Assessing and Improving the Accuracy of GlobeLand30 Data for Urban Area Delineation by Combining Multisource Remote Sensing Data

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***Abstract*— For a long time, the available global products of the urban area extent were limited to a coarse spatial resolution, e.g., Moderate Resolution Imaging Spectroradiometer (MODIS) global land cover (GLC) 500-m data and European Space Agency GlobCover 300-m data. This limitation was broken by the GlobeLand30 data, which is the world's first 30-m resolution GLC data set. However, detection accuracies of urban areas for the GlobeLand30 data (i.e., artificial surfaces) are not satisfactory. Therefore, in order to refine the detection accuracy of urban areas on the basis of the GlobeLand30 data, we propose a novel framework for urban area delineation by combining a set of remote sensing images and a geographical information system database, including the GlobeLand30 data, the National Land Cover Database (NLCD), the Land Use Interpretation Map (LUIM) of China, and Landsat images. First, the GlobeLand30 and land use/land cover products (e.g., NLCD or LUIM) are overlapped, and the study area is then separated into reliable and unreliable areas with a majority voting rule. Finally, the unreliable areas are confirmed by use of the Landsat data with a multiclassifier system. Experiments were conducted over two study areas that, respectively, represent typical patterns of American and Chinese urban areas: 1) the states of Utah, Mississippi, and Pennsylvania in the U.S. and 2) the provinces of Ningxia, Fujian, and Jilin in China. The results show that the accuracy of the GlobeLand30 data for urban area delineation can be significantly improved by integrating the multisource data and using the multiclassifier system.**

***Index Terms*— Classification, data fusion, GlobeLand30, land cover, land use, Landsat, National Land Cover Database (NLCD), urban.**

I. Introduction

URBAN areas largely comprise buildings, streets, and other infrastructure and concentrate population, energy, and materials. Although occupying only 0.5% of the earth's land surface, urban areas hold half of the world's population and significantly affect our lives. In recent decades, urban areas have been further developed through the process of urbanization, especially in developing countries. This rapid urbanization is one of the most important factors for human-induced land-cover and land-use change, and has led to serious environmental problems, such as air, water, and soil pollution, from local to regional scales and even at a global scale [1].

Remote sensing (RS) data, owing to its rapid revisit, large-area coverage, convenient acquisition, and low cost, have become a major data source for urban area detection and urban dynamic monitoring [1]. In recent years, a number of studies have focused on this topic by exploiting Landsat imagery [2], Moderate Resolution Imaging Spectroradiometer (MODIS) data [3], and other RS images. In [2], Landsat imagery as well as TerraSAR-X data was used to delineate the urban areas of megacities at a series of time points. In [4], Landsat-5 and Landsat-7 data were used to extract the normalized difference spectral vector as spectral features for the mapping of human settlement extent.

In spite of the research progress achieved, it is still quite difficult to map urban expansion globally, since urban areas are rare, heterogeneous, and highly variable across locations [3]. Therefore, for a long time, the available global land-cover (GLC) products of urban areas were limited to a coarse spatial resolution, e.g., the MODIS GLC 500-m data and the European Space Agency GlobCover 300-m data [5]. This limitation has recently been broken by the GlobeLand30 data, which is the world's first 30-m resolution GLC data set, produced by processing more than 20 000 Landsat and HJ-1 (at 30-m resolution) images covering the entire earth's land surface (about 150 million km^2) [6].

However, the detection accuracies of the urban areas for the GlobeLand30 product (corresponding to artificial surfaces) are not satisfactory, with a producer's accuracy of 79.8% and 86.9%, respectively, for 2000 and 2010 [6]. In this context, the objective of this research is to focus on the urban areas, and assess and improve their detection accuracy based on the GlobeLand30 data. To this aim, we propose a novel and efficient framework for urban area delineation by combining multiple RS images and a geographical information system (GIS) database, including the GlobeLand30 data [6], the National Land Cover Database (NLCD) [7], the Land Use Interpretation Map (LUIM) of China [8], and Landsat images. This idea was motivated by the deficiency in the current urban area detection methods, which consider only limited data sources and focus on only one or two RS images at a time. In contrast, the proposed method aims to integrate

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TABLE I
RS AND GIS DATA SOURCES CONSIDERED IN THIS RESEARCH

Source	Producer	Description	Location	Citation or website	Spatial unit
GlobeLand30	National Administration of Surveying, Mapping and Geo-information (NASG)	10 land-cover classes	Global	http://www.globallandcover.com/	30 m
NLCD	Multi-Resolution Land Characteristics (MRLC) Consortium	16 land-cover classes	U.S.	http://www.mrlc.gov/	30 m
LUIM	Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC)	6 first levels and 25 second levels of land-use categories	China	http://www.resdc.cn	30 m
Landsat images	Global Land Cover Facility (GLCF), Goddard Space Flight Center (GSFC)	7 multispectral bands	Global	http://www.landcover.org/	30 m

multiple complementary information sources, and is expected to achieve superior performance compared with the existing land use/land cover (LULC) products at a spatial resolution of 30 m. Meanwhile, in this way, the uncertainties can be gradually reduced by exploiting the different data sources hierarchically.

The RS and GIS data sources considered in this research are described in Section II. The proposed urban area delineation method integrating multisource RS and GIS data is described in Section III. In Section IV, the details of the study areas are provided. The experimental results are presented and analyzed in Section V. The final conclusions follow in Section VI.

II. MULTISOURCE DATA CONSIDERED IN THIS LETTER

In this section, the multisource data considered in this letter for the urban area delineation are listed in Table I and are briefly described as follows.

A. GlobeLand30

In 2010, a GLC mapping project, with the aim of developing a GLC data set at a 30-m resolution, was launched in China [6]. Within a four-year period, this data product was organized by the China National Administration of Surveying, Mapping, and Geo-information, including ten kinds of surface coverage classes for the years 2000 and 2010 [6]. The images utilized for the GlobeLand30 classification included Landsat-5 Thematic Mapper (TM) images, Landsat-7 Enhanced TM Plus images, and HJ-1 multispectral images. In addition to these multispectral images, a large amount of auxiliary data were also used in the process of data production. In this letter, the GlobeLand30 data set of artificial surfaces in 2010 is used.

B. National Land Cover Database

This is a national LULC product for the U.S., created by the Multi-Resolution Land Characteristics Consortium over the past two decades. The NLCD is designed to provide spatially explicit national land-cover data sets across the U.S. The NLCD 2011 product [7] is the most recent national LULC product, with a 16-class land-cover classification scheme at a 30-m resolution. NLCD products have been produced every five years (1992, 1996, 2001, 2006, 2011), and the developed lands derived from the NLCD 2011 product are focused on in this research.

C. Land Use Interpretation Map

The primary goal of the LUIM is to accurately capture the dynamics of the land-use properties in China [8].

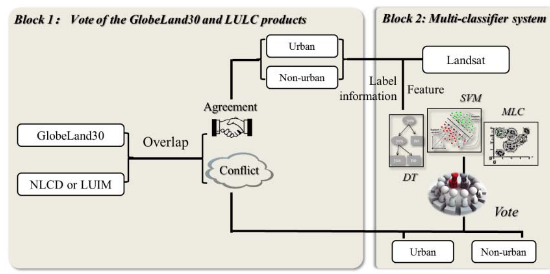

Fig. 1. Proposed urban area delineation method integrating multisource data.

The data set is provided by the Data Center for Resources and Environmental Sciences of the Chinese Academy of Sciences, including 6 first levels and 25 second levels of land-use categories. These land-use categories were generated by visual interpretation of Landsat images at a 30-m spatial resolution. In this letter, we use the built-up areas derived from the LUIM 2010 product.

D. Landsat Images

Landsat-5 TM images contain seven bands (midinfrared, near-infrared, and visible bands as red, green, and blue, with a 30-m spatial resolution; and a thermal band with a 120-m spatial resolution). In this letter, Landsat-5 TM images from 2010 were obtained from the GLC Facility (GLCF) at the University of Maryland. All the bands, except for the thermal band of the TM images, are used in our classification process.

III. METHODOLOGY

The proposed urban area delineation method integrating multisource RS and GIS data is demonstrated in Fig. 1. In detail, the proposed framework consists of two blocks.

A. Block 1: Vote of the GlobeLand30 and LULC Products

Both the GlobeLand30 and LULC products (e.g., NLCD or LUIM) can provide 30-m resolution urban areas. However, the accuracy of the existing LULC products is not satisfactory. For instance, the producer's accuracy of the developed lands is 72% and 74%, respectively, for the NLCD in 2001 and 2006. The first step in the proposed method is to overlap the GlobeLand30 and LULC products (e.g., NLCD or LUIM) and separate the urban areas and nonurban areas into reliable and unreliable areas. For simplification, a majority voting strategy is employed, i.e., the regions that are labeled as urban or nonurban areas (referred to as U and NU in the following text) by both the products are viewed as reliable, and the remaining areas are unreliable or conflicts, which are further processed by the Landsat images. It should be noted that the reliable areas are subsequently used to generate training samples for the multiclassifier system, so as to automate the processing (see Block 2).

B. Block 2: Multiclassifier System

The residual conflict areas are finally classified by a multiclassifier system [9]. The classifiers considered in this research are the maximum likelihood classifier, decision tree, and support vector machine. The decision rule of the multiclassifier system is majority voting, i.e., a pixel is identified as urban or nonurban when at least two of the three classifiers show the same prediction. In order to ensure the automation of the proposed scheme, all the training samples are selected from the reliable areas for both the U and NU pixels. In this letter, 5000 urban area pixels and 5000 nonurban area pixels in each state or province were randomly collected as training samples.

The merits of the proposed framework are summarized as follows.

1) *Integrative:* The data sets considered in this research refer to existing LULC products and RS images. Note that the data and images are not simply stacked, but are adequately exploited in a hierarchical way.
2) *Efficient:* The whole processing flow aims to gradually reduce the uncertainties for urban area delineation by only focusing on the unreliable pixels and the conflicts between different data sources. Most of the urban extent is identified by integrating the existing LULC products, and the original Landsat images are only processed if necessary (i.e., when there is a disagreement between the GlobeLand30 and LULC products).
3) *Accurate:* Nearly all the urban areas are determined by at least two data sources, and the most uncertain regions are identified by Landsat imagery. Moreover, the classification accuracy for the most uncertain areas is guaranteed by a multiclassifier ensemble strategy [9].
4) *Automatic:* The proposed scheme for multisource data urban area mapping is fully automatic, and does not require sample collection or manual editing. The training samples input to the classifiers can be automatically generated from the reliable areas.

IV. Study Areas

In order to assess the quality of the GlobeLand30 data and to validate the proposed method, the two study areas (U.S. and China) and their corresponding LULC data sets (NLCD and LUIM) were considered for the urban area delineation.

The states of Utah, Mississippi, and Pennsylvania were selected in the U.S. (Fig. 2). These states represent different urban landscapes in the U.S. On the one hand, these three specific test areas have different geographic environments, such as location, landform, climate, etc. For instance, according to the Köppen Climate Classification System [10], the states of Utah, Mississippi, and Pennsylvania belong to dry, temperate, and continental climates, respectively. On the other hand, the socioeconomic characteristics (e.g., gross domestic product population) of these three specific test areas also vary, as illustrated in Table II.

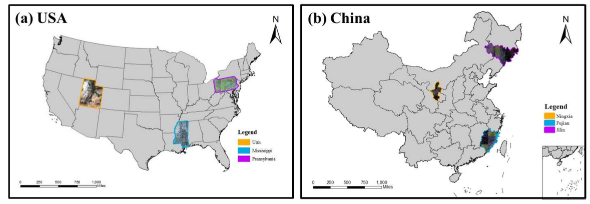

Fig. 2. Study areas. (a) Three selected states in the U.S. as well as their 2010 Landsat images. (b) Three selected provinces in China as well as their 2010 Landsat images.

(a) Utah (b) Mississippi (c) Pennsylvania

Fig. 3. Results produced by the proposed method in the three selected states of the U.S.

TABLE II

Socioeconomic Characteristics of the Selected States/Provinces

Country	State/Province	GDP (millions)	Population (thousands)
U.S.	Utah	118,491 USD	2,764
	Mississippi	95,539 USD	2,967
	Pennsylvania	585,650 USD	12,702
China	Ningxia	168,965 CNY	6,330
	Fujian	1,473,712 CNY	36,930
	Jilin	866,758 CNY	27,470

Likewise, we selected the provinces of Ningxia, Fujian, and Jilin in China. The geographic environments and socioeconomic characteristics of these provinces are compared in Fig. 2 and Table II.

V. Results and Discussion

In this section, we discuss the results produced by the proposed method as well as the existing products for the two study areas.

A. Urban Area Delineation in the U.S. by Combining the GlobeLand30 Product and the NLCD

The results produced by the proposed method are shown in Fig. 3 for the three states of the U.S. The regions in white represent the urban areas, while the dark areas represent the nonurban areas.

A number of test regions were randomly selected from the three states to validate the urban area mapping accuracy of the different products (Fig. 4). Meanwhile, in order to better show the ground reference and evaluate the quality of the different products, the original Landsat images, as well as high-resolution images derived from Google Earth, are also displayed.

By observing the examples in Fig. 4, it can be generally stated that the urban area extent delineated by GlobeLand30 is subject to omission errors. This phenomenon is consistent

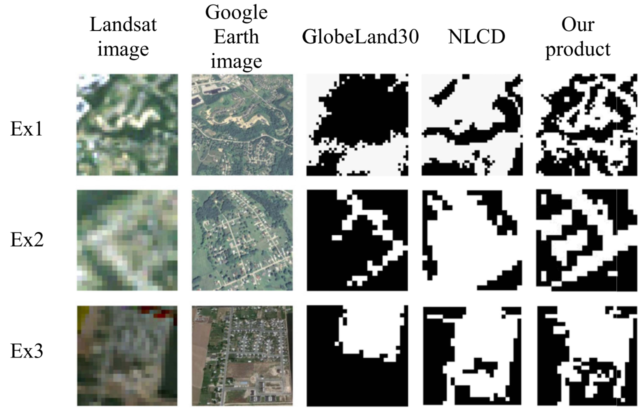

Fig. 4. Some test examples randomly selected from the study areas.

with the accuracy assessment reported in [6], where 13.3% of the urban areas are wrongly identified as other land-cover classes. On the other hand, however, it can be clearly seen that the proposed method improves the quality of the GlobeLand30 product by introducing additional data sources. Specifically, in Ex1, where a residential scene is shown, a number of large roofs are omitted by GlobeLand30 but are identified by the proposed method. In Ex2, which is also a residential region, the urban area extent extracted by the proposed method is more complete than that of GlobeLand30. Moreover, by comparing the NLCD and our product, it can be seen that both the products are accurate, but the results of the proposed method retain more details and better preserve the shape of the urban areas.

A quantitative accuracy assessment is provided in Table III, where the test samples for the urban (102 058 pixels) and nonurban (94 950 pixels) regions were carefully identified by manual photointerpretation from the Google Earth images. It should also be noted that the test sites were randomly selected from the study areas.

The quality of the NLCD and our urban area delineation product are satisfactory, i.e., the overall accuracies (OAs) of both the data sets are greater than 80%. In particular, the OA of our product is greater than 90%. The user's accuracy of the urban areas for the GlobeLand30 product is 81.5%, which is close to the results reported in [6], i.e., 86.7%. The producer's accuracy for the GlobeLand30 product is 70.1%, lower than the NLCD and our product, which is consistent with the observation made in Fig. 4, i.e., the urban areas derived from the GlobeLand30 product are underestimated to some extent. On the basis of the GlobeLand30 product and the NLCD, whose OAs for urban area delineation are 76.6% and 82.9%, respectively, the proposed method significantly improves the quality of the existing products, obtaining an OA of 91.2%. The increase in the accuracy can be attributed to the proposed multilevel urban area delineation scheme, where the uncertainties are reduced by introducing additional data sources.

B. Urban Area Delineation in China by Combining the GlobeLand30 Product and the LUIM

For the three provinces of China, the urban area delineation results obtained by the proposed method are shown in Fig. 5.

TABLE III

Accuracy of the Urban Area Delineation Obtained by the GlobeLand30 Product, the NLCD, and Our Product. (a) GlobeLand30, Kappa = 0.533, OA = 76.6%. (b) NLCD, Kappa = 0.666, OA = 82.9%. (c) Our Product, Kappa = 0.824, OA = 91.2%

	Urban	Non-urban	Overall	UA (%)
Urban	72340	16448	88788	81.47
Non-urban	29718	78502	108220	72.54
Overall	102058	94950	197008	
PA (%)	70.08	82.68		

(a)

	Urban	Non-urban	Overall	UA (%)
Urban	94885	22619	117504	80.75
Non-urban	7173	68331	79504	90.50
Overall	102058	94950	197008	
PA (%)	92.97	75.13		

(b)

	Urban	Non-urban	Overall	UA (%)
Urban	92071	7248	99319	92.70
Non-urban	9987	87702	97689	89.78
Overall	102058	94950	197008	
PA (%)	90.21	92.37		

(c)

(a) Ningxia (b) Fujian (c) Jilin

Fig. 5. Results produced by the proposed method in the three selected provinces of China.

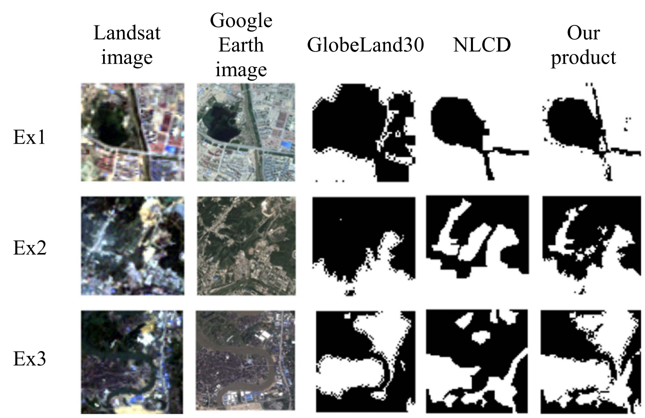

Fig. 6. Some test examples randomly selected from the study areas.

A number of test regions were randomly selected for visual comparison (Fig. 6) and a more precise analysis (Table IV). Moreover, the test samples for the urban (122 512 pixels) and nonurban (112 448 pixels) regions were carefully identified by manual photointerpretation based on the Google Earth images.

From the qualitative and quantitative results shown above, it can be seen that the results of the proposed method are more consistent with the real boundaries compared with the GlobeLand30 product and the LUIM. Moreover, the proposed

TABLE IV

ACCURACY OF THE URBAN AREA DELINEATION OBTAINED BY THE GlobeLand30 Product, the LUIM, and Our Product. (a) GlobeLand30, Kappa = 0.579, OA = 78.9%. (b) LUIM, Kappa = 0.765, OA = 88.3%. (c) Our Product, Kappa = 0.840, OA = 92.0%

	Urban	Non-urban	Overall	UA (%)
Urban	91719	18846	110565	82.95
Non-urban	30793	93602	124395	72.25
Overall	122512	112448	234960	
PA (%)	74.87	83.24		

(a)

	Urban	Non-urban	Overall	UA (%)
Urban	108938	13989	122927	88.62
Non-urban	13574	98459	124395	87.88
Overall	122512	112448	234960	
PA (%)	88.92	87.56		

(b)

	Urban	Non-urban	Overall	UA (%)
Urban	112043	8269	120312	93.13
Non-urban	10469	104179	114648	90.87
Overall	122512	112448	234960	
PA (%)	91.45	92.65		

(c)

TABLE V

ACCURACY OF THE URBAN AREA DELINEATION OBTAINED USING ONLY THE LANDSAT DATA SOURCE

	Urban	Non-urban	Overall	UA (%)
Urban	83587	16064	99651	83.88
Non-urban	18471	78886	97357	81.03
Overall	102058	94950	197008	
PA (%)	81.90	83.08		
Kappa = 0.649, OA = 82.4%				

method improves the accuracy of the GlobeLand30 product for urban area delineation. By fusion of the GlobeLand30 and 30-m LULC products (e.g., NLCD or LUIM), we can achieve more accurate urban area delineation results at the spatial resolution of 30 m. The proposed method is able to delineate urban areas in both America and China effectively, and has the potential to be extended to other countries.

C. Comparison With the Classification Results Obtained Using Only Landsat Data

Table V shows the accuracy of the classification results obtained using only Landsat data based on the multiclassifier system for the randomly selected test regions in the U.S., where it can be seen that this method produces a much lower accuracy than the proposed method.

Such a result can be potentially explained by the fact that the spectral information about the Landsat data source is insufficient for delineating urban areas. For instance, the bare land and the urban areas have a similar spectral response. Thus, it is difficult to discriminate the urban areas from bare land using only the Landsat data source. Moreover, the training samples need to be obtained by detailed visual interpretation and exhaustive field campaigns in the study area, which will take a lot of time and manual work for training the classifiers. The existing LULC products (NLCD), which have been edited manually, show more accurate results than the method using only the Landsat data source based on the multiclassifier system. Therefore, in this letter, we aim to produce a more accurate urban area map by integrating the existing LULC products, and only classifying the unreliable pixels from the Landsat data.

VI. CONCLUSION

The GlobeLand30 data, which have recently been released to the public, is the world's first 30-m resolution GLC data set. This research was aimed at assessing the detection accuracy of urban areas based on the GlobeLand30 data, and improving its accuracy by utilizing additional data sources. Specifically, we have proposed a multilevel scheme integrating multiple information sources, which can reduce the uncertainties for urban area delineation gradually and efficiently. The proposed scheme consists of two blocks: 1) vote of the GlobeLand30 and LULC products, such as the NLCD or the LUIM of China, to separate the urban areas into reliable and unreliable areas and 2) the multiclassifier system to classify the unresolved regions. The proposed scheme was tested with randomly selected samples from three states of the U.S. (Utah, Mississippi, and Pennsylvania) and three provinces of China (Ningxia, Fujian, and Jilin). The experimental results confirm that the proposed method can significantly improve the urban area mapping quality of the existing LULC products, e.g., GlobeLand30, NLCD, and LUIM. Additionally, it should be noted that the training samples input to the classifiers can be automatically generated from the existing urban area products (reliable areas), which can reduce the cost of manual labeling.

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