Satellite Based Monitoring of Deforestation Driven by Population Growth in West Africa

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Abstract

The study describes typical evolution of forest cover in West Africa based on Ghana’s example. In this region, the population is highly dependent on forestry products which represent a vital part of the economy. The effect of population growth on natural resource utilization studies is very profound. This study assesses land use change in the Ashanti Region of Ghana within a 25 year period. The analysis of land use change uses a combination method in Remote Sensing (RS) to explain the effect of population growth on natural resource. The procedures used include: (i) a data pre-processing (geometric corrections, radiometric corrections, subset creation and image enhancement) of epoch Landsat images acquired in 1986, 2007, and Disaster Monitoring Constellation (DMC) 2011; (ii) classification of multispectral imagery (iii) Change detection mapping. The results show a very grim picture of the extent of forest loss due to anthropogenic factors such as Agriculture and settlement. Population and Environment Relationships such as Linear views: Malthus and Boserup, Multiplicative perspectives and Development-dependency perspectives all being applicable in the area of study.

Keywords

Population, Environment Relationships, Remote Sensing, GIS

1. Introduction

Developing countries have been imperiled to a grim problem of fast growing population which results in intensifying environmental degradation (Lorey, 2003; Pimentel & Pimentel, 2010; Srivastav & Srivastav, 2015). Surging population growth rate with low per-capita income has exacerbated environmental condition. An intricate and dynamic relationship is perceived between population and environment (Zaman et al 2011). They are closely entwined with each other. The link between population and environment is intermediated by a number of cultural, political, socio-economic and evolving variables which comparatively differs significantly from one context to another. Economists, biologists, and environmentalists have been debating the role of population in environmental degradation over the last forty years (Hummel et al., 2009).

Population is a key source of environmental degradation (Goudie, 2013). Population impacts mainly on the environment via the use of natural resources and production of waste (Eitzen et al., 2013; El-Kholy, 2012)). Population is linked with environmental stress such as reduction of ecosystem complexity, loss of biodiversity and the alteration of the all-important biogeochemical cycle (Asthana and Asthana, 2006).

Ghana’s rapid population growth is degrading the environment through expansion and intensification of agriculture, expansion of human settlements (urbanization) and other economic activities (Adanu et al., 2014; Adu et al., 2012; Adu-Poko et al., 2012; Ashaley, 2012; Rudorff et al., 2010; Veldkamp & Lambin, 2001). Rapid population growth adversely affects the natural resources and environment
Population increase is a significant contributing factor in the adverse land cover change and the resultant land degradation. There are dire consequences for agricultural land and forest resources in Ghana as a result of rapid population growth and low economic standards of living (Peprah et al. 2014). Benneh et. al. (1990) reasoned that, among the three reasons that have contributed to greater competition for land, previously covered by trees and now without of vegetation, one is demographic pressures. As population rises, so too does the need for land, to expand settlement infrastructure and other utilities.

Remote sensing provides the best means for studying vast areas of the Earth’s surface for investigation, mapping, and then monitor ecosystem structure and activities (Miller et al, 1998). Remote sensing exquisitely reveal exactly where and when deforestation is taking place and provide baseline information for assessing forests, land-cover and land-use changes. In a study of land cover changes in West Africa for the period of 1975–1990 based on remote sensing was undertaken it was concluded that, the sample based land cover change approach using medium resolution satellite images offers a reliable method for the evaluation of land cover dynamics over large areas (Vittek et al., 2014).

This study employs remote sensing to make effective analysis of the land use/cover change between the years 1986 – 2011 in Ashanti Region. The resultant changes will then be integrated into a socio-economic comparative study in order to draw conclusions on the general patterns and causes of forest cover and land use change over the period of study.

2. Methodology

2.1. Study Area

Ghana is located along the west coast of Africa and covers about 23 million hectares. It is bounded by the Ivory Coast to the west, Burkina Faso to the north and Togo to the east and the Gulf of Guinea (part of the Atlantic Ocean) to the south (Figure 1). It lies between latitude 4° 45’ and 11° 11’ north and extends from longitude 1° 14’ east to 3° 17’ west northern part of the region. 24 forest reserves, which represent about 40% of the forest reserves in Ghana, are located here (www.ghana.gov.gh).

The Ashanti Region occupies an area of 24,390km² which is 10.2% of the land area of Ghana (www.ghanaweb.com). It has the highest population in Ghana, with a population of 4,780,280 (GSS, 2013). The Ashanti Region is subdivided into the 30 districts with the population of the region residing mostly in the Kumasi metropolis and the adjoining districts. The Region produces abundant food supplies and cash crops like Cocoa, oil palm, citrus, cashew, cotton, tobacco and bast fiber are cultivated on large scale. Ashanti leads in poultry industries and large poultry feed mills in the Country. An ample quantity of bamboos and canes grow naturally in its forest belt. Large deposits of gold, bauxite and various mineral deposits of economic value such as silica, manganese, iron, limestone, clay, mica, copper, platinum, tin arsenic and lithium, and are found in the Region (www.ghanaweb.com).

The Area of Interest contains the following administrative districts Offinso, Ahafo Ano South, Atwima Mponua, Amansie West, Atwima, Afigya Sekyere, Kwabre, Kumasi Metro, Bosomtwe-Kwanwoma, Amansie Central, Amansie East, Asante Akin South, Asante Akim North, Ejisu-Juaben, Sekyere East, Afigya Sekyere and Sekyere West. A meteorite lake called Bosumtwi, is located within an ancient meteorite impact crater. This natural lake provides livelihood in the form of fishing industry to the surrounding communities and serves as a popular tourist attraction destination to both local and foreign tourist (Jones, et al., 1981).
Table 1. Remote Sensing Images for the study.

<table>
<thead>
<tr>
<th>Area Of Interest (AOI)</th>
<th>Data</th>
<th>Date of Acquisition</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ashanti Region</td>
<td>Landsat TM</td>
<td>11/01/1986</td>
<td>30.00</td>
</tr>
<tr>
<td></td>
<td>Landsat ETM+</td>
<td>19/02/2007</td>
<td>28.50</td>
</tr>
<tr>
<td></td>
<td>DMC</td>
<td>19/01/2011</td>
<td>22.00</td>
</tr>
</tbody>
</table>

Table 2. Reference data for study.

<table>
<thead>
<tr>
<th>Reference Data</th>
<th>Acquisition Date</th>
<th>Scale</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topographical Map</td>
<td>2008</td>
<td>1:50,000</td>
<td>Survey Department, Ghana</td>
</tr>
<tr>
<td>Aerial Photograph</td>
<td>2004</td>
<td>1:10,000</td>
<td>Survey Department, Ghana</td>
</tr>
<tr>
<td>Land Cover Map</td>
<td>2002</td>
<td></td>
<td>Forestry Department, Ghana</td>
</tr>
<tr>
<td>Digitised Topographical Map</td>
<td>2002</td>
<td>1:50,000</td>
<td>Geomatic Eng. Dept., KNUST</td>
</tr>
<tr>
<td>FPP Ground truthing and verification data</td>
<td>2012</td>
<td></td>
<td>Forestry Department (FPP-Ghana), Ghana</td>
</tr>
</tbody>
</table>

2.2. Materials

Satellite images and reference data employed for this study were obtained from the Forestry Commission of Ghana, under the Forest Preservation Program (FPP-Ghana) 2011/2012.

2.3. Image Processing

The study concentrated on the forest and land use change for the periods 1986, 2007 and 2010 covering twenty five (25) years. ERDAS Imagine 9.1 was used to perform image processing which included the following processes: pre-processing, image classification, accuracy assessment, and production of a change map. ARCGIS 10.0 was used to produce the output maps. Pre-processing of the epoch images entailed geometric corrections, radiometric corrections, subset creation and image enhancement.

Pre-processing involved the following processes; geometric corrections, radiometric corrections, subset creation and image enhancement.

Geometric Corrections: The individual bands of each of the two images (Landsat TM and Landsat ETM+) were combined into single image using the Layer Stack tool in the Utilities toolbar of ERDAS Imagine 9.1. Bands 1, 2, 3, 4, 5 and 7 were stacked together. Band 6 which measures thermal reflectance was omitted because of its different spatial resolution of 120m and moreover the study was not measuring heat reflectance. The resultant stacked images which were in the global coordinate system, UTM WGS 84 were re-projected onto the Ghana datum, War Office which is based on Traverse Mercator Projection.

All the images (Landsat TM, Landsat ETM+ and DMC) were re-sampled to 30 x 30 meter pixel resolution to make accurate analysis of the datasets and comparability possible using Reproject in the Utilities toolbar of ERDAS Imagine 9.1.

Radiometric Corrections: Datasets were already corrected to some extent; but the 1986TM, and 2002ETM+ images were quite hazy and therefore corrected for haze using the haze reduction module in Erdas Imagine 9.1.

Creating Subsets (AOIs): The AOI was delineated from the whole individual epoch images for the respective epoch years and scenes. The subset tool in the Utilities in Erdas imagin9.1 was used for this process via the area of interest (AOI) tool.

Image Enhancement: The individual subset (delineated) images were enhancement to improve their visual interpretation which is vital during image classification. Histogram Equalization was used. This method is premised on assigning image values to the display levels on the basis of their frequency of occurrence (Lillesand and Kiefer, 2008).

2.4. Land Use Classes

After appraising satellite data, literature on the topic and author’s experience from the area it was deemed to use not only information on forest cover but also land use classes to characterize extend and directions of forest cover change. The following land use/cover classes were distinguished:

Forest: This covers all land with woody vegetation consistent with measurements used to outline Forests in the national greenhouse gas inventory. Additionally all vegetation structure that currently fall below, but in situ could potentially reach the Ghana’s threshold values.

Minimum Mapping Unit (MMU) is 1.0 ha; Minimum crown cover is 15 %; Potential to reach minimum height at maturity (in situ) as 5 meter

Agriculture: This designate cropped land, including rice fields, and plantation where the vegetation structure falls below the thresholds used for the Forest Land category. Land where over 50% of any defined area is used for agriculture, this may be currently cropped or in fallow and may include areas for grazing of livestock.
Settlement: These portray all developed land, including social utilities such as transportation infrastructure (roads and highways), built up areas, bare grounds and human settlements of any size.

Water: These comprise lands that are covered or saturated by water for all or part of the year (for example peatlands). It also includes reservoirs and natural rivers and lakes.

2.5. Image Classification

This study is used post-classification change detection to identify forest and other land changes that have occurred.

This technique is dependent on two thematic maps of different dates to detect changes; Image Classification was undertaken to extract thematic information from the images.

With aid from the reference data in Table 2 and the personal knowledge about the study area, fifty (50) training sites signifying the various land use/cover classes (Forest-10, Agriculture-20, Settlement-15 and Water-5) were digitized on the individual images using the AOI tool and named accordingly in the signature editor of ERDAS imagine 9.1.

After classification, the 50 classes were recoded into the various classes via the Image Interpreter/GIS Analysis/Recode tool in ERDAS Imagine 9.1. The 10 forest classes were recoded as one and given the colour deep green, the 20 Agriculture Classes recoded as Class two and assigned the assigned colour yellow; the 15 Built-Ups classes recoded as three and given colour Maroon and the 5 classes of water recoded as 4 and given colour blue.

Reference data extracted from table 2 were used to perform Accuracy Assessment. The Classifier toolbar of ERDAS Imagine 9.1. In all, one hundred and twenty (120) reference points from the FPP-Ghana field interpretation and verification data were used to assess the accuracy of the classified images. This study evaluated the accuracy of the classified images from the matrix generated. Calculation of areas in kilometers of the resulting land cover types for each study year was carried out subsequently.

3. Results

Figures 2, 3 and 4 are the extracted images from Landsat TM 1986 Landsat ETM+ 2007 and DMC 2011 respectively. They show the same area that are cloud free and are of interest to this study.

Accuracy assessment was performed on the 2011 DMC (current) image classification and an assessment report was generated in an error matrix, and a Kappa statistics. 83.33% was obtained as overall classification accuracy. Overall Kappa statistics of 0.7159 was realized. Accuracy assessments for 1986 TM and the 2007 ETM+ images were undertaken Reference data (table 2). Stratified random sampling method were employed to select reference points for the whole of the study area.

Table 3 gives the extent of the area of the individual land cover categories in square kilometer (km$^2$) and the percentage they occupied. Figure 5 portrays the trends of land cover changes in 1986, 2007 and 2011.

The map for 1986 (Figure 6) showed the Kumasi metropolis very green. As high as 75.16% of the land cover is forest.
The agriculture is the next in rank with 17.27%. Most of the populations are subsistent farmers. This explains why the agricultural lands are in clusters, where they appear as a big mass, they are subdivided into small farms. Settlement takes the 6.73%.

The land use/cover map for 2007 (Figure 7) shows the Kumasi metropolis and environs losing more than 30% of it forest cover. Agriculture has also increased and has taken much of the forest at 49.17%. Housing and social amenities (Settlement) have expanded in all directions. Water share of the land cover remains somehow constant at 0.80%.

The map for 2011 (Figure 8) shows the Kumasi metropolis has lost more forest cover to 25.54%. Agriculture is the dominant LULCC and has taken much of the forest at 56.90%. Housing and social amenities (Settlement) have expanded in all directions. Water share of the land cover remains somehow constant at 0.81%.

Table 3. Area of categories in kilometres-Kumasi and its environs.

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<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Forest</td>
<td>4891.11</td>
<td>2282.04</td>
<td>1662.23</td>
<td>75.16</td>
<td>35.07</td>
<td>25.54</td>
</tr>
<tr>
<td>Agriculture</td>
<td>1124.09</td>
<td>3199.53</td>
<td>3702.92</td>
<td>17.27</td>
<td>49.17</td>
<td>56.90</td>
</tr>
<tr>
<td>Settlement</td>
<td>437.84</td>
<td>973.39</td>
<td>1089.75</td>
<td>6.73</td>
<td>14.96</td>
<td>16.75</td>
</tr>
<tr>
<td>Water</td>
<td>54.16</td>
<td>52.24</td>
<td>52.30</td>
<td>0.84</td>
<td>0.80</td>
<td>0.81</td>
</tr>
<tr>
<td>Sum</td>
<td>6507.20</td>
<td>6507.20</td>
<td>6507.20</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
</tbody>
</table>

The table 4 shows the extent change of the area of the individual land cover categories in square kilometre (km²) and the percentage they occupied for 1986-2007 and 2007-2011. Figure 11 indicates the graph depicting the trends of land cover changes.

Figure 9 shows the extensive changes that have occurred on almost 50% of analysed area (3192.08 km²) between 1986 and 2007. The biggest change was recorded as forested land gave way to agriculture at 74.60%. Forest lost out to Settlement at 11.86%, while Forest marginally increased its’ at the expense of Agriculture at 4.20%. Agriculture gave way to Settlement at 9.34%.

Figures 10 show the changes that have transpired on almost 41% of analysed area (2440.11km²) between 2007 and 2011. The biggest change was again recorded as forested land gave way to agriculture at 55.48%. Forest lost out marginally to Settlement at under 1.0%, while Forest increased its share at the expense of Agriculture at 29.13%. Agriculture gave way to Settlement at 14.76%.
Figure 6. Land use/cover for Ashanti - 1986.
Figure 7. Land use/cover Ashanti-2007.
Figure 8. Land use/cover Ashanti 2011.
Figure 9. Change Trajectory 1986-2000.
Figure 10. Change Trajectory 2007-2011 2010 of Western.
4. Discussion

4.1. Remote Sensing: Land Use/Cover Classification

Remote sensing usage in the study of the changing pattern of LULCC is very perceptive and efficient. It provides one of the most precise means of assessing the magnitude and pattern of changes in LULCC over a period of time (Miller et al., 1998). Satellite data provides an important means in forest change detection studies because of the periodic and coverage of the satellites at relatively short intervals (Mas, 1999).

Utilizing remote sensing data for LULCC studies over large areas is very effectual, fast and relatively inexpensive as compared to other methods of LULCC studies. Yet getting the requisite satellite data for such studies is a huge challenge for researches in Africa due high cost. Researchers in Africa thus mostly rely on Landsat images (which are free) and donor funded programs.

Stratified random sampling was used in the selection of the training sites for the supervised classification. Stratified random sampling is using expert knowledge, the field area is distributed into strata that maximize the differences between units, and minimize the variation within each unit. Stratified random sampling produces results that are both largely unbiased and accurate. It produces data that is more representative of the entire population because of the special attention it pays to the smaller subgroups within a population. It is also the best way to obtain results that reflect the diversity of the population in question as pertained under the area of study.

The land use/cover classification for the study is very consistence with studies conducted by other researches such as (Hansen et al., 2013; Kim et al., 2014).

4.2. Land Cover Change Analysis

The land use/cover for 1986, 2007 and 2011 showed forest loss increasing from year to year. Agriculture and Settlements are the big gainers as the year go by.

The driver for deforestation and degradation is clearly anthropogenic. The Ashanti Region has the largest population in Ghana and the fastest growing population (GSS, 2013). The surge in population has direct consequence on the environment and the forests in particular. In Ashanti cocoa the highest cash crop earner of foreign exchange for Ghana is cultivated here (Glastra, 1993; Pouliot et al., 2012). The cause of the deforestation concur with works by (Michetti and Zampieri, 2014; Franks et al., 2014; Strassburg et al., 2013; Vu et al., 2014). Foley et al. (2005) and Feddema et al. (2005) working on global consequences of land use and the importance of land-cover change in simulating future climates respectively stated that land-use and land-cover change derive from the complex interaction of a big number of factors both natural and human induced.

4.3. Population and Environment Relationships

At the United Nations Conference on Environment and Development in 1992 held in Rio de Janeiro-Brazil, study
and attention in the linkages between population dynamics and environmental change received renewed impetus. The conference summary statement, 11 Agenda 21, 11 endorsed the development and propagation of knowledge on the links between demographic trends and sustainable development as well as environmental impacts (United Nations 1993).

There is diversity of opinion and approaches generally depict the discussion of population and environment relationships. Many of these perspectives overlap and many studies reflect the influence of more than one perspective (Marquette, 1997).

(a) Linear views: Malthus and Boserup.

Malthus and Boserup explicitly addressed the constricted topics of land use and food production. Malthusian theory (1798 and 1803, republished 1960) emphasizes that the growth of human populations always inclines to exceed the productive capabilities of land resources. Boserup (1981) proposed that population growth and resulting increased population density prompt technological changes, for example the use of ploughs or fertilizer, which permit food production to keep step with population growth. The reciprocal linear connections between population, technological change in agriculture, and environmental change are proposed. This opinion clearly applies to the prevailing conditions in the Ashanti Region this study show and population data over the years in Ghana indicate (GSS, 2013).

(b) Multiplicative perspectives: the “IPAT” equation.

Population size is seen as interacting in a multiplicative way with other factors to produce impacts on the environment. The “IPAT” equation is most common, in which: Environmental impacts = (Population size) (Level of affluence or per capita consumption) (Level of technology) or I = PAT (Ehrlich et al., 1993). The IPAT equation sees the combined interaction rather than independent effects of population size, consumption, and technology as important in determining environmental change. Population pressure due to high growth rates is one of the main proximate causes of environmental degradation as pertains in Ghana (GSS, 2013).

(c) Development-dependency perspectives

This focuses on how development processes arbitrate population and the environment relations. Prominence is placed on development trends which have kept the south 'dependent' on the North, e.g. mercantile exploitation and export of natural resources towards manufacturing centers in the North. Jolly (1991) stresses "dependency perspective" the overpowering role that common international political and economic forces act in determining both demographic factors such as population growth and environmental consequences such as degradation in developing countries. Repetition of this model in rapidly growing developing countries, as is the current tendency, is deemed as exacerbating negative environmental impacts. The timber sector is important in Ghana as it provides jobs and incomes for numerous local communities, and significantly contributes to Ghana’s foreign exchange incomes through timber products export. Since 1990 up to now, timber production is Ghana’s fourth biggest foreign exchange earner (FOSA, 2001; Lebedys, 2004; Odoom, 2008). Ghana earned €170 million from 0.5 million m$^3$ of wood product export in 2004 (Oliver et al., 2005). Ghana is the second largest producer of gold on the African continent and is also the tenth largest producer of gold in the world (Akabzaa, 2009). Ghana’s mining industry occupies 31,237 km$^2$ of land, representing about 13.1% of Ghana’s total land area of 238,608km$^2$. The Ashanti and Western Regions have the largest deposits of gold (Ghana Chamber of Mines, 2010).

5. Conclusion

This study employed the integration of Remote Sensing to analyze and quantify the land cover changes (amount, trend and location) that have occurred within the period of 1986 and 2011 in the Ashanti Region. Consistent digital remote sensing classification techniques were used to produce land use/cover map. A hierarchical level I land use and land cover classification which consists of Forest, Agriculture, Water and Settlement were utilized. The final classification accuracy was determined to be good by means of standardized accuracy assessment measures. The use of Landsat multi-temporal images and DMC to categorize land cover categories in the study area was done effectively and proved economical to study land use/cover changes at such a large-scale level.

There is an adverse consequence of rapid population growth on the forests a (Goudie, 2013). The dominating the broad clusters of proximate causes of tropical deforestation are the combination of agricultural expansion, wood extraction, and infrastructure expansion (Geist and Lambin, 2002). Increasing population require more land to put to agricultural use to provide food for the growing population. More lands have to be cleared or give way to provide places for settlements and other social amenities for the increasing population.

5.1. Limitations

Challenges with satellite data availability for the exact years impacted the study. More cloud free satellite images for the areas of study would have been much better.
5.2. Recommendations

The twenty-five year time span, 1986 - 2011, considered in this study is relatively a short increase of time in a protracted history of land use underlying forces, but even then the changes were insightful. To have forests in the foreseeable future in the Ashanti Region, major intervention and deliberate steps must be taken place to reclaim what is left of our forests. All efforts must be spent at salvaging what is left of our forest. Population growth must be curbed at all cost.

References


[40] www.ghanagov.gh.
