URBAN GROWTH IN CAMPINAS, BRAZIL, 1989-2010, AS ESTIMATED FROM LANDSAT IMAGERY

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ABSTRACT

Campinas City, Brazil is one of the 10 fastest growing cities in the world with just over a million people in 2010. Does the new growth show signs of urban/suburban sprawl? This study investigates a null hypothesis that growth in Campinas, Brazil cannot be characterized as urban sprawl because the growth in urban land use/land coverage(LU/LC) is the same as the population growth during the same period. Land use/land coverage was measured using Landsat TM imagery from 1989 through 2010. Unsupervised and supervised classification methods were combined to separate urban (including suburban) areas from non-urban areas. Near-infrared color composite images (NCC), the Transformed Normalized Difference Vegetation Index (TNDVI), band-6 thermal images and the Tasseled Cap analysis were produced. Population growth was estimated from official Brazilian census reports. The area was measured in the resulting urban/non-urban classes using the NCC images. The increase in urban LU/LC was 26.9% between 1989 to 2000 and 22.5% during 2000 to 2010. The population growth rate was 13.4% and 10.3% during 1991 to 2000 and 2000 to 2010. The growth in urban LU/LC was over double the population growth and the null hypothesis is rejected, concluding that there is evidence for urban sprawl in Campinas, Brazil. Other evidence includes the appearance of new urban areas separated from the central hub of urban growth in a "leap-frogging" pattern.

Keywords: Campinas, Brazil, Landsat, Urban Growth, Sprawl

INTRODUCTION

Brazil is a country with many natural resources and a growing economy and population. São Paolo is one of the largest cities in the world with a population of almost 19 million (Anonymous, 2011a; Koten, 2010). Just to the north of São Paolo is the city of Campinas which has the distinction of being one of the ten fastest growing cities of the world (Kotkin, 2010) with a population of about one million people (Anonymous, 2011b). According to the 2010 Brazilian census (Anonymous, 2011b), the urban population in Campinas continues to increase and the rural population is decreasing. The City of Campinas has been campaigning to bring in investors stressing that it is a green city and a great place to live and run a business (Anonymous, 2011a). How is Campinas growing and what impact does that growth have on the surrounding environment? Is the growth in the population by increasing the urban density and the use of high-rise buildings, or is the city growing outward from the central business district? What is the impact of the urban growth on the human quality of life?

There is much literature characterizing urban sprawl, its definition and how to measure it and its impact (Ewing et al., 2002; Johnson, 2001; Harold et al., 2003). Ewing et al. (2002) cites the quote from Justice Potter Stewart on pornography that "most people would be hard pressed to define it, but they know it when they see it"; the same applies to urban sprawl. A general definition is when the increase in urban LU/LC grows at a faster rate than the population growth rate (Ewing et al., 2002). Bhatta et al. (2010a) reviewed much of the recent literature looking for a better definition of urban sprawl and found like Ewing et al. (2002), there is much disagreement on an exact definition but most agree that unorganized and uneven urban growth is a basic indicator. In general, researchers agree that urban sprawl represents a costly, poor use of available resources with several negative implications for society (Ewing et al., 2002; Bhatta et al., 2010a). New areas that grow away from the city center are typically of single use, low density areas, with increased dependence on private vehicles for transportation and in general a lower access to necessary services and goods.

Many researchers have stressed the importance of using GIS and Remote Sensing to study urban sprawl and the measure of impervious surface is a vital tool (Kumar et al., 2008). Satellite imagery and GIS tools are in common practice and many locations are generating public information critical for the planners (Anonymous, 2002; Sawaya et al., 2003; Sudhira et al., 2004; Yuan, 2008). Impervious surface estimates, vegetation indices and land surface temperature (LST) using Landsat imagery have been studied by many researchers (Yuan and Bauer, 2007; Yuan, 2008; Meng et al., 2010).

The city government of Campinas published in 2006 their plan for urbanization and land use for the county (Anonymous, 2011c). In The Plan the county is divided into nine Macrozones and each one has its development plan (Figure 1). The urban city center is in the Macrozone 4, which has been defined for priority urbanization. Macrozone 1 is an area under environmental protection.

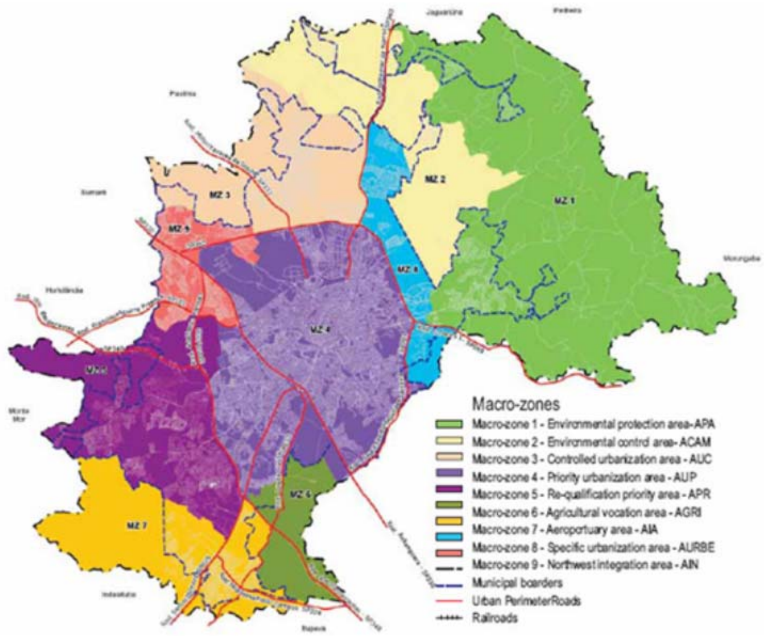

Figure 1. Map of São Paulo's Campinas County, State of São Paulo, Brazil.

METHODOLOGY

Study Location

The study area is Campinas City, Campinas County, State of São Paulo, (Fig. 2). The city coordinates are: 22° 54′ 3″ S, 47° 3′ 26″ W Datum WGS84. The 2010 population was estimated at 1,080,999 (IBGE, 2010) with over 98.3% in the urban region. The population density was 1,359 inhabitants/km² for 2010 (IBGE, 2010). The municipal area of Campinas covers 795.667 square kilometers.

Data Collection

Data sources are defined in Table 1. The internet was used to look for sources for the GIS layers as well as to obtain population data from Campinas, Brazil. DIVA holds a large collection of GIS layers and several relevant layers with administrative areas, roads and rivers and water bodies were obtained. First a small-scale GIS database of Brazil was built to learn the context around the study site before focusing on a more local study. The administrative areas 1 and 2 were located but the file for the 3rd had the same information as the 2nd; thus the state and county boundaries were obtained, but not the city boundaries so this study is carried out at the county level.

Population estimates for the city of Campinas were available at the Brazilian Institute of Geography and Statistics (IBGE) website. The most recent census was in 2010 and population estimates were available from 1970. Landsat imagery was located at the USGS Earth Explorer website site.

Figure 2. Map of São Paulo's Campinas County, State of São Paulo, Brazil.

Nearly cloud free imagery was searched for Path/Row 219/76 and selected when available between 1989 and 2010.

Table 1. Data sources.

Information Type	Source
Landsat 5 TM	Landsat 5 TM 7-band raster image. LT52190762010108CUB00. Collected 4/18/2010. WRS Path/Row: 219/76.
Landsat 7 ETM+	Landsat 7 ETM+ 7-band raster image. L71219076_07620001023. Collected 10/23/2000. WRS Path/Row: 219/76.
Landsat 4 TM	Landsat 4 TM 7-band raster image. LT42190761989298XXX03. Collected 10/25/1989. WRS Path/Row: 219/76.
Brazil Administrative Shape Files	DIVA GIS http://www.diva-gis.org/gdata
Brasil Census Population Data	Brazilian Institute of Geography and Statistics. http://www.ibge.gov.br/home/

Census Population Data

The census population estimates were plotted against year, and the growth rate was calculated. In this case, growth is defined simply as the percent change between two successive estimates.

Image Analysis

ERDAS Imagine 2010 was used for the image processing. The image processing and analyses followed these steps:

1. Download full level 1 data files and uncompress;
2. Stack layers of 7 bands to combine into a single file;
3. Rectification of the images using the image from April 2010 as the reference, and resampling with a square pixel size of 30x30m.
4. Reproject to a map projection UTM 23S, WSG84;
5. Subsample the images to a block surrounding Campinas country using a file with the AOI to assure they have the same coverage;
6. Create and evaluate natural color (RGB=321) and NIR color composite (RGB=432) composite images;
7. Calculate and evaluate the Transformed Normalized Difference Vegetation Index (TNDVI);
8. Display and evaluate the thermal band 6 for each image;
9. Calculate the Tasseled Cap Analysis;
10. Classify the images with the objective being to identify and quantify the LU/LC including suburban areas if possible;
11. Accuracy assessment – only done subjectively for this paper by comparing with the original images and Google Earth.

The TNDVI was calculated as follows: TNDVI = ((NIR-Red/NIR+Red)+0.5))^(1/2)

A hybrid technique was used to classify the Landsat images. First, an unsupervised classification was done with 30 classes to generate a set of spectral signatures to evaluate for a supervised classification. After evaluating the set of 30 signatures, some were deleted and others were added. The separability analysis in ERDAS 2010 was used to evaluate the signatures. The land cover corresponding to the signatures was visually identified by comparing to the unclassified RGB images and Google Earth.

The Tasseled Cap analysis was performed on the image from April 2010 and the urban and suburban areas were very identifiable. However, this analysis was not possible for the other images because ERDAS 2010 could not find the sensor information associated to the data; this will be held for future work.

Integration with GIS

ArcGIS v10 was used. Shapefiles of Brazil administrative areas were used to create a map of the state of São Paulo and Campinas County. The country boundary was used to clip the Landsat images to the county area. The Campinas City use plan (Anonymous, 2006) was obtained which includes a map of their “macrozones”. Each macrozone is managed separately with its own land use plan. The boundaries of the macrozones were digitized from a JPG image (Campinas City Hall) using ArcGis 10 to use as another feature layer.

The sets of natural and near-infrared color composite imagery (NCC) were subjectively evaluated along with Google Earth to understand the features. The TNDVI images are displayed to show two classes: impervious surface areas, and everything else such as open vegetation areas, bare soil, and trees and forested areas. The Landsat TM band 6 thermal band was rendered as a psuedocolor image in ArcGis 10 to suggest urban heat areas. The images resulting from the supervised classification were recoded to only show the urban areas and everything else. The coverage in area of the urban areas in the classified images were estimated by multiplying the number of pixels by the area of each pixel (30x30m). The coverage and decadal increase in the urban land cover with the population estimates and growth rates were plotted. Images were clipped to the Campinas County boundary.

RESULTS

The urban and suburban areas in Campinas County, Brazil are very clear in the NCC imagery (Fig. 3). In these images red is the reflectance from green vegetation, blue is constructed surfaces (impervious) and green shades are bare soil.

The TNDVI is another good way to identify urban areas. Water would have the lowest numbers but is not separated in the present analysis. Figure 4 shows the urban areas identified by TNDVI from 1989, 2000 and 2010. Especially in the urban center (Macrozone 4) the increase in urban land cover is quite apparent.

Urban areas generate heat and vegetation enhances cooling; this has been called the Urban Heat Island effect. Figure 5 shows the hot spots in Campinas County measured by the thermal band on the Landsat satellites. Base soil can get very hot and is apparent in the other macrozone,; for the priority-area for urbanization (Macrozone 4), the increase in heat is quite apparent.

The Tasseled Cap analysis shown in Figure 6 is quite striking. The features are very clear and even the suburban areas are clearly separated (orange colors) from the urban areas which as shown in red (when observed under zoom). The blue lines are the roads and could be combined with the red urban areas to estimate impervious surfaces. Classification of a series of Tasseled Cap images and measurement of the land cover could be valuable for future work.

The urban area and some of the suburban areas were identified with the final supervised classification recoded into a binary thematic map; urban areas and non-urban areas. Figure 7 shows the urban areas identified for each image year; 1989, 2000 and 2010. Again, the increase in urban areas is evident especially in the Macrozone 4.

Figure 8 shows the urban areas overlaying the three years showing that more growth occurred during 1989 and 2000 that the later period. Table 2 shows the population estimates from 1970 to 2010; growth rates have been decreasing from 43% during 19700-1980 to 10% during 2000 and 2010 (Figure 9). The amount of urban land cover has been increasing (Table 3); the rate of increase in urban coverage during the last 30 years has been over double the population growth rate (Figure 9).

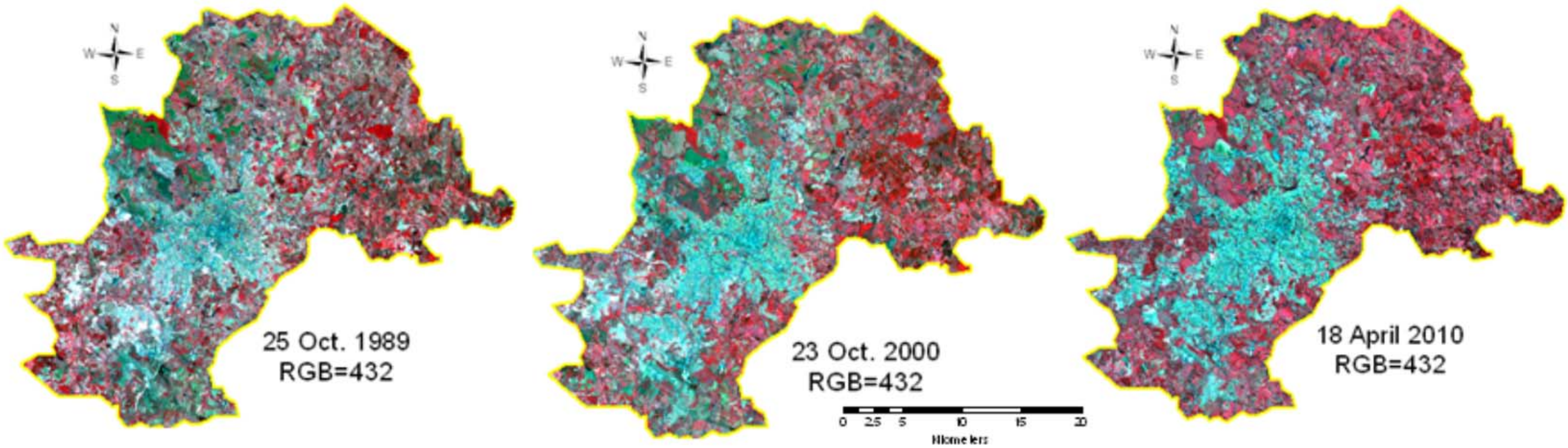

Figure 3. Near-Infrared false color (RGB=432) from Landsat imagery.

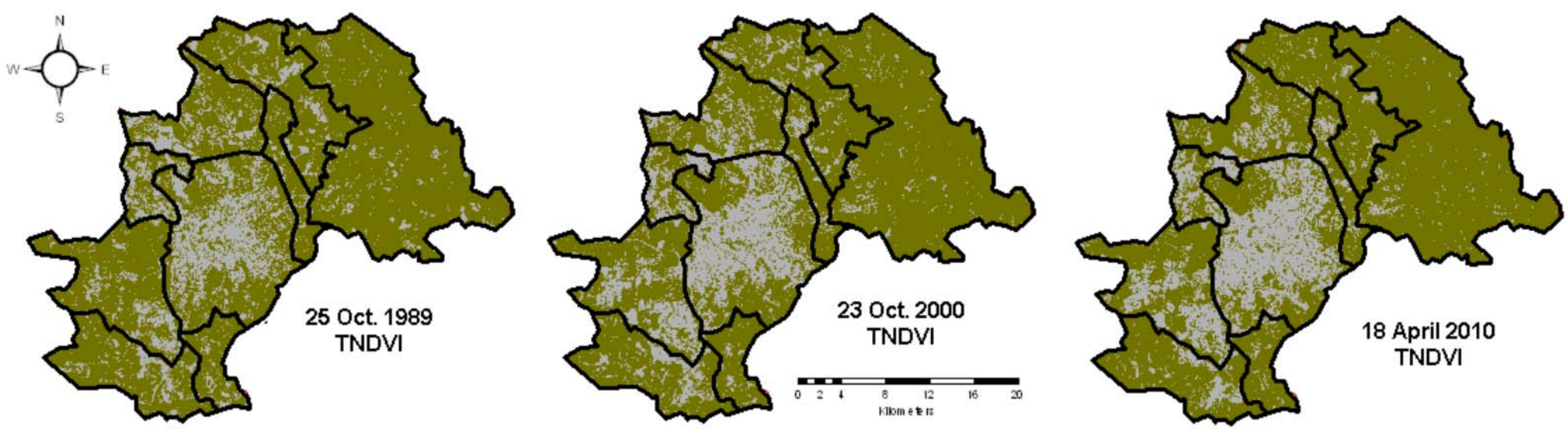

Figure 4. TNDVI analysis from Landsat imagery was rendered into two classes; urban and non-urban. The boundaries for the Macrozones are shown in black.

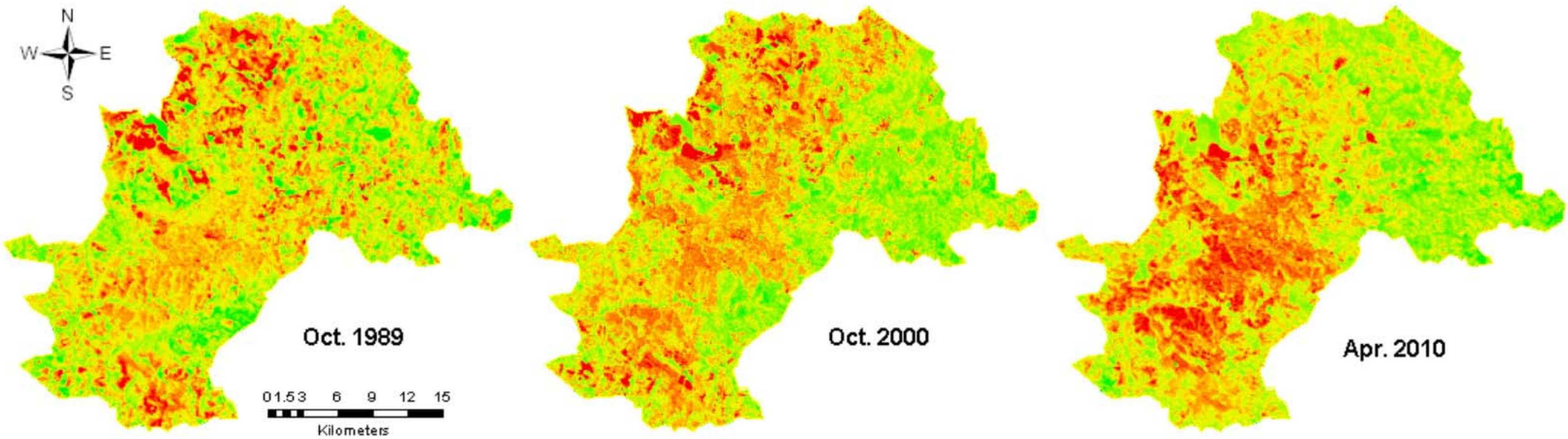

Figure 5. Landsat TM band 6 thermal image rendered in psuedocolor to show the high spots of urban heat in Campinas county. Red is the higher temperature.

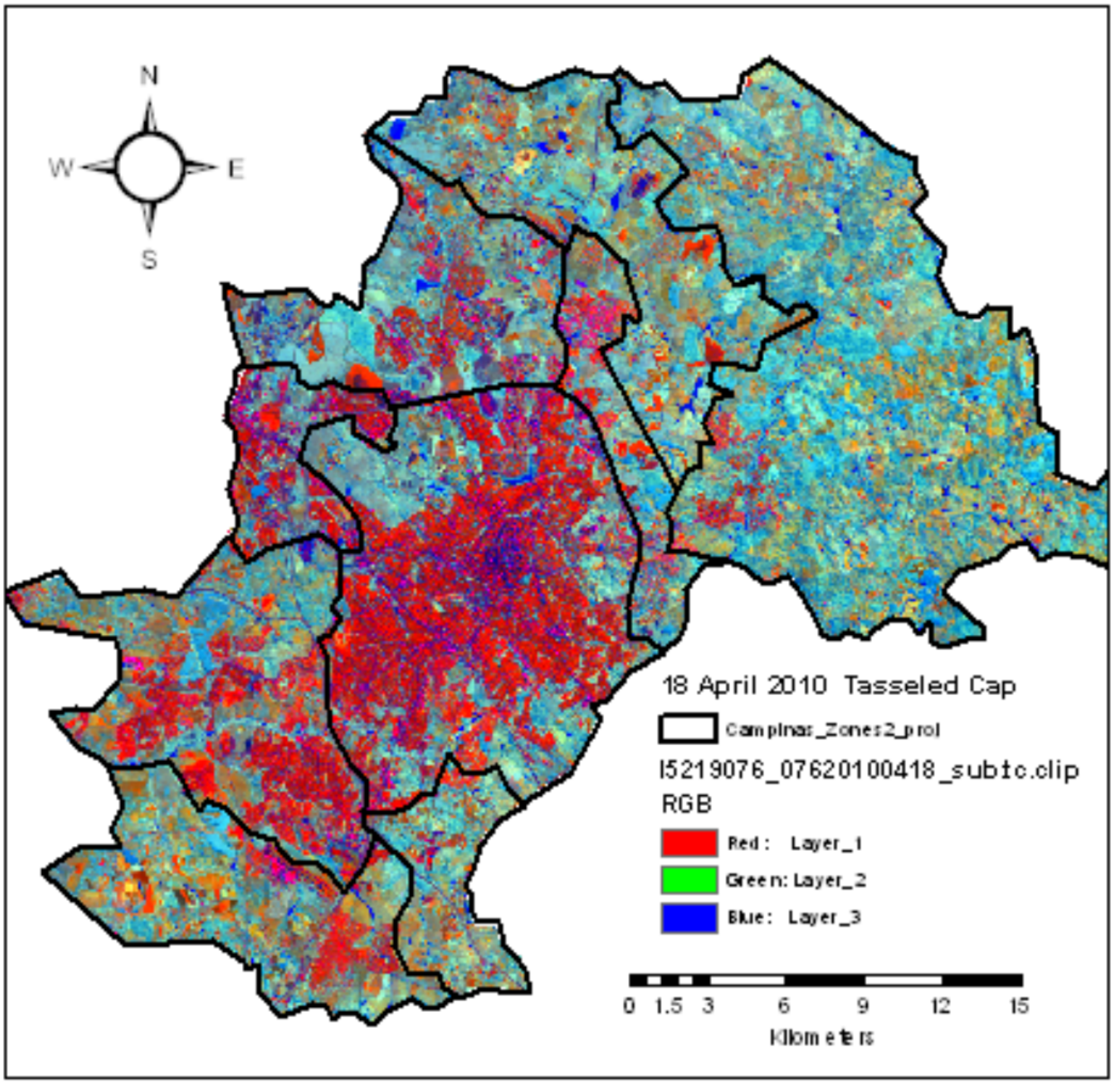

Figure 6. Tasseled Cap analysis on Landsat 5 TM image from 18 April 2010. RGB is rendered from the TC bands 1, 2 and 3; the boundaries for the Macrozones are shown in black.

Table 2. Population estimates from the official Brazilian Census and the percent of population growth.

Year	Rural Pop.	Urban Pop.	Total Pop.	% Change Urban Population
1970	40,395	335,469	375,864	
1980	73,151	591,415	664,566	43.3%
1991	22,671	824,924	847,595	28.3%
2000	16,366	953,030	969,396	13.4%
2010	18,546	1,062,453	1,080,999	10.3%

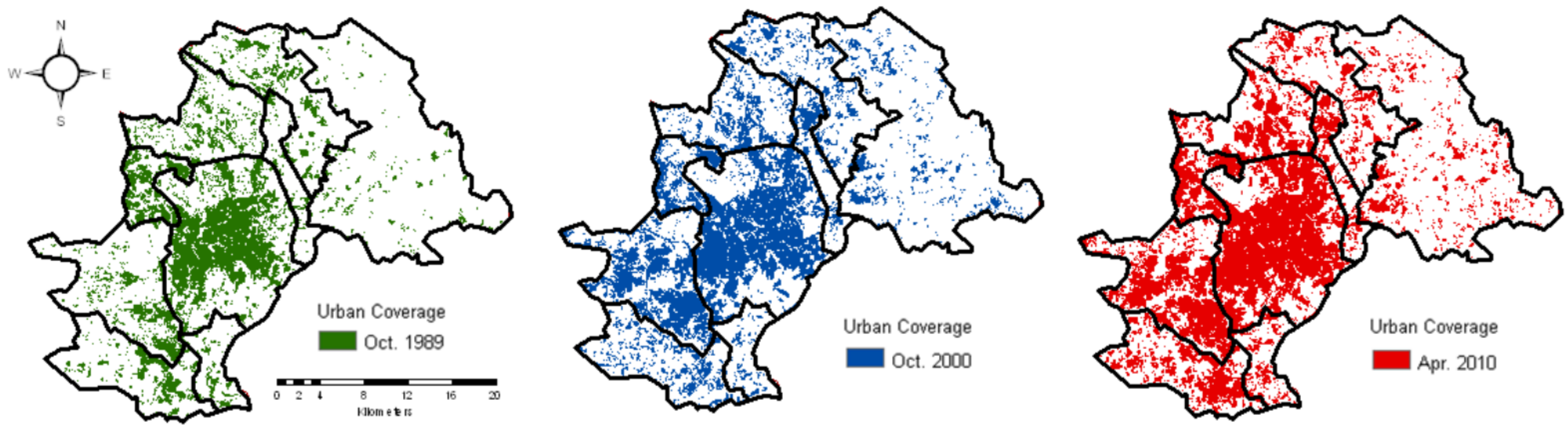

Figure 7. Landsat TM imagery after a supervised classification and recoding to show only the urban areas in 1989, 2000 and 2010; the boundaries for the Macrozones are shown in black.

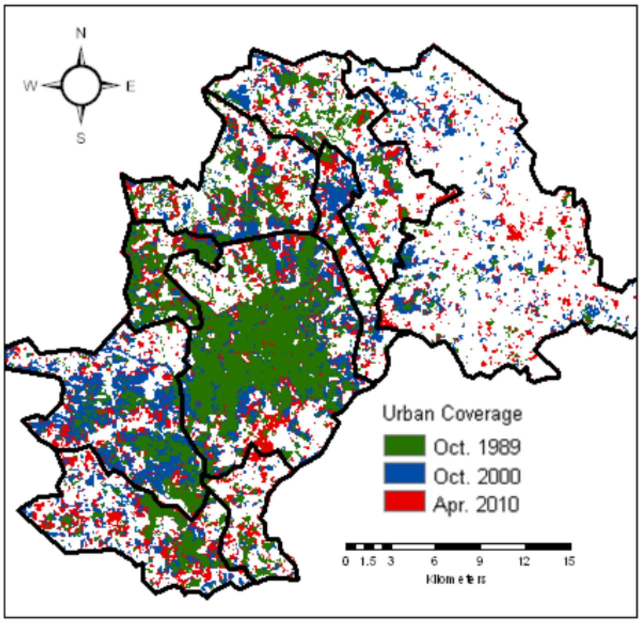

Figure 8. Landsat TM imagery after a supervised classification and recoding to show only the urban areas. Urban land coverage in 1989, 2000 and 2010 is overlaid to show the changes with time.

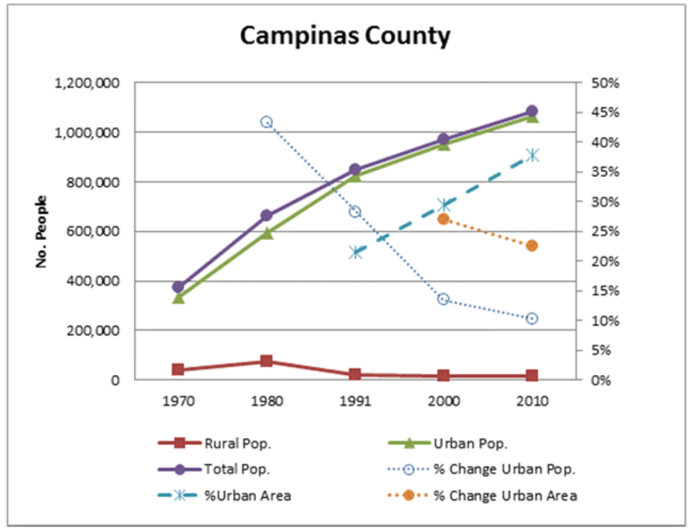

Figure 9. Census population estimates, and population growth rate; percent area with urban land coverage and the percent of change in urban land coverage for 2000 and 2010.

Table 3. Urban coverage in km2 estimated from the classified Landsat TM images; percent urban area, and the percent change in urban land use/land coverage.

Year	Pixels	Km2	%Urban Area	% Change Urban Land Use/Land Cover
1989	190006	171.005	21.5%	
2000	259866	233.879	29.4%	26.9%
2010	335220	301.698	37.9%	22.5%
Total Area for Campinas (Km2)			796.746	

CONCLUSIONS

Comparing the images during 1989-2010, and the population growth rates compared to the rate of increase in urban land coverage, it must concluded that the null hypothesis should be rejected; there is evidence that suggests that Campinas County is showing signs of Urban Sprawl . The urban area land coverage is increasing faster than the population is growing, and the growth pattern shows the 'leap-frogging' affect where isolated areas (mostly suburban) are popping up with less access to required services. The natural color and NCC images show the distribution of the urban areas growing out from the city center. The growth has not been concentric but is in discontinuous radial extensions of the city.

The formal land development plan was published by the city of Campinas in 2006 and the individual plans for each Macrozone are underway (Anonymous, 2011c). Therefore, we are observing the results of either not having a previous plan or not supporting it with the necessary laws. We could expect that if the new plan is followed, new urban growth should be more organized.

Seasonal changes in vegetation and agricultural cycles are likely to have some effect on these results. The April 2010 image shows many differences from the October image; changes in the agricultural cycles as well in the tree leaf colors make a very different spectral environment. Of course this doesn't change the urban area but it does change the surrounding areas which makes the image classification more difficult. Another issue is that bare soil is not an impervious surface, but when it is bared for construction that could count as urban land use but in the classification it can get confused with other bare soil areas. More fields were bare in October compared to April. So the local vegetation cycles should be used to determine when is the best time to collect imagery and use imagery from all the same dates as available.

Another problem is the lack of a good accuracy assessment of the signatures used for the classification. More work is necessary with the signature extraction and evaluation, and to determine the user and producer's accuracy statistics. In this case the separation of the urban area from everything else was the main focus, but within the urban area many pixels are mixed at Landsat resolution. Higher resolution imagery will permit more detail to study the urban centers and better classify the green areas within the city. The open areas in the county provide recreation opportunities for people, but the green areas in the city (Urban Tree Canopy) was difficult to measure in this study. The thermal images suggest areas of urban heat and where increased green areas need to be established. In the urban center downtown areas you can see some areas with trees and small parks but elsewhere the constructed density is very high. The housing construction style is with very small yards and many structures seem to be sharing walls (Google Earth). The more affluent areas have more green space and there are two lines of homes between the access streets vs. three in other areas of the city. The counties to the east are agricultural and can provide Campinas County with the necessary fresh goods.

Image feature extraction from complicated urban areas might be improved by using an object-oriented analysis instead of the pixel-based classification used in the present study (Bhaskaran et al., 2010); that is another area for future work.

The Confederation of US Mayors (Anonymous, 2008) expressed the importance of improving the amount of urban tree cover in their cities. The American Forests (2011) makes recommendations for humid areas in the USA (Table 4). Another important follow-on study would be to determine the urban and vegetation proportions in each of the Macrozones and how they have changed in time compared to the LU/LC cover city plan.

Table 4. Recommendations for Urban Tree Cover (Anonymous, 2008) .

Average tree cover counting all zones	40%
Suburban residential zones	50%
Urban residential zones	25%
Central business districts	15%

The LU/LC for urban areas needs to be estimated for 1970 and 1980 to improve our understanding of the historical trends in both population and urban LU/LC growth. Next steps for this study are to use very high resolution (<4m) imagery as a source of ground truth to calibrate and validate the classifications in the Landsat imagery. The Tasseled Cap analysis appears to provide important spectral information and should be compared between the years to evaluate any improvement in the classification accuracy. Finally using very high resolution imagery it will be possible to evaluate the Urban Tree Canopy in different sectors of the city.

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