MODELLING VEGETATION LOSS AND GREENHOUSE GAS EMISSIONS IN KADUNA, NIGERIA

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ABSTRACT Tropical forests and other vegetated landscapes like grasslands and wooded savannahs play a major role in the global carbon sequestration process and their conservation and protection offers immense potential for reducing greenhouse gas emissions and global warming. This study aims to model the rate of vegetation loss as a result of diverse anthropogenic processes like urbanization, agriculture and infrastructural development in the fast growing city of Kaduna in northwest Nigeria. Land use change analysis between 1990 and 2009 is conducted and a transition potential map is produced based on the established pattern of change and the land use change driver variables determined for the study area. This is achieved by a hybrid technique that integrates cellular automata, Markov chain analysis and artificial neural networks. The model is then used to predict land use change scenarios between 2001 and 2009. Model validation is achieved by way of computing the ROC statistic using the simulated and actual land use maps of 2009. Having obtained satisfactory outcomes, the model is then used to predict the urbanization scenario between 2009 and 2040. Interventions are then proposed to reduce sprawl and loss of vegetated land based on certain constraints placed on the land use change processes and the simulation is then run again to 2040 to produce an alternative scenario of land use change to serve as a basis for the implementation of the REDD project. The REDD model utilizes a methodology for calculating and evaluating net anthropogenic greenhouse gas (GHG) emission reductions due to the implementation of a REDD project. This methodology is based on the World Bank's Bio-Carbon Fund Project (BioCF) methodology for estimating reductions of GHG emissions for mosaic deforestation. Reductions in GHG emissions are calculated by subtracting the estimated carbon that would be saved through a REDD project intervention, along with the estimated carbon loss through leakage from the estimated carbon loss without the implementation of a REDD project intervention. The difference is known as additionality, and implies the net GHG emissions that are reduced owing to the implementation of the REDD project. The results obtained show significant reduction in GHG emissions based on the proposed planned interventions to reduce tropical land consumption and vegetation loss in Kaduna.

1. INTRODUCTION

Carbon dioxide (CO_2) is by far the most prominent greenhouse gas released by anthropogenic processes, accounting for about 85% of total emissions weighted by the global warming potential (EEA, 2008). Although uncertainty exists as to the likely climatic changes that the greenhouse effect may bring about, the role of transportation in the production of greenhouse gasses is clear. CO_2 is a by-product of any engine that burns carbon-based fossil fuels (Munshi, 2013). The amount of CO_2 released per unit of transportation service (i.e, per tonne-kilometre) is directly related to the energy consumption of the mode providing that service. One litre of petrol fuel releases 2.28 kilograms of CO_2 while one litre of diesel releases 2.58 kilograms of CO_2 (IEA, 2008). At the same time that urban transportation is causing the emission of CO2 into the atmosphere, urban expansion is depleting the surface area for carbon sequestration as it consumes naturally occurring vegetated landscapes.

Tropical forests in particular and other naturally occurring vegetated landscapes like wooded and grassland savannahs play an important role in the sequestration of carbon. This makes the conservation of natural vegetation cover and the areas in which they are found critical to the efforts of reducing greenhouse gas emissions and by extension the greenhouse effect. To achieve this conservation, improved planning of urban expansion that places certain restrictions on land development so as to preserve forests, woodlands and grasslands is required. This kind of conservation can be achieved through a REDD (Reducing Emissions from Deforestation and Forest Degradation) project. REDD is a climate change mitigation strategy that is aimed at protecting and maintaining forests. A REDD project aims to establish constraints to development such that certain areas are protected. The main purpose of a REDD project is to establish protected areas in order to reduce deforestation caused by anthropogenic processes. Such conservation efforts and improved planning of urban expansion would require tools and methods that allow for an effective assessment of current urban conditions, establishment of subsisting trends and patterns as well as reliable forecasts of future planned and unplanned scenarios. Land use change models are the most suitable tools for carrying out the aforementioned tasks (Mas et al. 2004; Vermeiren et al. 2012; Arsanjani et al. 2011).

In this study, a land use change model that permits the simulation of future scenarios of urban growth and development is integrated with a REDD model to determine and model anthropogenic greenhouse gas emissions reductions owing to urban expansion without (unplanned) and with (planned) a REDD project intervention. To establish a REDD project, the potential impact of a project or development over its lifetime must first be estimated. This requires an assessment of the historical trends in land cover change in the area under consideration and the creation of two future scenarios of change, the business as usual scenario where the past land change trends continue unimpeded and the planned or sustainable development scenario that preserves certain amounts and areas of land. The difference in carbon stocks between the first and the second scenarios, known as additionality is the measure of the carbon offset that results as a consequence of implementing the REDD project (Eastman, 2014). The model was applied to Kaduna in northwestern Nigeria and the results demonstrate how better planning of urban expansion may lead to reductions in greenhouse gas emissions.

2. DATA REQUIREMENTS AND METHODS

2.1 Data requirements

Landsat TM imagery of Kaduna for 1990 and Landsat ETM+ imagery of Kaduna for 2001 and 2009 were used in manually extracting land use maps of the study area based on the Anderson classification. All the satellite images were geometrically registered. Three land cover categories namely built up, water bodies and open savannah were identified by means of visual interpretation of the true color composites of the Landsat imagery. Land use maps of 1990, 2001 and 2009 were then produced from the images (figure 1). Table 1 provides a summary of the spatial data used in the study.

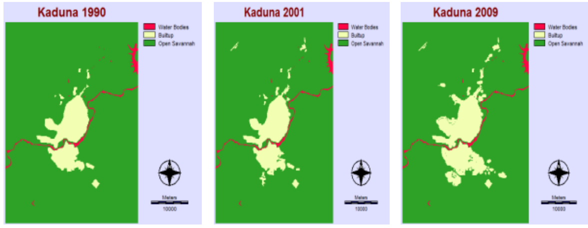

Figure 1: Land use maps of 1990, 2001 and 2009

Table 1: Spatial data used in the study

Data	Source of data	Date
Landsat images of the study area	GLCF and USGS	1990, 2001, 2009
Land cover maps of the study area	Landsat images	1990, 2001, 2009
Primary Roads Network	Google Earth/ Kaduna state ministry of lands	2001
Topographical map of the study area	Kaduna state ministry of lands	2010
Digital Elevation Model	Derived from topo map	2010
Slope map	Derived from topo map	2010
Distance from primary roads	Derived from road networks map	2001
Distance to city center	Derived from land cover map	2001
Distance to built-up areas	Derived from land cover map	2001

2.2 Methods

2.2.1 Simulation methods. Land use change analysis was conducted for the study area by cross tabulation of the earlier derived land cover map of 1990 as the input earlier land cover image and the 2001 land cover map as the input later land cover image. Transition potential modelling was used to group land use transitions into a set of sub-models and then utilized to explore the potential power of the chosen explanatory variables. In the current study, the change analysis showed that there is only one set of transition, from open savannah category to built-up category. The explanatory variables chosen for this study are slope, elevation, roads network, distance from existing built-up area, distance from roads network and distance from the city center. In order to predict change, the transition was empirically modelled using multi-layer perception (MLP) neural network. The MLP works by creating a random sample of cells that experienced the transition being modelled and an additional set of random samples for each of the cases of pixels that could have, but did not go through transition. Thus the neural network will be fed with examples of two classes, one transition class and one persistent class (representing cases where each of the “from” classes remains the same). We are only interested in the first transition class, but the neural network will train better if it has both classes. The examples given are used by the MLP to train on and develop a multivariate function that can predict the potential for transition based on the values at any location for the explanatory variables. It does this by taking half the samples it was given to train on automatically and it reserves the remaining to test how well it is doing. The MLP constructs a network of neurons between the input values from the driver variables and the two output classes (transition and persistence classes), and a web of connections between the neurons that are applied as a set of weights that are initially random. These weights structure the multivariate function. With each pixel it looks at from the training data, it gauges its error and adjusts the weights. As it gets better at doing this, the accuracy increases and the precision improves (i.e., the RMS error declines).

The transition potential modelled previously was used to create several types of predictions through a dynamic land cover change process. After specifying an end date, the quantity of change in the transition from open savannah to built-up is modelled using the Markov Chain analysis. The Markov Chain premise is a stochastic progression that depicts the probability of one state being altered to another state. The Markov Chain produces a key descriptive outcome that determines the probability of change from one land use category to another, which is a so-called transition probability matrix" (Arsanjani et al., 2011 pp. 331).

For model validation, the ROC statistics is employed. The ROC module employs the Relative Operating Characteristic (also known as the Area Under the Receiver Operating Characteristic Curve – or AUC), an excellent method to assess the validity of a model that predicts the location of the occurrence of a class by comparing a suitability image depicting the likelihood of that class occurring (i.e., the input image) and a Boolean image showing where that class actually exists (i.e., the reference image). Once validation is concluded, the model is then used to simulate a future urban expansion scenario based on the established trends and conditions between 1990 and 2009. This is known as the business as usual scenario. Constraints and incentives are operationalized in the model by creating images whose pixels are coded with values that are used as multipliers to the transition potential map (figure 2). A multiplier of 1.0 has no effect. Multipliers greater than 1.0 act as incentives (they increase the potential for transition of a pixel) while multipliers less than 1.0 act as disincentives. The essence of these new inputs is to enable the simulation of an alternative future urban expansion scenario that is different from the business as usual scenario.

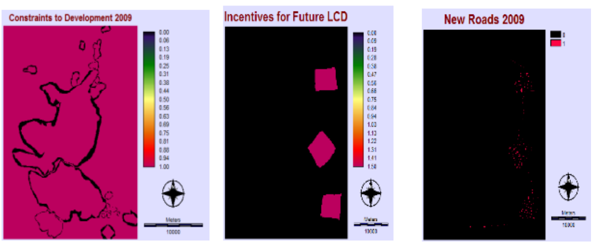

Figure 2: Constraints and incentives to urban expansion

2.2.2 The REDD methodology. Typically, REDD projects are modelled based on a 30 year projection with intermittent assessments every 5 years. This means that 6 prediction maps will be produced over the 30 year prediction between 2009 and 2040 as is the case in this study. The carbon reporting is done based on these intervals. The REDD model utilizes a methodology for calculating and evaluating net anthropogenic greenhouse gas (GHG) emission reductions due to the implementation of a REDD project or the deliberate protection of certain areas of interest from anthropogenic change processes. This methodology is based on the World Bank's Bio-Carbon Fund Project (BioCF) Methodology for Estimating Reductions of GHG Emissions for Mosaic Deforestation. The BioCF methodology requires three basic spatial or geographical data inputs. These are known as the project area, the leakage area and the reference area (figure 3). The project area is the geographic extent of the area under consideration for a REDD project; the leakage area refers to the area around the project area that may experience impacts as a result of the creation of the protected area, that is the area to which development is channeled in the perspective of urban land use change or the area to which deforestation is relocated; and the reference area is the entire area of study encompassing the project and leakage areas. In addition to the spatial data inputs, a number of other parameters such as the carbon density – which is 67.1 Mg/ha (Brown and Gaston, 2001) in the case of the wooded savannah vegetation that is predominant in the Kaduna City Region – and a number of predetermined constants are specified. Reductions in GHG emissions are calculated by subtracting the estimated carbon that would be saved through a REDD project intervention, along with the estimated carbon loss through leakage from the estimated carbon loss (in this case through land use and cover change) without the implementation of a REDD project intervention. The difference is known as additionality, and implies the net GHG emissions that are reduced owing to the implementation of the REDD project. The first task required in the computations is that of creating a baseline. The baseline is an estimation of carbon loss when there is no REDD intervention based on the persistence of historical rates of land use and cover change. Then the computation based on the REDD intervention scenario and this is the estimated amount of carbon saved as a result of the REDD intervention less the amount of carbon loss due to leakage.

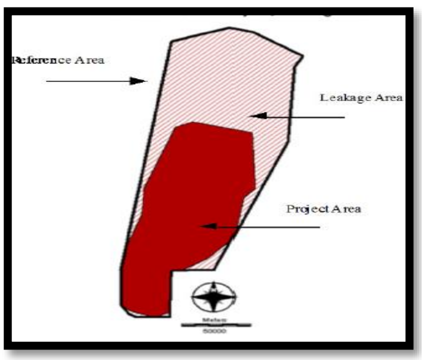

Figure 3: Spatial data inputs for REDD project

3. RESULTS

3.1 Land use change analysis, validation and prediction of future development scenarios. The land use changes that have taken place in the study area within the 19 year period for which change analysis was carried out shows that the built-up category gained 10.65% while the open savannah category lost 1%. As such, the built-up category grew to 14,127.02ha in 2001 from 12,767.25ha in 1990, an increase of 1,359.77ha. The water bodies' category recorded neither increase nor decrease, which is consistent with normal expectations. Based on the results of the land use change analysis for the period between 1990 and 2009, the evaluation of the 6 explanatory variables in the transition potential sub-model and the transition potential surface (figure 4) that was subsequently created, the model was calibrated and employed to predict and simulate urban growth over an 8-year period from 2001 until the year 2009. The choice of 2009 as the end date of the first stage of land use change prediction is based on the availability of the actual land cover map for that year which can be used in evaluating and validating the model. The simulated map is shown in figure 4. Between 2001 and 2009, the built-up category increased by 981.1757ha (approximately 6.95%), growing to 15,108.1936ha. Arsanjani et al. (2013) argues that there is no unique worldwide concensus on how to evaluate the results of existing predictor models. Models are built for specific aims and purposes and as such the criteria for evaluation and validation of results should take into consideration such aims. Furthermore, scale is an essential consideration in any cross-comparison of maps as outcomes may be sensitive to scale and certain patterns are only evident at certain scales (Pontius et al. 2004).

The validation of the model was undertaken by computing the ROC statistic using a map of actual change between 1990 and 2009 as the reference image and the simulated land cover map of 2009 as the input image. The ROC statistic was obtained at 0.69, a reasonably strong value that is good enough to make the results of the simulation acceptable.

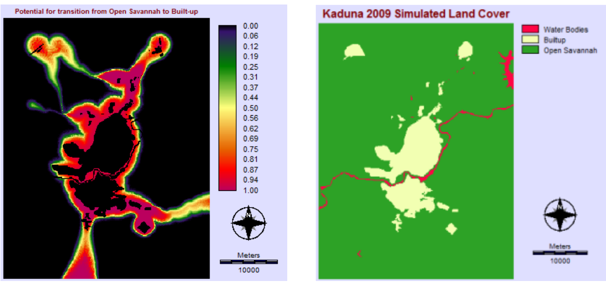

Figure 4: Transition potential surface and simulated map of 2009

Further visual analysis and comparison of the simulated and actual land use maps of 2009 reveal that the customized model is generally a reliable estimator in terms of change quantification, allocation and continous space modelling. The results also showed the strength and robustness of the model based on its ability to model actual suitabilities and not neighborhood or contiguity effects. However, the model only employed environmental variables as potential explanatory factors leaving out socio-economic variables that also play a vital role in the process of urban growth (Arsanjani et al., 2011).

Urban growth for Kaduna was further simulated to 2040 based on established trends between 1990 and 2009 so as to further investigate its future pattern and extent. The result of that simulation shows that the built-up category further increased by 79.0% (i.e from 15,108.20ha to 27,049.22Ha) invariably reducing the size of the open savannah category by the same measure. This is the future business as usual scenario (figure 5). Based on the introduction of new urban planning regulations or alteration of existing ones, a future urban growth and development pattern that is markedly different from the future business as usual pattern results (figure 5). The built-up area of the city that was projected to reach 27,049.22ha (270.50km^2) in the business as usual scenario is projected differently at 21,876.00ha (218.76km^2) in the sustainable development scenario owing to the effects of the planned interventions. This represents a net savings in land consumption of 19.13%. This future sustainable development scenario is the result of the implementation of the REDD project in the study area.

In order to implement the REDD model, the constraints and incentives defined to produce the sustainable development scenario were used to create the input spatial data required. These are the REDD project area which defines the area to be protected and the REDD leakage area which defines the area in which further urban expansion is permitted (figure 6).

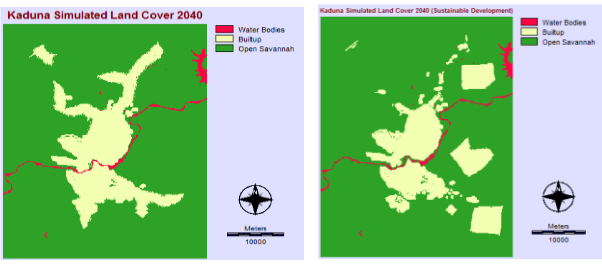

Figure 5: Future BAU and sustainable development scenarios

The model outputs the carbon account calculations in an Excel Spreadsheet workbook made up of eight tables labelled according to the BioCF reporting convention. For the purpose of interpreting the results, the tables can be categorized into three groups namely tables for Co_2 emissions, tables for non-CO_2 emissions and tables for net GHG emissions. The tables carry different types of information which is created during the carbon accounting computation. The formula employed in the calculation is given by:

C-REDD = (C-Baseline) – (C-Actual) – (C-Leakage)

The results show that the amount of carbon that the REDD project will protect given a departure from the business as usual urbanization scenario is

1,606,147.09tCO_2e (tonnes of CO_2 equivalent).

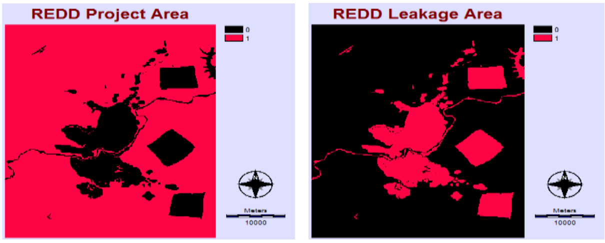

Figure 6: REDD project and leakage areas

It is evident from the results of the REDD model that the future sustainable development scenario is a more environmentally sustainable development option as a cumulative 1,606,147.09tCO_2e (tons of CO_2 equivalent) will be saved or prevented from being released into the atmosphere with its attendant consequences due to the reduction in the conversion of the open savannah land cover category to the built-up category by 2040. Whereas, if the business as usual scenario was allowed to continue without any planning intervention, only -354,408.26tCO_2e would have been saved by 2040.

4.0 CONCLUSION

The simulation methods and the REDD methodology employed in this study have demonstrated that where relevant tools are applied, it is possible to not only develop alternative scenarios of future development patterns but also evaluate these different scenarios in terms of their advantages and drawbacks in relation to the goals of sustainable development. Even though the integration of the simulation and REDD methodology described here is at an early thus crude stage of development, the promise and potential it holds as a valuable technique for urban planners and decision makers in sustainability assessment is immense. This is because the simulation and REDD methods are developed in a user friendly software environment that does not require the development of complex programme codes and specification of complicated modelling parameters. All that is required to increase accuracy and reliability of results is an improvement in the quality of the input data.

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