Validation of urban boundaries derived from Global population density data, MODIS and nighttime lights satellite imagery

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Abstract
Global population density data compiled on a 30" X 30" latitude/longitude grid. Census counts were apportioned to each grid cell based on likelihood coefficients, which are based on proximity to roads, slope, land cover, nighttime lights, and other information. Population density data integrated with MODIS and nighttime light DMSP data have been proposed as a useful tool for monitoring urban expansion around the world, but determining appropriate thresholds for delineating cities remains a challenge. In this study we present a new approach. We used coarse resolution satellite data to delimit urban boundaries for cities with different level of urbanization and economic development, and compared the results against boundaries derived from fine-resolution Landsat ETM+ imagery and other existed continental scale urban map. Our comparison highlights population density data integrated with MODIS and nighttime lights DMSP data are good source for global urban mapping.

Key word: Urban mapping, population density data, MODIS, DMSP, Landsat ETM+

1. Introduction

Approximately half of the World population lives in urban areas. Urban areas are expanding rapidly in many parts of the world. 90% of urbanization is occurring in low-income countries, however, it is difficult to measure accurately rates of urban growth. While such information is more readily available for high-income countries, maps of settlements in low-income countries are often outdated, inaccurate or nonexistent.

Satellite remote sensing has long been a useful alternative for mapping the expansion of urban uses. However, common approaches remain problems. Imagery from fine-resolution sensors such as Landsat or SPOT provides a level of detail sufficient to distinguish urban from non-urban land uses in most cases. Unfortunately these sources are too expensive for most university researchers to acquire and process at continental scales. Imagery from coarse resolution sensors such as the nighttime lights DMSP data, are poorly registered, and exhibit "blooming" effects that inflate city boundaries (Elvidge et al., 1996). Recent coarse resolution global urban mapping from MODIS and GLC2000 were unsatisfactory, because of tedious process of training data collection. Population density data integrated with MODIS and nighttime lights DMSP offer a opportunity for easily and correctly mapping urban areas (Alimujiang et al., 2006) .

A major challenge for applying population density data with MODIS and DMSP imagery to delineate urban area is choosing appropriate thresholds. This paper describes ongoing efforts to produce reliable representations of urban areas at 1 km resolution, as part of a larger project of GLCNMO (Global Land Cover National Mapping Organization). The primary goal of this paper is to map GLCNMO urban land cover at 1km spatial resolution by Population density data, DMSP and MODIS-NDVI data. Three major tasks were involved in this study. First threshold population density data and MODIS – NDVI data based on continents with the reference of fine-resolution Landsat ETM+, then classified urban and not-urban class. The second task was to combine urban derived from population density with DMSP data and MODIS-NDVI data. Third task was to validating the final urban mapping with Landsat ETM imagery also other existed continental scale urban maps. Our objective is to contribute to the development of rules for deriving more accurate urban boundary information from population data, MODIS and DMSP. If such a rules can be developed, it will be more useful in monitoring the rate of urbanization around the globe.

2. Data and methods

2.1. Data

(1) Population density data: Global population data compiled on a 30" x 30" latitude/longitude grid. Census counts were apportioned to each grid cell based on likelihood coefficients, which are based on proximity to roads, slope, land cover, nighttime lights DMSP, and other information. This data downloaded following website (www.ornl.gov/sci/landscan/index.html).
(2) DMSP-OLS data: The files are cloud-free composites made using all the available archived DMSP-OLS smooth resolution data for calendar years. The products are 30 arc second grids, spanning -180 to 180 degrees longitude and -65 to 65 degrees latitude. A number of constraints are used to select the highest quality data for entry into the composites. (http://www.ngdc.noaa.gov/dmsp/maps.html)
(3) MODIS-NDVI data: MODIS/Terra Nadir BRDF Adjusted Reflectance 16 Day L3 global 1km SIN grid product (MOD43B4NBAR) data (MODIS) with seven bands (band 1-7) were used. MODIS data in 2003,starting from 3 December 2002 to 16 December 2003, were acquired from USGS in 10d x 10d of Sinusoidal format. These data were then mosaic and reproject into Geographic Latitude/Longitude. NDVI was calculated using following formula.NDVI= (NIR-Red) / (NIR+Red). A Maximum Value Composition (MVC) was then applied to all NDVI images with the aim of selecting pixels less affected by clouds and other atmospheric perturbations (Holben, 1986).
(4) Validation data: Landsat Enhanced Thematic Mapper (ETM+) images, which were reasonably close in date to the time frame of the Population data imagery, were acquired from Global Land Cover Facility at the University of Maryland (http://glcfapp.umiacs.umd.edu/). Visually interpolate ETM data was compared with 1km resolution GLCNMO urban map.
(5) Other urban map: Three global urban maps were obtained for comparing. The Digital Chart of the World's (DCW) populated places was developed originally for the US Defense Mapping Agency (DMA) using DMA data. DCW coverage is represented as polygons at 1:1000000 scales(Danko, 1992). A global land cover classification at a spatial resolution of 1 km, using 14 years of imagery from the NASA/NOAA Pathfinder Land (PAL) Advanced Very High Resolution Radiometer (AVHRR) data set (Hansen et al., 1998) was downloaded from the Global Land Cover Facility, University of Maryland (URL: http://www.glcf.umiacs.umd.edu/data/landcover/), and the "urban" land cover class extracted. GLC2000 (Global Land Cover 2000) at a spatial resolution of 1km was obtained from the website (http://www-gvm.jrc.it/glc2000/Products/)

2.2. Methodology

2.2.1 Delineating Urban lands in Landsat ETM+ data

We identified urban lands in our study areas by performing the commonly used supervised maximum likelihood classification on each. Performing this classification without the use of a priori probabilities, we initially produced as many as 10 classes of land cover. We then drew on our knowledge of the study areas and additional published maps to merge these classes into urban and non-urban land use classes.

2.2.2 Processing population density data, MODIS and DMSP

Different thresholds were given population density data, MODIS-NDVI and DMSP, respectively based on continents and regions with the reference of fine resolution Landsat ETM+. When using population density data, higher threshold area required with higher levels of population density continents. Lower thresholds are required lower levels of population density with higher levels of economic development places. When applying NDVI data, higher threshold are given to the urban with low vegetation cover, lower thresholds are given to the urban with higher vegetation cover.

2.2.3 Integrating population density, MODIS and DMSP

Nighttime lights DMSP data used to exclude small villages area in the urban map derived from population density data. MODIS-NDVI applied to exclude large parklands amidst urban areas (i.e. Golden Gate Park or Mount Tamalpais in San Francisco and Kamakura area in Tokyo) or mixed agricultural–industrial zones (Fig.1).

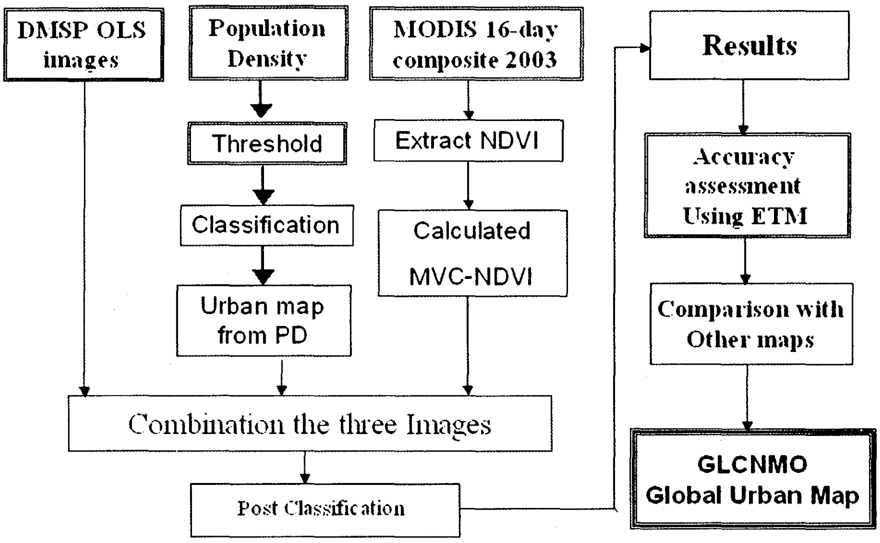

Fig.1 Flow chat of methodology

3. Result and discussion

Using the ETM-derived urban land use classes as a standard, we performed an accuracy assessment on the GLCNMO urban boundaries images to produce confusion matrices summarizing the GLCNMO urban by integration population density data with MODIS and DMSP is acceptable or not. We also compared the overall land area falling within the GLCNMO urban boundaries with the Landsat ETM-derived area, to draw attention to difference in shape and position. The result of these comparisons urban derived from ETM with GLCNM urban are summarized in fig.2.

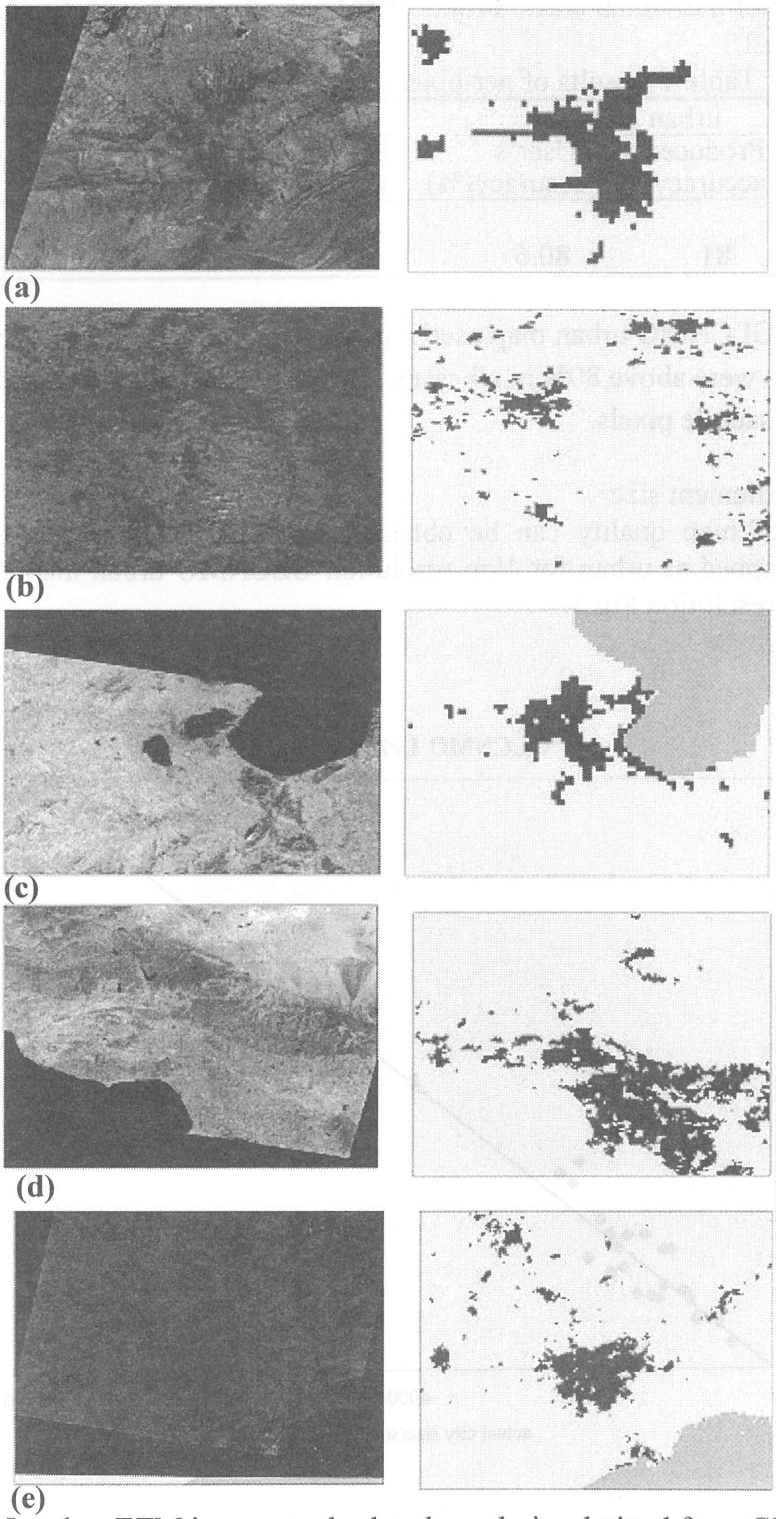

Fig.2 Landsat ETM images and urban boundaries derived from GLCNMO
(a) Urumqi, China in Asia. (b) Birmingham, UK in Europe. (c) Tunis, Tunisia in Africa (d) Los angels, USA in North America. (e) Sao Paulo Bazil in South America

3.1 per-pixel comparison

The per-pixel agreement between the Landsat ETM+ data and GLCNMO urban land cover was examined at the level of individual cities. Producer's, User's and overall accuracies were calculated and displayed in table.1.

Table.1 Results of per-pixel comparison

Urban map	urban class		Non-urban class		overall
	Producer's accuracy(%)	User's accuracy(%)	Producer's accuracy(%)	User's accuracy(%)	Accuracy (%)
GLCNMO	81	80.6	93	93.2	89.8

Table.1 result shows GLCNMO urban map user's, producer's and overall accuracies for both urban and non-urban classes were above 80% in all cases. This indicates accurate classification of both urban and non-urban sample pixels.

3.2 Comparison of settlement size

A second measure of map quality can be obtained from estimates of city size. This method compares the area mapped as urban for 1km resolution GLCNMO urban map against the Landsat ETM+ data at a 30m resolution Fig.3.

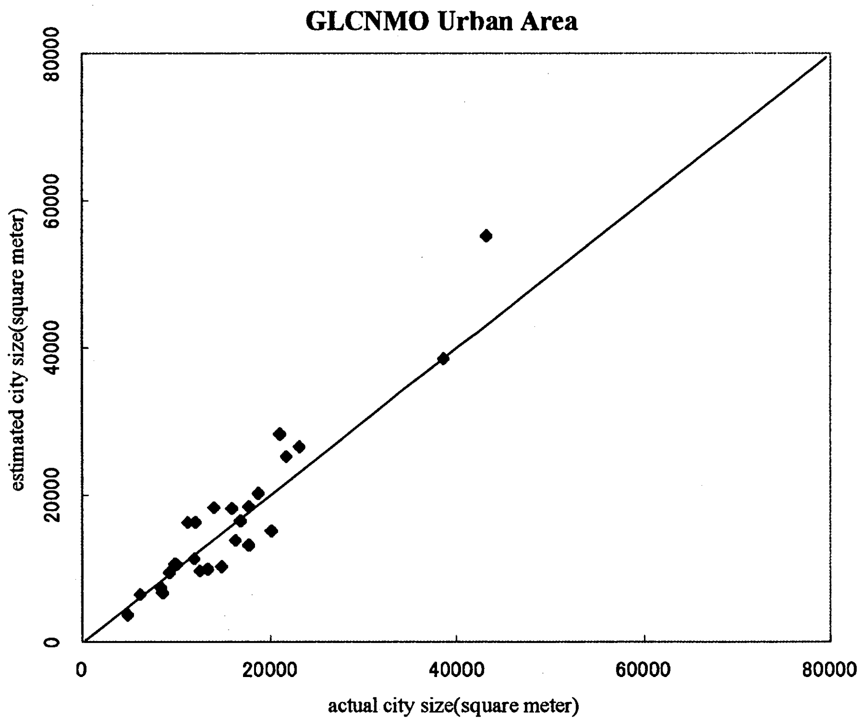

Fig.3 a comparison Landsat ETM-estimated settlement size against estimated settlement size by GLCNMO

The location of each of the points above or below the one-to-one line on the scatterplots indicates whether an urban area has been overestimated or underestimated. Fig.3 shows that urban area is estimated accurately for many areas, there is overestimated in some cases and underestimated in others by GLCNMO.

4. GLCNMO urban map comparison with other urban map

Effective use of classified maps requires thorough analysis and quantification of map quality. Each raster 1 km urban map (DMSP-OLS, GLC2000, DCW, GLCNMO) was coregistered to uniform Goode`s Interrupted Homolosine projection. Fig 4 shows a subset of each of the four maps under test for Cheng du China.

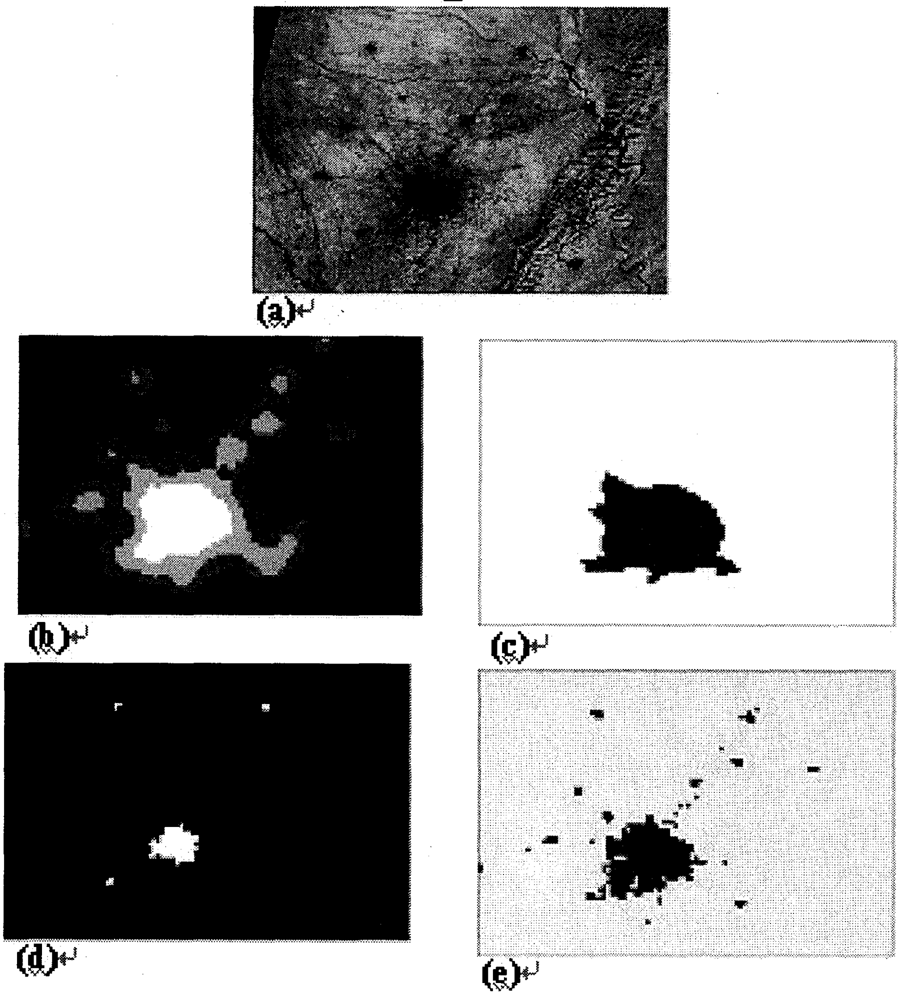

Fig.4 Chengdu mapped by the four settlement maps under test, with the high resolution Landsat ETM. The Chengdu area showing (a) 30m Landsat imagery (urban areas appear purple); (b) the nighttime lights DMSP data (blue boundary represents commonly used threshold); (c) the urban data from the GLC2000; (d) the urban map from DCW; and (e) GLCNMO Urban map produced in this research

Fig.4 shows that nighttime lights DMSP data overestimate urban area (fig.4-b), the GLC2000 data, overestimated some area and underestimated other (fig.4-c), the DCW data underestimated urban area. And GLCNMO urban map achieves the closest and least biased fit to the "true" city size.

4. Conclusion

These results demonstrate that, for cities at different levels of development, quite different thresholds are required when using population density imagery to delineate areas that approximate the urban areas seen in Landsat TM imagery. Higher thresholds are required with higher levels of population density continents. Lower thresholds are required lower levels of population density with higher levels of economic development places. We have shown that it is not possible to settle upon a single threshold that can be used to delineate urban boundaries across the board, it leaves open the possibility that thresholds can be chosen for continents at comparable levels of Population density, development and urbanization.

Compared with any other existed 1km resolution continental scale urban map, GLCNMO is more accurate. The population density data integrate with nighttime lights DMSP and NDVI offers a useful perspective for monitoring the extent and level of urbanization at a global scale.

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