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Evaluation and Monitoring of the Aerial Woody Plant Biomass of the Classified Forests of Forest Guinea on the Basis of Satellite Imagery Data

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ABSTRACT

Guinea has a large block of tropical rainforests that reflect a high carbon dioxide (CO2) sequestration potential. Accurately determining the quantity and distribution of carbon in these forests will make it possible to assess CO2 emissions associated with deforestation and degradation. The objective of this research is to explore the contribution of remote sensing to the estimation of plant biomass in the classified forests of Forest Guinea (Guinea). The "Random Forest" method allowed us to predict the aboveground biomass by integrating the biomass samples from the study area. The results of the carbon stock estimates (in tonnes) for the three (3) Classified Forests and two (2) Biosphere Reserves of Forest Guinea were compared to the studies of Nasi et al. (2011) and Gibbs et al. (2014). Generally speaking, our methodology made it possible to arrive at estimates higher than those of Gibbs et al. (2014) and lower than those of Nasi et al. (2011). These results obtained from MODIS data could be considered as average values of the biomass gradient and carbon stock estimates for these different Forests and Reserves in the said area. However, we note the existence of two (2) Areas where we obtained higher values compared to the aforementioned studies, namely the Ziama classified forest (17.58 - 544.12 t/ha and 60.53 teCO2/ha) and the Mount Nimba Biosphere Reserve (25.39 - 300.44 t/ha and 42.18 teCO2/ha).

Keywords: Assessment; Monitoring; Biomass; Woody Plant; MODIS; REDD; Forest

INTRODUCTION

For several decades, the International Community has become aware of the increasing degradation of natural resources. Dependence on these resources and their rapid disappearance are all reasons that have led to moving towards sustainable management of renewable resources. In addition, problems related to water management, the high frequency of extreme climatic events and the need for sustainable management of forest ecosystems have appeared essential.

Tropical deforestation is at the heart of international debates. Indeed, it appears to be a major component of the destabilization of global forest resources. Acting on water, soils, climate, economy and sociology, but also on biodiversity. The implementation of sustainable forest resource management programs has become a solution to maintaining tropical forests. Thus, all of these components must be integrated into the design of Sustainable Development today [1].

Measuring and monitoring the aboveground biomass of vegetation has become a major research topic in recent years. This is due to its important role in the biogeochemical carbon cycle but also in international climate negotiations (Zolkos et al., 2013).

In 2009, the United Nations Framework Convention on Climate Change (UNFCCC) established guidelines for assessing carbon stocks in forests, at a global scale, through the implementation of the REDD (Reducing Emissions from Deforestation and Forest Degradation) program (Houghton et al., 2010). These three components are: (i) measuring the spatial extent of forests and their changes; (ii) assessing carbon stocks and emissions; (iii) verifying findings and implementing REDD activities [2]. Given the extent of tropical forests and the difficulty of access, remote sensing methods have long been considered essential tools for collecting data and producing biomass maps at more or less large scales (Gibbs et al., 2007; Clark & Kellner, 2012). Currently, the main remote sensing tools used for biomass mapping in tropical Africa are: optical sensors, RADAR (Radio Detection And Ranging) and LiDAR (Light Detection and Ranging).

Accurate estimation of tropical forest biomass is an important issue for programs such as REDD+ and other environmental policies. This research studies how lidar metrics help estimate aboveground biomass. These biomass estimation methods, whether based on field data (forest inventories) or remote sensing (satellite or airborne optical imagery, LiDAR, RADAR,), all depend on inventory data combined with allometric equations for calibration (Gibbs et al., 2007) [3]. In Guinea, the statistical system is almost non-existent in forest management. This has made it difficult to quantify the pressure factors on forests, the volumes of wood and charcoal produced or consumed, and the deforested or degraded areas. According to the FAO (FRA, 2010), Guinea's forest cover has decreased from 7.2 million ha in 1990 to 6.5 million in 2010, a loss of approximately 10% of its forest cover. Carbon stocks are now estimated at an average of 25.5 metric tons per ha [7]. The Guinée Forestière has a dense humid forest and has been considerably cleared (after having been relatively little exploited for its wood), to the point that there are only a few tens of thousands of hectares left, concentrated mainly in two classified forest massifs (the forests of Ziama (112,300 ha) and Diecké (64,000 ha) as well as in a few small forests that are difficult to access or protected by customs.

This forest region is currently the zone of agricultural expansion (coffee, rice, oil palm, rubber), immigration (populations from the North, but also refugees from Liberia), mining (iron, gold and bauxite). Human pressure on the forest is considerable and its clearing continues in an unplanned manner. Thus, it is reduced to its simplest expression. The objective of this research is to explore the contribution of remote sensing for the estimation of aerial plant biomass. The work will be organized in two approaches: an approach that explores the coupling (recalibration and forcing) between remote sensing data and standardized study models and an operational approach which consists of comparing estimation methods based on remote sensing: (1) the empirical relationships between growth and vegetation indices calculated from remote sensing data and (2) the forcing of a forest species growth model with data from MODIS sensors.

TOOLS AND METHODS

Presentation of the study area

The Guinea Forest Region is located at the western end of the large Guinean-Congolese rainforest and is situated between 7°50’ and 10°33’ West longitude and 7°27’ and 8°90’ North latitude. It covers an area of 49,374 km2 (i.e. 20% of the country’s total area) and is dominated by the highest point in Guinea (Mount Nimba 1752 m). Its relief is quite marked and tormented by the juxtaposition of high massifs with steep slopes (Mount Simandou and Mount Nimba) followed by

low plateaus, plains, lowlands and flood valleys.
This forest region is characterized by a humid subequatorial climate and the exceptional length of the rainy season (between eight and nine months). It records an average rainfall of around 2500 mm/year. The classified forests include: Ziama 119,019 ha, Pic de Fonc 25,600 ha, Diécké 64,000 ha, Mont Béro 23,600 ha and Mont Nimba 19,500 ha.

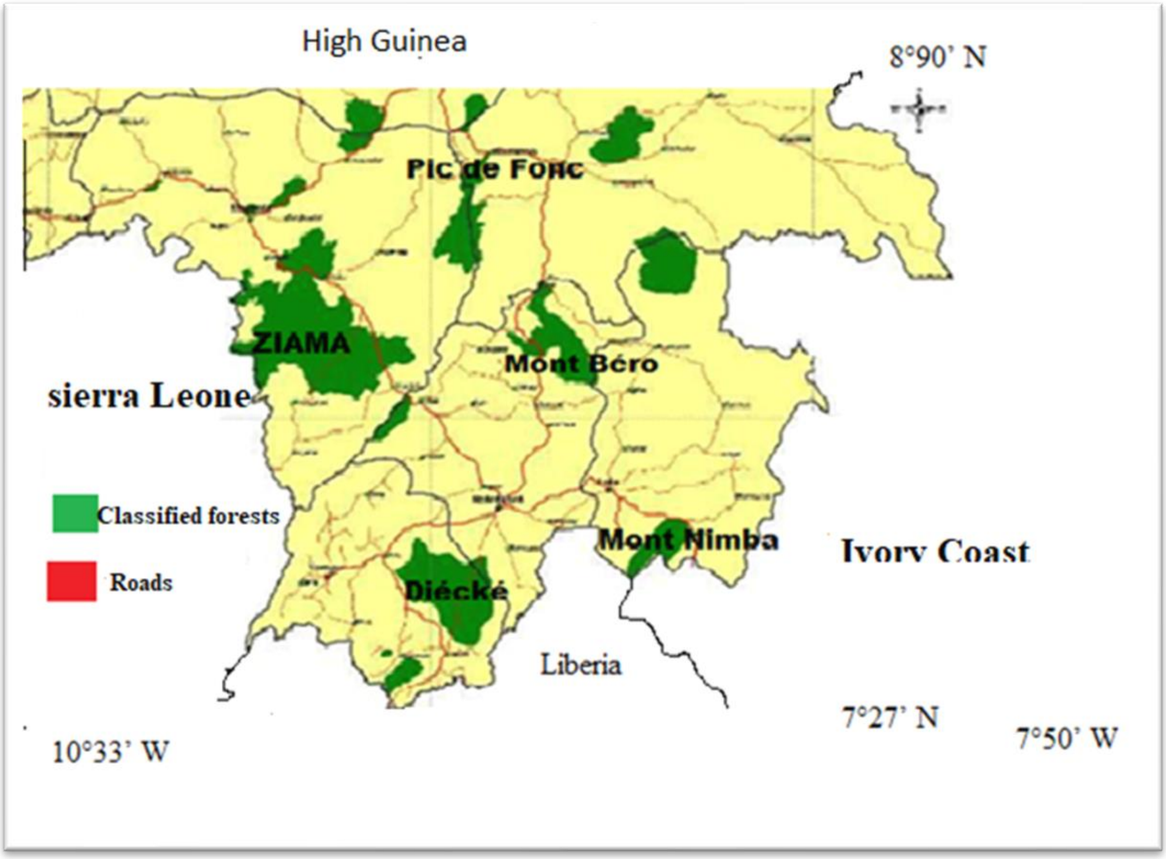

Figure 1 – Map of Forest Guinea (Classified Forests)

Data
The radiometric data used are obtained with the SPOT4 and SPOT5 satellites. The MODIS Sensor measures reflected and emitted energy in the visible and infrared using 36 channels. Bands 1 and 2 are of particular interest; they measure the following wavelengths:

- Band 1: 620 - 870 nm ;
- Band 2: 841 - 876 nm.

Its 2330 km sweep in the direction of the ground track is done with a spatial resolution varying from 250 m to 1-5 km. MODIS (Moderate Resolution Imaging Spectrometer) data are collected on NASA's "rapid fire" website (http://rapidfire.sci.gsfc.nasa.gov). The raw HDF MODIS data can be accessed via the EOS Data Gateway. (Http://redhook.gsfc.nasa.gov/~imswww/pub/imswelcome/).
The NDVI (Normalized Difference Vegetation Index) is constructed from the red and near-infrared channels. It highlights the difference between the visible red band and the near-infrared band. This index is sensitive to the vigor and quantity of vegetation. The highest values of this index correspond to highly photosynthetic vegetation.
MODIS raw images are made available to the public, the following websites offer these images in archive form:

- ftp://ladsftp.nascom.nasa.gov/ http://e4ftl01.cr.usgs.gov/ ftp://n4ftl01u.ecs.nasa.gov/
- http://ladsweb.nascom.nasa.gov/ http://reverb.echo.nasa.gov/reverb/

The instruments record data in 36 spectral bands ranging from 0.4 μm to 14.4 μm, the table below summarizes the characteristics of the first 7 bands.

Table 1 : The first 7 spectral bands of MODIS/TERRA

N°	Spectral bands	Wavelength	Spatial resolution (m)
1	Red	0.62-0.67 μm	250
2	Infrared	0.84-0.87 μm	250
3	Blue	0.45-0.47 μm	500
4	Green/Yellow	0.54-0.56 μm	500
5	Infrared	1.23-1.25 μm	500
6	Infrared	1.62-1.65 μm	500
7	Infrared	2.10-2.15 μm	500

The spatial resolution varies from 250 m to 1 km, sometimes reaching 5600 m. Overall, the different spectrometers take a complete image of the Earth every 1 or 2 days. They are designed to provide large-scale measurements of global phenomena, such as variations in the Earth's cloud cover, the radiation budget, and various processes occurring in the oceans, on the ground, and in the lower atmosphere. On-board calibrators allow the instruments to be calibrated in flight.

Materials

The MODerate-Resolution Imaging Spectroradiometer (MODIS) is a series of scientific observation instruments coupled to an on-board satellite system, launched by NASA aboard the Terra satellite in 1999, then aboard the Aqua satellite (two satellites of the EOS - Earth Observing System, a NASA program intended for long-term observation of the Earth's soils, biosphere, atmosphere and oceans).

Table 2 : Vegetation indices (VI)

Name	Acronym	Formula	Reference
Vegetation Ratio Index	RVI	$\rho_{PIR} \quad \rho_{rouge}$	Birth et McVey (1968)
Normalized Difference Vegetation Index	NDVI	$\left(\rho_{PIR} - \rho_{rouge}\right)$ $\left(\rho_{PIR} + \rho_{rouge}\right)$	Rouse et al. (1974)
Transformed vegetation index	TVI	$\overline{NDVI + 0,5}$	Deeng et Rouse (1975)
Difference Vegetation Index	DVI	$\left(\rho_{PIR} - \rho_{rouge}\right)$	Turcker (1979)
Soil Adjusted Vegetation Index	SAVI	$1 + L\left(\rho_{PIR} - \rho_{rouge}\right)$ $\rho_{PIR} + \rho_{rouge} + L$	Huette (1988)
Vegetation Index Green	VIg	$\left(\rho_{vert} - \rho_{rouge}\right)$ $\left(\rho_{vert} + \rho_{rouge}\right)$	Gitelson et al. (2002)

Aboveground dry biomass is calculated using the MONTEITH equation (1972) :

$$Baer = \int_{to}^{t} R_g \varepsilon_c \varepsilon_i \varepsilon_b dt$$

Or B_{aer} - the amount of plant matter produced above ground (g m^{-2}) during the period between *t* and t_0, Rg is the incident global radiation (MJ m^{-2}), ε_c - is climate efficiency, ε_i - is the interception efficiency, and ε_b - is the conversion efficiency of intercepted radiation into dry aerial biomass (g MJ-1).

In this work, we have chosen the 1000 m resolution images, because it is the only resolution where all the parameters are found. For the software used: QGIS 3.12.1 for image processing, ENVY 4.7, for the study of correlations and Microsoft Excel 2016 for the numerical processing of the data.

Methodology

A statistical model of the "Regression Tree" type has been used in many remote sensing studies. In this study, we used the "Random Forest" to predict the aerial biomass by integrating the biomass samples of the classified forests of Ziama, Mount Nimba, Diécké, Mount Béro and Pic de FONC with the reflectance measurements of the 7 MODIS bands over the period 2010-2018.

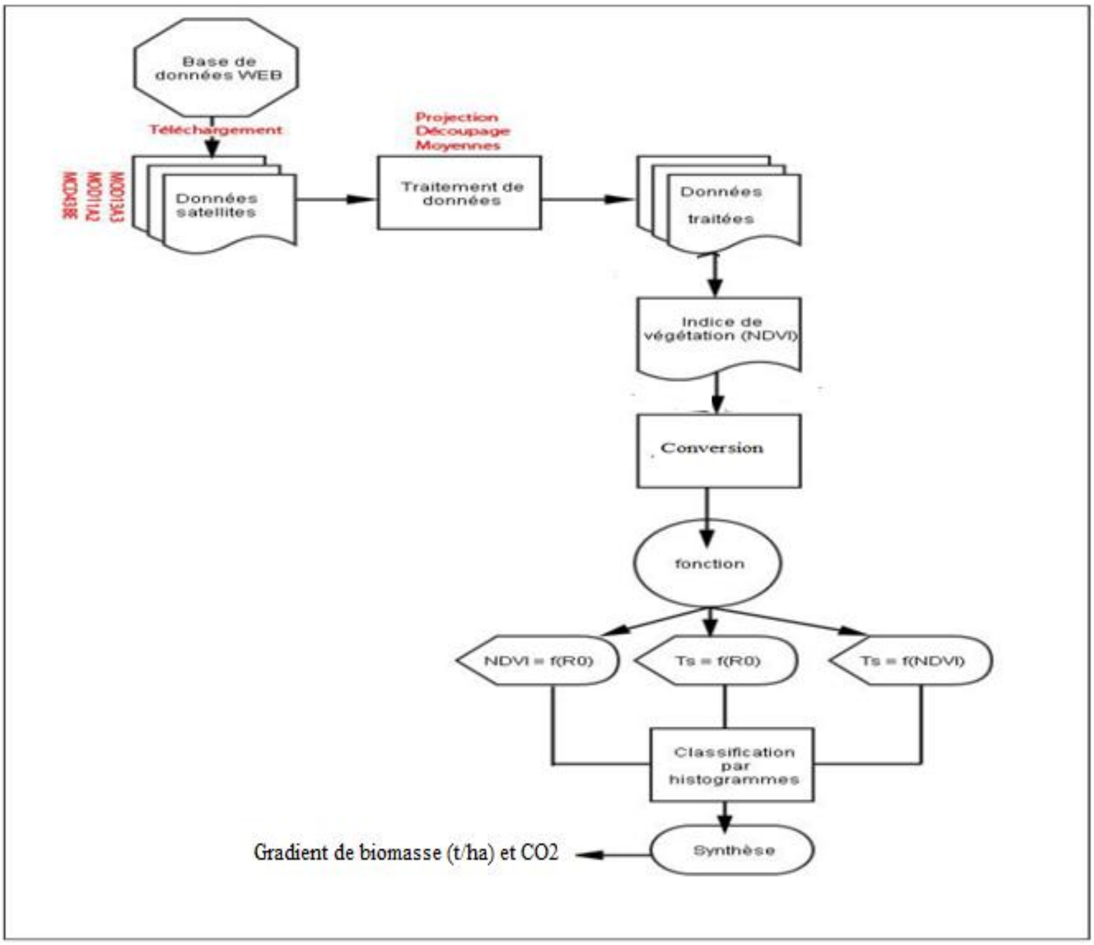

Figure 2 - Block diagram of the research methodology

RESULTS AND DISCUSSIONS

The aboveground woody biomass presents a biomass gradient ranging from 22.91 - 278.48 t/ha. High values are concentrated in the Ziama and Mount Nimba Classified Forests. However, it should be noted that significant biomasses are obtained for the forests of Mount Béro and Pic de Fonc. Low biomasses are observed in the North of Mount Béro, South of Pic de Fonc and West of Ziama. In these areas, the vegetation is characterized by a cover of sparse trees of smaller size than that of dense humid forests. This landscape is dominated by the reflectance of bare soil.

The statistical model developed for this study shows that 79% of the variance of the aboveground woody biomass gradient records a root mean square error of 11.51 t/ha with a correlation coefficient of 0.87. The relationship between the biomass gradient and the height of the vegetation cover has led to results from the Geoscience Laser Altimetry System (GLAS) lidar data for large trees associated with high biomasses and small trees with lower biomasses.

It should be noted that forest biomass is linked to tree size (DBH, height and density) and the number of trees per unit area. Lidar measurements are therefore very useful for estimating biomass. This confirms that our results are consistent with those of other Lidar studies of tropical forest biomass [8 and 9].

This assessment allowed us to make estimates of carbon stocks by vegetation type, by zone or for the entire region. The total carbon stock estimated in the study area by MODIS data (see Table 1) with most of the carbon contained in the Dense Humid Forests and the mosaic class.

Table 1. Estimation of aboveground biomass and total carbon stock from MODIS GLC 2000 data in the Classified Forests of Forest Guinea.

Name	Surface (ha)	Biomass (t)	Gradient (t/ha)	Organic carbon ($teCO_2$/ha)
Ziama	119 019	5251849	17,58 - 544,12	60,53
Nimba	19 500	1958741	25,39 - 300,44	42,18
Béro	23 600	456987	5,36 - 159,36	8,13
Pic de Fonc	25 600	2365987	12 - 192,42	38,81
Diécké	64 000	3589743	21,73 - 196,08	23,55
Total	251 719	13623307	278,48	173,21
Nasi et al 2011(RDC)	5043	31496587	56,17- 849,16	1275,88
Gibbs et al 2014(Gabon)	465,51	2548697	24,25 - 178,21	356,87

The table above presents the results of carbon stock estimates (in tonnes) for the Forests and Biosphere Reserves of Forest Guinea compared to the studies of Nasi et al. (2011) and Gibbs et al. (2014). In general, our methodology allowed us to obtain estimates higher than those of Gibbs et al. (2014) and lower than those of Nasi et al. (2011).

These results obtained from MODIS data could be considered as average values of the biomass gradient and carbon stock estimates for these different Forests and Reserves in this area of Guinea. However, we note that there are two (2) areas where we obtained higher values compared to the aforementioned studies, namely the Ziama classified forest (17.58 - 544.12 t/ha and 60.5304teCO2/ha) and the Mount Nimba Biosphere Reserve (25.39 - 300.44 t/ha and 42.1848teCO2/ha).

CONCLUSION

Africa has one of the largest blocks of tropical rainforests in the world and has a high potential for carbon dioxide (CO2) emissions. Precise knowledge of the quantity and distribution of carbon in these forests will allow us to accurately assess CO2 emissions associated with deforestation and degradation. In addition, it has allowed us to take stock of the variability of Guinea's vegetation cover.

To carry out this study, we used the basic data of the Normalized Vegetation Index (NDVI) from MODIS sensors (offering a wide range of satellite data usable for environmental study, the TERRA platform) and the combined TERRA/AQUA platform (offering pre-calculated geophysical parameters on images available for download). The comparison of the NDVI values calculated from SEVIRI images shows an underestimation compared to those calculated from NOAA AVHRR.

These results obtained from MODIS data could be considered as average values of the biomass gradient and carbon stock estimates for these different Forests and Reserves of the Guinean forest zone. However, we note that there are two (2) Areas where we obtained higher values compared to the aforementioned studies, namely the Ziama classified forest (17.58 - 544.12 t/ha and 60.5304teCO2/ha) and the Mount Nimba Biosphere Reserve (25.39 - 300.44 t/ha and 42.1848teCO2/ha).

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In terms of recommendations, it is necessary to strengthen investments in the Guinean forest region in order to provide solutions to the multiple problems due to climate change phenomena and the requirements of sustainable development. In addition, to reorganize the management and safeguard policy of this forest area in terms of exploitation.

Declaration by Authors

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