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Authors
Uhl, Johannes H.
Leyk, Stefan
Florczyk, Aneta J.
et al.

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Assessing Spatiotemporal Agreement between Multi-Temporal Built-up Land Layers and Integrated Cadastral and Building Data

Johannes H. Uhl[1], Stefan Leyk[1], Aneta J. Florczyk[2], Martino Pesaresi[2], Deborah Balk[3]

[1] University of Colorado Boulder, Department of Geography, Boulder, CO 80309, U.S.A.
Email: {johannes.uhl; stefan.leyk}@colorado.edu

[2]European Commission – Joint Research Centre (JRC), Institute for the Protection and Security of the Citizen (IPSC), Global Security and Crisis Management Unit, 21027 Ispra, Italy
Email: {martino.pesaresi; aneta.florczyk}@jrc.ec.europa.eu

[3] City University of New York, Institute for Demographic Research and Baruch College, New York, NY 10010, U.S.A.
Email: deborah.balk@baruch.cuny.edu

Abstract

There is an increasing availability of multi-temporal land use and built-up land datasets. However, little research has been done regarding the spatiotemporal uncertainty of these data products. In this work we present an approach that has the potential to be applicable for spatiotemporal evaluation of the novel Global Human Settlement Layer (GHSL) created by automatic classification of global collections of Landsat data recorded in the epochs 1975, 1990, 2000, and 2014. The proposed approach produces the reference data by integrating publicly available parcel and building data and derives agreement statistics with the GHSL.

1. Introduction

The Global Human Settlement Layer (GHSL) project aims to assess the human presence in the planet by estimating the amount of built-up area based on remote sensing data and census data (Pesaresi *et al.* 2015). In Pesaresi *et al*. (2013) the GHSL information production workflow was tested for sensors ranging between 0.5 and 10m spatial resolution, which usually perform very well in detection of built-up areas but are typically constrained regarding data access, redistribution rights, and are typically not available consistently for long periods of time. For these reasons, these data are difficult to use for spatiotemporally uniform and systematic extraction of built-up areas on global, national or even regional level. Therefore, the GHSL workflow was tested with global collections of publicly available Landsat imagery collected in the past 40 years (Pesaresi *et al.* 2016). The Landsat GHSL dataset is available as seamless global mosaic at high spatial resolution (approx. 38m) and for various points in time (1975, 1990, 2000, 2014, see Figure 1a). GHSL data offers promising opportunities for population projections, disaster management and risk assessment (Freire *et al.* 2015; Freire *et al.* 2016), as well as for analysing and modelling urban dynamics and land use change.

Before such novel data products can be made available to the research community, an extensive quality assessment is required. However, such assessments are difficult due to the lack of reliable reference data particularly for earlier time periods and in less developed regions. In this paper we present and discuss a novel approach to evaluate multi-temporal spatial data on built-up land such as GHSL or developed land cover classes using publicly available parcel (cadastral) data integrated with building footprints in the U.S.

The aim of this study is to establish a protocol for future testing the accuracy of fine-scale multi-temporal products derived from automatic classification of satellite data featuring the presence of built-up areas. The selection of the test areas discussed here are driven and constrained by the availability of the reference data and consequently the results derived are not statistically representative of the whole information contained in the GHSL products but merely serve the purpose of testing the proposed approach and inherent data sensitivities.

2. Data and Method

Open data policy makes cadastral, tax assessment and occasionally building data publicly available – often as GIS-compatible format – for many regions in the U.S. Furthermore, parcel data usually contains rich attribute information related to the type of land use, characteristics of the structure and the year when a structure in a parcel has been established (built year). Based on this information snapshots of built-up parcels can be created for the same points in time used in GHSL (Figure 1b). Building outline data are becoming increasingly available and are used here to spatially refine the geometries of parcel units to the built-up areas. This refinement is very effective in rural areas where parcel units can have large area extents. The integration process of parcel data and building data is complex and has to resolve geometric and topological conflicts to be meaningful. Based on the building footprints enriched with parcel information, the built year attribute is used to create reference snapshots of refined built-up areas that correspond to the GHSL time periods (Figure 1c).

In this study, reference datasets were created for 19 administrative regions (e.g., counties and cities) within the U.S. where the required data are publicly available. The reference layer for each study region was rasterized to create a GHSL-compatible spatial resolution (Figure 1d) and compared pixel-wise to the GHSL built-up areas. Confusion matrices were built to derive several measures of agreement (see e.g., Fielding and Bell 1997) that quantify the overall classification agreement between reference data and GHSL in each study region and for each GHSL category (i.e., four time periods and a not built-up class). Agreement measures were created for areas that changed from not built-up to built-up within each time period, and for the overall (cumulative) built-up area identified for each point in time.

Figure 1. (a) GHSL built-up areas, (b) parcel-based reference data, (c) reference data based on building outlines, and (d) final reference dataset rasterized and resampled to GHSL resolution for a subset of Boulder County (Colorado).

Agreement statistics are expected to vary significantly between urban and rural areas. To examine such trends, the percentage of urban area reported in the 2010 U.S. census county summaries was used to classify the 19 study areas into regions of predominantly urban and rural character. Using thresholds of urban area coverage ranging from 30% to 90% (increments of 10%), the behaviour of agreement measures over time was observed for urban and rural study regions.

3. Results

Several agreement measures were calculated a) regarding the area that changed from not built-up to built-up in each time period, and b) regarding the overall (cumulative) built-up area labelled at each point in time. As an example, the evaluation of changes in built-up land shows that User´s accuracy decreases from recent to earlier epochs but increases for the built-up areas before 1975 (Figure 2a). Since the earliest time period usually covers more built-up area than more recent time periods, the GHSL classifier seems to perform better for built-up land prior to 1975 than for small proportions of change to built-up land in recent time periods. For the cumulative built-up land at each point in time, User´s accuracy tends to decrease for earlier time periods (Figure 2b).

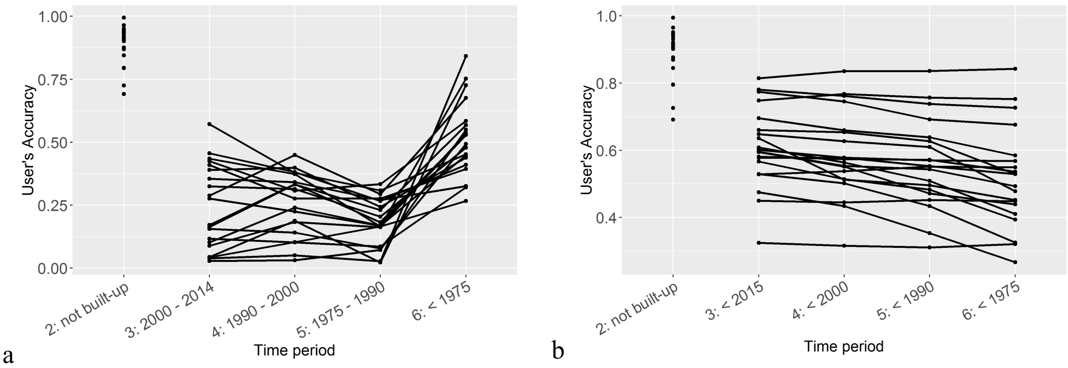

Figure 2. Behaviour of User's accuracy for GHSL built-up labels over time: (a) for changes in built-up area per time period, and (b) for overall (cumulative) built-up areas for each point in time.

As mentioned, the behaviour of GHSL agreement measures over time was analysed separately for urban and rural areas. For a threshold of 50% of urban area coverage the accuracy measures show a different behaviour in urban and rural areas. While the trends of these measures over time are similar for urban and rural areas, the magnitudes differ, considerably. For example, PCC is higher in rural areas than in urban areas (Figure 3a). This effect is particularly strong for the cumulative built-up areas rather than changes in built-up land over separate time periods (not shown). User's accuracy, as another example, shows a similar trend, it is lower in earlier epochs however, it shows higher magnitudes in urban areas than in rural areas (Figure 3b). The results varied with changing threshold for urban/rural distinction but showed similar trends.

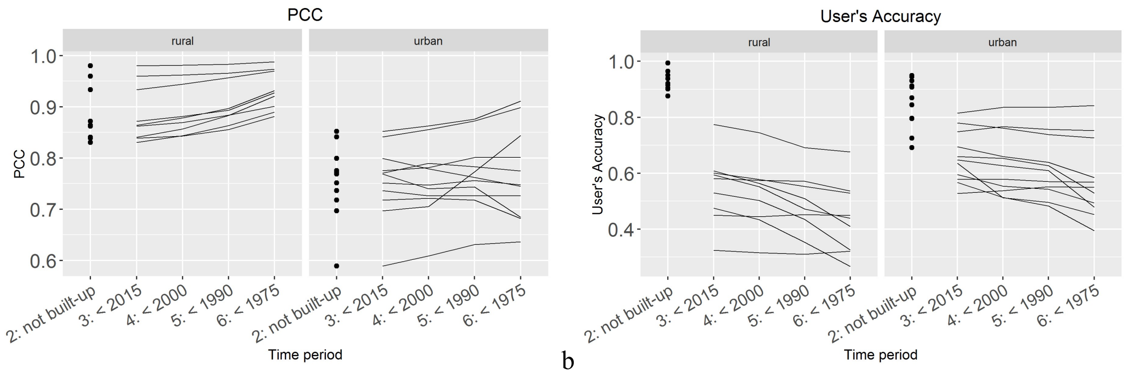

Figure 3. Temporal behavior of (a) PCC and (b) User's accuracy for GHSL overall (cumulative) built-up areas in urban and rural study areas using a threshold of 50% urban area coverage.

4. Discussion

The proposed approach allows assessing spatiotemporal agreement between remote sensing-derived built-up labels such as GHSL and publicly available reference data, such as parcel data including built year information and building outline data. It can be observed that agreement measures vary from recent to earlier epochs, and that these variations show different patterns in urban and rural regions. In addition, different agreement levels are obtained for the assessment of cumulative built-up area for each point in time versus the change in built-up land between two points in time. These results give room for further exploration, interpretation and analyses. However, for an adequate interpretation of the agreement measures, thematic uncertainty in the abstract definition of built-up land in GHSL and temporal inaccuracy of the built-up year in the reference data, as well as spatial uncertainty due to displacement errors between satellite-derived labels and the reference data need to be investigated and properly modelled. In addition to these uncertainties, the sensitivity of the agreement measures to the urban/rural thresholds will need to be tested in more detail including aspects of spatial variation in the agreement measures.

Once these issues are examined a first quantitative evaluation of the GHSL will be performed to provide a broader understanding of inherent uncertainty across space and time in GHSL built-up area and inform the future user community on fundamental quality aspects if GHSL is applied to similar settings in other countries where no validation data may be available.

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