URBAN USE OF VHR IMAGES ON BUKAVU (DEMOCRATIC REPUBLIC OF THE CONGO)

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ABSTRACT

The main purpose of this study was to show potential uses of very high resolution (VHR) image in an urban analysis of Bukavu in the Democratic Republic of Congo. As for many of the Third-World cities, Bukavu grew up during the last decades and available topographical information on Bukavu dates back to the middle of the twentieth century. This lack of updated information can be compensated by an appropriate use of VHR images. In this study, IKONOS image recorded on the 14th February 2001 was used.

Image registration are highly dependant on accurate Digital Elevation Models (DEM), these last ones are also useful in urban analyses. The range between the minimum and maximum altitudes observed in the image was more than 500 meters. Furthermore, the viewing inclination angle is more than 28 degrees. In this case, orthorectification is mandatory for correcting relief displacements. Nevertheless, the lack of good Ground Control Points (GPS's) on the old topographic maps and the failure to collect field verification data in Bukavu explains the remaining global 2D RMSE of 10 meters.

For easier image interpretation, multispectral (4m) and panchromatic (1m) images were fused together by means of the LMVM algorithm. Depending on the object, the Computer Aided Photo Interpretation (CAPI) uses or does not use the near infrared information (true or false colour composite). For a more detailed interpretation about the city morphology we draped the 1m multispectral fused image over the 1m resolution DEM grid.

The Built-up Area Index (BAI) computed on the urban mask obtained by CAPI and classification of the vegetation, was compared with the 1954 situation interpreted from topographic maps. The present city shows higher BAI values and in the same time the centre of the city has clearly shifted southward. Statistical analyses are also done on built-up versus slope data.

The lack of good GCP's and the use of DEM produced inaccurate orthorectification which was not adequate for topographical features extraction. Nevertheless the present extensions of Bukavu built-up areas are more than the double of those observed at the beginning of the last half century. New constructions are located on steeper slopes where landslides are frequents. More features could be extracted from the Ikonos image if good GPS measurements were made and if verification by the city authorities was possible. Some practical applications of this study could involve determining better location of new Bukavu extensions.

1 INTRODUCTION

Bukavu, situated on the southern bank of the Kivu Lake, is the capital of South-Kivu province (east of the Democratic Republic of Congo). The study area is rectangular (6.5 x 8 km) and drawn in red on Figure 1. The Ruzizi River at the east of Bukavu corresponds to the Rwanda border.

As for many of the Third-World cities, Bukavu grew up during the last decades and available topographical information was not updated (Figure 1). Topographical information dates from the middle of the twentieth century (1). One of the main purposes of this research was to evaluate if VHR imagery could be used to update this cartographic gap. Figure 1 shows that the clouds of this tropical region are located just outside of Bukavu city, hence we were able to use a cloud-free image.

To start urban analyses based on the VHR image, a DEM was necessary to orthorectify the image. In this study we tried to develop a DEM based on different kinds of data.

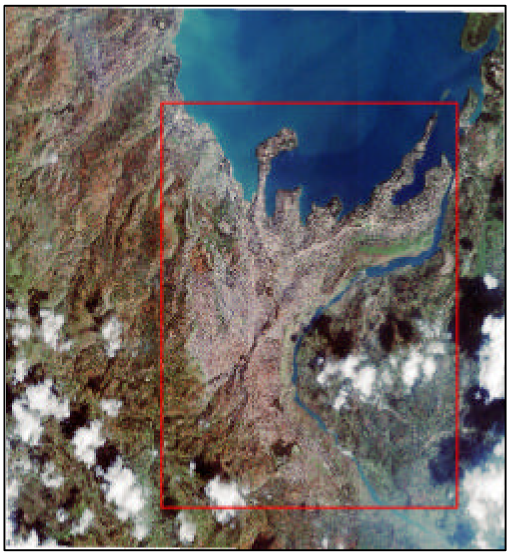


Figure 1: Selection of study area on the Ikonos image of the 14th February 2001.

We developed a DEM based on the available but old aerial photographs and one based on old topographical maps. Both have their limitations but are useful because we were not able to measure accurate GCP's on the field.

(a) Kaduttu (b) ISP (c) Nguba

Figure 2: The growth of Bukavu can be seen on the Ikonos image by observing new settlements

Figure 2 (a) shows new very dense housing developments in the southwest of the city (Kaduttu) in direction of the strong slope. TheFigure 2 (b) is at the same scale than the two other images and the old big building can be clearly seen on the west border of the image. Going from west to east, three other bands can be identified, the first one is constituted by new buildings, and the second one keeps its green appearance due to the implantation of various big buildings of the ISP school. The last band can only be seen in the centre of the eastern border of the image, it corresponds to very densely new settlements. On the last image (c) of the Figure 2, the big villas of the fashionable area along the Kivu Lake banks contrast with the new very densely distributed settlements of the south in the direction of the Ruzizi River.

2 METHODS AND RESULTS

2.1 Geometrical correction

First a DEM was created using aerial photographs dating from 1959 and a set of GPS's. The GPS's were selected on topographical maps of 1957. But due to the growth of the city (see Figure 2), the photographs were redundant in the collection of accurate GCP's, thus the quality of the DEM produced was not accurate enough for geographical research.

By classifying and digitising the 25m contour lines of the topographical maps we created a new DEM. This was done on a semi automatic manner. A grid DEM was interpolated using the digital contours together with the digitised ridges, valleys and additional points. The range between the minimum and maximum altitudes observed was more than 500 meters in a neighbourhood of 5 kilometres radius. Furthermore, the viewing inclination angle of the IKONOS image was more than 28 degrees. In this case orthorectification was mandatory for correcting relief displacements. Nevertheless, the lack of good GPS's on the old topographic maps and the impossibility to perform a GPS survey in Bukavu explains the remaining global 2D RMSE of 10 meters.

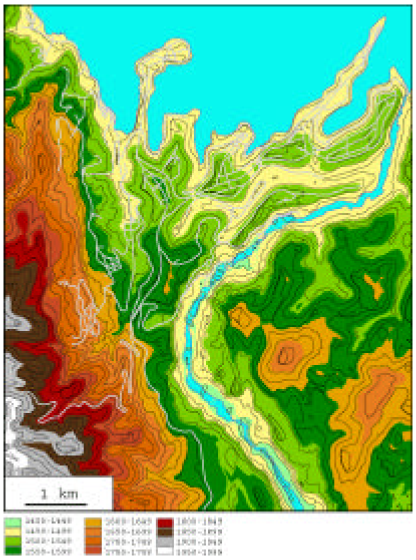


Figure 3: Digital Elevation Model of Bukavu

2.2 Visual interpretation

Computer Aided Photo Interpretation (CAPI) was preferred to numeric classification for three main reasons. First, the standard numerical classifier is not yet enough robust to take into account high values of local variance observed on VHR images. Second, as the roofs are often covered by vegetative or mineral material taken close to the houses, it was extremely difficult to separate houses from others land-cover features as the registered spectral characteristics were similar. Thirdly, the outdated map (see Figure 4b) was not useful in training area selection needed for numeric classification.

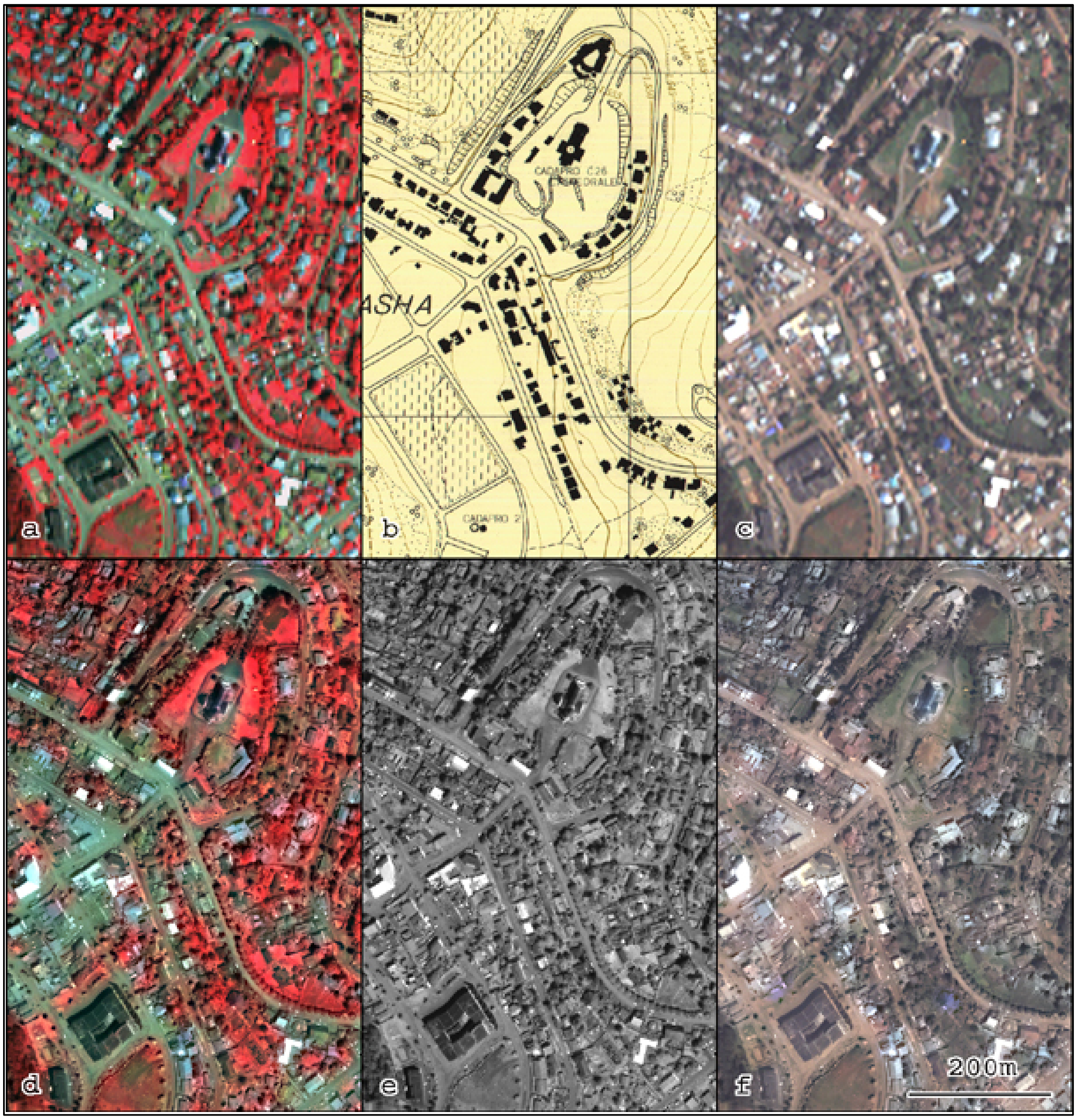


Figure 4: Fusion of the panchromatic (1m) with the multispectral (4m)

a) Infrared false colour composite (4m) b) Old topographic map (1954) c) True colour composite (4m)
d) Fusion (1m) e) Panchromatic image (1m) f) Fusion (1m)

To enable better visual interpretation, the geometrical richness of the panchromatic band must be merged with the spectral richness of the multispectral bands through a fusing process. In fact, the main purpose of this fusion is to inject the geometric detail of the panchromatic into the multispectral image. To guarantee a stable interpretation key, this process tries to preserve the spectral characteristics of the multispectral bands. The LMVM (Local Mean and Variance Matching) algorithm (2) developed by SURFACES was used for the fusion. Figure 4 obviously shows the improvement obtained by this process (compare Figure 4a with 4d or 4c with 4f). Depending on the object, the Computer Aided Photo Interpretation (CAPI) uses or does not use the near infrared information (true or false colour composite)

For a more detailed interpretation of the city morphology we draped the 1m multispectral fused image over the 1m resolution DEM grid. This information could be used to simulate a three dimensional flight over the city of Bukavu. This was done with the PCI Geomatica software (PCI

Geomatica V8.2). Figure 5a shows a 3D view of the main street of Bukavu and Figure 5b gives an idea about steeply sided setting of the Ruzizi valley. The characteristic localisation of the settlements along the contour lines is also clearly visible on Figure 5c.

Figure 5: 3D view of Bukavu

2.3 Built-up area

To analyse the evolution of the city during the last half century, envelope polygons of built-up area were drawn in the same way for the 1954 and 2001 situations. For 1954, topographical maps at 1:5 000 and at 1:10 000 for a small part at the east of the city were used. For 2001, VHR satellite image was the main source of the interpretation. To take into account the density variation observed inside of the envelope polygon, the vegetation was excluded on the base of an automatic classification of the 2001 image. The same mask of vegetation for the two situations was removed because of the lack of information on the status of vegetation in 1954. This resulted in an overestimation of the built-up area of 1954 and in an underestimation of the built-up area of 2001 (buildings hidden by the vegetation). Figure 6 shows in red the built-up area of 1954 and the present situation is given in pink. Between these two dates, built-up area grew at least from 375 to 888 ha.

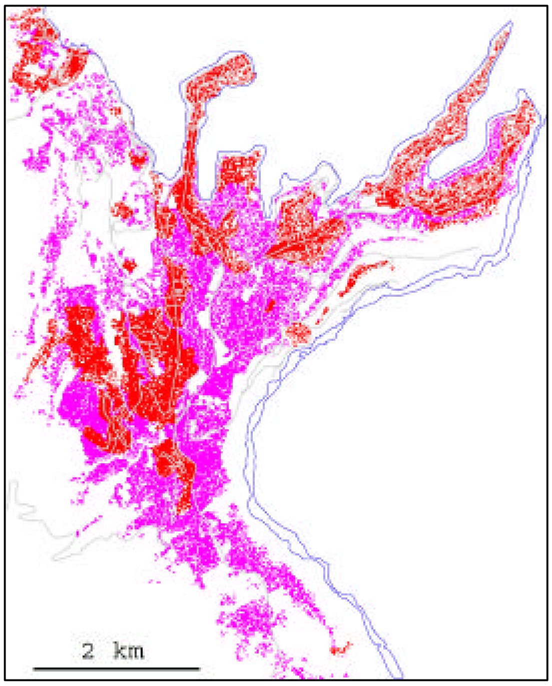


Figure 6: Built-up area of Bukavu (1954 situation in red, 2001 situation in pink)

The Built-up Area Index (BAI) was calculated because it is a very robust index that remains relevant even if it is computed on an image with some vagueness. This index is very easily computed in two steps in a moving window. First, the number of built-up pixel falling within the circular window is calculated and then in the second stage, the value is divided by the number of pixel of the window to express the result in percentage. In this case the radius of the moving window is 31 pixels. Figure 7 shows that there is presently a strong connection between the various nucleuses of the city and that the centre of the city has shifted southern in comparison with the 1954 situation.

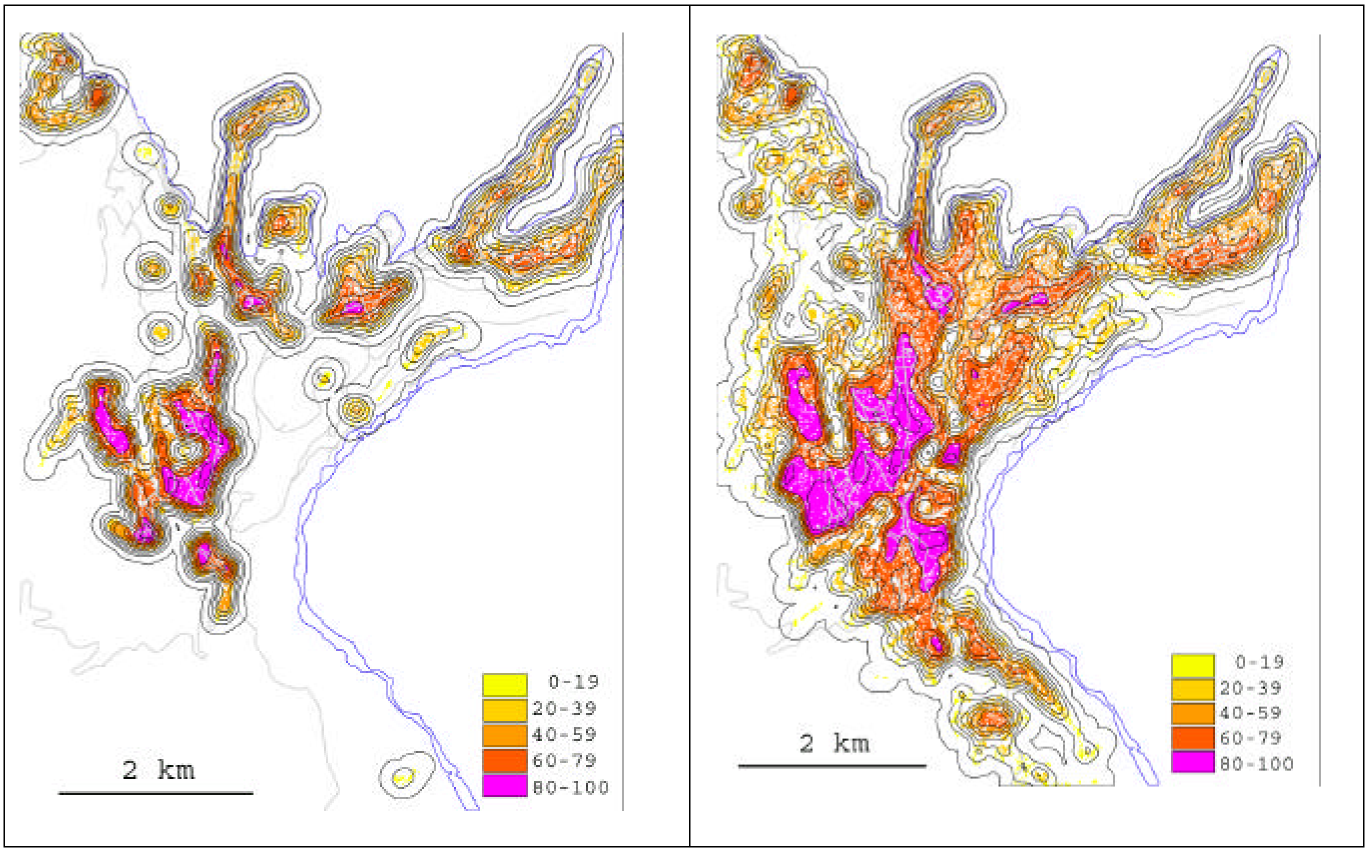


Figure 7: Built-up Area Index of Bukavu in 1954 (on the left) and in 2001 (on the right)

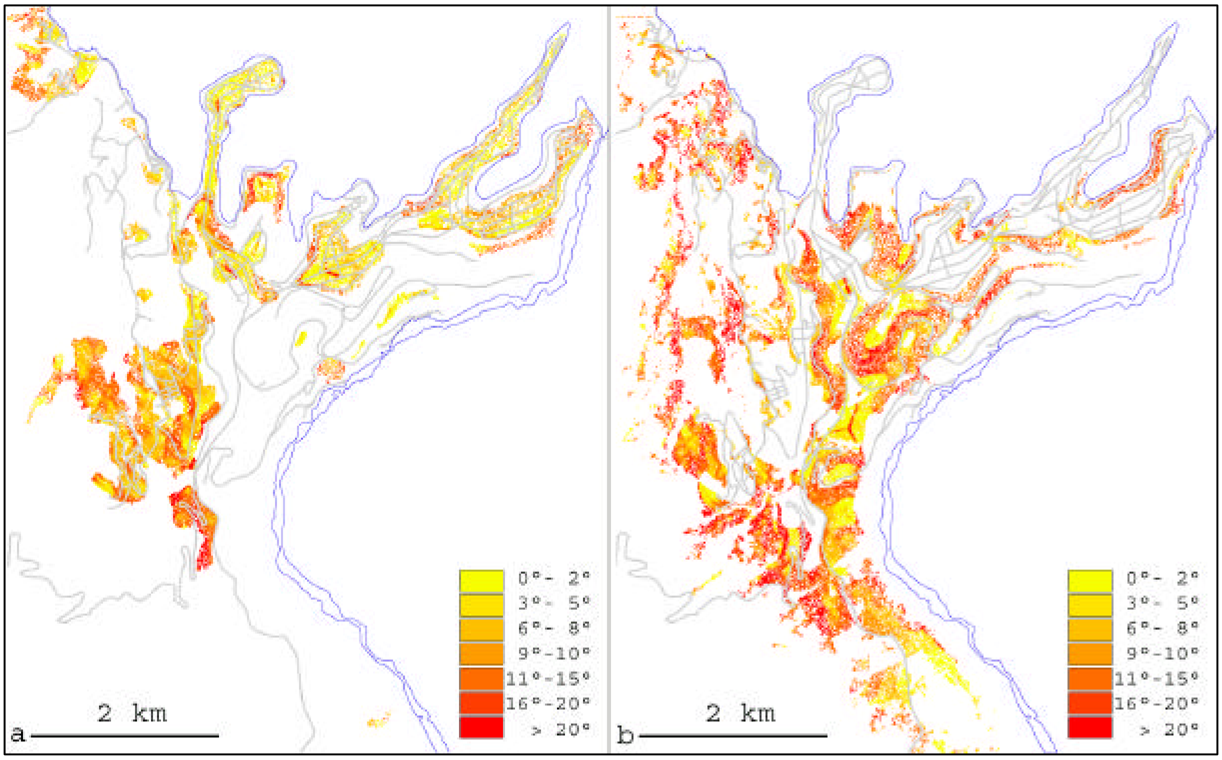
2.4 Urban statistics according to slope

Due to the lack of information on land ownership policy in Bukavu favouring or discriminating the growth of the city in one or in another direction, we focused our research to the slope which is one of the most important physical factors (3). Contrary to the temperate zones, the equatorial ones are not really affected by the slope aspect.

The slope was computed in degree from the DEM. Figure 8 allows the determination of built-up area change relative to the slope between 1954 and 2001. It can be observed that the extensions of the city are southward towards the steepest slopes. Table 1 shows that the built-up area growth is at least of 512 ha during the last 50 years. The 11-15° slope class is characterised by the most important growth of the built-up. Between 1954 and 2001, the relative importance of the two first classes decreases and contrary to the three last classes who increases. It is obvious that the city is expanding on the steeper slopes and this is a real problem considering that Bukavu is at high risk of landslide occurrences.

Table 1: Built-up area evolution observed between 1954 and 2001 according to slope

Built-up area according to the slope						
	1954		2001		growth	
Slope (degree)	(in ha)	(in %)	(in ha)	(in %)	(in ha)	(in %)
0° - 5°	137	37%	244	27%	105	20%
6° - 10°	142	38%	271	31%	131	26%
11° - 15°	71	19%	205	23%	134	26%
16° - 20°	18	5%	109	12%	91	18%
> - 20°	8	2%	59	7%	51	10%
Total	375	100%	888	100%	512	100%



a) 1995 b) 2001

Figure 8: Evolution of the built-up areas according to the slope

3 CONCLUSIONS

Even if the geometrical correction was not as well as desired and that it was impossible to conduct fieldwork, VHR images give very useful information on city growth and developments. These images are appropriate in urban analyses where rapid changes occurred without any updating of the cartographic database.

Some practical applications were realized within the framework of this research and these could be useful through interaction between researchers and the city planning officials of Bukavu. This data can be applied together with GIS in developing tools for locating of new services or equipment, division of the country into new districts based on various criteria, proposition of new extensions of the city and many more (4). This shows that the future potential application of this data is crucial and that there is further research potential within this field.

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REFERENCES

Vansteenvoort, L., De Man, J., Gamanya, R., De Maeyer, P., Hart, J. & Beyers, R. (2002): Cartography of Kahuzi-Biega national Park 2002. Proceedings of the conference "Space Applications for Heritage Conservation", Strasbourg, France, 5-8 November 2002, 4 p., on ESA Cd-Rom.

Cornet, Y., de Béthune, S., Binard, M., Muller, F., Legros, G. & Nadasdi I. (2001): RS Data Fusion by Local Mean and Variance Matching Algorithms: their Respective Efficiency in a Complex Urban Context. Proceedings of IEEE/ISPRS Joint Workshop on Remote Sensing and Data Fusion over Urban Areas, Rome, 8-9 November 2001, 106-111.

Binard, M. & Nadasdi, I. (1998): Utilisation des images satellitaires à très haute résolution pour la mise en œuvre de la révision des plans de secteur, Bul. Société géographique de Liège, 34, 1998, 85-94.

Donnay, J.P., Barnsley, M. & Longley, P. (editors) (2001): Remote Sensing and Urban Analysis, GISDATA Series 9, Taylor & Francis, London, 268 pages.