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The Mapping of the Urban Growth of Kinshasa (DRC) Through High Resolution Remote Sensing Between 1995 and 2005

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1. Introduction

The study of urban growth in Kinshasa is not a new topic, as shown by the work on the dynamics of housing in the 1970s (Flouriot et al., 1975; Pain, 1978). These authors followed the spatial extension of Kinshasa by collecting old cartographic documents and comparing them. Flouriot (1975) combined a cartographic approach with household surveys to follow the long-term housing growth.

The advent and development of remote sensing and Geographic Information Systems (GIS) have changed the methods, making it now possible to map and quantify urban growth quickly and easily. More recently in Kinshasa, Tshibangu et al. (1997) have integrated into a GIS a vegetation map drawn by Compere in 1960. This was possible thanks to the interpretation of aerial photographs and Landsat and SPOT images conducted respectively in 1982 by Wilmet and 1987 by Nsekera to quantify the urban sprawl. Delbart and Wolff (2002) evaluated the extension of the city of Kinshasa from an old map (1969) and the delineation of the city in 1995 observed on a SPOT image (from 1995). The current extension of the city (between 1995 and 2005) is not precisely known, but the figures are around 600km² (Lelo Nzuzi, 2008). The purpose of this chapter is to map and quantify urban growth between 1995 and 2005 using a time series of high resolution satellite images.

2. Study area

The city of Kinshasa province, located between 4 ° and 5 ° south and between 15 ° and 17 ° east, is the largest city in the Democratic Republic of Congo. It covers an area of 9965 km² (De Saint Moulin, 2005), about 600 km² being only urbanized. The city had 400,000 inhabitants in 1960 and reached more than six million in 2008, the average annual growth rate between 1960 and 2003 would therefore be about 6.80% (Lelo Nzuzi, 2008).

Kinshasa has grown in the plains bordering the Congo River. The plain 300 metres above sea level covers about 200 km². This is the most industrialized area and formerly the most

densely inhabited, commonly called the "ville basse" (low city). After independence in 1960, the city has spread into the complex hills surrounding the city and low peaks around 600 m above sea level. This area is mainly occupied by slums, called the "high".

3. Data

Two SPOT images dating respectively from March 31, 1995 and July 1, 2005 were used. They are recorded in panchromatic and multispectral modes. Their radiometric quality is variable. The 1995 images have a cloud cover of 7% in multispectral and 5% in panchromatic, while the 2005 images have 6% of cloud cover in multispectral mode and 10% in panchromatic mode. The presence of these clouds is evidence of the difficulty of obtaining cloud-free images for areas located in the sub-equatorial climate. To make the different images comparable, a radiometric correction was performed. Unfortunately, due to the low correlation between the red and the green bands, it did not yield good results and was abandoned.

Other data were collected, digitized and georeferenced, if necessary, to analyse urban growth of the city. This entailed using the old cards to map the growth of Kinshasa over the long-term, population data and the relief and major roads.

In addition, to map the dynamics of the habitat of the Atlas of Kinshasa (Flouriot, 1975), the map "District Urban Leopoldville 1/60 000" presents the urban area in 1920. Plan Leopoldville (map 1/15 500 published by the bookseller Congo Leopoldville) gives the limit of the city in 1954. The map "Plan of Commons of Kinshasa and its Environs" to 1/20 000 published in 1959 by the Geographic Institute of Zaire is the drawing of municipal boundaries of the urbanized area in 1959. The map "City of Kinshasa-health zones" (Card 1/20 000 published in 1969 and revised in 1997 from the bottom of the base map of Kinshasa), provisional edition, published by the Geographical Institute of Zaire has the delineation of municipal boundaries of the urbanized area in 1969. All these documents are completely overwhelmed by the current situation (Delbart et al., 2002; Fox et al., 1997) and require updating.

The population data used suffers from both a paucity of quality and reliability in a country where the offices of the civil state are characterized by operating failure and where the general census of the population is not regularly organized. With the exception of the 1984 population numbers from the 1984 census, the others are mere projections of the National Institute of Statistics.

Coverage maps scale 1 / 10 000 by the Geographical Institute of the Belgian Congo (IGCB) dating from 1958 covering the city of Kinshasa have been scanned. The contours at a contour interval of 5 metres were digitized by students from MA1 geography at the university, corrected and interpolated by Mathieu De Maeyer (IGEAT / ULB) by the spline technique to produce a digital terrain model and derive the slope.

Some roads (in the north of the city and the far east, after the airport) were digitized from the SPOT panchromatic band (of 10 April 2000) and a plan of the city of Kinshasa (1 / 10 000) of March 1970 created by the Geographical Institute of the Congo. The roads in the west and south were measured and corrected by DGPS Pathfinder software. The railway was also digitized from the map of the city of Kinshasa. The roads of the southern part were digitized using only the SPOT panchromatic band of the 10 April 2000.

4. Methodology

Two approaches for change detection exist. "Image-image" comparison methods imply a radiometric normalization; this standardization is difficult to implement on data from different seasons and radiometric quality is also variable (Singh, 1986; Alphan, 2003; Coppin et al., 2004; Yuan et al., 2005). In addition, they do not identify the nature of change. Comparison methods compare the post-classification classifications of land produced independently at different dates (Gupta et al., 1985). The other group of methods is less sensitive to differences in season and they identify the nature of change but are susceptible to misclassification. To detect changes, classifications are compared in pairs. From this comparison, a map where the changes can be located and a change matrix that summarizes the amount and the nature of these changes are derived.

4.1 Geometric correction and cutting recovery images

To detect changes, it is essential that the SPOT images are properly stowed from the geometrical point of view.

This is why the latest panchromatic image has been corrected from an image of higher resolution. This is a panchromatic IKONOS image from 2002 of a resolution of 1 m corrected itself with control points measured in absolute mode with a Garmin GP60 GPS. Root mean square errors of 9.46 m on the hilly part and 4.14 m on the plain were obtained.

Then all the other images SPOT (panchromatic and multispectral mode) were corrected on the panchromatic SPOT image, corrected with a polynomial function of first order and the nearest neighbour method. All are projected onto the ellipsoid WGS 84 UTM coordinates, zone 33 south.

Geometric corrections lead to RMS errors smaller than the size of a pixel with 29 to 35 control points (Table 1), which is acceptable according to Moller-Jensen (1990) and is suitable for a detect changes study.

Image	Cell (m)	Control points number	XRMS (cell)	XRMS (m)	YRMS (cell)	YRMS (m)
Spot panchromatic 1995	10	30	0.44	4.4	0.57	5.7
Spot multispectral 1995	20	34	0.49	9.8	0.54	10.8
Spot multispectral 2005	20	29	0.53	10.6	0.44	8.8

Table 1. RMS errors after geometric correction

Not all SPOT images have the same spatial extension. In addition, their size being 60 km on each side, is wider than the extension of the city of Kinshasa. The images of 1995 and 2005 were cut to the same extension.

4.2 Land use classification

Given the uneven quality of SPOT images and the strong texture of the buildings, they were classified by a supervised method and object-oriented software using eCognition.

4.2.1 Legend

The legend distinguishes four categories: the built-up, the non built-up (vegetation and bare soil), water and clouds.

Some classes are difficult to discriminate using only spectral characteristics, especially so in countries in sub-Saharan Africa. The spectral confusions are numerous, for example, the fields are easily confused with the built-up. Production facilities and services, and the buildings for residential use in some places have the same spectral signature as the sand and burned areas. To overcome these problems, we have enriched the description of spectral regions of texture parameters (see 4.2.3).

4.2.2 Selection of training and validation areas

Training and validation areas were selected based on a visual interpretation of SPOT images supported by a consultation of Google Earth and the plan of the city of Kinshasa, and edited by Aquaterra Kin Art in 1997, ensuring changes due to differences between dates of these documents. 68 areas were selected in common areas of the SPOT images. To ensure an equivalent content of classes on each date, only areas unchanged between 1995 and 2005 were selected. The sample was divided into two, 34 areas for training and 34 for validation.

4.2.3 Choice of attributes

The attributes used in the classifications were chosen on the basis of visual interpretation. The regions are described in terms of spectral averages in each spectral band and the NDVI and the textural point of view, by the standard deviations on the green and red bands, and two textural parameters of Haralick (1973), such as homogeneity and entropy of the panchromatic band.

4.2.4 Segmentation and classification

eCognition was used to perform segmentation and classification. This software can simultaneously use a variety of data, panchromatic and multispectral images or vector data bases, and can create multiple levels of segmentation using a hierarchical approach.

The segmentation algorithm is the "multiresolution segmentation." According to the "Definiens Developer 7 User Guide" (2007), this algorithm merges the pixels into segments of image by minimizing the average heterogeneity and maximizing their respective homogeneities. It can do the same with image segments from a previous segment. The procedure iteratively merges the pixels or segments, as long as the maximum threshold of heterogeneity is not exceeded. Homogeneity is defined as a combination of spectral properties and form. The spectral homogeneity is based on the standard deviation of the distribution of the colour and consistency of form is based on the deviation from a compact or smooth (Cantou et al., 2006). The procedure can be influenced by the scale factor that

limits the size of the resulting segments. The segmentation was performed on the image of 2005 spectral bands of green, red and near infrared respectively, giving them a weight of 2, 1 and 1. The scale parameter was chosen by trial and error and set at 20 with the shape parameter 0.1 (0.5 for compactness and 0.5 for smoothing).

The algorithm for supervised classification of the nearest neighbour was used. It ranks the regions according to their proximity to areas of statistical training.

4.2.5 Validation

The classifications are evaluated by comparing 34 areas of validation within the matrix of confusion. Indices are calculated to assess the quality of results (Richards, 1993):

- The overall accuracy,
- The overall Kappa,
- The Kappa class.

The overall accuracy is good (> 80%) obtained for the different classifications (Table 2). The Kappa coefficient is only acceptable for the classification of 1995 (85%) and 2005 (92%). The classification of 2000 has a poor Kappa (64%) caused by the fog that covers the southwest of the city. This result will therefore not be used subsequently.

Years	Overall accuracy (%)	Kappa Coefficient (%)
1995	93	85
2005	96	92

Table 2. Classification accuracy

Extensive field visits conducted in late January 2009 to the end March 2009 in the extension zones of Kinshasa to understand the factors of urbanization has revealed the existence of different confusions and omissions in the class "building". For example, here are some for the image of 1995 and 2005. They are located in Figure 1 and identified in Table 3.

Confusions errors in 1995	
Zone 1	Canoes to the east of Industrial Limete
Zone 2	Island Mimosa
Zone 3	Fields and sand pit in the southwest in the commune of Mont Ngafula
Confusions errors in 2005	
Zone 1	Sand pit area behind the camp CETA and fields of vegetable crops
Zone 2	Field burned to the east of the city
Zone 4	Island Mimosa with large rocks and a mining company in building materials
Zone 5	Sand bank to the west
Errors of omission in 2005	
Zone 3	Residences in the area of the general staff of the Congolese armed forces (abundance of vegetation)

Table 3. Confusion and omission errors for the class built-up in 1995 and 2005

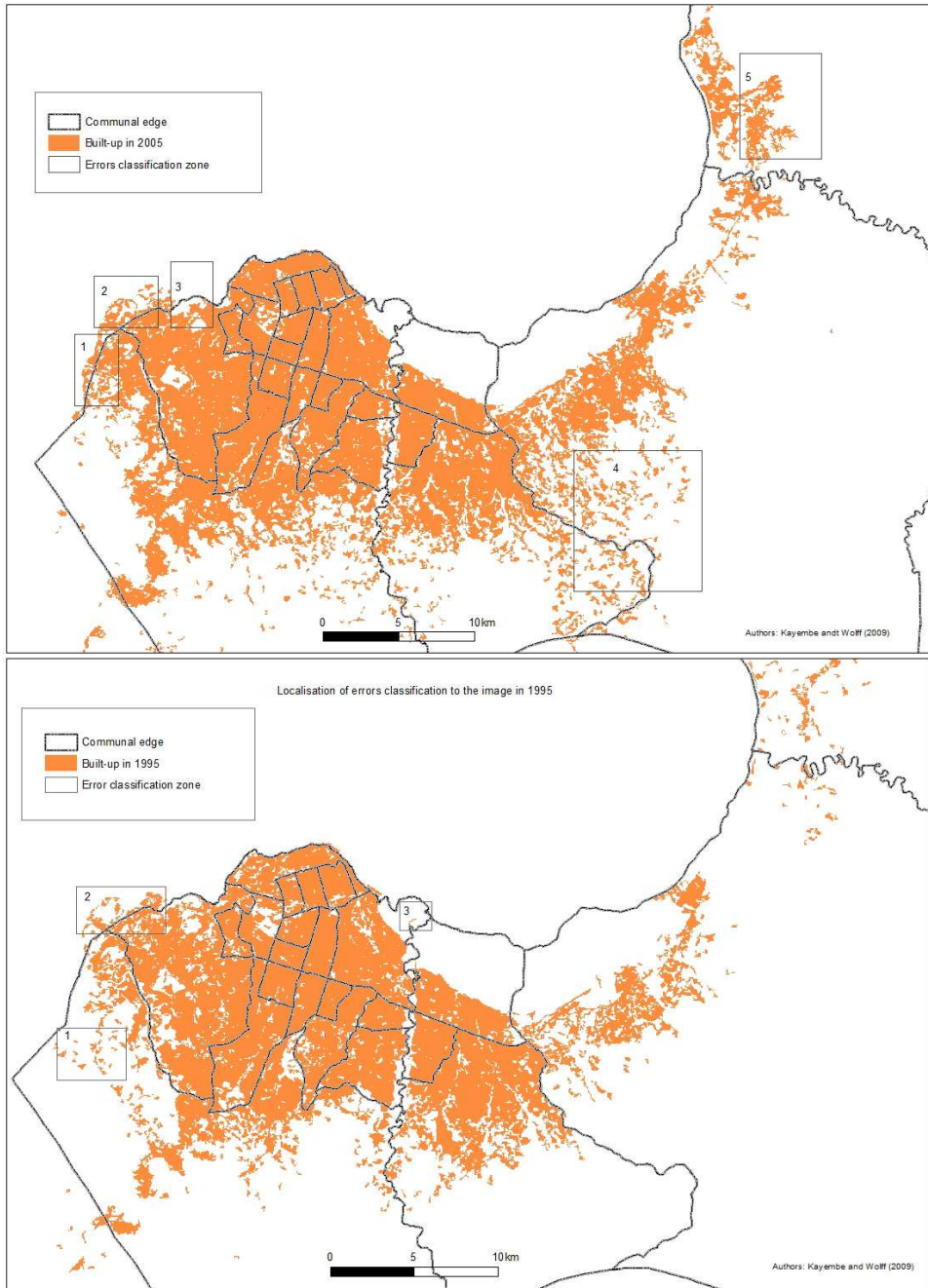


Fig. 1. (a and b): Location of misclassification (Source: Delbart and Wolff, 2002 for the map of municipal boundaries)

These errors will not be included in the analysis.

The results obtained at different dates are generalized by removing polygons classified as "built" with an area less than 1km² and the inclusion of less than 1 km² within the urban sprawl.

The superposition of classes "built" on two successive dates can map the evolution of the building when the matrix changes can be quantified.

5. Results

5.1 Urban growth

The location change was analysed using:

- Field visits conducted in-depth from the end of January 2009 through to March 2009 in the extension zones of Kinshasa to understand the factors of urbanization,
- The layout of the lines of roads and railways digitized,
- Maps and plans of the city of Kinshasa,
- Population data,
- The digital elevation model and slope map.

The map resulting from the comparison of land use classifications in 1995 and 2005 shows that the extensions of the city is concentrated in the southwest and northeast of Kinshasa (Figure 2).

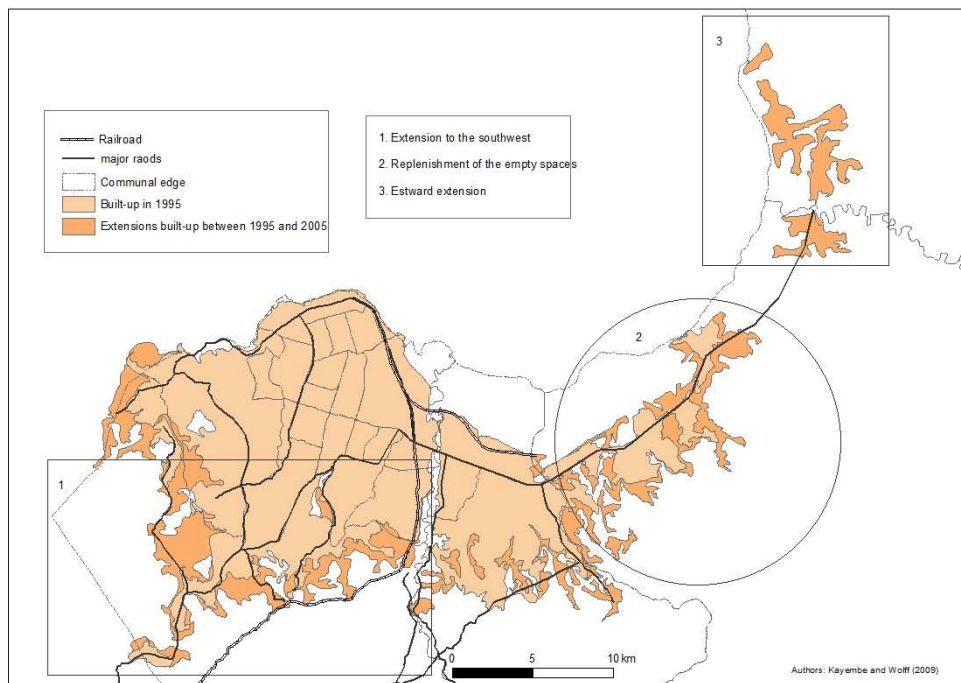


Fig. 2. Evolution of urban sprawl between 1995 and 2005 (Sources: Images Spot KJ 3 096-358 March 31, 1995 and KJ 4 096-358 July 01, 2005)

The spatial extension in the southwest took place mainly along the roads of Matadi and Lutendele (Zone 1). This process concerns the cities of Benseke, Kimbondo, Sans Fil and Matadi Mayo on the road to Matadi, and the cities of Lutendele, Kimbala, Zamba and Mazanza on the road to Lutendele. Cities such as Benseke and Kimbondo or Kimbala and Zamba have even joined in 2005.

To the east, there is a filling of interstitial spaces (Zone 2) and extension (Zone 3). Indeed, in neighbourhoods Mpasa I, II and III, Mikonga and the Badara camp, to the east of the River Ndjili, the blanks were filled. While in the far east, across the river Ndjili (Kinkole), the built-up was extended.

Urban growth can be explained by a population growth (5.1.1). Its spatial location can be explained by two main geographical factors beyond the simple distance to downtown, also an employment centre, the relief (5.1.2) and lines of communication (5.1.3).

5.1.1 Urban growth and population growth

Table 4 shows the evolution of the population of the extent of the city of Kinshasa and its density. In 45 years, the population rose from 400,000 to 7.5 million inhabitants in 2005, while the building area covered 6800 ha in 1960 against 43,400 in 2005. The population density tripled between 1960 and 2005 from about 60 inhabitants / ha in 1960 to 170 inhabitants / ha in 2005, on the whole, the city has expanded and become denser.

Years	Population	Surface (ha)	Density (hab/ha)
1960	400000	6800	59
1967	901520	9470	95
1969	1051000	12903	81
1973	1323039	14600	91
1975	1679091	17992	93
1981	2567166	20160	127
1984	2653558	26000	102
1995	4719862	31007	152
2000	6000000	39518	151
2005	7500000	43414	173

Table 4. Evolution of the population, the extent of Kinshasa and its density (Sources: Lelo Nzuzi, 2008; Yebe Musieme, 2004; Delbart et al., 2002; Mbuila Matot, 2001)

When reporting on data on population and built-up areas in 1960, one can compare the growth in urban population. Figure 3 shows that the extension of buildings characterized by an index of 600 in 2005, while the population has an index of nearly 1900.

To compare growth rates, there is data on a semi-logarithmic graph (Figure 4).

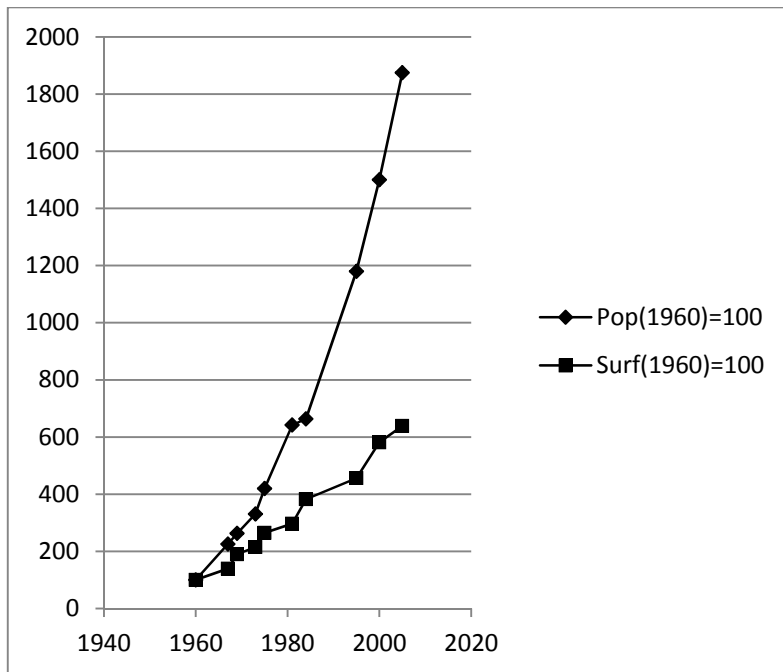


Fig. 3. Urban growth and population growth (Sources: Lelo Nzuzi, 2008; Yebe Musieme Beni, 2004; Delbart et al., 2002; Mbuila Matot, 2001)

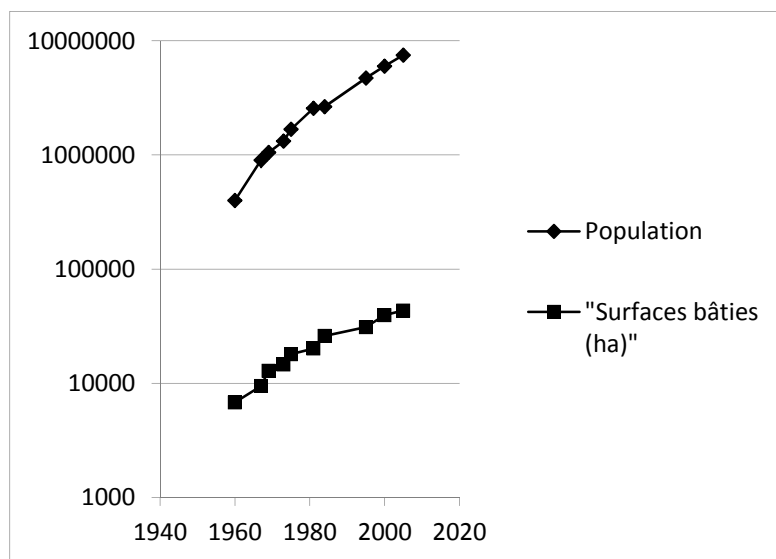


Fig. 4. Semi-logarithmic graph of urban growth and population growth (Sources: Lelo Nzuzi, 2008; Yebe Musieme Beni, 2004; Delbart et al., 2002; Mbuila Matot, 2001)

Figure 4 shows that the average growth rate of the population is less than the extension of the city. The average growth rate of the population over the period 1960-2005 is 6.73%, while that of the built area is 4.21%. Applying this growth rate to the built area of 2005 to calculate the extension of the city in 2009, we do not get the 600 km² regularly cited, but only about 510 km².

By analysing the slopes, one can compare the growth rates, they both appear to decline in 1981 (Table 5). This result confirms the observations of Bruneau (1994).

Growth rate	Population	Urban
1960-1981	9.26%	5.31%
1981-2005	5.07%	3.25%

Table 5. Population growth rate

The first period covers the 20 years after independence (until 1981). It is characterized by a very high population growth and rapid expansion space. During the second period, the population growth rate slows sharply, although it remains high, from 9.26% between 1960 and 1981 to 7.5% between 1981 and 2005. The spatial extension grew at a slower pace and passes from 5.31% between 1960 and 1981 to 3.25% between 1981 and 2005.

5.1.2 Urban growth and relief

According to the observation of existing maps and plans (Figure 5), the extension to Kinkole phases that have characterized the spatial development of Kinshasa since its inception are confirmed.

Born in the west to the Bay of Ngaliema, the city had its first developments to the east with the birth of the ancient cities (Kinshasa, Barumbu, Lingwala, Kintambo) and Gombe (formerly Kalina) in the late 1920s. From then the city grew to the south with the birth of new cities (Kasavubu and Ngiri-Ngiri) between 1930 and 1940. It was during the 1950s that the city took over the management of the east with the merger of Kalina (Leo West) and Leo. Compared to the town of 1959, we find that the city is much more extensive in the south, southwest and east (beyond the communes of Kimbanseke and Masina). Comparing the growth of map altitudes and landforms, we observe that Kinshasa was first extended in the plain corresponding to the extension of the Malebo pool and until independence in 1960 (Figure 6), the colonial authorities strictly prohibited constructions on the hills in the absence of a particular development.

After independence, the city expanded to the southwest on the plateau to the east and the plains. For the period 1995-2005, the growth has continued in the same directions.

To the east, it extends the plain due to the narrow width of flat land in the east (Biyeye, 1997). Indeed, the extension behind the neighbourhoods Mpsa I, II, III and Mikonga did not take place because of steep slopes; this is how urban sprawl has moved beyond the city Kinkole.

To the west of the river Ndjili, areas of flat plains to the south are being built upon, urbanization covers steep slopes (Figure 7), but they are unfit for human settlement in the absence of appropriate management. Indeed, these areas of steep slopes are subject to

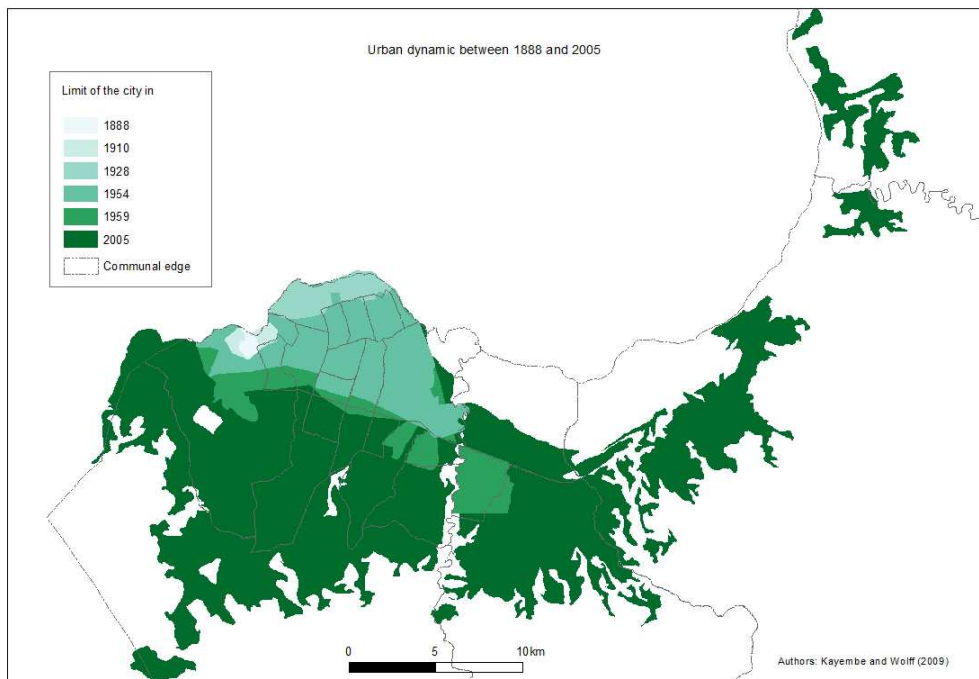


Fig. 5. Urban growth in Kinshasa from 1889 to 2005 (Source: historical maps collected by Johan Lagae, Department of Architecture and Urban Planning, Ghent University)

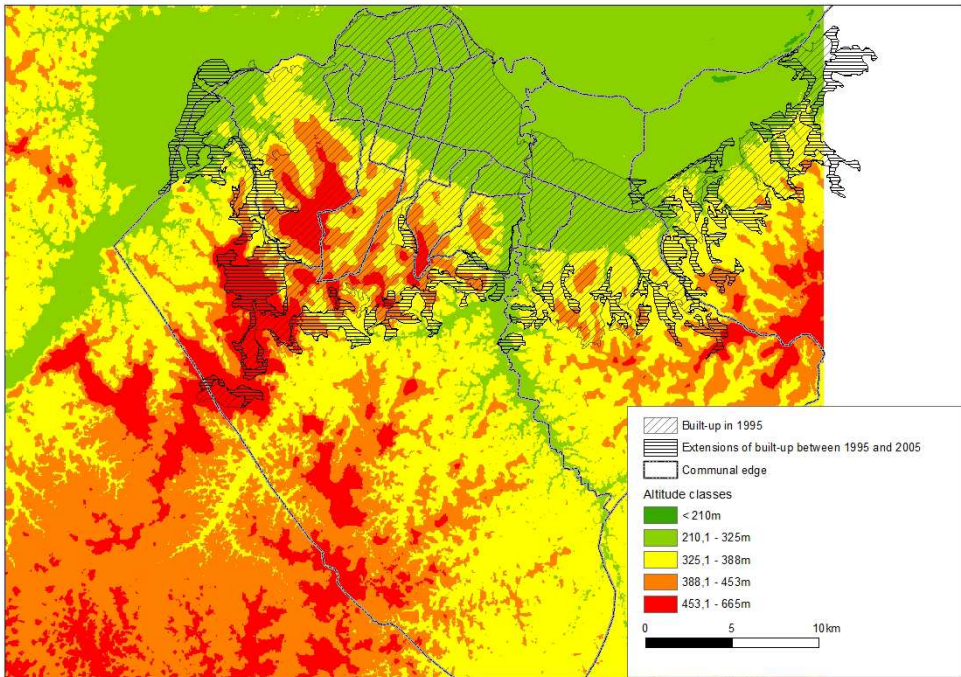


Fig. 6. Urbanization and altitude (Source: Mathieu De Maeyer/IGAT / ULB to the DTM, unpublished)

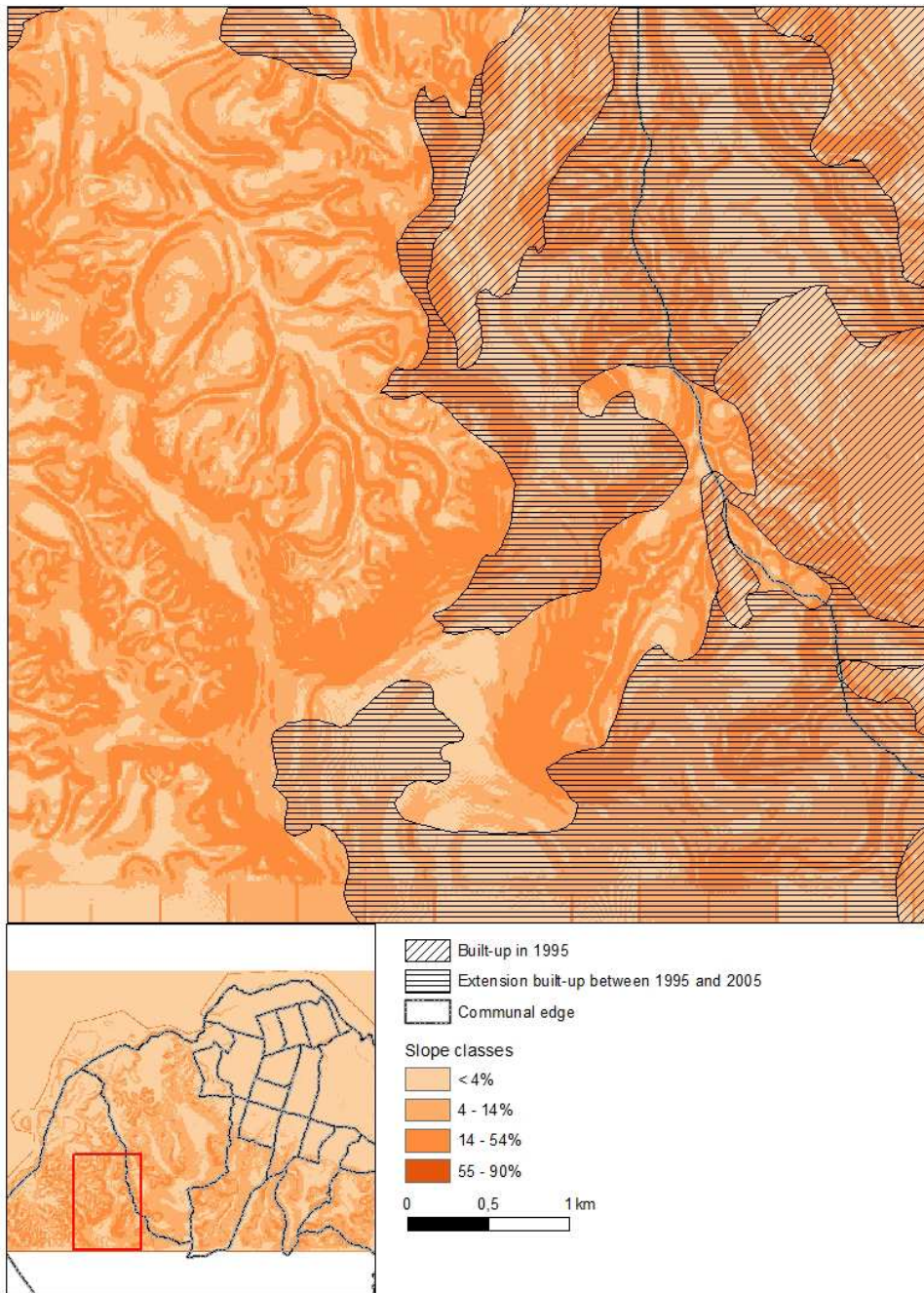


Fig. 7. Urbanization and slope (Source: Mathieu De Maeyer, IGEAT / ULB for the slope map, unpublished)

significant risk of erosion as they are laid bare (Van Caillie, 1990, 1997). In addition, the plains downstream of these steep slopes are affected by floods because of silting. These areas contain steep slopes occupied by the poor. In the future, urbanization will continue to locate in areas of high slope, as is already happening in many places on the hillsides (Camping areas, Kindele, etc.).

5.1.3 Urban growth and major roads

Figure 2 shows that urban growth is more influenced by the roads along the railway. If before independence the railway played a role in the location of industrial areas, the urban railway had not developed, now it has not facilitated access to downtown as a centre of employment and therefore has not polarized urban growth. The roads in Matadi and Bandundu, as well as routes to the drop in Lukaya and to Lake Ma-Vallée, correspond to areas of urban growth today.

Despite the role of highways in urban growth, there are areas that develop latest far from downtown and away from these axes. Indeed, an urban extension area has been observed since the 1990s, south and east of the camp which houses the faculty of the University of Kinshasa. This is the area south Cogelos and neighbourhoods Tchad, Mandela and Department Plateau to the east. These areas develop in the absence of urban amenities. Indeed, they are connected to almost none of the service water supply of REGIDESO. The population is supplied fitted to the sources (Mayi ya Libanga, Mayi ya Niwa, Mayi ya Zamba) or the fountain. This is the case in the district of Mbiti. Where the water is high, people dig a well. The lack of urban amenities does not limit urban growth in Kinshasa. The bottom line for people is to have a home.

The quantitative analysis of urban growth compared to major communication axes, made in the GRASS software, shows that 47.5% of the growth took place at more than 1 km of main roads. Beyond this 1 kilometre threshold, the advantage of proximity to the main roads can be neglected and the neighbourhood effect becomes more important in the sense that people settled near existing neighbourhoods, but at a greater distance from the road.

This helps to highlight the fact that the major communication axes are not always, or are no longer, a major factor in urban growth.

6. Conclusions

Two high-resolution satellite images (SPOT) of 1995 and 2005 were used to map and quantify the urban growth in Kinshasa relatively quickly and with an acceptable reliability. The city spreads very quickly on its margins primarily to the east and southwest along the road to Matadi and Bandundu allowing access by public transport to the city centre which polarizes the bulk of urban employment. However, since the early 1990s, neighbourhoods are growing away from the city centre and transport routes (e.g. district Cogelo, Tchad, Mandela, Department, Plateau), yet they do not benefit from any urban convenience. The extension of the city after 1960 did not spare areas of steep slopes unfit for human settlement in the absence of a particular development. These areas are home to the poor.

By measuring the average growth rate of the population and the extension of the city over 45 years (from 1960 to 2005), it was found that it is 6.73% versus 4.21% for that of the built-

up area. The average growth rate of built surface applied to the surface, built in 2005 to calculate the area built in 2009 revealed some significant errors with the figures regularly quoted.

In the future, a study could be carried out to understand the logic which pushes people to occupy the steeply sloping zones where the problem of gully erosion is acute.

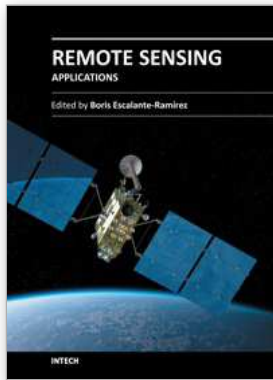
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