MONITORING THE REOPENING OF ROADS IN THE DEMOCRATIC REPUBLIC OF CONGO WITH EARTH OBSERVATION DATA

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ABSTRACT

Infrastructure projects are particularly important for the socio-economic development. But roads can also have a large impact on natural environment while opening new tracks. Changes in the accessibility of remote areas could increase illegal activities, in particular the illegal timber logging.

Within the Global Monitoring for Environment and Security (GMES) project called G-Mosaic (GMES Services for Management of Operations, Situation Awareness and Intelligence for Regional Crises), the critical asset working group developed geo-spatial information to monitor human and environmental impact of reopening roads, in DRC (Democratic Republic of Congo). This paper presents the Earth Observation (EO) derived tools to monitor forest changes along the route between Kisangani and Bunduki/Bondo. The EO monitoring service combines frequently large area monitoring at high resolution (20 - 30 m) with detailed annual monitoring at very high resolution (0.5 m). First results quantify the number of clear-cuts along the road in the Rubi-Tele reserve. The number of patches increase from 2010 to 2011 but the total area in these clear-cuts is constant during the period.

The potential application of the developed tools in the context of REDD will be further developed in the REDDiness project. The project was obtained in the last calls of the 7th European Commission (EC) Framework Programme and has just started in 2011. In REDDiness, up-to-date Earth Observation (EO) techniques will be adapted to local situation in order to assist Central African countries in addressing the challenges of Reducing Emissions from Deforestation and forest Degradation (REDD). For both G-Mosaic and REDDiness projects, there is a high interest of measuring and mapping changes in the world's humid tropical forests to derive national and regional figures for multilateral agreements and sustainable forest management.

INTRODUCTION

Roads-rehabilitation projects in the Democratic Republic of Congo (DRC) aim to re-establish lasting access between provincial capitals and districts and territories. According to the respective funding organization, these road projects must be sustainable both for the population and the natural environment. This mandatory condition is usually assessed in impact studies done by field visits during the whole project. This paper describes the potential use of Earth Observation (EO) techniques to assess these socio-environmental impacts and complete the field studies.

New road projects are of high importance for population development but could have a large impact on the environment while opening new tracks for timber logging. The positive and negative impacts on access to services for the population and the size of the population that will be affected by the road project can be measured and mapped using satellite information. Usually police offices are in charge of controlling trees cutting practices. New encroachment analysed by remote sensing techniques could quantify the impact on the forest and provide alternative information for the check control points.

EO data are a powerful tool to make quick land cover or forest assessments on large areas. Timely and accurate change detection of Earth's surface features provides the foundation for better understanding relationships and interactions between human and natural phenomena to better manage and use resources (1). In general, change detection involves the application of multi-temporal datasets to quantitatively analyse the temporal effects of the phenomenon.

G-Mosaic is a GMES (Global Monitoring of Environment and Security) project under the 7th Framework Programme developing EO derived information services for security related activities. The aim of this project is to demonstrate the use of EO data in providing support to the definition and implementation of Security related core services. With the aim of increasing critical asset security in areas outside Europe by providing specific geo-spatial information, the G-MOSAIC Critical Assets Monitoring Service (CTA) monitors the rehabilitation of the road 'RN4' in DRC. The G-Mosaic results are delivered to the project's official user: OSFAC (Observatoire Satellital des Forêts d'Afrique Centrale). OSFAC is closely involved in an exchange of data and expertise in particular to integrate their local expertise within an European project.

This paper presents in the next chapter the study area, the data including imagery acquired in G-Mosaic and ancillary data necessary to study the road rehabilitation impacts and the results in terms of changes in the forest cover. In the line of this G-Mosaic analysis, the paper is focused on a methodology to evaluate a specific critical asset: the 'RN4'. Results presented are preliminary results of G-Mosaic. Final results will be delivered at the end of the project.

However in a more general context, the paper discusses the link between this analysis and the analysis proposed to be carried out in another European project called REDDiness. REDDiness was obtained in the last calls of the 7th European Commission (EC) Framework Programme and has just started in February 2011. In REDDiness, up-to-date Earth Observation (EO) techniques will be adapted to local situation in order to assist Central African countries in addressing the challenges of Reducing Emissions from Deforestation and forest Degradation (REDD). There is an explicit link in EO techniques used in these two projects. The link will be described in the discussion while only G-Mosaic results will be demonstrated in the paper itself.

METHODS

Study area

The DRC road segment that is monitored within G-Mosaic is the RN4 going north from Kisangani to Bunduki and Bondo (Figure 1). The RN4 connects Kisangani in the north with Buta, Dulia, Bondo and Monga towards the border with the Central African Republic in Ndu. The area of interest is 6000 km^2. The region is situated at the equator, where the climate is characterized by abundant rainfall. The vegetation is an extremely dense equatorial forest which is loaded with various species of trees and animals. The soil in the region is very rich (iron and other). It is known as a mining area with a high activity of artisanal diamond mining (2).The main activities of the population in this region are agriculture, hunting and artisanal mining. The most important cultivated crops are manioc, bananas, rice, maize and arachides. The main industrial cultivated crops in the region were cacao, hevea (rubber), coffee and palm oil. However, in 2007 these plantations were in an abandoned state (3).

In April 2007, the Congolese press reported on the state of the road 'RN4' between Kisangani and Banalia: "The road between Kisangani and Banalia … has become a real pain and a headache for its users because of its advanced state of impracticality ... This road section is now dotted with so many obstacles such as erosion, gullies, holes, mud holes, making the movement of vehicles, motorcyclists, cyclists and pedestrians difficult. … In several places the road is narrowed, transformed into a trail and covered with bamboo and other trees. The situation becomes more critical at the crossing of the river Aruwimi to go to Buta. The local Office of Road no longer exists for many years. This is paralyzing the road traffic between Buta and Kisangani….".

In response to this situation, a World Bank road rehabilitation project (Pro-route, P101745) has started to improve the quality of the RN4 from Kisangani northwards towards the Central African Republic. The terrain work started in September 2009, the latest news states that works have advanced to 50km North of Banalia.

Three hot spots have been selected on this road for a finer analysis of the forest impact and assessment of potentialities of EO data in that analysis. These hotspots are located: (i) in Banalia, the first city to be reached by the rehabilitation team where they have experienced technical challenges in crossing the river, (ii) in Rubi-Tele, which is classified as a reserve or domain by IUCN and should then be preserved from large forest exploitation, and (iii) Aketi which is located in an area mentioned as potentially highly exploited for its forestry resources (4). However the third hot-spot is not described in this paper. Only the two first hot-spots, Banalia and Rubi-Tele, are presented as first results here.

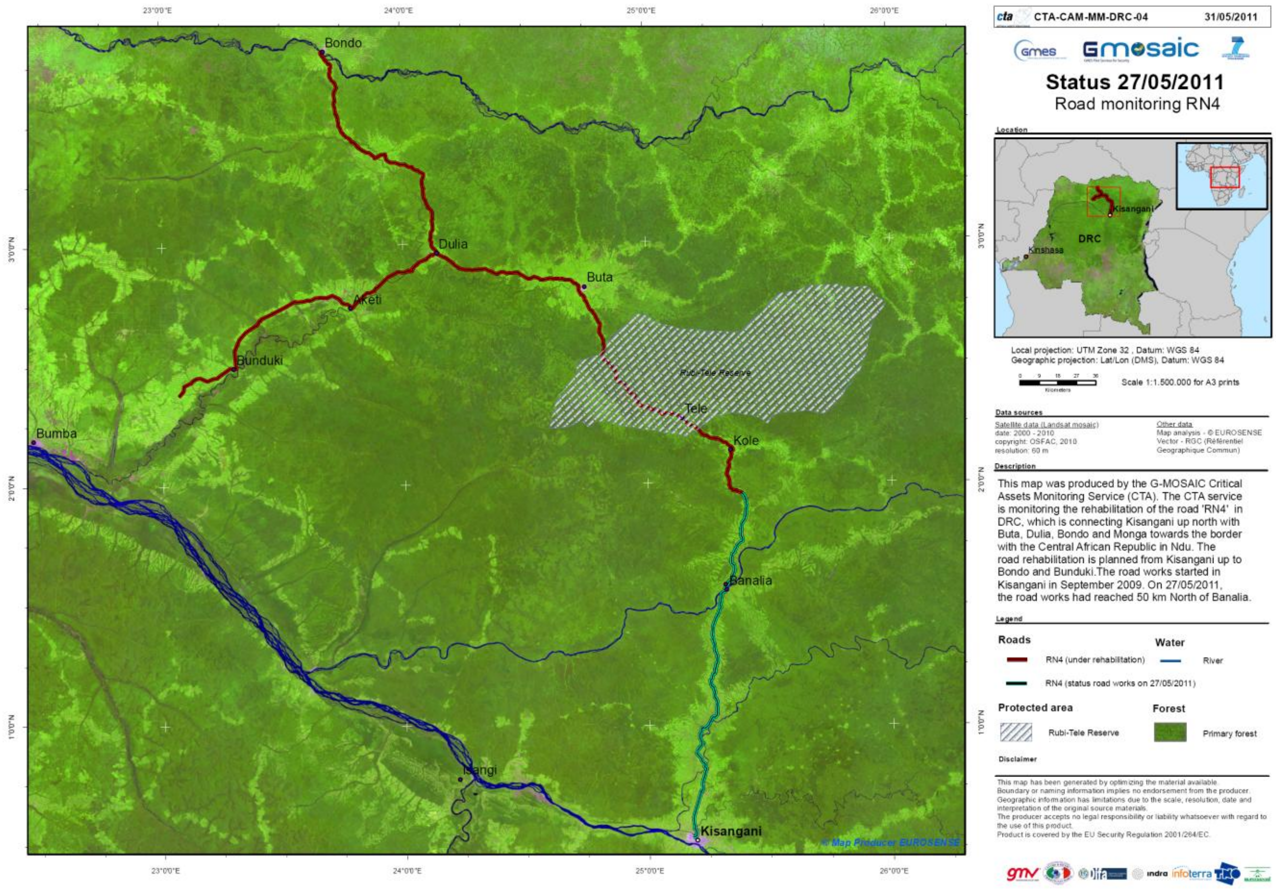

Figure 1: Area of Interest (AOI) of the RN4 monitoring critical asset of G-Mosaic, RDC (Background: Landsat mosaic 2005 – 2010, © OSFAC).

Banalia is a territory in the Tshopo district (in the Eastern Province of DRC), as well as the name of the capital town of the territory. The territory has a surface of 23.430 km². The estimated population is 102.511 habitants according to the local authorities; however, the UN is talking about 200.000 habitants. The territory is crossed by two main rivers: Arwimi (Aruwimi) and Lindi. According to the integrated food security classification of July 2008, Banalia territory is in acute food and livelihood crisis. The main causes of this crisis are said to be mining issues and isolation. The mining activities in Banalia are causing an abandonment of agricultural activities, hereby abandoning children to the elderly. Only 3 % of the habitants in Banalia territory are said to have access to drinking water (5).

The RN4 road crosses one reserve area: the *Domain De Chasse De Rubi-Tele* reserve established in 1930 in the World Database on Protected Areas and covering 90.080km^2. The International Union for the Conservation of Nature (IUCN) classifies protected areas according to their management objectives. The categories are recognised by international bodies such as the United Nations and by many national governments as the global standard for defining and recording protected areas and as such are increasingly being incorporated into government legislation (6). This category system includes Strict Nature Reserve, Wilderness Area, National Park, Natural Monument, Habitat/species Management Area, and Protected Lansdscape as the first five categories with decreasing level of protectiveness. Rubi-Tele is Category VI: Protected area with sustainable use of natural resources. These areas should conserve ecosystems and habitats together with associated cultural values and traditional natural resource management systems. They are generally large, with most of the area in a natural condition, where a proportion is under sustainable natural resource management and where low-level non-industrial use of natural resources compatible with nature conservation is seen as one of the main aims of the area more.

Data

Because of ease of interpretation and long-term robust classifications methods, EO optical sensors provide the most interesting data for forest monitoring. It is therefore important to maximize the use of optical sensors in the areas where this is possible. However, as the working region is situated just north and south from the equator, winds originating from the northern and the southern hemisphere join in this the Intertropical Convergence Zone (ITCZ) which unfortunately often appears as a band of clouds. Up to 200 precipitation days per year are measured in this area. Because of this cloud coverage, a combined approach using optical and SAR sensors, which are able to penetrate through clouds, can be envisaged for a monitoring on a regular basis such as for REDD issues.

The G-Mosaic project has given a priority to optical imagery which is the mandatory first stage to better understand the processed occurring in this region. A combination of high resolution (DMC data of 22 m resolution) and Very High Resolution (Ikonos/Geoye and Quickbird data of less than 1 m) has been acquired on the selected area. The new generation of Very High Resolution (VHR) satellite images offer a rich source of useful information to support the understanding of illegal or legal timber logging in relation to road management. However while the resolution allows a better visibility of the changes the automated classification of these images is also challenging (see methods section below). After 2 years acquisition request, the AOI is completely covered twice at High Resolution (HR) and there are two acquisition dates for the three hotspots (six images) at Very High Resolution (VHR). The EO data was collected within the frame of the project (Table 1).

Table 1: List of EO data acquired by the G-Mosaic project for road monitoring in RDC.

AOI	Sensor	Spatial resolution	# scenes	Acquisition date
Kisangani - Bunduki/Bondo	DMC	22 – 32 m	8	20/10/2009-13/05/2010
Kisangani - Bunduki/Bondo	DMC	22 m		13/01/2011-15/02/2011
Banalia	IKONOS-2	1 m	1	29/03/2010
Banalia			1	
Rubi-Tele	Geo-Eye-1	0.5 m	1	27/04/2010
Rubi-Tele	Geo-Eye-1	0.5 m	1	19/03/2011
Aketi	Quickbird	0.6 m	1	05/02/2010
Aketi	IKONOS-2	1 m	1	27/03/2011

While EO data provides the basic information for regular monitoring of such large areas, new EO acquisitions are not the only source of spatial information. Ancillary data such as earlier forest maps (7,8,9), geodatasets of the places, (Referenciel Geographique Commun - RGC) or protected areas and roads (10) are indispensable. In this paper, we explicitly compared the G-Mosaic analysis with the most recent map of the Central African forest, the FACET (Forêts d'Afrique Centrale Evaluées par Télédétection) atlas (11). In collaboration between OSFAC, South Dakota Universtity (SDSU) and University or Maryland (UMD), the FACET project aims to quantitatively evaluate space and time changes in forest cover using multi-date EO data. The final map covering the whole territory of DRC is a composite image integrating the decrease of the forest cover in the periods 2000-2005-2010. The composition resulted from a search in 8.881 archive data of the Landsat Enhanced Thematic Mapper Plus (ETM+) instrument (Landsat images are available at http://landsat.usgs.gov/).

We identified five reasons argumenting this comparison. Firstly, FACET is the most recent forest maps of RDC and the last date of the time-frame is 2010, which is the first date of our G-Mosaic analysis. These two dataset correspond well in time. Secondly, OSFAC has the status of "official user" in G-Mosaic and we developed a close collaboration with them. The special link between OSFAC and the G-Mosaic project increases the interest of comparing results. However, OSFAC combines an expertise in Remote Sensing with a strong knowledge of local forest management, which gives a high value to their mapping product. Collaboration with OSFAC within G-Mosaic allows us to acquire this dataset as soon as it has been released. Thirdly, the general aim of using EO data in G-Mosaic project is to better understand the impact of the rehabilitation of the road on spatial processes of legal and illegal logging. With its multi-date analysis of trends in forest changes, FACET provides an excellent source of information about the basic processes occurring in Central African Forests. Fourthly, G-Mosaic approach plans to carry out a two resolutions analysis including VHR and HR data. FACET dataset is specifically produced at the HR resolution chosen in the project. While they used Landsat data (30 m resolution), we acquired DMC data (22 m resolution, see Table 1). The comparison of this product with our HR products will be done in a future step of the project. Fifthly, the methodology applied in this FACET atlas refers to one methodology recognised internationally and applied in several projects aiming to map deforestation or to provide inputs to the REDD mechanisms.

Methods

The first step in monitoring space and time changes in forest cover is to determine the nature of the changes in terms of process in time and space. Forest cover maps derived from remotely sensed images are the best tools in that monitoring. Desired remote sensing imagery/data are then identified and existing ancillary data are gathered. Processing procedure includes pre-processing steps such as radiometric and geometric calibration but also the definition of a relevant classification scheme and the type of method used to define the classes (12).

The forest cover maps can be derived in two ways: visually by a human interpreter and quantitatively by a computer-based automated procedure. The former method has the advantage of using human pattern recognition, which is still far superior to any machine-based vision technique in terms of accuracy. Unfortunately, it is also tediously slow when compared to the processing speed of such automated procedures. Most of the time, semi-automated image classification methods are proposed to combine the advantages of both techniques. The most common techniques to quantitatively derive thematic maps from remotely sensed imagery are either pixel-based or object-based (13). These authors compared both techniques while dealing with VHR information and concluded that object-oriented methods are potentially best suited to manage the increase in resolution and the complex content of these images. As stated in (4), no automated change detection method was found to be as efficient as visual interpretation. Consequently, a semi-automatic object-oriented classification is chosen in the image processing method carried out in this study.

Image pre-processing

Dealing with multi-date image datasets requires that images obtained by various sensors (Table 1) at different times are comparable. In terms of radiometric calibration, standard VHR and HR products are delivered with a “Standard Geometrically Corrected” calibration including already minimum radiometric corrections. The second generation of UK-DMC satellites give a 22 m resolution with higher geometric quality than the first generation. For both the HR as well as the VHR dataset, the geometrical calibration takes the Landsat Global Land Survey (GLS, http://gls.umd.edu/) dataset as reference data. This dataset integrates Digital Terrain Models (DTM) from various sources such as GLS Landsat data, which have a geometric accuracy up to 18 m.

Pan-sharpening

Integrating multi-spectral and higher resolution panchromatic bands is often the first pre-processing step in classification services. Pan-sharpening method is based on a pixel-level fusion method, in which the lower resolution multispectral image’s structural and textural details are enhanced by adopting the higher resolution panchromatic image corresponding to the multispectral image. In this study this step has not been carried out in order to compute the spectral information without any distortion related to the pan-sharpening. The object-oriented automatic classification is done on the four multispectral bands while the panchromatic band is introduced in the visual interpretation, which follows the automatic process.

Object-based classification

One motivation for the object-oriented approach is the fact that, in many cases, the expected result of most image analysis tasks is the extraction of real world objects, proper in shape and proper in classification. This expectation cannot be fulfilled by traditional, pixel-based approaches (14). As an alternative to pixel-based classification with salt-and-pepper effect, segmentation approaches propose a reflexive mapping procedure that operates on individual regions, i.e., groups of adjacent pixels that are assigned to the same land-cover or forest-cover class by the classifier. Instead of allocating individual pixels to a pre-defined forest-cover class one-by-one, the image is divided into regions of similar pixels prior to classification. The so-called segments do not necessarily have any meaning and can be considered as image primitive. The most common image segmentation techniques are region growing algorithms, watershed segmentation, texture segmentation and the object-oriented approach of eCognition / Definiens (14). This last technique handles image primitive at different scales as objects in a hierarchical network. The objects not only have spectral properties but shape, texture, context and information from super or sub-objects are also included in the classification. While HR data are commonly classified with pixel-based approached, object-oriented ones are better suited to deal with the rich information content of HR and VHR imagery (12) but also to propose accurate estimation of deforestation (4).

The automatic classification carried out in this project is developed in eCognition v8.0. A set of rules, or module, define each class (see section *Forest-cover classification* below) in a specific order. The first discrimination is done between *Built-up areas* and *Primary forest*. Then the *Cleared areas* are subtracted from the *Primary forest* class and subsequently the “*rivers*”, *grasslands* and then *secondary forest* are discriminated. A parameterized approach is developed so that the developed methodology can be easily replicated on a new image.

Bands composition indices

To better discriminate some classes in the forested images, two combinations of bands have been processed before integration as another band in the classification. The Normalized Difference Vegetation Index (*NDVI*) is one of the well-known simple numerical indicators interesting in several classed definition such as vegetation but also clouds, water and shadows. It has been largely studied that *NDVI* is directly related to the photosynthetic capacity and hence energy absorption of plant canopies. The *NDVI* is a ratio per pixel between spectral bands in visible (red) and near-infrared, namely the near-infrared radiation minus visible radiation divided by near-infrared radiation plus visible radiation. Vegetation Index is not the only combination of bands that can be introduced as input in classification. In this study we also used the sum of the three visual bands (red, blue, green) to discriminate specific classes.

Forest-cover classification

The historical mapping of forested areas in the so called “benchmark forest area map” is the mandatory information in forest monitoring either for forest planning or REDD decision making. The forest change processes in Central Africa are particular in several points (4): (i) small deforestation areas needing fine scale imagery, (ii) non-uniform distribution of deforestation, (iii) important cloud cover, (iv) high frequency of forest changes.

Monitoring of Land Use (LU) classes conversion (forest to other land use) can be mapped at multiple scales using available EO data. Several existing forest mapping approaches use EO (Landsat, MODIS, MERIS and SPOT-VEGETATION) data to estimate the forest surfaces on the overall Congo Basin (15,4). In this paper, we choose to refer to FACET classification recently produced by OSFAC. The classification method used in FACET is adapted from (8). MODIS (Moderate Resolution Imaging Spectroradiometer) data have been used in the pre-processing of Landsat data. Cloudy areas, covering 0.4% of the DRC territory have been filled with MODIS data. The classification method proposed in FACET has several definitions that should be mentioned as the basic assumptions of our forest-cover classification:

- Forest is defined as an area with trees of more than 5 metres and a canopy density of more than 30%
- Primary forest class is a mature forest with a canopy cover of more than 60%
- Secondary forest is a non-mature forest with a canopy cover of more than 60%
- Woodland is defined by a density between 30% and 60%

- Non-forested area are quantified and spatially referenced according to the time period when alternative land-use has replaced the forest-cover area
- Permanent water bodies

Forest cover loss contains the lost forest in the period 2000-2005 and the period 2005-2010. It is divided into three categories: lost from primary forest, secondary forest and woodland. For comparison purposes, these classes will be merged with the non-forested area because our classification is done in 2010 and does not include a vision of historical changes.

However, if our classification is largely inspired by this legend, in order to compare each products, the fact of using VHR data (table1) with a more complex content but also more details in the imagery induce some changes in the classification scheme. The legend used for the classification of the VHR imagery differs from the FACET classification in the following points:

- Primary forest class is a mature, dense forest with a canopy cover of *more than 95%*
- Secondary forest is a more heterogeneous forest with a canopy cover of more than 80%

A class integrating recently cleared area or agricultural area, called “grassland” is introduced in the classification. The canopy cover is below 20%.

The class “Bare soil” is also distinguished from the broad class called “non-forested” in the FACET to identify the areas where no new vegetation has emerged yet. In many cases, the fallen trees are still on the terrain.

While FACET legend identifies only the non-forested areas, the G-Mosaic VHR classification allows us to spatially localize built-up areas or roads. These two classes help to better localize the specific changes in terms of their accessibility to people or remote cities. They are essential tools in providing information for policy support as, for example, in forest management or REDD monitoring.

Built-up area contains houses and related terrain. They are usually bordering a road network.

- Road
- River

G-Mosaic VHR classification scheme is more detailed than the FACET one but there are a lot of reasons explaining the choice of comparing these products (see data above). Table 2 illustrates the conversions between the two legends.

Table 2 : conversion table between FACET and G-Mosaic forest classification legends.

FACET classification legend	VHR classification legend
Non-forested area /Forest cover loss	Bare soil, Built-up area, Grassland, Road
Woodland	- (not present in our working area)
Secondary forest	Secondary forest
Primary forest	Primary forest
Permanent water bodies	River

Clouds, shadow and haze information

Because of the localisation of our study area inside the ICT zone, clouds should be taken into account. Clouds are a basic assumption on Central African forest images. By definition, no spectral information is available in the cloud areas. No thematic information can then be derived. Moreover, in the neighbourhood of the clouds, the cloud-shadow presents altered spectral values. On the VHR images acquired, we also detect some hazy areas. Unfortunately, within these areas spectral values differ from the range of normal values, the automatic classification method cannot be carried out in these areas. These three categories of reflectance need specific pre-processing steps. Automatically detected with a specific composition of bands, a mask localizes the clouds. The clouds are filtered out automatically. While the clouds remain unclassified areas where we cannot provide any information, the two other categories are dealt separately. The areas are first segmented automatically and afterwards visually classified .We should note that there is another category of shadows in such images: the shadows of the trees. These are automatically merged within the primary forest class.

Accuracy assessment

The accuracy of the forest cover maps is measured using a stratified random point sampling strategy. The term stratified refers to the varying amount of validation points in each land cover class. The number of validation points in each class depends on the area of the land cover class. The distribution of the validation points is random. For each land cover classification, the overall accuracy, the Kappa coefficient and the Omission and Commission Error per class are calculated.

The Overall Accuracy is the number of correctly classified validation points divided by the total number of validation points. It is expressed as a percentage.

The Omission Error is calculated for each validated class. An error of omission results when a validation point is omitted from its correct class. It can have a value between 0 and 1. A class with omission error 0 means that no omission errors have been measured for that class.

The Commission Error is also calculated for each validated class. An error of commission results when a validation point is committed to an incorrect class. It can have a value between 0 and 1. A class with commission error 0 means that no commission errors have been measured for that class.

The Kappa Coefficient is a discrete multivariate technique to interpret the results of a confusion matrix. It can have a value between 0 and 1. A kappa value of 0 would mean that the classification is as good as a random classification. A kappa value of 1 means a perfect match between reference and classified data.

Since no independent reference data is available, the image used for the classification is also used for this accuracy assessment in the following steps:

1. The image is opened in a GIS software, together with the delineation of the classification and the validation point dataset
2. An image interpreter zooms to each validation point and interprets the correct class for the validation point based on the image and the MMU. The image interpreter takes in account the delineation of the classification during his/her interpretation.
3. The visual interpretation of the image interpreter is compared with the classification results in a confusion matrix.
4. Overall Accuracy, Omission and Commission Error are calculated from the confusion matrix.

RESULTS

The first G-Mosaic results presented in this paper are still to be further developed, analyzed and refined within the next months of the project. This paper describes three products:

- VHR basic maps: two maps of Banalia at two different resolutions already delivered in June 2010, Figures 2 and 3, and a map of the study area in Rubi-Tele, Figure 4, and their accuracy assessment
- a comparison of the VHR G-Mosaic classification results with the most recent forest classification, the FACET dataset (only on the study area of Rubi-Tele, Figure 5) by converting the VHR results in the legend scheme of the FACET but also by comparing the main classes per grid cell
- a forest change analysis of the VHR data between the two dates of acquisition (2010 and 2011) on the hot-spot of Rubi-Tele: Figures 6 and 7.

The forest cover analysis carried out until now in G-Mosaic is focused on the VHR images acquired in this project. While the first image has been acquired on Banalia first part of the rehabilitation project, the second image on this site is not yet available within the project even though the acquisition was planned for 23/02/2011. We then particularly focused our change analysis on the second site:

the Rubi-Tele domain. In terms of forest changes, this site has a specific high level of interest because of its status of protected areas (Figure 4). It is also assumed that even the first road works increased the road accessibility of Rubi-Tele Reserve, such as crossing the river in Banalia, which can have a large impact on the forest logging impact.

VHR basic forest maps (Banalia/Rubi-Tele)

While the first maps on Banalia have been delivered in 06/2010 before publication of the FACET project, they present another classification legend. The second classification, on Rubi-Tele is in line with the FACET classification assumptions for the reasons described above. For comparison purposes, the second classification scheme will be applied a posteriori on the Banalia image as well.

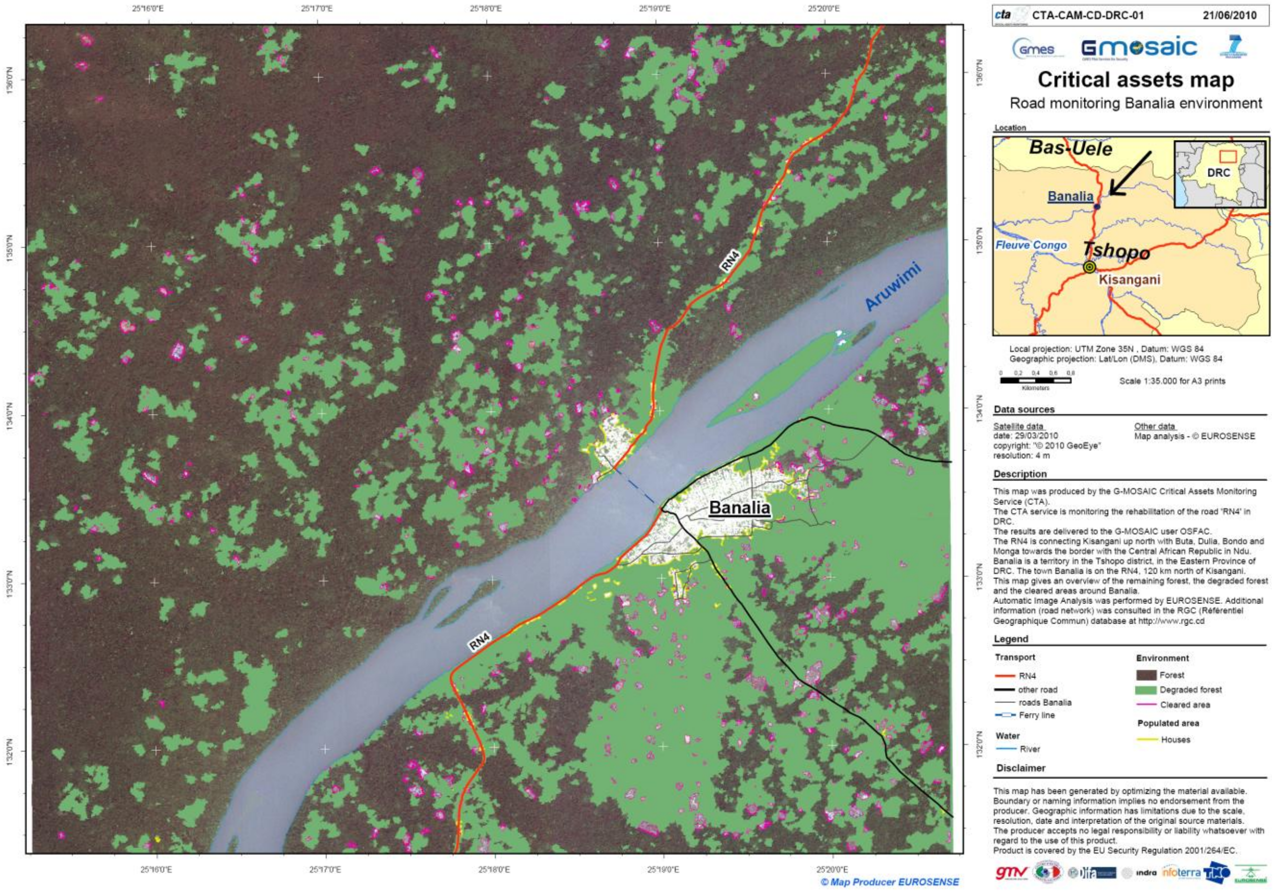

Figure 2: VHR basic map on Banalia, RDC (@2010 GeoEye).

Figure 2 shows the town Banalia and its direct environment. The background of the map is a multispectral IKONOS-2 scene with a resolution of 4m, acquired on 29/03/2010. On this map, the vectorized areas in green are degraded forest areas. These areas are very likely to be a mixture of regrowing forest vegetation ("recent grassland"), small agricultural fields, old plantations. The recently cleared forest areas are delineated in pink. No re-growth of vegetation is seen on these spots, which means that they are probably cleared and/or burned very recently. The RN4, which is currently being rehabilitated, is shown in red. The road is crossed by the Aruwimi river in Banalia. A ferry must be taken to cross the river and continue the road on the RN4. The populated area of Banalia and the houses along the road are delineated in yellow. This map was produced using the semi-automatic procedure based on an object-oriented methodology for which cleared and degraded areas were classified automatically. Roads and populated areas were digitized manually by a photo-interpreter.

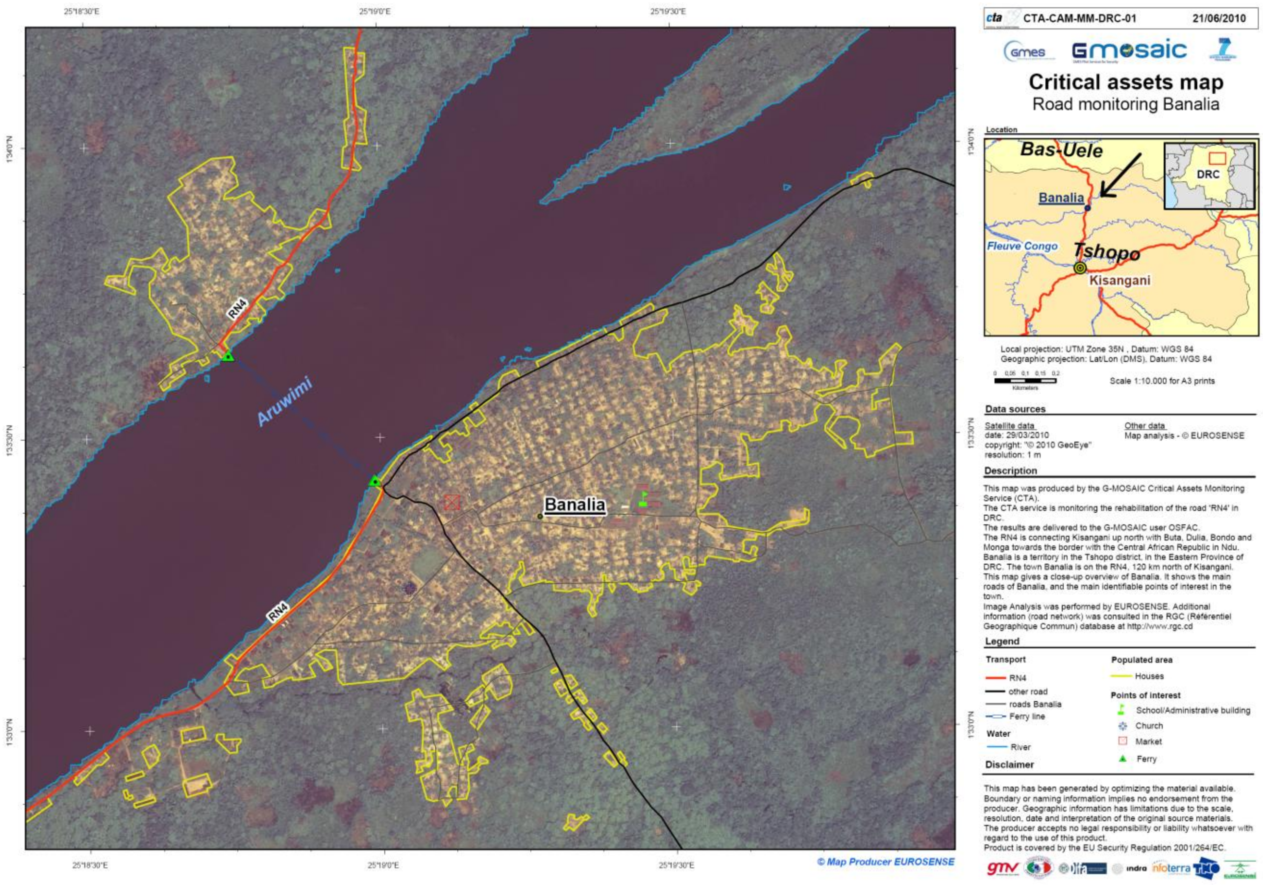

Figure 3: Focus on the built-up area of Banalia, RDC (panchromatic image @2010 GeoEye).

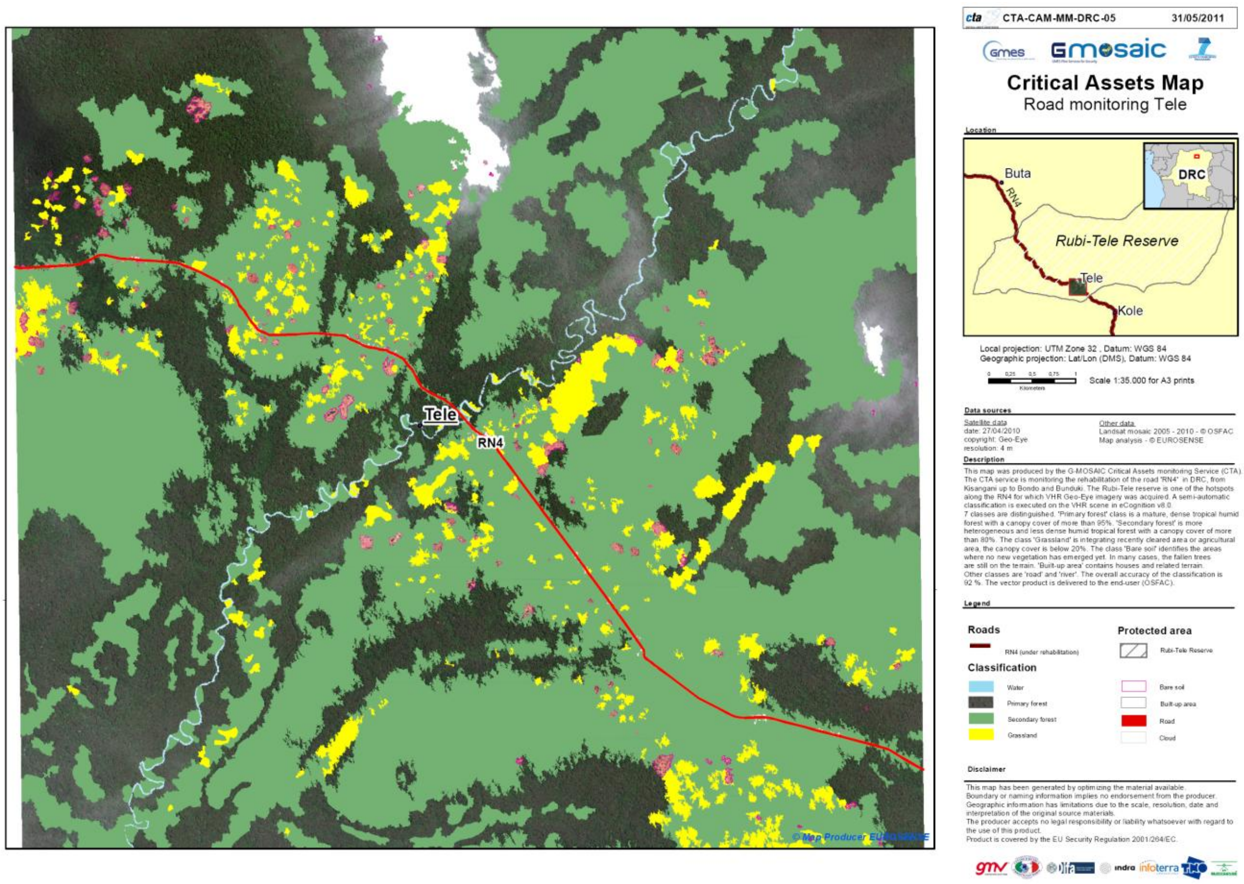

Figure 4: Focus on the built-up area of Rubi-Tele, RDC (panchromatic image @2010 GeoEye).

Figure 3 shows the town Banalia. The background of the map is a multi-spectral pan-sharpened IKONOS-2 scene with a resolution of 1 m, acquired on 29/03/2010. The RN4, which is currently being rehabilitated, is shown in red. The road is crossed by the Aruwimi river in Banalia. A ferry must be taken to cross the river and continue the road on the RN4. The populated area of Banalia and the houses along the road are delineated in yellow. The image interpreter digitized four main points of interest: the church, a school/administrative building, the market place, and the ferry station. Additionally, the main roads in Banalia were digitized as well. This map was digitized by an experienced image interpreter. The data from the Référence Géographique Commun was used as an external reference and ancillary data source. The main points of interest are subject to image interpretation.

Figure 4 shows the hot spot area of Rubi-Tele. The background of the map is a multi-spectral GeoEye scene with a resolution of 4 m, acquired on 27/04/2010. The work of rehabilitation that is ongoing on RN4 has not reached this area. The path of the RN4 is shown in red. Primary forest is shown in dark green (original image), Secondary forest is shown in light green. Grassland is mapped in yellow and Bare soil is delineated in pink. The river crossing the village Tele is mapped in blue.

Table 3: Percentage of each class in the VHR image covering Banalia (100km^2).

Class	**Area (%)**
Cleared area	1.7
Degraded forest	25.0
Dense forest	64.1
Built-up area	1.4
River	7.7
TOTAL	100

Table 4: Percentage of each class in the VHR image covering Rubi-Tele (100km^2).

Class	**Area (%)**
Bare soil	0.78
Grassland	4.19
Secondary forest	48.24
Primary forest	44.04
River	0.43
Built-up area	0.06
Road	0.04
Clouds	1.93
TOTAL	100

The comparison of Table 3 and Table 4 give us some clues as to the specific forest processes occurring in Central African Forest. Table 3 illustrates the various land cover in the area of Banalia on the VHR image of 2010. Table 4 presents these percentages of land cover on the VHR image covering the hot-spot of Rubi-Tele. These tables differ because on the second image we have been influenced by the classification of the FACET project. These two classifications can still be compared on the general understanding. In terms of built-up areas, Banalia present 1.4% and Rubi-Tele a lower percentage of 0.06%. Banalia is a small RDC city, which is visualised on Figure 3, while the image in Rubi-Tele covers a remote rural area protected by international regulations. The most interesting class to be compared is the percentage of cleared areas (bare soil in Rubi-Tele). There is nearly 2% of cleared areas in Banalia, identified in pink on Figure 2, and only 0.8% in Rubi-Tele which is in line with the status of protected area. The change in the classification scheme between the two locations increases the difficulties in comparing the other percentages but the dense forest in Banalia should be similar to the primary forest in Rubi-Tele. In fact, a quarter of the total areas are degraded forested area in Banalia and nearly half of the area is degraded forested area (*secondary forest*) in Rubi-Tele. This difference in degraded forest should be further investigated through our collaboration with OSFAC, official user of G-Mosaic products.

According to the method explained before, we carried out an accuracy assessment of these basic VHR maps. However, we should keep in mind that the same imagery is used in the classification as in the accuracy assessment procedures. A stratified random point dataset is generated and interpreted by an experienced image interpreter, using the VHR imagery as background. The visual interpretation results are compared with the automatic classification in an error confusion matrix. The critical assets map of Banalia (Critical assets map 1, Figure 2) has an overall accuracy of 87.5%, the critical assets map of Banalia environment (Critical assets map 2, Figure 3) has an overall accuracy of 88.3%. Detailed results of the accuracy assessment is given in Tables 5 and 6 below. The accuracy assessment on the region of Rubi-Tele is of 0.92% (see Table 7). These high validation levels give a good confidence on these basic maps.

Table 5: Accuracy assessment of the Critical assets map 1 of Banalia.

		VALIDATION					
CLASSIFICATION		Dense forest	Built-up area	Cleared area	Degraded forest	Water	TOTAL
	Dense forest	61	0	0	3	0	64
	Built-up area	0	20	0	0	0	20
	Cleared area	3	0	17	0	0	20
	Degraded forest	11	0	0	13	0	24
	Water	0	0	0	0	8	8
	TOTAL	75	20	17	16	8	136

Overall accuracy: 87.5%

Class	Omission error	Commission error
Dense forest	0.15	0.05
Built-up area	0.09	0
Cleared area	0	0.15
Degraded forest	0.19	0.46
Water	0	0

Table 6 : Accuracy assessment of the Critical assets map 2 of Banalia

		VALIDATION					
CLASSIFICATION		Dense forest	Built-up area	Cleared area	Degraded forest	Water	TOTAL
	Dense forest	61	0	0	3	0	64
	Built-up area	0	20	0	0	0	20
	Cleared area	3	0	17	0	0	20
	Degraded forest	8	2	0	15	0	25
	Water	0	0	0	0	8	8
	TOTAL	72	22	17	18	8	137

Overall accuracy: 88,3%

Class	Omission error	Commission error
Dense forest	0.15	0.05
Built-up area	0.09	0
Cleared area	0	0.15
Degraded forest	0.17	0.40
Water	0	0

Table 7 : Accuracy assessment of the Critical assets map of Rubi Tele

	Dense forest	Built-up area	Cleared area	Degraded forest	Water	TOTAL
Dense forest	61	0	0	3	0	64
Built-up area	0	20	0	0	0	20
Cleared area	3	0	17	0	0	20
Degraded forest	8	2	0	15	0	25
Water	0	0	0	0	8	8
TOTAL	72	22	17	18	8	137

Comparison of VHR and HR resolution maps

Beside the increase of resolution and decrease of the extent area, the use of VHR image provides more information than HR about the local forest processes. For a better understanding of the potentials of VHR data, the hot-spot basic maps are compared to the most recent forest map, the FACET map. The comparison between the VHR classification (on Rubi-Tele) and the FACET reference dataset is done in three steps:

- Conversion VHR classification into same legend as FACET data
- Transformation VHR classification into the same grid as FACET data
- Comparison per pixel

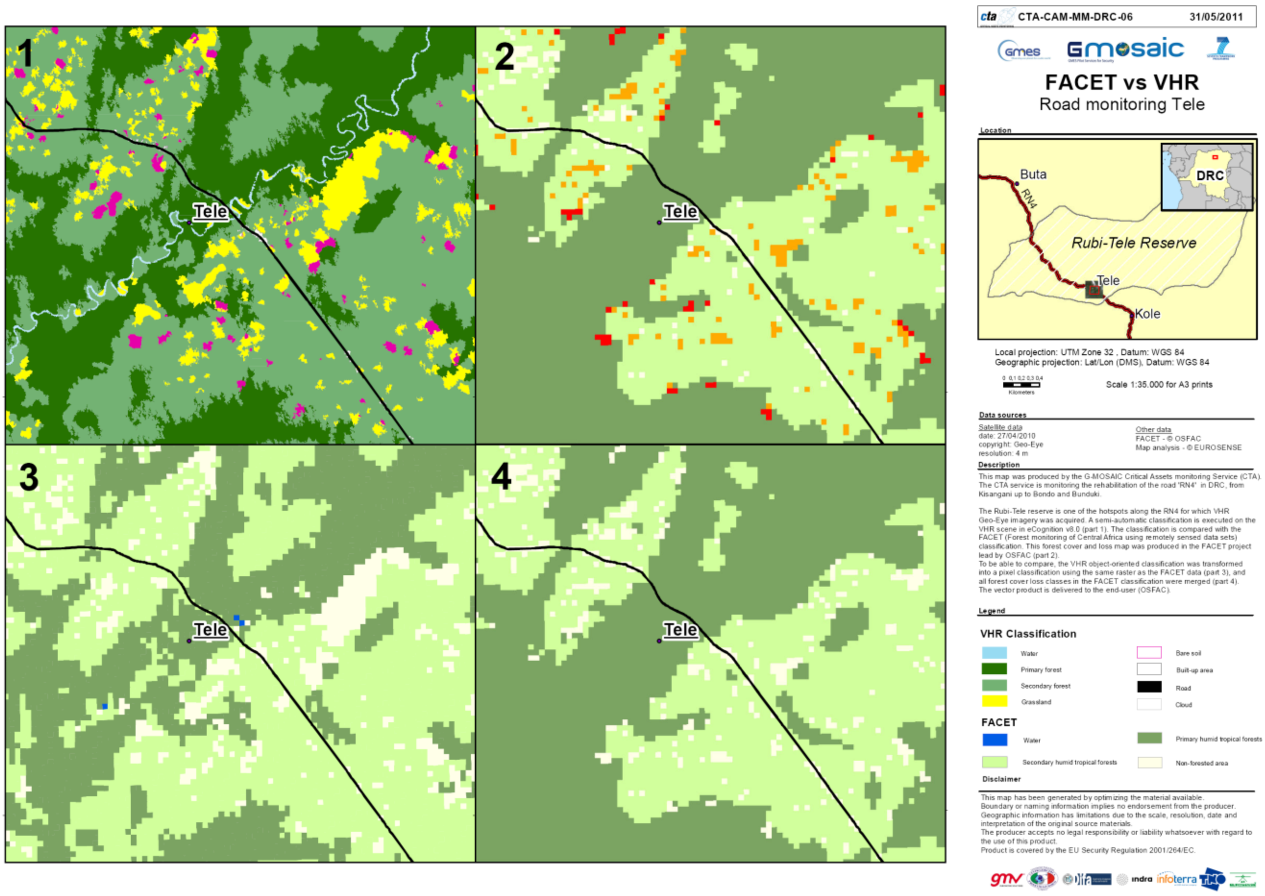

Figure 5: A semi-automatic classification is executed on the VHR scene in eCognition v8.0 (part 1). The classification is compared with the FACET (Forest monitoring of Central Africa using remotely sensed data sets) classification. This forest cover and loss map was produced in the FACET project lead by OSFAC (part 2). To be able to compare, the VHR object-oriented classification was transformed into a pixel classification using the same raster as the FACET data (part 3), and all forest cover loss classes in the FACET classification were merged (part 4). The vector product is delivered to the end-user (OSFAC).

By the juxtaposition of the two maps, the FACET classification and the conversion of the VHR maps in the FACET scheme, Figure 5 illustrates that the major visual difference between these two classification refer to the definition of the primary/secondary forest. The VHR resolution allows distinguishing a really dense forest from another type of forest that is defined as secondary forest. Further support from our local colleagues needs investigations on this definition in the next months of G-Mosaic, during the user workshop planned in June 2011.

The comparison of these two maps can be done by a confusion matrix. Table 8 highlights a higher figure of non-forested areas (5.05 km^2) than in the FACET dataset (2.73 km^2). As clearly identified visually on Figure 5, the percentage of secondary forest is more than double in the VHR map than on the FACET. While in comparison the percentage of "primary forest" occupies 76.81% of the complete hot-spot.

Table 8 (a): comparison of G-Mosaic VHR maps and FACET reference maps in their percentage of land cover in the Rubi-Tele hot-spot, RDC, (b) confusion matrix with (c) omission and commission errors in this comparison

Class FACET	Class VHR	VHR Area (km²)	FACET Area (km²)
Non-forested area	Cleared area	0.78	-
	Built-up area	0.06	-
	Grassland	4.21	-
		5.05	2.73
Woodland	0	0	0
Secondary forest	Secondary forest	48.93	21.16
Primary forest	Primary forest	44.18	76.81
Permanent water bodies	River	0	0
TOTAL		98.16	100.14

		FACET					
	CLASSES	Clouds	Non-forested areas	River	Secondary forest	Primary forest	TOTAL
VHR classification							
	Non-forested area		335		664	277	1276
	River			1		9	10
	Secondary forest		383		4853	8446	13682
	Primary forest		35		357	12073	12465
	TOTAL		753	1	5874	20805	27433

Omission and commission error in FACET versus VHR classification

COMPARISON FACET WITH VHR CLASSIFICATION		
CLASS	Error Omission in FACET	Error Commission in FACET
Non-forested area	0.74	0.55
River	0.90	0
Secondary forest	0.65	0.17
Primary forest	0.03	0.42

Overall Accuracy: 62.92 %

VHR forest change detection over Rubi-Tele

For data availability reasons, the change detection analysis is focused on the area of Rubi-Tele. *A priori*, the Banalia hot-spot was more interesting for its proximity to the segment of RN4 that is currently under rehabilitation. However, the VHR image of 2011 in Banalia has not yet been made available to the G-Mosaic project. We then focused the change analysis on the second hot-spot. Chosen for its location in the middle of the protected domain this hot-spot presents a specific interest to question the impact of increasing the accessibility in improving the road quality because it is supposed to be managed on a sustainable way. Measuring and quantifying changes between 2010 and 2011 are important to prove the good management measures of the domain even in the context of this on-going rehabilitation.

Figure 6 illustrates the spatial comparison of the specific class 'Bare soil' over the two dates (2010 and 2011). This class identifies the areas where no new vegetation has emerged yet. In many cases, the fallen trees are still on the terrain. The analysis shows that there are no changes in cleared areas percentage (0.78%) between the two dates. There is an increase in the number of patches, the number of cleared areas from 185 in 2010 to 207 in 2011, while their size has decreased from 0.42 ha in average in 2010 to 0.37 has in average in 2011.The total area of bare soil is remained stable at the time of the two acquisitions. The vector product is delivered to the end-user (OSFAC).

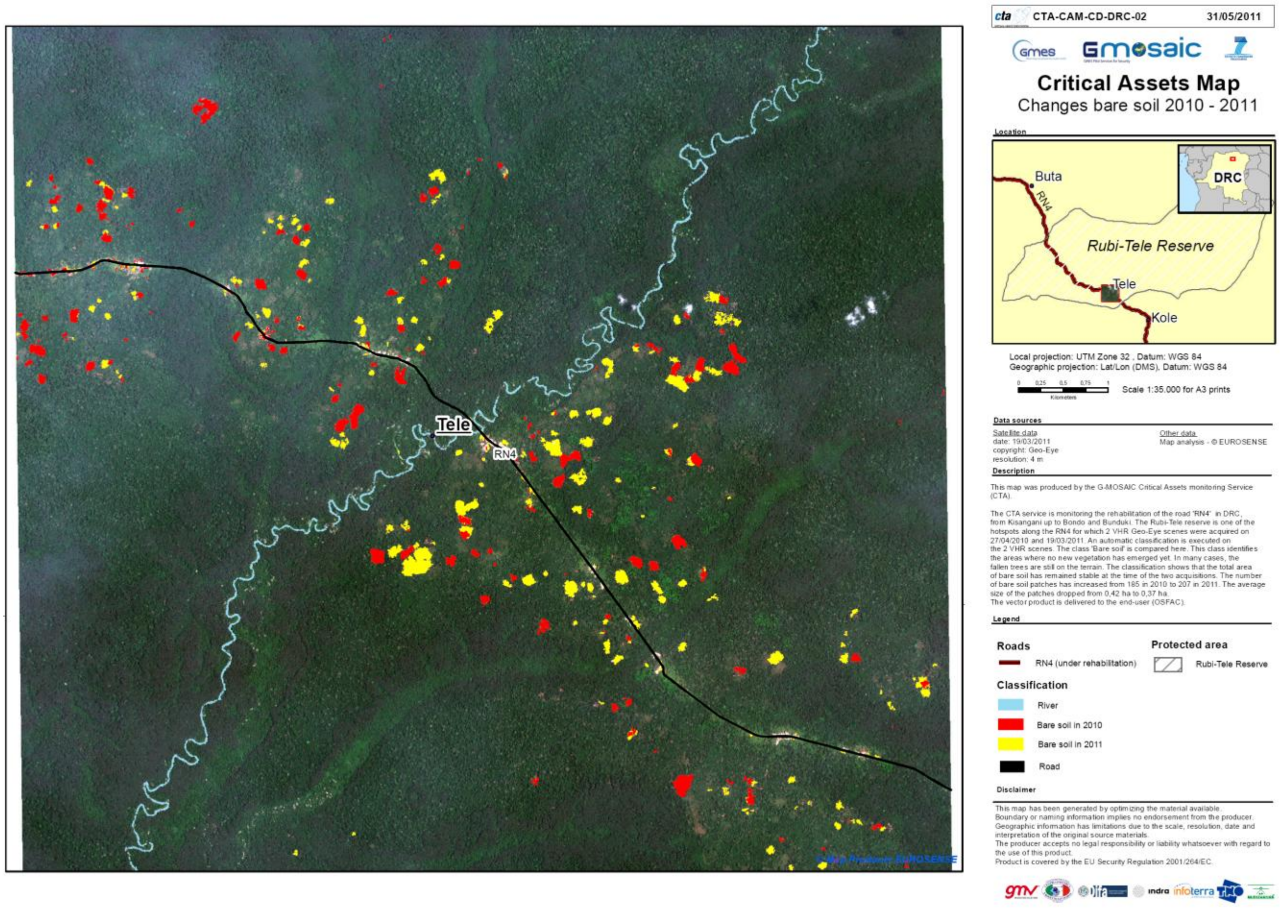

Figure 6: Changes in 'bare soils' between 2010 and 2011 in Rubi-Tele, RDC.

The origin of the class 'Bare soil' in 2011 is shown on Figure 7. The bare soil mapped in 2011 is attributed to separate classes, based on the original class in 2010. This analysis shows that the majority of the bare soil in 2011 was mapped as secondary forest in 2010 (52.9 ha). The second largest conversion is from grassland into bare soil (14.1 ha). 5.1 ha of primary forest has been transformed into bare soil in 2011, while 4.8 ha was already mapped as bare soil in 2010. The vector product is delivered to the end-user (OSFAC).

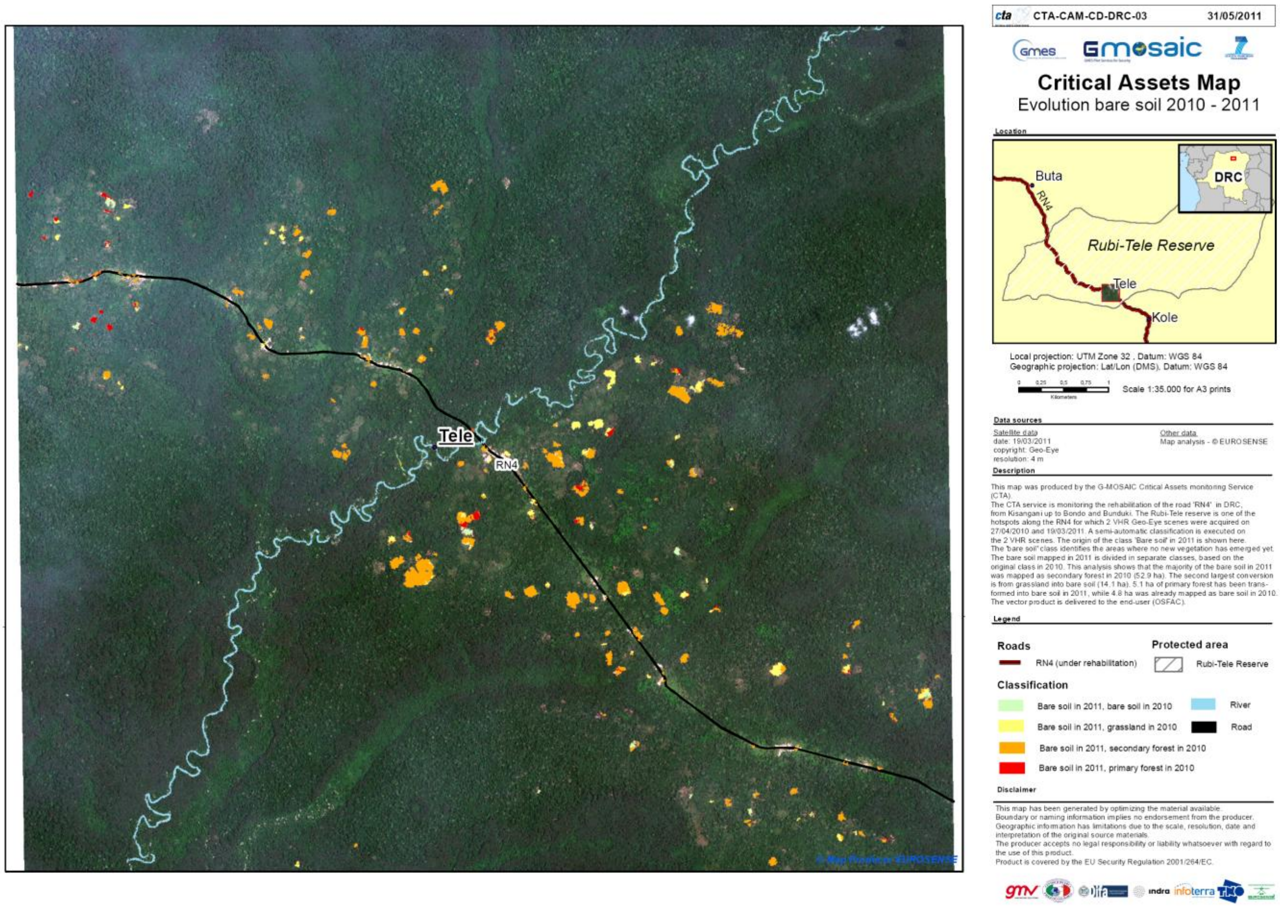

Figure 7: Identification of classes from 2010 transformed in "bare soil" in 2011.

DISCUSSIONS AND CONCLUSIONS

The first results of the accuracy assessment carried out on the basic maps are really positively high. This is corroborated by the comments received from our official users, our colleagues from OSFAC. These maps can help to better understand the local processes occurring in these hotspots as well as the potential of these data for forest management, impact of road rehabilitation project or policy support, such as the REDD mechanisms for example. However, we have to keep in mind that without independent reference dataset, the accuracy assessment methodology checks with a random sample the classification by visual interpretation. This could be further validated through a real field visit.

This paper proposes a method to compare and integrate HR and VHR information by converting the VHR results through a grid-based conversion table. This grid approach will help us to replicate this spatial analysis both on the other hotspots and on the other HR dataset that has been acquired within the G-Mosaic project (DMC data see Table 1).

While the VHR products have an added value related to their resolution which allow the clear observation of the real objects such as standing or fallen trees, it is impossible, for price consideration, to cover the complete area. Thus VHR data have to be combined with HR data to monitor the forest changes.

The time analysis between 2010-2011, on the Rubi-Tele image, shows that there are no changes in the cleared surfaces. While the spatial patterns of the cleared areas are slightly different, there is no major impact of the reopening works of the RN4 in the protected area. The figures on these two dates provide quantitative arguments on that. Of course, as the road has not reached Rubi-Tele domain, the figures have to be updated on a regular basis to monitor the environmental impacts of the road.

This paper presents the methodology and the first results of this monitoring. The analysis should be further developed and investigated on the two other hotspots. The same methodology should be applied on Banalia VHR hotspot where the road has already been rehabilitated for some months, and on Aketi VHR hot-spot where several studies identify high levels of deforestation.

The official G-Mosaic user of these products is OSFAC. The first delivery of VHR maps has been welcomed in June 2010. Their involvement will increase in the next months, by their participation at the user workshop planned in June 2011.The demonstration of the method and results presented in this paper, in line with the products that they developed should be further discussed to develop operational products in the frame of road impact monitoring or REDD policy.

The extensive use of FACET dataset, as reference map, makes a clear link between the local expertise and the European GMES project. Better integration and cooperation between EU partners and local institutions clearly improve the understanding of forest processes. The EC FP7 project called REDDiness will be an opportunity to create a close cooperation in the frame of forest mapping but also REDD measuring, reporting and validating methods.

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