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An Assessment of Urbanization Using Historic Satellite Photography: Columbus Metropolitan Area, Ohio, 1965

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Abstract : We present an analysis of urban development and growth with reconnaissance satellite photographs of Columbus metropolitan area acquired by the Corona program in 1965. A two-dimensional polynomial linear transformation was used to rectify the photos against United State Geological Survey (USGS) Large-scale Digital Line Graph (DLG) data georeferenced to Universal Transverse Mercator (UTM) coordinates. The boundaries of the Columbus metropolitan area were extracted from the rectified Corona image mosaic using a Bayesian approach to image segmentation. The inferred 1965 urban boundaries were compared with 1976 USGS Land Use and Land Cover (LULC) data and boundaries derived from 1988 and 1994 Landsat TM images. The urban area in and around Columbus approximately doubled from 1965 to 1994 (~110%) along with population growth from 1960 to 1998 (~50%). Most of the urban expansion results from development of residential units.

Key Words : Corona, Columbus, Urban sprawl, Landuse changes.

1. Introduction

The U.S. Census Bureau (1998) defines a metropolitan area as a core area containing a large population nucleus, together with adjacent communities having a high degree of economic and social integration within that core. The USGS Urban Dynamic Research Program (US Geological Survey 1999) reported that metropolitan areas in the United States are growing at unprecedented rates, creating extensive urban landscapes.

Urban sprawl is a pressing issue for all metropolitan areas in the United States (Buchanan and Acevedo 1997). Sprawl modifies patterns of regional land use and land cover. Land use changes associated with urban sprawl can be extensive, but the gradual evolution of land usage from rural to urban applications can mask impacts on the environment and quality of life. One way to understand and document land use change and urbanization is to establish benchmark maps. These maps can be compiled from traditional ground surveying and assessment techniques, aerial photography, and satellite imagery. Satellite imagery is particularly valuable because of accessibility to any part of the world, large spatial coverage for placing changes in a

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regional context, and increasing resolution for better interpretation.

Landsat (NASA's Goddard Space Flight Center 1998) and Spot (CNES and SPOT 1988) satellites have been providing multispectral images of the Earth continuously since the early 1970's. Landsat carried Multi-Spectral Scanner (MSS) and Thematic Mapper (TM) imaging sensors. TM provides 7 bands of coverage and MSS provides 4 bands of coverage. MSS provides 80-m resolution and TM with 30-m resolution in the VIS/IR bands and 120-m in the thermal/IR bands. Spot carried two High Resolution Visible (HRV) pushbroom instruments, which provide 20-m resolution multispectral imagery and 10-m panchromatic imagery. More recently, Landsat Enhanced Thematic Mapper+ (ETM+) and IKONOS data became available. The ETM+ operates at three different resolutions, 30 meters for bands 1-5, and 7, 60 meters for band 6, and 15 meters for band 8, and IKONOS operates at two different resolutions, 1-m panchromatic and 4-m multispectral.

Until recently, researchers were limited to airborne data as a source for high-resolution broad-scale coverage for the era preceding Landsat. Now more extensive coverage at higher resolution has become available through declassification of early satellite reconnaissance photography. Corona (McDonald 1995 and Wheelon 1997), along with Argon and Lanyard, are the first three operational imaging satellite reconnaissance systems used from the late 50's through the early 70's. Early Corona satellites (KH-1, KH-2, and KH-3) carried a single panoramic camera, while later Corona satellites (KH-4, KH-4A, and KH-4B) carried two panoramic cameras looking 30 degrees apart: one looking forward and the other looking aft. A rotating panoramic camera with approximately 61-cm focal length scans over a 70? arc at a constant angular rate and photographs an area approximately 18-km by 220-km during a single scan at an altitude of approximately 180-km. These satellites collected high-resolution imagery ranging from 12-m to 2-m between 1960 and 1972. These early systems extend the historical satellite imaging record more than a decade into the past. They provide a timely, systematic, and comprehensive coverage of the Earth's surface available to urban environmental researchers. From these data, scientists can monitor land use patterns, which are critical to assessing the environmental impact of population growth and urbanization.

The primary objective of this study is to build a spatially referenced temporal database that reflects urban growth for the Columbus, Ohio metropolitan area from 1965 to 1994. To do this, we combined early historical satellite data with a more recent land use coverage data and more recent satellite images. The land use data for this study is the USGS 1:250,000 Land Use and Land Cover (LULC) data (Anderson *et al.* 1976). Two Landsat TM images acquired in 1988 and 1994 provide more recent satellite data.

2. Materials and Methods

The 1965 reconnaissance photographs collected by a KH-4A system over Columbus consist of approximately 3-m spatial resolution filmstrips. Two filmstrips were scanned at 7-μm pixel resolution using the Intergraph PhotoScan TD®. This pixel resolution is commensurate with a spatial resolution of the original film product. The Corona data were co-registered to USGS Large-scale Digital Line Graph (DLG) data derived from USGS 1:24,000 topographic maps (U.S. Geological Survey 1990) using a two dimensional polynomial linear transformation. 30 geometrically, well-distributed ground control points (GCP) were selected from the USGS DLG data and were used during rectification of the scanned image. Root mean square (RMS) error between the measured GCPs and the predicted image positions based on the polynomial transformation was about 15-m (5 pixels). Finally two rectified image strips were mosaicked and radiometrically balanced using a blending function (Davies 1990) to remove the seamline between the two strips (Fig. 1).

We used urban or built-up land classes of the LULC data to delineate urban boundaries on all of our image data. The classes include seven subcategories: residential, commercial and services, industrial, transportation, industrial and commercial complexes, mixed urban or built-up land, and other urban or built-up land (Anderson *et al.* 1976). Because the classes correspond to structures identifiable in the satellite imagery, we believe that we have a consistent comparison between the three data sets. Finally a GIS system was used to compile and integrate the temporal urban boundary data between 1965 and 1994.

Urban boundary information was manually digitized from the 1965 Corona mosaic. Urban signatures were manually assigned by comparing the mosaic with attribute files associated with the LULC data in the city core. A similar approach was used to identify rural type-areas. Then these signatures were manually interpreted across the rest of the image. In addition, photo-interpretation of urban features such as commercial and industrial building blocks, transportation networks, streams, and family home blocks was done. Note that the generalized urban boundary may contain undeveloped land that is completely surrounded by developed areas (Bell *et al.* 1995). Consequently, small rural-type areas (e.g., school research farms) contained within urbanized areas were ignored during boundary mapping.

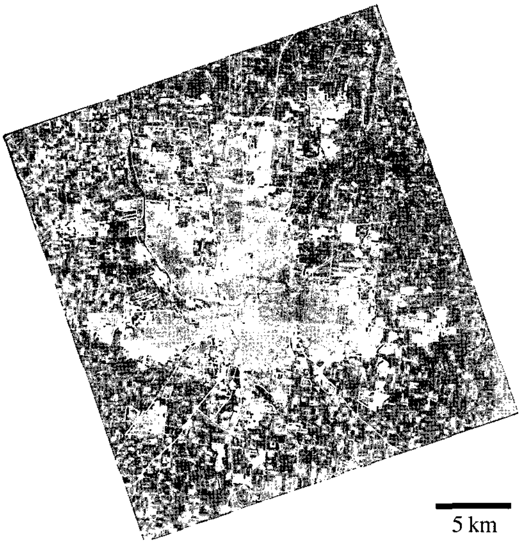


Fig. 1. Urban boundaries (white) derived from a 1965 reconnaissance satellite image of metropolitan Columbus.

We obtained two preprocessed, georeferenced 1988 and 1994 Landsat TM data from the Ohio Department of Natural Resources and the Department of Civil and Environmental Engineering and Geodetic Science at The Ohio State University, respectively. The image pixel sizes are respectively 25-m and 40-m, which represent a slight over or under sampling of the nominal 30-m Landsat TM pixel resolution. The quoted geolocation error is one pixel. The same approaches used for the Corona mosaic, such as comparison of attribute files of the LULC data, photo-interpretation, and generalization of the boundary, were also used to delineate the urban boundaries of 1988 and 1994 Landsat TM data. In addition, multispectral characteristics of the Landsat TM data were used to identify urban land cover.

3. Results and Discussion

The Columbus metropolitan area is located in central Ohio and one of three largest metropolitan areas in the state (Cleveland-Akron, Cincinnati-Hamilton, and Columbus are listed in order of size). Interstate Highway 70, US Route 40, and State Routes 16, 161, 204, and 665 cross the metropolitan

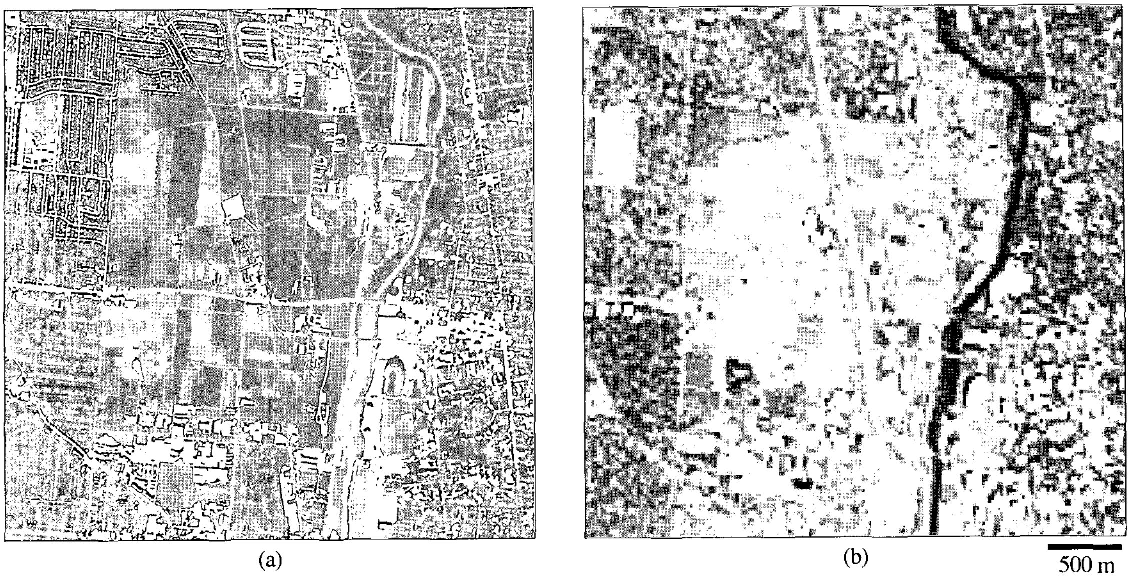


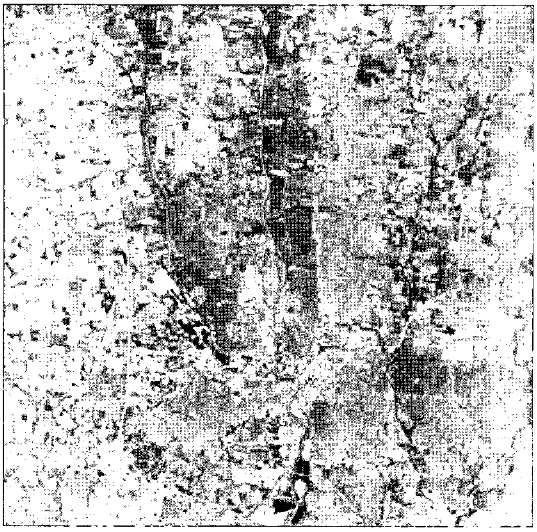
Fig. 2. The Ohio State University and vicinity. (a) The black and white image of historic satellite image, 1965 (3 m). (b) False color composite of bands 4, 2, and 1 from a 1994 Landsat TM image (25 m). The Ohio State University is located in the right side corner of each image. The center of the 1965 image covers the University Experimental Farms.

area east/west, and Interstate Highway 71, US Route 23, 33, and 62, and State Routes 3, 104, 256, 315, 317, and 605 run north and south. The confluence of the Olentangy and Scioto Rivers is located near downtown Columbus.

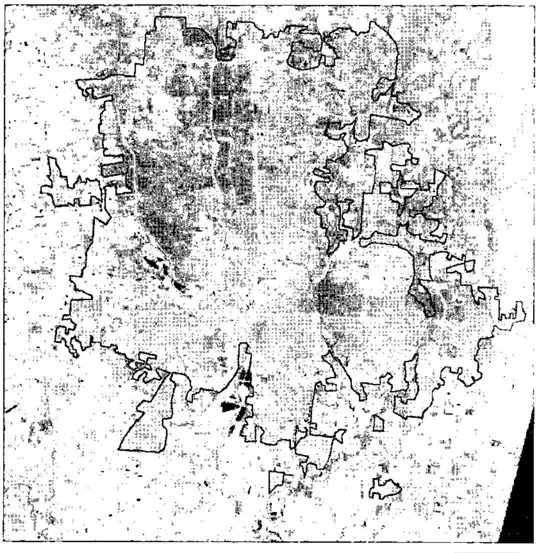
The Corona mosaic (Fig. 1) is an intriguing snapshot of the Columbus metropolitan area and its surroundings as it appeared in 1965. It has many important attributes for urban mapping. Coverage of the filmstrips is extensive enough so that only two have to be mosaicked to provide contextual information about the city, suburbs and rural environments. The high-resolution data enable easy discrimination between urban and rural areas. Streams, rivers and reservoirs are readily identified. Roads, streets, and highways under construction (e.g., I-270) are evident, as are large buildings, parks, sports facilities, and commercial establishments. Single family homes are not resolvable in the image though some sense of the density of homes can be gained from the texture in the images. Fig. 2(a) illustrates an area around The Ohio State University. At this scale we can clearly see the football stadium and "Oval" of the university.

Some areas in the 1965 Corona image are difficult to classify. For example, Fig. 3 shows an area just west of the Scioto River. The light-colored areas in the 1965 satellite photograph suggest something related to urban development. The 1976 LULC data, however, classifies these areas as non-urban land use

Fig. 3. Quarry along the Scioto River photographed in 1965.



(a)



(b)

Fig. 4. (a) A false color composite of bands 4, 3 and 2 (b) A false color composite of bands 5,3, and 2 of Columbus, Ohio (1988) and the urban boundaries (black).

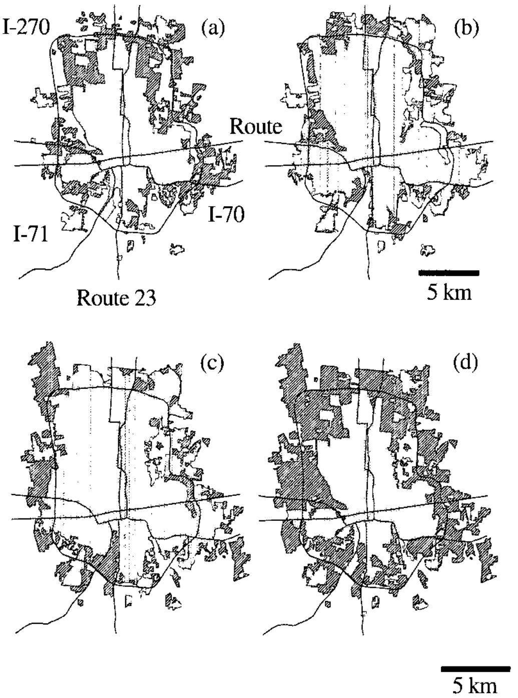


Fig. 5. Urban change maps between 1965 and 1994. Light areas represent urban areas at the start of the comparison. Hatched areas represent urban areas at the end of the comparison: (a) 1965 - 1976 urban change map (48.8 %), (b) 1976 - 1988 urban change map (11.3 %), (c) 1988 - 1994 urban change map (29.4 %), and (d) 1965 - 1994 urban change map (114.4 %).

type. We visited the site and found that most of the area is used as a quarry and contains excavation equipment.

The 1988 Landsat TM image shown in Fig. 4a is a false color composite of bands 4, 3 and 2. Spatial resolution often limits the easy identification of structural units, but multi-spectral data help overcome this limitation. In particular, the incorporation of the mid-IR bands (bands 5 and 7) greatly improve our ability to segment the TM data. Fig. 4b shows the false color composite of bands 5,3 and 2, illustrating the dramatic improvement in discrimination between urban and non-urban areas. The trade-offs between resolution and spectral coverage are further illustrated in Fig. 2. The figure shows the region near the Ohio Sate University and the university farms. Urban structures are easily identifiable in the 1965 Corona image enabling land-use separation. Urban structures are more difficult to identify in the 1994 TM image (b) but land use patterns are made evident by their spectral signature.

Urban change detection maps (Fig. 5) provide a

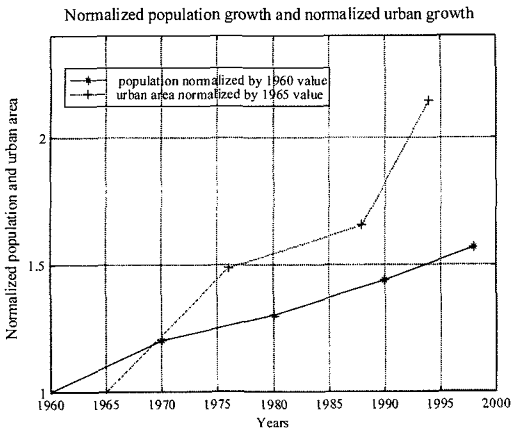


Fig. 6. Comparision of normalized population growth (1960 to 1998) (Sharp and Winland, 1999) and urbanization (1965 to 1994) in Columbus metropolitan area.

visualization of land use cover changes associated with urbanization since 1965. The comparison of the historical high-resolution digital image and the current land use maps illustrates that the Columbus metropolitan area expanded largely to the North and East (Fig. 5a). Much of the development between 1965 and 1976 is associated with Route 23 and 40, I-70 and I-71 that are the major east/west and north/south arterial road networks through the city. By 1994, the pattern is more homogeneous probably as a result of the construction of the I-270 outer belt (Fig. 5b and 5c).

The areal extent of urban development was measured from each data set. The areas were normalized by the area measured in 1965. They are plotted in Fig. 6 along with population data (U.S. Census Bureau 1998) normalized to the 1960 value in order to investigate any relationships between urbanization and population growth. Fig. 6 shows that the urban area in and around Columbus approximately doubled from 1965 to 1994 (~90%) along with population growth from 1960 to 1998 (~48%). Increase of urban area proportional to population growth indicates that most of the expansion results from development of residential units as confirmed by inspection of the TIGER/Line® Files prepared by the Bureau of the Census (1997).

4. Conclusions

Historical satellite data were found to be suitable for establishing a benchmark for land use patterns in and around Columbus, Ohio for 1965. Comparison of these data with later land use maps shows that the urban area in and around Columbus approximately doubled since 1965. Most of the expansion results from development of residential units. The visualization of urban expansion through the temporal data contributes to the research and technology base needed to understand land use change and urbanization.

Acknowledgements

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