MAPPING INACCESSIBLE AREAS BY INTERGRATING REMOTE SENSING DATA AND HISTORIC CARTOGRAPHIC DOCUMENTS

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ABSTRACT

The cartography of several developing countries is characterized by lacks in the spatial coverage and the recentness on mid scales and large scales. This is especially the case in Central Africa. Certain countries have had the advantage of being mapped recently on a mid-scale (e.g. Ruanda in the '80). Other countries encounter great arrears in their cartography for historical, economical, political and geographical reasons.

The Kivu region, in the east of the Democratic Republic of Congo, is one of these regions with a lack of up-to-date cartography. Because of the political circumstances, the region is hardly inaccessible and almost no recent field data is available. In this framework the possibilities are investigated for combining remote sensing data with available documentation for the production of up-to-date base maps. A thematic interpretation of multitemporal satellite imagery indicates land use and vegetation changes in the area.

For the production of satellite image maps of difficult accessible regions, the existing documentation is critical for the quality of the maps. The GCP for the georefereing and the classification of the satellite images must be extracted from the available information. Also a part of the thematic information on the satellite image map is derived from the existing cartographic documents because no extensive fieldwork can be executed.

1. INTRODUCTION

1.1 Cartography in developing countries

Great parts of developing countries are characterized by the lack of up-to-date maps. Available maps are mainly produced in small scales and are obsolete thus offering only poor information.
Most of the tropical regions are under pressure of various sources, they are subject to rapid political, socio-economic and environmental changes. For the monitoring of these changes, the daily management of the environment, humanitarian activities and interventions and the reorganization of the infrastructure, a reliable planimetric and thematic basis is required. For the governments and organisations, it is of major importance to be aware of the exact location of the working area and to have a clear overview of the actual situation. Dispose of reliable up-to-data maps fulfils a basic information need for the efficient development of managing and monitoring plans. Base maps give the opportunity to position and fill in own collected information of the region.

1.2 Remote sensing of developing countries

A satellite image gives a synoptic view of an area at a certain moment. It contains a huge amount of recent information that is suitable for mapping purposes. Satellite images show clearly the vegetation coverage, access roads, rivers, human settlements and installations, agriculture and other evidence of human activities. This information, and other additional information, can be extracted from remote sensing data, collected in a geographic information system (GIS) and visualised as a map.

For inaccessible regions, satellite imagery gives the only opportunity to collect recent information, in a fast and easy manner, covering the complete area. Satellite image archives can also give snapshots from different moments in time. Comparison of this information enables an evaluation of land cover and land use changes.

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2. STUDY AREA

2.1 The Kivu region

The region of Kivu is situated in the east of the Democratic Republic of Congo, near the border with Uganda, Ruanda, Burundi and Tanzania. This region is densely populated and rich in mineral commodities and agricultural products. It has a complex socio-cultural network because it is situated in the migration corridor with several ethnical, social and cultural communities. These communities are furthermore strongly influenced by the vicinity of other countries and the political events which are manifesting there.

Except from the socio-economic environment, the natural environment stands under extreme pressure. The mineral fortune is exploited by a large number of small companies and individuals, most time without interest for the environmental context.

An example of the natural valuables in the region, standing under large pressure of the war, is the Kahuzi-Biega National Park. The park is situated in the east of the Kivu region, 50km west of the town of Bukavu and is a vast area of primary tropical forest, dominated by two spectacular extinct volcanoes, Kahuzi and Biega. It has a diverse and abundant fauna; one of the last groups of mountain gorillas (consisting of only some 250 individuals) lives at between 2100m and 2400m above sea level. This park consists of two parts, the western lowland part that is inaccessible for safety reasons and the highland part in the east with limited accessibility for park guards. The Wildlife Conservation Society (WCS) collaborates with the local park managers in monitoring the park and co-operated with the pilot project that is subject of this paper.

2.2 Satellite image maps for Kivu

The Kivu region is a typical example of a region with a lack of a recent covering cartography. The most recent maps date from the period before 1960 and are geometrically unreliable. The consequences of the political events for the land use and the environment and the high dynamics of the population makes it necessary to create new base maps. Because of the political instabilities, a conventional topographic mapping is out of the question.

In this context, a pilot project was set up to develop a methodology for the production of a recent cartography based on satellite imagery and existing documents and without extensive fieldwork. The study area in the Kivu region is limited by 24°E to 29°E and 1°S to 4°S (Figure 1). This is an area of nine square grades and is covered by nine maps each of one square grade on a scale of 1 to 200 000. The satellite image maps give basic information about the position of roads, rivers, settlements, limits, etc. A thematic interpretation is given as a change detection analysis of the land cover.

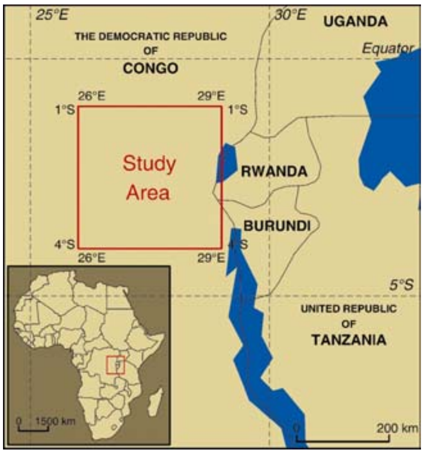


Figure 1. Study area in the Democratic Republic of Congo.

3. DATA ACQUISITION

3.1 Satellite imagery

Satellite imagery is the source of recent information of the study area that is used as a basis for the creation of a recent cartography. The complete study area is included in a spatial coverage of 9 Landsat ETM+ images. These Landsat ETM+ images were taken between August 1999 and February 2001. For this area, a complete spatial coverage of Landsat TM images was retrieved from image archives; these images date from June 1984 until August 1987. Image archives also had Landsat MSS images from September 1972 until August 1975 available, covering the study area, except for two images in the western part. Based on these three spatial coverages, important land cover change can be detected over 2 periods of 10 years time.

The humid tropical climate is responsible for a high cloud cover. Cloud free images are therefore difficult to obtain. Because of the limited duration of the pilot project, Landsat ETM+ images had to be bought at a certain moment, although cloud free images weren't available. The cloud cover of the Landsat TM images is good but the Landsat MSS images are very cloudy. Landsat MSS archives don't give better alternatives. The cloud cover of the images will make it difficult to assess change detection over the three time periods.

3.2 Existing documentation

An inventory of the cartographic documents and historical geodetic surveys was made up [9]. It provides an overview of the existing documentation for the Kivu region and confirms the assumption that no recent detailed information is available.

The only map series that covers the complete study area is the 'Cartes de Territoire' on a scale of 1 to 200 000. The geometric accuracy of this map series is very heterogeneous and depends on the availability of aerial photographs and the level in which the region was explored. Large-scale maps are mostly made up in a locale network without reference to a national system (e.g. maps for exploitations).

The relief, climate and penetrability have been the cause of the absence of airborne photography, resulting in turn in the lack of regular cartography. Some strips of aerial photographs are available but cover only a very limited part of the study area.
'Le Canevas Planimétrique du Kivu-Maniema' [6] (last revision in 1968) is an important historic geodetic survey that covers the study area, except from 2 central parts. It contains a list of coordinates of 900 survey points and an overview map of the network with the lines of sight on a topographic background. The coordinates are given in UTM projection with the ellipsoid of Clarke 1880.

4. DATA PROCESSING

4.1 Cartographic production process

A satellite image map is a cartographic document based on georeferenced satellite images (classified or not) combined with additional information. For the creation of the satellite image maps of Kivu, a conventional production process was followed, as shown in
Figure Figure 2.

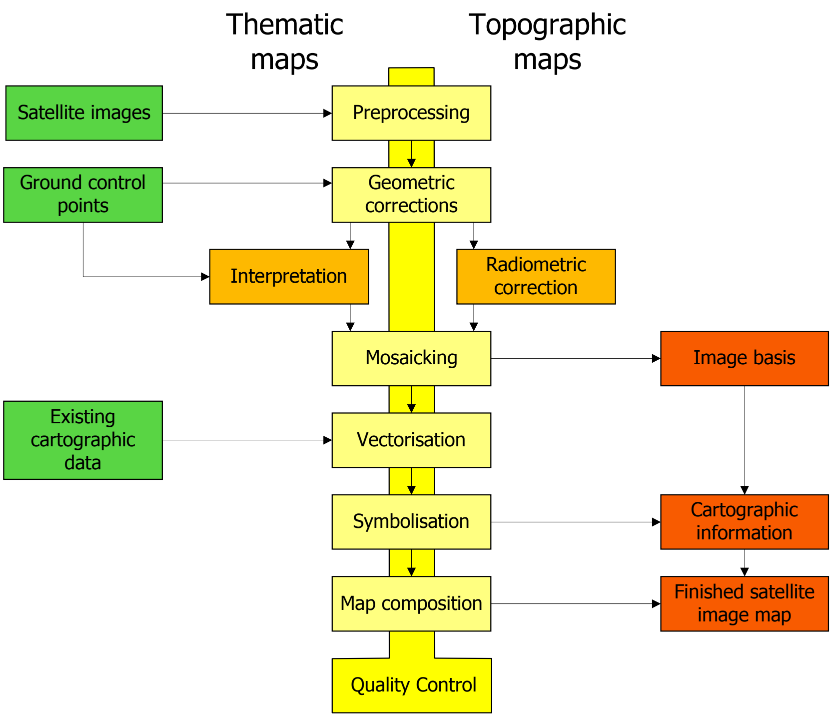


Figure 2. Production process of satellite image maps

Although specialized software is available for image processing and cartographic processing, the production of satellite image maps, encounters some difficulties, for inaccessible regions without a recent cartography.

4.2 Image Processing

To use satellite imagery as geometric basis for a map, it has to be georeferenced and a set of reliable ground control points (GCP) is needed. It is also preferable to use a digital elevation model (DEM) to eliminate the radial displacements when there are important height differences. The satellite images are georeferenced to the UTM projection with ellipsoid of Clarke 1880. This ellipsoid is generally used in the region and is therefore chosen as reference for the satellite image maps.

Due to the political circumstances, it is impossible to collect GCP on the field. The GCP must therefore be extracted from the available documentation. The majority of the existing maps are of no use for georeferencing because they are unreliable, obsolete or do not indicate the used reference system and coordinates. The few maps that are usable only cover a very small part of the study area. This deficit of reliable cartographic documents forms one of the difficulties in the realisation of an up-to-date cartography for the Kivu region.

The possibility was investigated to use the survey points of the geodetic survey ‘Le Canevas Planimétrique du Kivu-Maniema’ as GCP. The ground signals of the survey points are, if they still exist, to small to be visible on the Landsat ETM+ images (resolution of 15m in panchromatic). To position the survey points on the images, the interpretative method shown in Figure 3 was followed. The overview map of ‘Le Canevas Planimétrique du Kivu-Maniema’ (Figure 3a) shows the survey points and lines of sight. Most of the survey points are mutually visible over long distances and in several directions. This implicates that these survey points are positioned on the most elevated points of the relief. On the overview map and the ‘Carte de Territoire’ (Figure 3b), the survey point is positioned relatively to topographic elements, like rivers and roads, which are visible on the satellite image. Like this, the supposed position of the survey point is assessed. This can only be done with sufficient certainty if the elevated point is clearly pointed out. Using this working method, enough GCP were extracted to georeference the satellite images with a RMSE smaller than 90m (3 pixels) with a first order transformation and a nearest neighbour interpolation resampling. A correction of the radial displacements couldn’t be executed because no covering DEM was available.

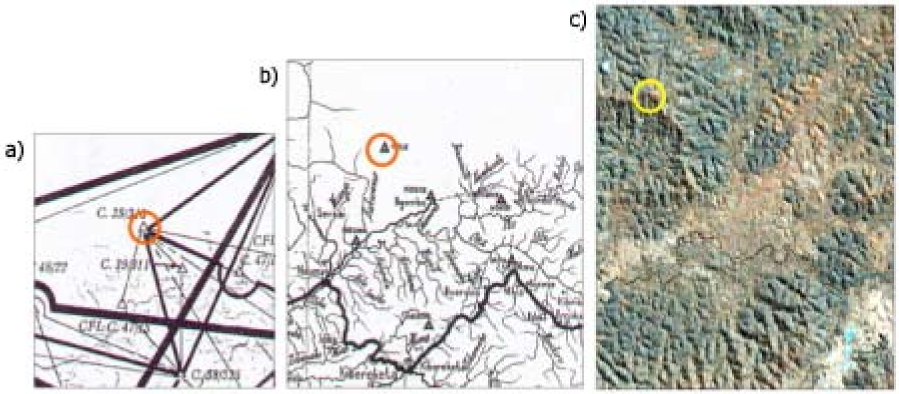


Figure 3. Position of a ground control point on a) overview of 'Le Canevas Planimétrique du Kivu-Maniema', b) on 'La Carte de Territoire de Punia, and c) on the image.

The nine satellite images are put together in one mosaic covering the complete study area with an adaptation of the radiometric characteristics of the images. This mosaic uses the band 4, 5 and 7 of the Landsat images which is a good combination for the analysis of geologic information.

The satellite images are processed using the software Geomatica.

4.3 Vector data

The cartographic information on a satellite image maps originates from available conventional sources, such as maps or field data, or is obtained through image interpretation and analysis. This additional information is digitized and managed in a geographic information system (GIS). Topographic elements like roads, rivers, lakes, settlements, airstrips, etc. are vectorised directly on the georeferenced image. Invisible elements, like borders, toponymy, hydronymy, etc. are derived from the ‘Cartes de Territoire’. These maps, covering the country, don’t have a good geometric accuracy but are an important source for this kind of information. The cartographic information was vectorised in AutoCAD Map and collected in ArcView.

4.4 Map composition

The cartographic vector data is symbolised and combined with the image basis. This is done in the cartographic editing program Mercator S/A of Esko-Graphics that gives the opportunity of an adequate symbology because of the selective masking possibilities (Figure 4 [1]. The visual presentation of a satellite image map differs a lot from the conventional topographic maps. The symbolisation is adapted to the varying background colour of the satellite image so that it is clearly legible but covers as little image data as possible.

The satellite image map is completed with marginal information.

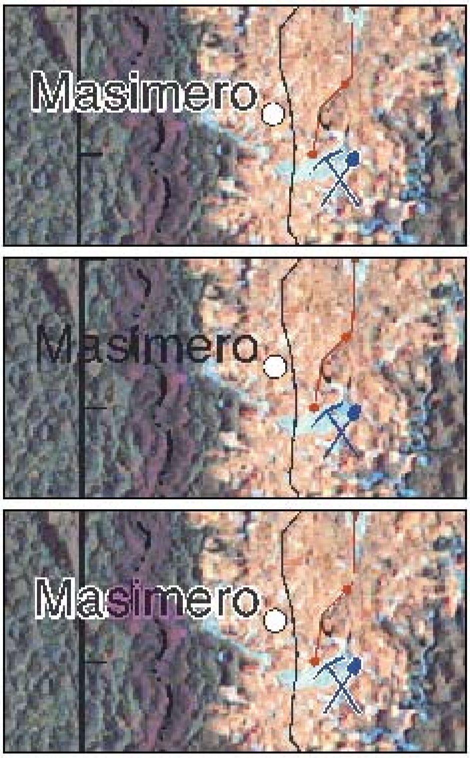


Figure 4. Use of selective masking to augment the legibility of the map

4.5 Classification

To classify satellite imagery, it is necessary to define a number of vegetation classes that are identifiable on the satellite images with minimum error and without any fieldwork. These vegetation classes were established together with field experts and based on scientific research [2]. Ten different classes were defined: dense vegetation, secondary vegetation, bare soil, agriculture, savannah, swamps, clouds, shadow, water, culture. The available Landsat TM and ETM+ images were classified with supervision taking representative pixels as samples for every class.

The classes are very large and can be used for the whole Kivu region or comparable landscapes. By using large classes, the classification errors are limited because of less overlap between the spectral characteristics of the different classes.

5. RESULTS AND DISCUSSION

5.1 Image processing

Using the survey points of ‘Le Canevas Planimétrique du Kivu-Maniema’, it was possible to position a sufficient amount of GCP with a RMSE smaller than 90m. To assess the geometric accuracy of the georeferencing, some additional GCP are needed to use as check points. These additional GPS are not available from the existing documentation because it was already used for the georeferencing of the images.

For the area of the Kahuzi-Biega National Park highlands, the georeferencing was tested using GPS measurement points, taken by the Wildlife Conservation Society (WCS). These GPS points were taken with handhold GPS on features that are clearly identifiable on the images. This was the only feasible manner to take a limited amount of GCP in a part of the study area. It is impossible to carry around more sizeable equipment in the area, like DGPS, due to the political circumstances. The accuracy of the handhold GPS is sufficient for the georeferencing of the Landsat images with a resolution of 30m.

The GPS coordinates are referenced to the UTM projection using WGS ’84. Because the satellite images are georeferenced to the UTM projection using the ellipsoid of Clarke 1880, the GPS points aren’t compatible. By transforming the GPS points they fit within the limit of 90m. When they are positioned without transformation, a systematic translation of 300m to the SW is encountered. This translation is due to the use of different ellipsoids.

The nine satellite images are put together in one mosaic for the complete study area. This continuous mosaic is then cut into separate parts to use as background for each of the nine map sheets. Because the mosaic combines more than two images, it is difficult to find an appropriate look-up table for each of the nine satellite images to become one radiometric continuous mosaic. This is also influences by the change in vegetation cover from west to east of the study area. Most images are well integrated accept for one image on the map sheet S3/26 (Figure 5). This image has a high cloud cover. Some large clouded areas are replaced by parts of the Landsat TM image.

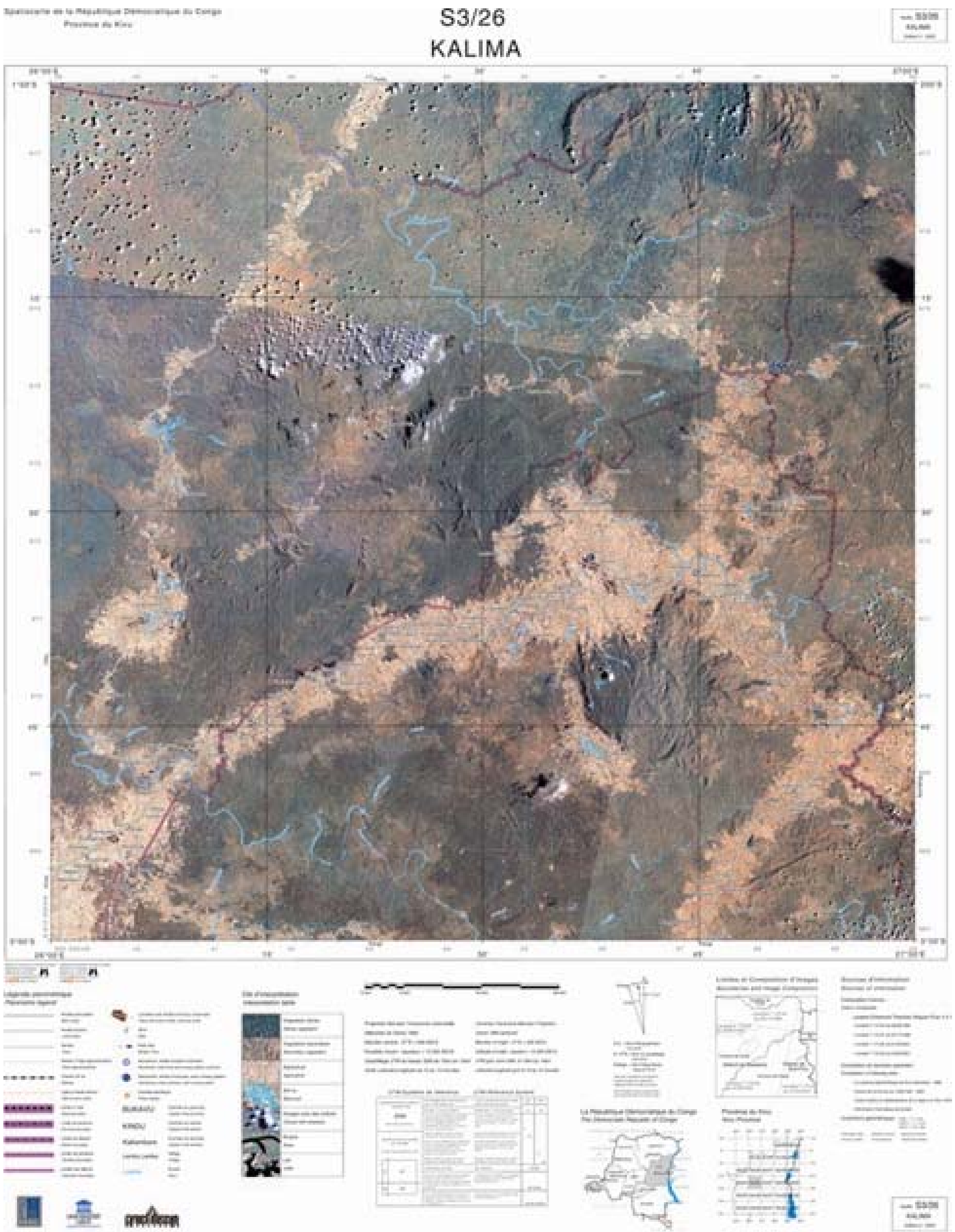


Figure 5. Map sheet S3/26 Kalima (reduction of the original format 60cm x 80cm).

5.2 Cartographic information

The cartographic information was checked by locals. These people also don't have access to the major part of the area but know it very well. Especially the toponymy that was derived from the Cartes de Territoire is strongly adapted after the verifications.

The GIS that contains all information is updated frequently in function of the availability of new information.

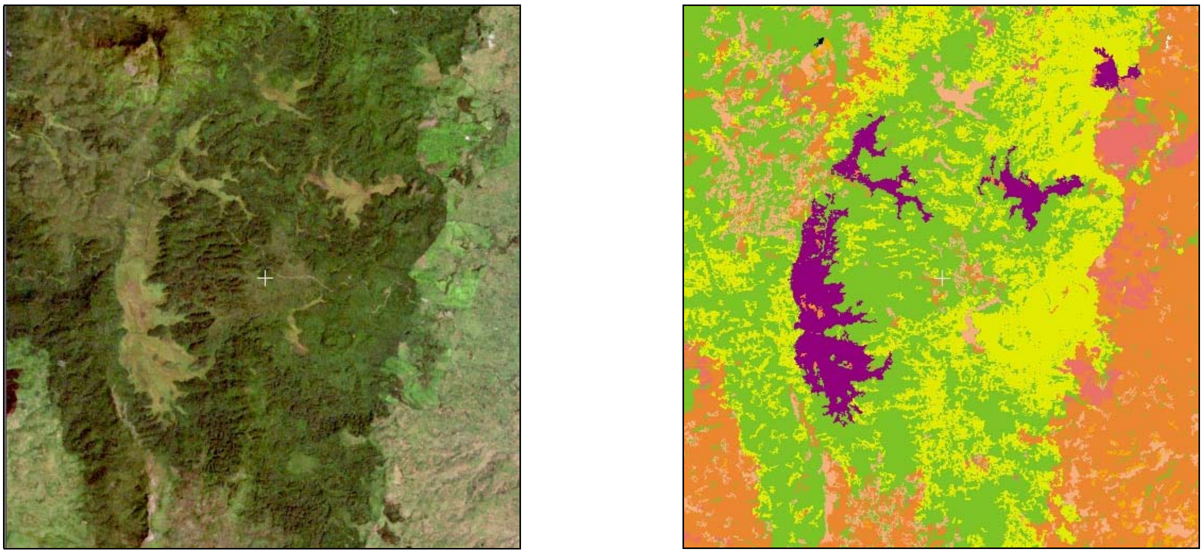
5.3 Classification

Figure 6 shows the classification results for the image, covering a part of the Kahuzi-Biega highlands. The following colour interpretation key is used:

- dark green: dense vegetation;
- yellow: secondary/less dense vegetation;
- purple: vegetated swamps;
- light orange: bare savannah;
- orange: agriculture;
- pink: cultivated areas with eucalyptus trees;
- white: clouds, shadow;
- blue: water.

The classification of the Kahuzi-Biega National Park highlands could be improved because the Wildlife Conservation Society (WCS) was able to collect some field data. A given transect was followed measuring GPS locations at certain points and noting down a description of the location (vegetation type, canopy cover, water regime, substrate, soil colour, dominance canopy, canopy tree height, dominance tree species, understory type, canopy leaf phenology and extras). With this information the list of vegetation classes could be optimized and [11].

But this working method is not the key to reach a much more detailed vegetation classification. For a smaller region and a larger classification detail, it is better to analyse the image manually and draw polygons of different spectral reflectance. In the second step these polygons must be checked on the field, which is very time consuming and requires complete accessibility of the study area.



a) b)

Figure 6. a) True color Landsat ETM+ image of a part of the Kuhuzi-Biega National Park, and b) the classified image.

6. APPLICATION

The Wildlife Conservation Society is currently coordinating a biological monitoring program in the Kahuzi-Biega National Park in cooperation with UNESCO World Heritage Program. Accurate up-to-date base maps are indispensable for the coordination of this project. On the base maps, GPS positions of survey data and law enforcement data can easily be plotted using GIS.
Wildlife survey results can thus be correlated with vegetation and other thematic features (such as roads and settlements) on the map. The temporal analysis of satellite images provides an assessment of human encroachment and vegetation changes in the park.

Cooperation with other organisations, active in Kivu, is set up by the UNESCO World Heritage Program in the framework of Surveillance of the Gorilla Habitat (SOGHA). SOGHA aims at monitoring the habitat of the Mountain Gorillas in Central and East Africa by putting together a geographic information system (GIS), producing basic updated maps and setting a Remote Sensing Unit at the UNESCO WHC for managing this and future projects.

7. CONTINUATION

The same techniques are used in a project for the mapping of the five national parks of the Democratic Republic of Congo. In this project, the radial displacement due to high differences is taken into account.

8. CONCLUSION

Although the production of satellite image maps is a well known technique in a number of institutes and laboratories, original solutions have to be found in conditions of difficult access or inaccessibility of the terrain. In this case, the interpretation of a historic geodetic survey has lead to a sufficient number of GCP.

The use of historic cartographic documents made it possible to give some thematic information about features that can't be extracted from remote sensing data. The verifications of locals and the reconsideration of the images after their remarks, augmented the reliability of the maps.

These satellite image maps (paper version and GIS) can be used for further research of the area. They are base maps that form an important support for the future research and development of the area, including the National Park of Kahuzi-Biega.

The realization of satellite images is a good alternative to get an up-to-date basic cartography of an area that is difficult to access. The number of maps that can be finished without carrying out field surveys, together with the geometrical accuracy depends on the characteristics of the available documentation for the area.

9. ACKNOWLEDGEMENT

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