuracies ranging from 70 to 80 percent (Homer et al. 2004, Xian et al. 2009). Accuracies were not reported for the percent impervious datasets. Greenfield et al. (2009) conducted an accuracy assessment of the 2001 percent impervious dataset and found imperviousness predictions were underrepresented by 5 percent. The accuracy of the 2006 percent impervious dataset has not been assessed.

The purpose of this study was to evaluate the accuracy of the 2006 percent impervious dataset at multiple ground resolutions. Understanding limitations of these data will allow researchers, government agencies, municipalities, and other end users to make informed decisions regarding use of the percent impervious dataset.

Methods

To determine accuracy of the 2006 percent impervious dataset, impervious surfaces visible in high resolution (i.e., one-foot) digital imagery in three study areas in Arkansas, USA, were digitized using a Geographic Information System (GIS). The study areas were Drew County, Pulaski County, and the area encompassing the city of Hot Springs, Arkansas (Figure 1). These areas were selected because each contains a range of development intensities (rural, urban, and suburban). Imagery was obtained from the Arkansas Geographic Information office download site (http://www.geostor.arkansas.gov). The most recent one-foot digital imagery available for the Pulaski County and Hot Springs study areas was obtained by aircraft between December 2005 and February 2006. These dates correspond with the timeframe that imagery used to create the 2006 NLCD was collected. One-foot digital imagery from 2006 was not available for Drew County; however, one-foot imagery obtained via aircraft in 2010 was available. To maintain the same spatial resolution for reference data in each study area, impervious surfaces for Drew County were digitized using the imagery collected in January 2010.

Approximately three hundred sample locations were randomly generated for each study area. Sample locations for the Pulaski County and Hot Springs study areas were generated in spring 2009 using ESRI ArcMap 9.3 (Environmental Systems Research Institute, Redlands, CA). Detailed sampling procedures were not available for the Pulaski County and Hot Springs study areas. Sample locations were assumed to have been randomly generated using GIS such that 6 30 x 30 cells separated each sampling location. Although methods underlying the sampling schema are unknown, the resultant sampling intensities are similar to those reported in Jarnagin et al. (2004). Ratios of percent impervious dataset cells to sample locations from the Pulaski County and Hot Springs study areas were used to determine the sampling intensity for Drew County (Table 1).

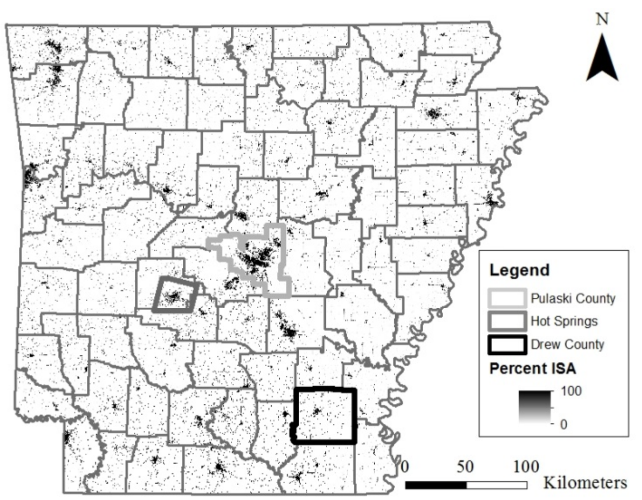

Figure 1: Study sites in Pulaski County, Drew County, and around the city of Hot Springs, Arkansas were chosen because each contains a range of urban, suburban, and rural development intensities.

Table 1: Sampling intensity by study area.

Study area	Number of NLCD cells	Number of sample locations	Cell to sample plot ratio
Pulaski Co.	2,323,175	294	7,902
Drew Co.	2,404,598	342	7,301
Hot Springs	839,554	317	2,648

A 5x5 sampling grid of cells (i.e., 22,500m^2) centered on each sample location was established. Although detailed metadata and procedures for digitizing reference data were not available for the Pulaski County and Hot Springs study areas, it is believed all buildings, parking lots, sidewalks, and roads visible in the imagery within each 22,500m^2 sampling grid were manually digitized (Figure 2). It is also believed, following Brabec et al. (2002), that unimproved or gravel roads were not considered impervious. Following these assumptions, all impervious surfaces visually identifiable within each 22,500m^2 sampling grid in Drew County were manually digitized in spring 2013 using ESRI ArcMap 10.1 (Environmental Systems Research Institute, Redlands, CA). Each 22,500m^2 grid of digitized impervious surfaces was subset to a 3x3 grid of cells (8,100m^2), and a single cell (900m^2), centered on each sample location. Digitized impervious surfaces were considered to be reference data (i.e., ground truth).

To determine if there were differences in accuracy of percent impervious dataset estimates at different ground resolutions, ISA values were calculated for both the percent impervious dataset and reference data for each ground area (i.e., 900m^2, 8,100m^2, and 22,500m^2). Reference data ISA values were calculated by taking the percent of impervious surface coverage within each sampling grid. Percent impervious dataset ISA values were calculated as the average of percent impervious estimates for each cell within a sampling grid. All analyses were performed on similar ground areas (e.g., Pulaski County, Hot Springs, and Drew County 22,500m^2 data were combined in a single database) (Table 2).

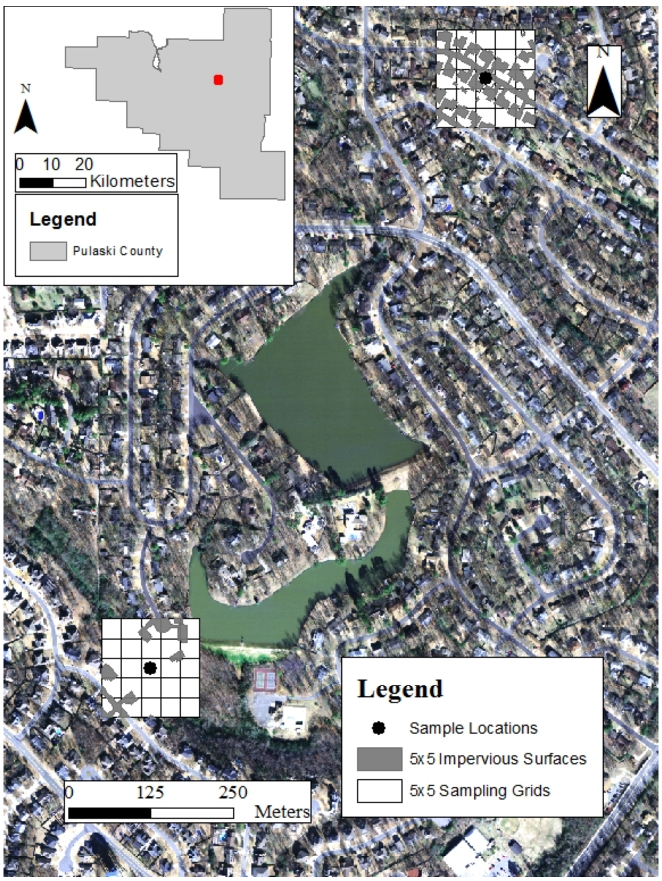

Figure 2: Example of impervious surfaces digitized inside 22,500m^2 sampling grids overlaid on one-foot digital imagery.

Wilcoxon's (1945) signed-rank tests were used for each ground area to determine if percent impervious estimates and digitized reference data were significantly different. Root mean square error (RMSE), mean absolute error (MAE), and systematic error (SE) were also calculated for each sampling grid to characterize accuracy of percent impervious estimates. Equations used for these calculations follow Xian and Homer (2010) and are expressed as:

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(\hat{I}_i - I_i\right)^2\right]^{1/2} \quad (1)$$

$$MAE = \frac{1}{N}\sum_{i=1}^{N}\left|\hat{I}_i - I_i\right| \quad (2)$$

$$SE = \frac{1}{N}\sum_{i=1}^{N}\left(\hat{I}_i - I_i\right) \quad (3)$$

where $\hat{I}_i$ is the NLCD percent impervious dataset estimate for sample i; I_i is the reference data value for sample i; and N is the number of samples.

Table 2: Example of 22,500m^2 database.

Grid number	Study area	NLCD ISA (%)	Reference data (%)
6	Pulaski Co.	1	12
6	Drew Co.	0	0
8	Pulaski Co.	7	6
10	Hot Springs Co.	0	3

A contingency table was constructed for each ground area to quantify overall accuracy, commission error, omission error, and the kappa coefficient (Campbell 2007, Lillesand et al. 2008). The contingency tables were constructed using 10% ISA classes (e.g., 0-10%, 11-20%, 21-30%, etc.).

Results

Cumulative distributions were graphed for each sampling grid size to visually identify differences between the percent impervious dataset and reference data (Figure 3). The distributions show that approximately 95% of cells fall between 0% and 30% imperviousness. Above 30% impervious, the percent impervious dataset and reference data had similar distributions at all three ground areas.

Wilcoxon's signed-rank tests did not show a statistically significant difference between the percent impervious dataset and reference data at the 22,500m^2 ground area; however, there was a statistically significant difference in the data at the 8,100m^2 and

$900m^2$ ground areas (Table 3).

RMSE values ranged between 5 to 10, MAE values ranged between 2 and 4, and SE values ranged between 0 and -1 (Table 4). Contingency tables showed that accuracy of the percent impervious dataset for each ground area ranged from 87% to 89%, and kappa coefficients ranged from 0.32 to 0.52 (Table 5).

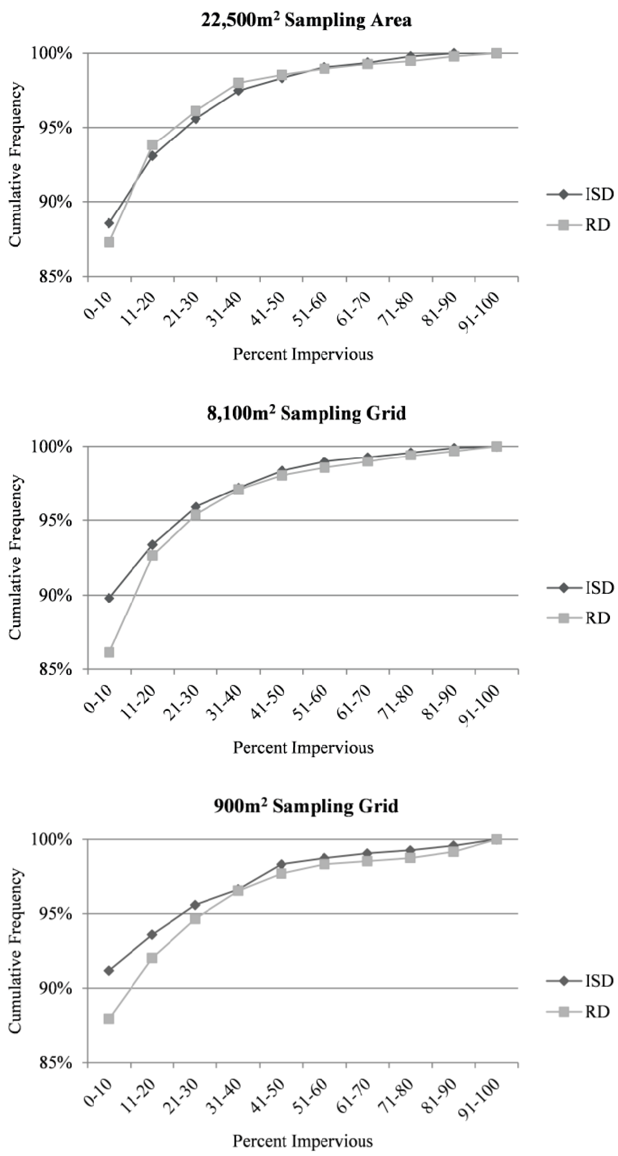

Figure 3: Cumulative distributions for the percent impervious dataset and reference data at $22{,}500m^2$, $8{,}100m^2$, and $900m^2$ ground areas.

Discussion

The cumulative distributions show a greater discrepancy between the percent impervious dataset and reference data when ISA is below 30%; therefore, the percent impervious dataset underrepresents low impervious values. These discrepancies decrease as ground area increases. This indicates the percent impervious dataset is more accurate at predicting ISA at larger ground areas.

Table 3: Signed-rank test of percent impervious dataset and reference data by ground area.

Ground area	Data source	Mean rank	Ties	*z*	*p*
$22{,}500m^2$	NLCD RD	196.35 183.52	574	-1.896	0.058
$8{,}100m^2$	NLCD RD	133.53 152.37	662	-4.124	>.001*
$900m^2$	NLCD RD	87.1 93.5	772	-2.904	0.004*

*Percent impervious mean ranks had a statistically significant difference at the 95% confidence level ($\alpha = 0.05$).

Wilcoxon's (1945) signed-rank tests showed a statistically significant difference between the percent impervious dataset and reference data at the $900m^2$ and $8{,}100m^2$ ground areas. Reference data mean ranks were larger than percent impervious dataset mean ranks, which indicates higher levels of imperviousness were detected in the digitized reference data (Table 3). The lack of a statistically significant difference between the percent impervious dataset and reference data at the $22{,}500m^2$ ground area indicates the percent impervious dataset is more accurate at predicting imperviousness at larger ground areas.

Table 4: Error terms for each sampling grid size.

Sampling grid size	RMSE	MAE	SE
$22{,}500m^2$	5.21	2.05	-0.15
$8{,}100m^2$	6.25	2.35	-0.86
$900m^2$	9.95	3.31	-0.92

Furthermore, errors associated with these data decrease as ground area increases, indicating more accurate ISA predictions at larger ground areas (Table 4). Relatively low MAE values for each ground area show that absolute differences between the percent impervious dataset and reference data are low. SE values are low for all ground areas and negative values show ISA values are larger in the reference data. This indicates the percent impervious dataset underrepresents imperviousness.

Contingency tables for all ground areas showed the overall accuracy of the percent impervious dataset was greater than the common contingency table benchmark of 85% (Table 5). However, kappa coefficients decrease as ground area decreases. This suggests that overall accuracy in small ground areas are more likely to be achieved by chance.

Statistically significant differences between the percent impervious dataset and reference data, high error terms, and low kappa coefficients at small ground areas suggest the percent impervious dataset does not capture small or dispersed impervious surfaces well. Lack of statistically significant differences, low error terms, and high kappa coefficients indicate larger ground areas are more appropriate for use.

Table 5: Overall accuracy and kappa coefficients by sampling grid size.

Ground area	Overall accuracy	Kappa coefficient
22,500m^2	89%	0.52
8,100m^2	87%	0.44
900m^2	87%	0.32

Conclusions

The 2006 percent impervious dataset is an easily obtainable dataset that allows researchers, government agencies, municipalities, and other end users to map the spatial extent and intensity of impervious surfaces across the conterminous United States. When compared to digitized reference data at large ground areas, these data were found to be sufficiently accurate. However, these data may not be suitable for use at fine spatial resolutions due to the tendency to underrepresent imperviousness. Differences in surface types could impact ISA estimates; therefore, further studies are needed to determine how well different impervious surfaces are detected in the NLCD percent impervious datasets.

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