MONITORING AND PREDICTING THE URBAN DEVELOPMENT OF GUATEMALA CITY, GUATEMALA.

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ABSTRACT:

Remote sensing has proven to be an efficient tool to study the development of cities. Cities uncontrolled expansion can bring many challenges and problems including the increase of carbon dioxide concentration and the need for a larger transportation and services network. Guatemala is the country with the highest urbanization rate in America, and its largest city is Guatemala City, which shows a rapid increase in population from 1,813,825 inhabitants in 1994 to 3,207,600 in 2012. Governmental institutions need to prepare for this city's expansion and population increase by making the most sustainable decisions for land use, services distribution and natural disasters prevention. The objective of this research is to monitor and predict the development of the urban area of Guatemala City for the following six years using spatial data and statistical analysis. The study first collected related satellite images, statistical data and GIS (Geographical Information Systems) data to observe the urban changes of the city in the last twenty years. Then, the changes were studied through the analysis of a supervised classification performed on three Landsat images of Guatemala City, corresponding to the dates of 1994, 1999, 2003 and 2014 respectively. Statistics of the four images were then processed and integrated with other geographical and demographical databases to examine the changes in the city using GIS, and provide information for the creation of an urban development model. Specifically, a logit-based CA (cellular automata) model was applied to simulate the city's expansion. Images of 1999 and 2003 were used to calibrate the model and images from the year 2003 and 2014 were used to confirm its accuracy. The model presented two accuracies of 0.78 and 0.75 in predicting the growth of the city, according to this model, the City of Guatemala will grow a 37.5% in the next six years.

1. INTRODUCTION

Urban areas can be defined in a physical aspect as "places characterized by a built up environment, consistent of non-vegetative, human-constructed elements" (Miyazaki *et al*., 2012). These areas are in constant change. This paper is interested in the urban area development of Guatemala City, the capital of Guatemala. Guatemala City is located in Central America, and in 2012 it accounted for more than 3 million inhabitants (INE, 2013), and the city's population is still increasing. It is expected that the population increase will lead to changes in the urban size. An investigation shows that a 10% growth in urban population is associated with a 9.3 % increase in urban land cover (Shlomo A., 2011). By 2015 Guatemala City is likely to be counted amongst the eight most populated cities in Latin America (Cohen, 2003).

Population growth usually has an impact on population density. Population density should remain within a range that allows an appropriated operation of public transportation systems, affordable housing and conservations of energy and land. To achieve this, the expansion of cities must be properly planned for. How is it possible to monitor the size and changes of the city? Can the growth of Guatemala City be predicted? In order to contribute to the planning of Guatemala City's expansion, this paper intends to understand and predict the changes in its urban land cover for the following years. The research will be presented as follows: (1) the first part will describe the methodology used to study urban development in this project; (2) the second part will present the obtained results; (3) finally, the paper will discuss the conclusions of the study.

2. STUDY AREA

Figure 1 presents Guatemala City which is located in the south of Guatemala and has an extension of 692 km^2. The city is located in a valley surrounded by mountains and a volcano which is still active. Guatemala City is divided into seventeen municipalities and counts with one lake in the south of the city.

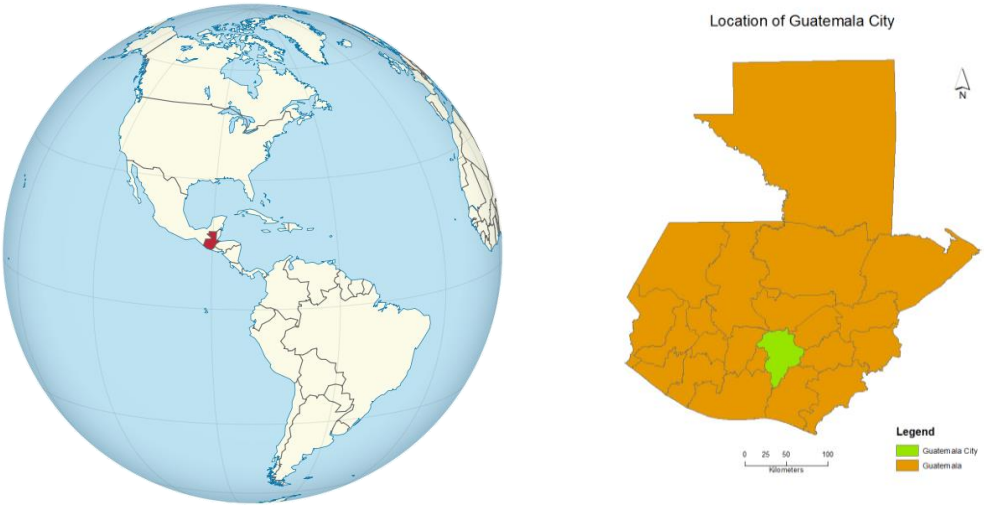

Figure 1: Location of Guatemala (left) © 2011 by TUBS*, and of Guatemala City (right)

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3. METHODOLOGY

3.1 Image classification

Landsat images that covered the legal boundary of the city of Guatemala were collected for five different years: 1994, 1999, 2003, 2013 and 2014. This allowed visualizing the changes in the land cover for the last twenty years. Due to vegetation changes in land cover, every image had to correspond to the same season; because the winter season, from November to April was the one with the least cloud cover, the winter season was the one that was selected for the study. Applicable images were found for the years of 1999 and 2003, but recent images corresponding to the winter season were covered by a large amount of clouds. To solve this, a mosaic of images of 2013 and 2014 was created using ERDAS mosaic tool.

To perform accurate calculations of the city expansion, the Landsat images were classified using ENVI's Smart Vector Machine (SVM) tool. By choosing training regions for urban areas, forests, agricultural areas, rocks and soils, and water bodies, this tool classified the entire Landsat image of 1994 into these five land covers. The same training regions were then verified to be unchanged for the years of 2003 and for the mosaic of 2013 and 2014. The two images were then classified using the SVM tool. The next step was to check on the accuracy of the classification. Two accuracy checks were performed: overall accuracy and kappa coefficient. To perform the accuracy check, a land cover map had to be used as reference.

3.2 Urban simulation

To perform the urban simulation, datasets such as, digital elevation model (DEM), city roads, schools and population density, from 1994 to 2014, were collected. In order to integrate remote sensing (RS) imagery and geographic information system (GIS), a logit-based CA (cellular automata) model was used to create landscape modeling that predicted the land cover changes in the city of Guatemala.

Practically, classified images from 1999 and 2003 were used to calibrate the model. The changes between these two maps gave a reference to the model as to how the city of Guatemala tends to grow. Afterwards, the model was applied to the 2003 classified image; the output was a prediction map on how the land cover of the city of Guatemala would look like

in 2014. This image was compared to the classified image of 2013/2014 in order to validate the model. Finally, the model was applied to obtain a prediction on the urban area of Guatemala for the year of 2020.

4. RESULTS AND DISCUSSION

After the SVM classification, an accuracy test was performed to make sure that the classifications were reliable. To do this, a land cover map from 1999 was used. Figure 1 presents an overlap of the urban territory represented in the land cover map and the urban pixels classified by the SVM in the Landsat image. Tables 1 presents the results obtained after performing the accuracy check.

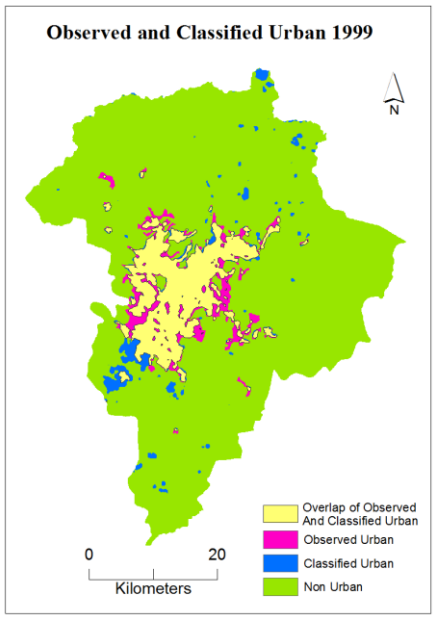


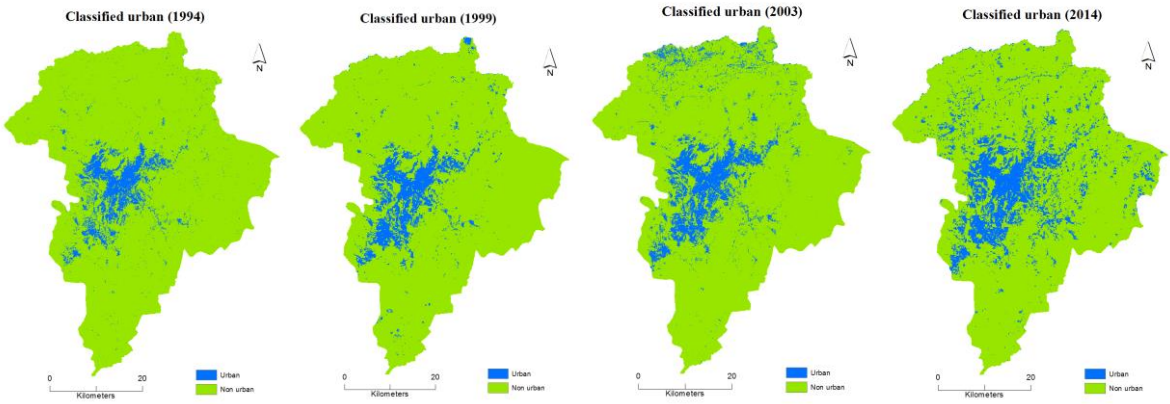
Figure 2
Overlap of the observed and the classified urban areas in year 1999

Table 1
Overall accuracy and Kappa coefficient

	Classified		
Observed	**Urban**	**Non-Urban**	**Total**
Urban	114	42	156
Non-Urban	31	813	844
Total	145	855	1000
Overall Accuracy		0.92	
Kappa Coefficient		0.71	

The classified image having an overall accuracy of 92% and the two images having a kappa coefficient agreement of 0.71, the results of the 1999 were considered as reliable to use in the prediction model. Figure 3 displays all the

classified images.



Figures 3
Classified images of the urban area of Guatemala City (1994 to 2014)

In the application of the urban model the 1994 map was only used as a reference that allowed to visualize the growth in a longer period. The first map to be input in the logit-based CA model was the classified map from 1999. The other inputs in the model were: the elevation and slope of Guatemala City, nearest distance to roads, nearest distance to schools and nearest distance to rivers. The output of the model was calibrated by the classified image of the year 2003. Afterwards, for model validation, the map from 2003 was used to create a prediction for 2014. The accuracy of these predictions was calculated through the comparison of these images with the classified images for the same dates. The two maps and the classified images are presented in Figure 4. The accuracies of the two maps are 0.78 (year 2003) and 0.75 (year 2014), respectively.

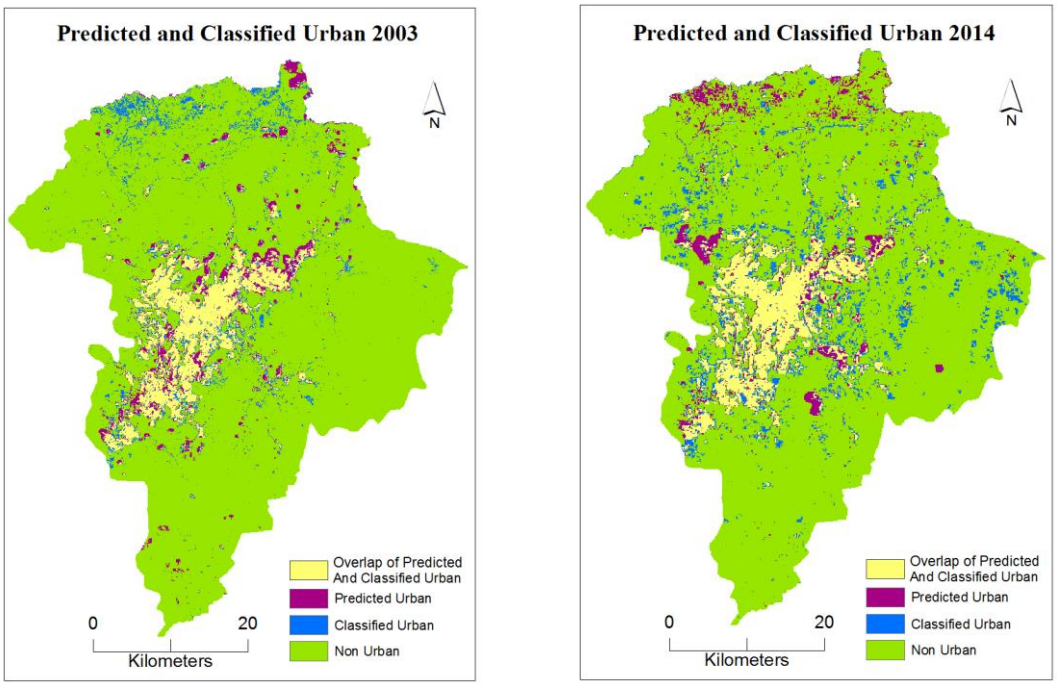


Figure 4

Comparison of classified and predicted growth of Guatemala City's urban area for 2003(left) and 2014(right)

Then, the model was used to calculate the urban area of 2020, the result is presented in Figure 5.

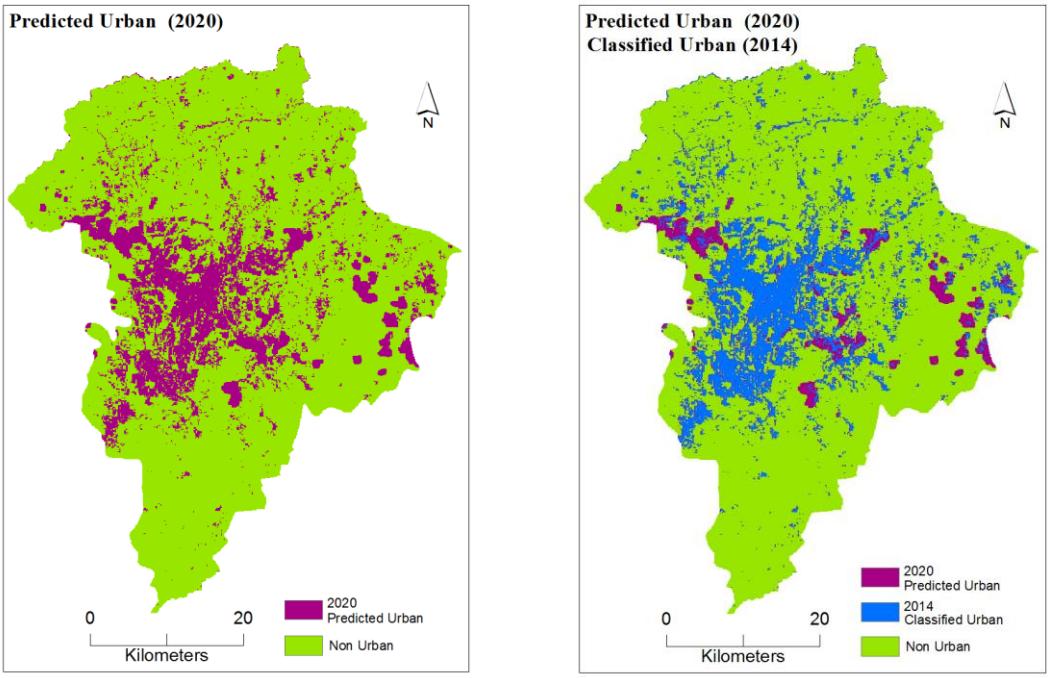


Figure 5
Prediction of Guatemala City's urban area for 2020

Figure 3 show a visible growth of Guatemala City's urban area. Table 2 presents the calculated growth of the City's urban area and of the population and also an estimate on the population growth (INE, 2011) and urban area growth for 2020. Table 3 presents the urban area and the population change from 1994 to 2014, from 1994 to 2020 and from 2014 to 2020.

Table 2
Urban area and population growth.

Year	Urban Area (km^2)	Population
1994	159.6	1813825
1999	187.9	2258041
2003	255.2*	2702257
2014	305.7*	3306616
2020	420.2*	3573179**

*Simulated urban area
**Projected population (source INE, 2011)

Table 3
Urban area and population change

Years	Number of Years	Urban area growth km^2	Urban area growth in % (growth rate, km^2/yrs)	Population increase (number of inhabitants)	Population increase in % (increase rate, pers/yrs)
1994 - 1999	5	28.3	17.8% (4.7)	493,573	27.2% (98,714.7)
1999 - 2003	4	67.3	35.8% (13.5)	394,859	17.1% (98,714.7)
2003 - 2014	11	50.5	19.8% (4.6)	604,359	22.4% (54,941.7)
2014 - 2020	6	114.5	37.5% (19.1)	266,563	8.1% (44,427.2)
1994 - 2020	26	260.6	163.3% (10.0)	1,759,354	49.2% (67,667.5)

At present rate, the population of the City of Guatemala will increase in 266,563 inhabitants. This is expected create a 37.5% growth from the 2014 urban area. The urban area will grow in 114.5 km^2.

5. CONCLUSIONS

The model presented a two accuracies of 0.78 and 0.75, supporting the reliability of the model for predicting the future urban area of the City of Guatemala. The city is expected to grow to the west and to the east. These areas of the country are characterized by being close to many schools and health centers, in the map of 2014 they are classified as forest and they are amongst the highest lands of the city, their altitude is above 1500 m.
Services, roads, and housing should be anticipated and planned for in the boundaries that are next to the growing areas. The accuracy of the prediction could be improved with a more precise classification and also with the use of more complete input data.

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