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Devising a Framework for Holistic Development of the Natural Capital in Africa using GIS and Remote Sensing Techniques

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ABSTRACT

A scheme is devised in an attempt to assess the natural environmental capital (resources and services) of the African continent using GIS (Geographical Information Systems) and remote sensing techniques, in order to pave the way for a sustainable development of these environmental resources, while ensuring at the same time a continuous flow of materials and continuous metabolism all over the continent humanosphere. This scheme highlights the various development schemes best fitted to each one of the main African biomes. Specific environmental management procedures are recommended, and the renewable energy source with the most potentiality is specified, in order to reduce CO₂ emissions and to enhance CO₂ sequestrations over the continent.

1. INTRODUCTION

Africa is witnessing the coming of a new era of steady development aligned along the recent changes in the international geopolitics. However so far, Africa has been the object of many extraverted development schemes, most of them being hardly economically, socially and ecologically viable for the continent as a whole in the long term.

In fact, for these development schemes to bear fruits and to be sustainable, we think that they have to be based on a new paradigm that should avoid as much as possible the blind copy of old models followed so far in most of the developed or developing countries. Most of these schemes have been characterized by large-scale environmental destruction, huge industrial wastes outpours and wide-spread pollutions of the air, water bodies and soils, for the sake of measurable economic development indicators alone (Miller, 2007; Chiraz, 2010).

The impacts of these changes, especially in terms of land development (human settlements, urban sprawl, slash and burn agriculture, fuel wood, bush fires, etc.), have been noted in the Congo River Basin, and are known to be part of a complex and ever-amplifying feedback cycle with global and regional climatic change as background (Sanga-Ngoie and Fukuyama, 1996).

Being nowadays the least advanced among the continents, Africa has nonetheless most of the assets it needs to fully and immediately embrace this approach to sustainable development. This can be especially possible if ways and means are devised so as (1) to monitor and assess, to protect, use and manage in an integrated and sustainable way, the African rich environmental capital and natural resources, and (2) to develop and use environment-friendly non-fossil energy resources with priority to integrating the economically-viable energy resources found within the continental perimeter. In other terms, African sustainable development has to be based on a thorough monitoring and consideration of its environmental and anthropogenic metabolism (Baccini and Brunner, 2012) as well as its capacity for integrated regional material flow (Brunner and Rechberger, 2004).

2. OBJECTIVES OF THE STUDY

In this note, we aim at assessing the potentials of the main environmental renewable resources in the African biomes. In our attempt to devise a scheme for sound and sustainable development at the continental scale, and from within the continent, we will mainly focus (1) on the relative natural capital that can be obtained from each one of these biomes, (2) on the overall availability of renewable energies in Africa, and (3) on the use of GIS and remote sensing techniques as the crucial instruments for data collection and integration both at the continental and the regional scales.

3. DATA SETS AND ANALYTICAL METHODOLOGY

In a previous study (Nonomura et al., 2003) using GIS techniques and remote sensing NOAA/AVHRR data (1985-1991), we obtained a digital vegetation model (DVM) map of the African continent based on Principal Components Analysis (PCA)

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of the NOAA channels 1, 2, 4 and 5 data. We foresee that this African land use/land cover map (Fig. 1) obtained for the early 1990s, hereafter the *Digital Vegetation Model (DVM)*, will serve as the reference database to which more recent maps obtained by analyzing later ages data will be compared to for any change analysis over the continent.

Then, noting that over this continent well-positioned on both sides of the equator, rainfall is the main limiting factor when one wants to secure a stable biomass (food and biofuels) production, a precise knowledge of rainfall amounts at every location of the continent is necessary (Mbereggo and Sanga-Ngoie, 2014). It is notorious that rainfall data records on the African continent are very often non continuous and obtained at largely dispersed stations. For this, we opted to create a digital rainfall map of Africa using the following steps: (1) Normalized Difference Vegetation Index (NDVI) and Precipitable Water Index (PWI) are calculated from channels 1 and 2, and from channels 4 and 5, respectively; (2) Regression analysis using the 1st PCA component of monthly mean NDVI and PWI (as X), and the contemporaneous monthly mean rainfall data of observational stations (as Y) is performed to fit a second order quadratic function; (3) After validation, the obtained regression equations are used to produce the digital images of monthly rainfall for all the continent.

4. RESULTS

The African DVM so obtained shows that seven main land cover types (biomes) prevail on the continent (Fig. 1), and the coverage areas of each one of them are estimated. Moreover, monthly rainfalls are calculated, and the values for typical months of the year are shown in Fig. 2, illustrating the annual seasonal changes in rainy and dry seasons over the continent. From these analyses, the following findings have been highlighted.

4.1 African climatic features

The features of African rainfall seasonality is illustrated by the change in location of the rainy areas following the annual changes in the position of the sun over the continent: dry season prevails over those areas with less than 50 mm of monthly rains, while rainy season covers those areas with more than 50 mm of monthly rains. This north-south annual migration of the zone of heavy rains also highlights the deep relationship between rainfall and the position of the Inter-Tropical Convergence Zone (ITCZ), over the continent.

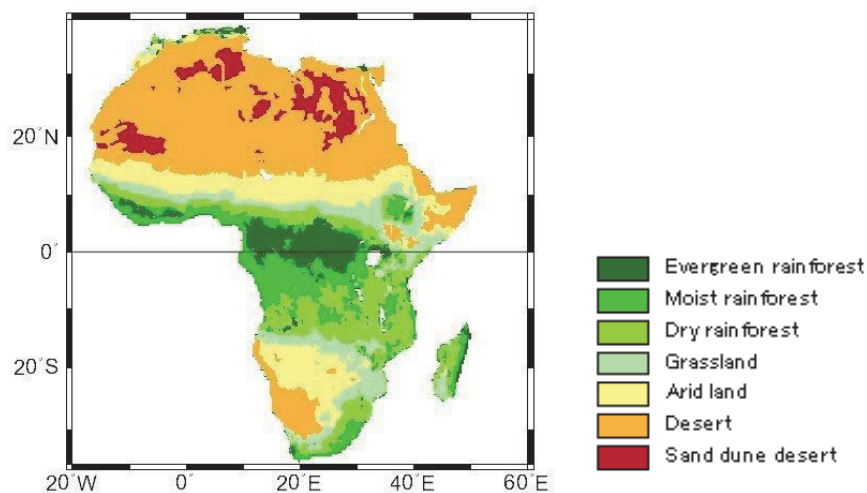


Fig. 1: The African Digital Vegetation Model (DVM)

4.2 Ecozones and Biomes in the African Biosphere

A combined evaluation of the African DVM and the regional climatic features shows that (Table 1):

- (1) Out of the 30,307,000km² of its total area, the African continent includes the following ecozones (biomes): Evergreen Rainforests (*Erf*: 6.6%), Moist Rainforests (*Mrf*: 10.6%), Dry Rainforests and Savanna Woodlands (*Drf*: 14.7%), and

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Grasslands (*Grl*: 10.0%), Arid lands (*Arl*: 15.3%) and 42.8% of Deserts (*Drt*) with large areas of Sand Dunes Deserts.

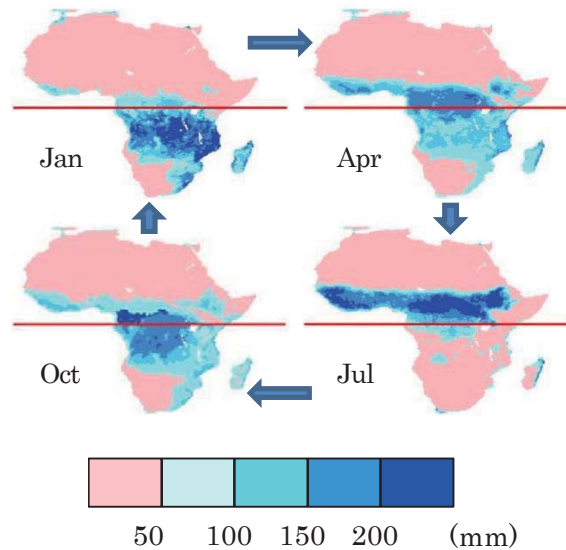


Fig. 2: Calculated African rainfalls for representative months: January, April, July, and October.

Table 1: Africa's main ecozones (biomes).

LU/LC Types	Area (10 ⁶ km ²)	Area (%)	Main Countries
<i>Erf</i>	2,006	6.6	*DRC, Cameroon, Congo, Gabon
<i>Mrf</i>	3.217	10.6	DRC, Angola, Tanzania, Congo, Cameroon
<i>Drf</i>	4.441	14.7	DRC, Angola, Tanzania, Zambia, Mozambique
<i>Grl</i>	3.031	10.0	South Africa, South Sudan, DRC, Ethiopia
<i>Arl</i>	4.656	15.3	Sudan, Botswana, Nigeria,
<i>Drt</i>	12.956	42.8	Libya, Egypt, Algeria, Sudan
Total	30.307	100.0	

*DRC: Democratic Republic of Congo)

- (2) In general, *Erf* and *Mrf* are found in areas with 0-2 months of dry season, while *Drf* and *Grl* prevail in drier regions with up to 8 months of dry season. *Arl* and *Drt* are characterized by almost no rains (more than 9 months of dry season).
- (3) Altogether, this information about the African land cover can be summed up into four main ecosystems with specific characteristics that have to be considered when development activities are concerned: **wet forests** (*Erl* and *Mrf*) covering 17.2% (5,220,000km²) of African lands, **Savanna Woodlands** (*Drf*) covering 14.7% (4,441,000 km²), **Grasslands** covering 10.0% (3,031,000km²) of the lands, and **Arid and Desert lands** (*Arl* and *Drt*) spreading over 58.1% (17,613,000km²) of the

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continent (Fig.1, Table 1, see details in Nonomura et al., 2013).

It has to be noted here that Africa has relatively small tropical rainforest coverages compared to other tropical landmasses (Central and South Americas, Southern and Southeastern Asia), while having the largest extents of grasslands and deserts (Miller, 2007). On the other side, African forests are mostly primary and virgin forests biomes (therefore, a very rich biodiversity) in comparison to mostly secondary or planted mono-cultural forests in the developed countries (Western Europe, Northern America). All these African biomes, known to be very fragile, are in strong need for conservation and protection, instead of random development and destruction as done so far.

5. POTENTIAL SCHEMES FOR SUSTAINABLE RESOURCES MANAGEMENT

From the above-mentioned findings, it becomes clear that, in its search for sustainable and balanced development, Africa has a lot to gain by wisely tapping in its huge environmental capital embedded in each one of its biomes, and on its untapped reserves of non-exhaustible renewable energy resources. At the same time, special attention has to be given for the restoration and preservation of those areas with fragile or unique ecosystems such as the deserts (*Drt*), arid lands (*Arl*) and the rainforests (*Erf*, *Mrf*, *Drf*) (Table 2).

Table 2: Potential schemes for sustainable development for Africa

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| <ul style="list-style-type: none"> - Deserts (<i>Drt</i>) : <ul style="list-style-type: none"> - Solar energy - Wind energy - Arid & Semi-arid Lands (<i>Arl</i>): <ul style="list-style-type: none"> - conservation - land restoration - Grasslands (<i>Grl</i>): <ul style="list-style-type: none"> - agriculture - ranching , cattle - biomass, biofuels - industrial tree planting - afforestation - Dry Rainforests (<i>Drf</i>): <ul style="list-style-type: none"> - conservation - reforestation, afforestation - Tropical Rainforests (<i>Erf</i> & <i>Mrf</i>): <ul style="list-style-type: none"> - air quality (CO₂) - CO₂ sequestration - biodiversity, conservation - Rivers and Lakes: <ul style="list-style-type: none"> - water resources, biotopes - hydro-electricity |
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An astounding amount of $24,141 \times 10^{15} \text{W}$ ($1,366 \text{ W/m}^2 \times 17,613 \times 10^9 \text{ m}^2$) of solar energy resource is reaching the African deserts surface (*Drt*) every second, while billions of megawatts of hydro-electricity power are there to be harnessed on daily basis from the main African Rivers (Congo, Niger, Zambeze, etc.) and their main tributaries flowing throughout the wet tropical rainforests (*Erf*, *Mrf*) area. Moreover, contrarily to Brazil and Indonesia where land development is almost impossible without systematic destruction of tropical rainforests (Yoshikawa and Sanga-Ngoie, 2011), agricultural development, for both food and renewable biofuels, can be developed on large-scales over African wet grasslands (*Grl*: 10.0%; $3,031,000 \text{ km}^2$), as well as on selected areas of the dry rainforests (*Drf*), while, at the same time, protection of biodiversity will be the main rule in the lush rainforests (*Erf*, *Mrf*). Tree planting for reforestation or for industrial use (lumber, paper) could be developed over the *Drf* areas,

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while systematic vegetation cover restoration plans have to be implemented for the climate-sensitive arid lands (*Arl*) areas.

6. CONCLUSION

Africa is known for its very poor and inconsistent atmospheric and climatological observational networks. Nowadays, remote sensing techniques are playing a very important role in providing reliable land cover data for every single place over this vast and very sparsely populated continent.

The fusion of these data together with available surface and statistical data on a GIS analytical platform has shown here that they can provide a sound basis for monitoring, assessing and planning for sustainable development of resources, especially the renewable ones, as well as for the restoration and conservation of African ecosystems for an endless flow of materials and continuous anthropogenic metabolism of this continent.

Scaling down the finding from the DVM to regional or local levels, using remote sensing data of appropriate time, spectral and spatial resolutions will make it possible to find out specific potentials and limitations at the country or area levels. If performed, these detailed quantitative assessments of the existing potentials for environmental land resources development and renewable energy generations, including solar, wind, bio- and hydro- energies, will pave the way to devising an integrated framework on the continental scale in terms of sustainable management, production and distribution. We think this integrated continental approach should be prioritized instead of the national schemes developed so far.

The DVM, the derived rainfall maps, as well as many other derivatives that can be obtained based on bio-physical or statistical relationships among observed parameters, could be the basis for re-defining new climatic maps as well as new *agro-ecological zones* (AEZ) using GIS and remote sensing techniques, which are shown here to be the right tools and techniques for sound decision-making aiming at appropriate action for sustainable development in Africa.

The scheme developed here is expected to contribute to both of the following: (1) reducing CO₂ emissions, especially those from fossil fuels, from the African continent, and (2) enhancing CO₂ sequestration by African forests (Sanga-Ngoie et al., 2012), and (3) supporting action for sustainable use and management of African ecological resources and its immense natural capital.

Acknowledgement

This notes is based on the contents of our presentation at the 2014 Symposium of the Kyushu Section of the Japan Remote Sensing Society, held at Saga University, Saga City, Japan on 2014.1.26. With all our deepest gratitude for been given this great scientific opportunity.

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