Integrating Remote Sensing, GIS, census and socio-economic data in studying the population-land use/cover nexus in Ghana. A literature review.

Abstract

Land is a very important asset and a means to sustain livelihood. In the face of a rapidly growing global population, increase in technological capacity, and affluence, the earth's land cover has been transformed especially in developing countries. At the same time, social organization, attitudes, and values have also undergone profound changes. In contemporary times, issues of sustainable development, pollution prevention, global environmental change and related issues of human-environment interaction have been a major concern globally. This concern has largely been sparked by the phenomenon of global warming and its consequences, which are threatening the very existence of humans on the surface of the earth. Remotely sensed data (mainly from aerial photographs and satellite images) in combination with Geographical Information Systems (GIS) have been observed to have potential scientific value for the study of population-environment interaction. This literature update provides an account of how Remote Sensing, GIS, census (mainly population and agricultural) and socio-economic (household, district and regional) survey data have been integrated in studying the population land-use/cover nexus in Ghana. It also identifies the major methodological challenges, and solutions.

Keywords: Population, Land use/cover, Remote Sensing, GIS, Ghana

Introduction

Land is a very important asset and a means to sustain livelihood. It is the key and finite resource for most human activities including agriculture, industry, forestry, energy production, settlement, recreation, and water catchments and storage. Land is a fundamental factor of production, and through much of the course of human history, it has been tightly linked to economic growth. It comprises biophysical qualities such as soil, topography, climate, geology, hydrology, biodiversity and political divisions. Land is also defined as consisting of such socio-economic factors as technology and management. Land use has been defined as the way in which, and the purposes for which, humans employ the land and its resources (Meyer, 1995). Land cover on the other hand has also been defined as that which overlays or currently covers the ground, especially vegetation; permanent snow and ice fields; water bodies or structures (USDA Forest Service, 1989).

In the face of a rapidly growing global population, increase in technological capacity and affluence, the Earth's land cover has been transformed especially in developing countries. At the same time, social organization, attitudes, and values have also undergone profound changes. In contemporary times, issues of sustainable development, pollution prevention, global environmental change and related issues of human-environment interaction have been a major concern of the global scientific community as well as citizens and policy makers of the world. This concern has largely been sparked by the phenomenon of global warming and its consequences, which are threatening the very existence of humans on the surface of the earth. In understanding global environmental change, a consideration should be made to the conditions and changes in land cover engendered by changes in land use; the rates of change in the conversion, modification and maintenance processes of use and the human forces and societal conditions that influence the kinds and rates of the processes (Lambin et al., 1999).

Remote sensing is not a new technology, since aerial photographs have been in widespread use for a half-century (Carls, 1947), and satellite images for a quarter-century (Estes et al. 1980). Ever since studies by Conant (1978), and Reining (1979), mainly in Africa, linked ethnographic data from local populations and the study of their subsistence systems with Landsat data, remotely sensed data have been observed to have potential scientific value for the study of human-environment interaction, especially land use/cover changes and have therefore been identified as a useful tool to aid the process of understanding human-environment interaction (Dale et al., 1993).

Furthermore, remote sensing and global positioning systems (GPS) have given rise to the advent of more precise and geographically referenced data on cover and use of land, which in turn have created opportunities for improved assessments and analysis. With the aid of these new data, researchers have now started to unravel the processes that drive the cycle of land use change and resource degradation. Airborne and Satellite remote sensing data have been proven to be one of the best techniques for monitoring forest clearing, shifting cultivation, and land use conversion patterns and has therefore been partnered with socio-economic surveys and censuses as well as other biophysical information gathering techniques, to bring about a better understanding of land use/cover dynamics and the factors that drive them (Quattrochi & Goodchild, 1997, Liu, 2001;

Veldkamp & Lambin, 2001; Parker et al., 2003; Walsh & Welsh, 2003; Walsh et al., 2003; Walsh et al., 2006).

Remote sensing is particularly very useful for population studies and the following are a few of the areas where it has been applied. Jensen and Cowen (1999) for example, identify three ways in which population estimates can be attained through remote sensing. These are (i) individual dwelling units count (ii) measuring urban extent and (iii) land use/cover classification. Remote Sensing can also provide intercensal population estimates. For instance nighttime lights have been used as a proxy to estimate population (Leddy & Mathur, 2002). Finally, remote sensing can also assist in planning censuses by identifying areas of new development and provide regular updates of new housing stock for planners.

This paper, which is a literature update, demonstrates how remote sensing, GIS, census and survey data have been integrated in studying the population land- use/cover nexus in Ghana. By doing so it brings together a diverse range of environmental, land use and demographic variables, as well as key socio-political processes, to define trends in changing land use/cover and their effects on livelihoods in Ghana. It traces the history and status of the wide range of remote sensing work in the country, pointing out the political and economic interests, which drove such data collection. Finally, it identifies the major methodological challenges, and suggested solutions provided by some researchers in this area of scientific enquiry.

The motivation for this paper is that few attempts have been made by researchers to piece together the numerous studies on the topic at the global level (de Sherbinin et al., 2002), and no attempt at all to undertake a similar exercise at the national level. This literature update is therefore expected to catalogue studies integrating remote sensing, GIS, census and socio-economic data in studying the population and land use/cover relationship in Ghana.

Studies in developing countries

Extensive studies on the human dimensions of global change have focused largely on indirect linkages between information embedded within spatial imagery and the core themes of the social sciences. These works are exemplified by assessments of the proximate causes of land use/cover change (e.g., slash-and-burn cultivation, clear cutting of timber), environmental constraints/opportunities associated with human activities (soil sustainability and zones of intensive cultivation), or assessment of infrastructure (e.g., green spaces, road networks) in planning (see Ehrlich et al., 1997; Petit & Lambin, 2001; Geist & Lambin, 2002; Lambin &Geist, 2003; Lambin et al., 2003; Bilsborrow et al., 2004; Frizzelle et al., 2005).

Other researchers have also used remote sensing data to analyse population and land use/cover change in many parts of the developing world. Notable among these areas are Thailand (Entwisle et al., 1998; Tang et al., 2004; Entwisle et al., 2005; Walsh et al., 2005), the Amazon region of South America (Skole & Tucker 1993; Moran & Brondizio 1998; Pfaff, 1997; Brondizio et al., 2002; Perz, 2002; Deadman et al., 2004; Moran et al., 2005; Brondizio, 2006), the Peten in Guatemala (Sever, 1998), the Chittagong region in Bangladesh (Rahman & Csaplovics, 1999), Costa Rica (Veldkamp & Fresco 1997; Kok & Veldkamp, 2000), Ecuador (Koning et al. 1999; Flora et al., 2004; Pan et al., 2004; Barbieri et al., 2006; Messina & Walsh, 2005; Messina et al., 2006; Mena et al., 2006), China (Verburg et al. 1999a; Verburg & Chen, 2000), Indonesia (Verburg et al. 1999b; Sunderlin et al., 2001), and Jordan (Millington et al., 1999).

The most extensive studies in sub-Saharan Africa using a combination of satellite and survey data to study the socio-economic drivers of land use and cover change are the ones by Guyer & Lambin (1993), Mertens & Lambin (1997), Lambin & Ehlrich (1997), Mertens et al., (2000), Mertens & Lambin (2000), Serneels & Lambin (2001a and 2001b), Stephenne & Lambin (2001), Diouf & Lambin (2001), and Stephenne & Lambin (2005).

Demographic trends in Ghana

Ghana has a surface area of about 238,537 km^2. In 1921, the country had a population of 2.2 million, which almost doubled within a period of 27 years, reaching 4.1 million in 1948. The population from then increased rapidly between 1948 and 1960, rising to 6.7 million. The 1970 census put the country's population at 8.6 million while in 1984, 12.3 million people were counted in the country. By the year 2000, Ghana's population had reached 18.9 million and projections show that it is currently about 22.6 million (PRB, 2006). The annual growth of the population has been recorded to be 2.4% during 1960-1970, 2.6% in 1970-1984 and 2.7% between 1984 and 2006. Due to rapid population growth, population density rose from 28 persons per km^2 in 1960 to 39 persons per km^2 in 1970. In 1984 it was 51 persons per km^2, in 2000 it reached 79 persons per km^2 and in 2006 it was estimated to be 95 persons per km^2.

The demographic trend in Ghana since 1970 can be said to have been that of a high but moderately declining fertility and a declining mortality. Total fertility rate (TFR) has declined from a high of around 7.4 children per woman in the 1960s (Caldwell, 1965) to 6.4 in 1988. In 1993, TFR was recorded as 5.5, which further declined to 4.6 in 1998 and 4.4 in 2003, i.e. a reduction of two children per woman within a period of 15 years (GSS, 1999 and 2004). TFR continues to be estimated at 4.4 in 2006 (PRB, 2006). Cultural beliefs and practices that encourage large family sizes and low modern contraceptive use are mainly responsible for the fertility rates among different population sub-groups in the country. Due to the issues mentioned, crude birth rate (CBR) has been high at about 45 per 1000 population in the 1960s and 1970s with marked declines observed only during the 1990s.

Mortality trends have also shown some steady improvements over the years. Infant mortality has declined from a level of 77 per 1000 live births in 1988 to 66, 57 and 64 per 1000 live births in 1993, 1998 and 2003, respectively. In 2006, IMR was estimated at 59 per 1000 live births (PRB, 2006). In the same way, overall under-five mortality, which was 155 per 1000 live births in 1988, declined to 119 in 1993, 108 in 1998 and 111 in 2003. This has all culminated in a steady decline in crude death rate (CDR). CDR which stood at about 23 per 1000 population in the 1960s, steadily declined to as low as 10 per 1000 population in 2006 (PRB, 2006). The fertility and mortality situation in the country implies that the natural population increase has shot up following a widening gap between fertility and mortality.

As far as migration is concerned, the trend and pattern in the country during the 1960s was more of rural-rural movements. This was as a result of the cocoa boom, where most of the forest areas in Ashanti, Eastern, Western and Brong Ahafo Regions became important receiving areas for migrants mainly for cocoa and other cash crop production.

The pattern of internal migration, however, changed in the mid-1970s towards the cities and large towns. According to the 1984 population census, in terms of volume, internal migration was 35.3% urban-urban, 25.3% urban-rural, 22.9% rural-rural and 16.6% rural-urban. On the international migration front, the contribution to Ghana's population growth has not been that much. Cross-border population movements between Ghana and her neighbours, i.e., La Cote d'Ivoire, Togo and Burkina Faso have constituted the main sources of international migration in Ghana in recent times. Another aspect of this phenomenon is the crossing of herdsmen from the neighbouring countries, particularly Burkina Faso, into Ghana with large numbers of their cattle during periods of drought. Finally, a number of refugees from the West African sub-region, particularly, from Liberia and Sierra Leone following the civil wars in those countries have also migrated to Ghana.

From the above, Ghana's population can therefore be said to have grown at a high rate of 2.6% since 1960 (GSS, 1989 and 2002). The current rate of population growth suggests that Ghana's population would double within the next 27 years and there is therefore little or no sign to show that Ghana's population growth rate has declined in recent times.

Population growth and land degradation in Ghana

Rapid population growth and low economic standards of living in Ghana have brought in their wake a lot of consequences for agricultural land and forest resources. As Benneh and Agyepong (1990) put it, among the three factors that have contributed to greater competition for land, hitherto covered by trees and now devoid of vegetation, includes demographic pressures. In their opinion, as population increases, so is the need for land, to expand settlement infrastructure and other utilities.

Furthermore, there has been increasing use of fuelwood in both urban and rural areas in Ghana, as it is the cheapest form of energy. Faced with development constraints, including low incomes, shifts from the use of fuelwood to use of cleaner fuel alternatives such as electricity, kerosene, and Liquefied Petroleum Gas (LPG) have not been possible. While large areas continue to be depleted, the trend of fuelwood use has been increasing in Ghana. According to the recent population and housing census in Ghana, conducted in 2000, 55.8% and 30.0% of Ghanaian households used wood and charcoal, respectively, for cooking (GSS, 2002). The annual rate of deforestation in Ghana was estimated to be 1.72% or 120,000 hectares during the period 1990-2000 (FAO, 2000). It can be concluded that Ghana's dependence on fuelwood is a large factor behind the deforestation witnessed in recent times.

Due to wasteful and uncontrolled forms of logging in Ghana, the country is increasingly under the threat of desertification. The northwestern section of Upper West Region, the eastern half of Northern Region and parts of Upper East Region are at the highest risk. Also, deforestation has led to increased soil erosion and loss of reliable water supply, all of which has brought about a marked decrease in agricultural productivity and a lowering standard of living among the population. As a result of rapid population growth, conflicts over land have been rife in Ghana, assuming various dimensions from minor conflicts between individuals and families to large scale ones between ethnic groups. The northern parts of Ghana constitute an area plagued with ethnic conflicts. Bloody conflicts, which have brought in their wake devastation of groups of people and in some instances desolation of entire settlements, have raged between the Nanumba and Konkomba (1980), Gonja and Vagla (1984), Konkomba and Bimoba (1990) and Nawuri and Gonja (1991). The loss of lives and property that is associated with such conflicts over land, places much socio-economic burden on the nation's scarce resources and, consequently, hampers development.

History of Remote Sensing in Ghana

Prior to 1901, there were only few survey and mapping activities. The first survey department, the Mines Survey Department, was established in 1901, but the Survey Department itself was set up in 1908 (Abu & Brimah, 1989). Aerial photography can be said to have begun in Ghana in earnest about 1946 with coverage of a small area on the dip slopes of the Kwahu Scarp around Abetifi by the then Royal Air force. According to Amatekpor (1999), a land use map of Ghana was not available until 1998. In his opinion, the land use map of Ghana, which was available in 1959, was not only obsolete, but also of little or no value for intensive land use planning. He further mentioned that the development of Remote Sensing and Geographic Information Systems (GIS) technology enabled Ghana to complete in 1998 a detailed land use/cover map of the whole country at a scale of 1:250,000 under the Ghana Environmental Resource Management Programme (GERMP).

Until 1956, only small areas (south-western coast, Nsaba cocoa growing area and parts of Mamprusi) were covered mainly for specific investigation such as oil exploration, agricultural census and land use planning. However, since 1972, satellite remote sensing coverage of Ghana has been available (Agyepong, 1989), and remote sensing technology has been applied to a great deal of natural resource management research in Ghana.

Some of these are, soil resources inventory, (Agyili, 1989), water resources research (Amuzu, 1989), forest inventory (Agurgo, 1989), disaster management (Kyem, 1989), land use inventory and mapping (Duadze et al., 1999), environmental monitoring (Amamoo-Otchere, 1989), geological problems (Adjei, 1989), rainfall calibration (Kakane & Hooijer, 1999), road map updating (Mensah & Nyamekye, 1999), and groundwater exploration (Banoeng-Yakubu, 1999).

Studies integrating Remote Sensing/GIS, censuses and socio-economic surveys in Ghana

Although this began later, Ghana has benefited from a few studies that combine Remote Sensing/GIS technology, censuses and socio-economic surveys to study the population-land use/cover nexus. For example, Benneh and Agyepong (1990), used a combination of the two methods, to conclude that population increase, development policies, urbanization and settlement expansion, logging, agricultural land use including wood fuel demands, have among others contributed to greater competition for land leaving areas formerly covered by trees devoid of vegetation and subsequently leading to wood fuel scarcity.

Kufogbe (1999) used a digital analysis of time sequential SPOT-XS images and the Makov chain model to assess the changes in the land use/cover over the period 1988 and 1994 in the Afram plains of Ghana. His results indicate that the dominant land cover comprises wooded savanna and transition forest. According to him, deforestation in the plains is indicated by various stages of forest re-growth, which have been associated with decline in cocoa cultivation from the beginning of the 1980s.

Braimoh (2004a) investigated the impact of seasonal migration on land-use/land-cover change in an area within the Volta Basin of Ghana. It was revealed that the most drastic land-cover change involved the conversion of woodland to agricultural land, while there was also a general transition to less vegetation cover. Socio-economic surveys revealed that most of the migration occurred during the post-structural adjustment period in Ghana with declining soil fertility accounting for the highest per cent of causes of migration. Multiple regression results highlighted the role of population size and distribution, marketing of agricultural produce and technological evolution of the household in determining agricultural land-use change.

Braimoh (2004b) further identified land use/cover change in a 5,400 km^2 area within the Volta Basin of Ghana using multi-scale, spatial statistical analyses and household surveys. Land cover change trajectories were also defined using multi-temporal Landsat TM images acquired in 1984, 1992 and 1999. Results show that the dominant land-cover change process was conversion of natural vegetation to cropland, which occurred at an annual rate of 5% between 1984 and 1999. Furthermore, linear multiple regression identified increase in household size, frequency of tractor use, proportion of rice marketed, child dependency ratio, labour availability and distance from localities to the main market as the major factors determining the amount of land a household cleared for agriculture. It was concluded that the choice of an appropriate scale for land use/cover change models to support land-use planning requires a trade-off between spatial detail and extent. At the scale of individuals, households and commercial farmers (30m – 1050m), land use change processes are highly heterogeneous, requiring a large amount of data for characterization. It was recommended that future land change models should be based on 3km to 7km spatial scales.

Relationships between cropland change and presumed determinants were analyzed at scales ranging from 30 to 5100 m using logistic regression by Braimoh and Vlek (2004). The plot of the odds ratio across the spatial scales indicated that both biophysical and social variables were important in explaining cropland change. In the first period (1984–92), biophysical factors were the dominant factors, while market-related variables were more dominant between 1992 and 1999. Response to changing economic opportunities was the underlying cause of this trend.

Codjoe (2004) used geo-corrected LANDSAT satellite images for 1991 and 2000 and population census of Ghana for 1984 and 2000 to assess the effect of population change on forest cover between 1990 and 2010 in the Volta River basin of Ghana. Population data, which was available at the local council level, was marched with forest cover at the local council level. The forest cover information was derived from land cover maps of 1990 and 2000. A local council map of Ghana was superimposed on the forest cover map using GIS applications. Proportions of forest cover for each local council were then determined and converted to actual area extent in hectares. Association between forest cover and population for 2000 was then determined from a simple regression model and was used to predict the effect of population growth on forest cover in the various local councils in 2010. The projected population for each local council for 2010 was inputted into the simple regression model. Together with the constant, the required forest cover in 2010 was determined. Predictions show that the Jaman and Brekum local councils areas that fall within the Black Volta sub-basin and the Kete-Krachi local council in the Daka sub-basin will have depleted forest cover in 2010, as a result of increases in population density.

Furthermore, Codjoe (2006), combines multiplicative and mediating variables with a demographic variable, in non-linear multiple regression models to assess the effect of population growth on agricultural land use in two agro-ecological zones of Ghana. Data from a retrospective household survey, population census reports of Ghana, for 1960, 1970, 1984 and 2000, agricultural census data for 1992 and 2000, and a land suitability map generated from remote sensing images were used. Predictions of cropped area required to meet anticipated population growth were computed for 2010, based on multiple regression models and projected populations. Required cropped area was matched with actual arable area that would be available, based on a land suitability analysis. Predictions from the study show that three and two districts in the dry and derived savannah zones, would, respectively, experience agricultural land shortfall. The rest of the districts in the two agro-ecological zones would have agricultural land available to support future population growth.

Finally Duadze (2004) also used a combination of LANDSAT satellite image for 1986, 1991 and 2000 and population census reports of Ghana in a study in the Upper West region of Ghana. Results show that population increased from 1984 to 2000 by 32% and since a high proportion (75%) of the economically active population were farmers, it was concluded that population played a role in land degradation. Declining soil fertility in the farmlands and increasing population, therefore caused pressure on land, which led to land degradation. This in turn caused the farmers to move to other areas to farm. This practice was argued to have resulted in progressive loss of woodland.

Methodological challenges

Despite the apparent usefulness of Remotely sensed data for social purposes, Rindfuss and Stern (1998) are of the opinion that remotely sensed images have not been a popular data source for social science research. Their reasons are that, firstly, the variables of greatest interest to many social scientists are not readily measured from the air. Many social scientists find visible human artifacts such as buildings, crop fields, and roads less interesting than the abstract variables that explain their appearance and transformation. Secondly, social science is generally more concerned with why things happen than where they happen. Even areas of social science in which one might expect a spatial orientation are curiously aspatial (Faust et al., 1997).

Furthermore, a major challenge faces the Remote Sensing and GIS community. The problem is to link people to pixels, and to do so at the appropriate spatial and temporal scales, so that the behaviour of individuals, households and communities can be linked to changes in land use/cover and to the population, biophysical and geographical processes that serve to define the landscape in terms of composition and spatial organization and their changes over time and space.

According to Carrao and Caetano (2002), the spatial resolution of the image affects the measurement in the landscape. This challenge arises mainly from geo-referencing land use data and linking it with the remote sensing data. Although there is the danger of mixing up the levels of analysis (Mayhew, 1997), land use/cover change trends can be easily assessed and linked to population data if the unit of analysis is the national, regional, district or municipal level. However, for a comprehension of the actual factors that influence land use at a very small level, i.e., the village level, the scale of analysis should be very small. Since that calls for a household survey, that is where the linkage between the two data sets is very difficult. Global Positioning Systems (GPS) have been used to circumvent this problem, but that only allows for smaller sample sizes due to time constraints (Rindfuss et al., 2002).

In using GPS, farmlands are geo-referenced and co-registered with the remote sensing image. A problem that may arise from this exercise is lack of good ground control points. Also, in some instances, farm size may be smaller than pixel size. Other problems include cloud cover on image, and error of classification during the processing of the image. It has been suggested that land use data should be made to conform to the remote sensing data at a common scale (Geoghegan et al., 1998).

Also, population census data at for example a district level can be transformed to conform to the grid of 2.5 by 2.5 latitude-longitude cells on the satellite image (Diechmann et al., 2001). Evans and Moran (2002) has linked household survey data to remote sensing images with the level of aggregation being the farm. One other limitation of using data from census and other sources is that significant causal factors may not be included in those public data sources thus; causal variables at the finest level may not be available.

Conclusion

Land is an essential asset and a means to sustain livelihood. It is the ultimate source of wealth, the natural capital for production and the foundation on which civilization is based. Land use/land cover plays an important role in global environmental change and sustainability including response to climate change, ecosystem structure and function, species and genetic diversity, water and energy balance, and agro-ecological potential. Studying the effect of population dynamics on land use/cover globally and for that matter Ghana in the past was not so successful until the advent of remote sensing and Geographical Information Systems.

Remote Sensing and global positioning systems (GPS) have given rise to the advent of more precise and geographically referenced data on cover and use of land, which in turn have created opportunities for improved assessments and analysis. With the aid of these new data, researchers have now started to unravel the processes that drive the cycle of land use change and resource degradation.

This literature update has demonstrated that even though remote sensing and GIS started quite late in Ghana, there have been some studies that integrate remote aensing, census and survey data to study the population-land use/cover nexus. However, these studies have encountered a major methodological challenge. This challenge is merging the satellite and census data into a single data i.e., aggregating the land cover data to conform to the boundaries of each district or municipality used in the analysis. The paper shows that land use/cover change trends can be easily assessed and linked to population data if the unit of analysis is the national, regional, district or municipal level. However, for a comprehension of the actual factors that influence land use at a very small level, i.e., the village level, the scale of analysis should be very small. Since that calls for a household survey, that is where the linkage between the two data sets is very difficult. Global Positioning Systems (GPS) have been used to circumvent this problem, but that only allows for smaller sample sizes due to time constraints.

REFERENCES

Abu, I., & Brimah, R. (1989). Remote sensing coverage in Ghana. In G.T. Agyepong et al. (Eds.), *Remote Sensing in Ghana* (pp. 18-21). Department of Geography and Resource Development, University of Ghana Legon, Environmental Protection Council in collaboration with National Remote Sensing Committee.

Adjei, A.O. (1989). Remote sensing applications to geological problems in Ghana: past experiences, the present and the future', In G.T. Agyepong et al. (Eds.), *Remote Sensing in Ghana* (pp. 89-91). Department of Geography and Resource Development, University of Ghana Legon, Environmental Protection Council in collaboration with National Remote Sensing Committee.

Agurgo, F.B. (1989). An exploratory investigation into the use of Landsat imagery in forest inventory work in Ghana. In G.T. Agyepong et al. (Eds.), *Remote Sensing in Ghana* (pp. 36-37). Department of Geography and Resource Development, University of Ghana Legon, Environmental Protection Council in collaboration with National Remote Sensing Committee.

Agyepong, G.T. (1989). A review of the development of remote sensing in Ghana. In G.T. Agyepong et al. (Eds.), *Remote Sensing in Ghana* (pp. 38-42). Department of Geography and Resource Development, University of Ghana Legon, Environmental Protection Council in collaboration with National Remote Sensing Committee.

Agyili, P. (1989). Preliminary soil survey of an area north of Kintampo using Aerial Photographs. In G.T. Agyepong et al. (Eds.), *Remote Sensing in Ghana* (pp. 58-62). Department of Geography and Resource Development, University of Ghana Legon, Environmental Protection Council in collaboration with National Remote Sensing Committee.

Amamoo-Otchere, E. (1989). Outline of possibilities of SPOT-1 image utilisation for resources inventorying and environmental monitoring in Ghana. In G.T. Agyepong et al. (Eds.), *Remote Sensing in Ghana* (pp. 52-57). Department of Geography and Resource Development, University of Ghana Legon, Environmental Protection Council in collaboration with National Remote Sensing Committee.

Amatekpor, J. (1999). *Soils and land-use in the Volta Basin, state of the art.* Volta Basin Research Project, University of Ghana, Legon: Gold Type Press.

Amuzu, A.T. (1989). Remote sensing application to water resources research in Ghana. In G.T. Agyepong et al. (Eds.), *Remote Sensing in Ghana* (pp. 29-31). Department of Geography and Resource Development, University of Ghana Legon, Environmental Protection Council in collaboration with National Remote Sensing Committee.

Banoeng-Yakubo, B. (1999). Application of remote sensing techniques and geographic information systems in lineament and fracture trace analysis to ground water exploration in the Upper West region, Ghana. In P.W.K. Yankson & M.S. Rasmussen (Eds), *Remote*

Sensing and Geographic Information Systems (GIS) in Ghana: Research, Applications and Collaborations (pp. 99-104). Legon: Media Design.

Barbieri, A.F., Bilsborrow, R.E., & Pan, W.K. (2006). Farm household lifecycles and land use in the Ecuadorian Amazon. *Population and Environment,* 27(1), 1-27.

Benneh, G., & Agyepong, G.T. (1990). *Land Degradation in Ghana*. London: Commonwealth Secretariat.

Bilsborrow, R.E., Barbieri, A.F., & Pan, W.K. (2004). Changes in population and land use over time in the Ecuadorian Amazon. *Acta Amazonica*. 34(4), 635-647.

Braimoh, A.K. (2004a). Seasonal migration and land use change in Ghana. *Land Degradation and Development*, 15(1), 37-47.

Braimoh, A.K. (2004b). *Modeling Land-use Change in the Volta Basin of Ghana*. Ecology and Development Series, No. 14. Gottingen: Cuvillier Verlag,.

Braimoh, A.K., & Vlek, P.L.G. (2004). Scale-dependent relationships between land-use change and its determinants in the Volta Basin of Ghana. *Earth Interactions*, 8(4), 1-23.

Brondizio, E.S., McCracken, S.D., Moran, E.F., Siqueira, A.D., Nelson, D.R., & Rodriguez-Pedraza, C. (2002). The Colonist Footprint: Toward a Conceptual Framework of Deforestation Trajectories Among Small Farmers in Frontier Amazonia. In: *Deforestation and Land Use in the Amazon* (pp. 133-161). C. Wood & R. Porro (Eds.) Gainesville, Florida: University Press of Florida.

Brondizio, E.S. (2006). Landscapes of the past, footprints of the future: historical ecology and the analysis of land use change in the Amazon. In W. Balee, & C. Erikson, (Eds.) *Time and Complexity in Historical Ecology: Studies in the Neotropical Lowlands* (pp. 365-405). New York: Columbia University Press.

Caldwell, J.C. (1965). Extended family obligations and education: A study of an aspect of demographic transition among Ghanaian university students. *Population Studies*, 19(2), 183-199.

Carls, N. (1947). *How to Read Aerial Photographs for Census Work*. Washington, D.C: U.S. Government Printing Office.

Carrao, H., & Caetano, M. (2002). *The Effect of Scale on Landscape Metrics.* Paper presented at the International Society for Remote Sensing of the Environment Conference, Buenos Aires, Argentina, 8-12 April.

Codjoe, S.N.A. (2004). *Population and Land Use/Cover Dynamics in the Volta River Basin of Ghana, 1960-2010*. Ecology and Development Series, No. 15. Gottingen: Cuvillier Verlag.

Codjoe, S.N.A. (2006). Population growth and agricultural land use in two agro-ecological zones of Ghana, 1960-2010. *International Journal of Environmental Studies*, 63 (5), 645-661.

Conant, F.P. (1978). The use of Landsat data in studies of human ecology. *Current Anthropology*, 19(2), 382-4.

Dale, V.H., O'Neill, R.V., Pedlowski, M., & Southworth, F. (1993). Causes and effects of land use change in central Rondonia, Brazil. *Photogrammetric Engineering and Remote Sensing*, 5(6), 997-1005.

de Sherbinin, A., Balk, D., Yager, K., Jaiteh, M., Pozzi, F., Giri, C., & Wannebo, A. (2002). *A CIESIN Thematic Guide to Social Science Applications of Remote Sensing*. Center for International Earth Science Information Network (CIESIN). New York: Columbia University.

Deadman, P., Robinson, D., Moran, E., & Brondizio, E. (2004). Colonists household decision making and land use change in the Amazon rainforest: an agent-based simulation. *Environment and Planning B*, 31:693-709.

Diechmann, U., Balk, D., & Yetman, G. (2001). *Transforming Population Data for Interdisciplinary Usages: From Census to Grid*. CIESIN Working Paper, Palisades, NY.

Diouf, A., & Lambin, E.F. (2001). Monitoring land-cover changes in semi-arid regions: Remote sensing data and field observations in Ferlo, Senegal. *Journal of Arid Environments*, 48: 129-148.

Duadze, S.E.K, Adu-Prah, S., Annor, J., & Dunyuo, S.S.B. (1999) National land use and land cover mapping using satellite imagery. In P.W.K. Yankson & M.S. Rasmussen (Eds), *Remote Sensing and Geographic Information Systems (GIS) in Ghana: Research, Applications and Collaborations* (pp. 54-65). Legon: Media Design.

Duadze, S.E.K. (2004). *Land Use and Land Cover Study of the Savannah Ecosystem in the Upper West Region (Ghana) Using Remote Sensing*. Ecology and Development Series, No. 16. Gottingen: Cuvillier Verlag.

Ehrlich, D., Lambin, E.F. & Malingreau, J-P. (1997). Biomass burning and broad-scale land-cover changes in Western Africa. *Remote Sensing of Environment,* 61, 201-209.

Entwisle, B., Walsh, S.J., Rindfuss, R.R., & Chamratrithirong, A. (1998). Land-use/land-cover and population dynamics, Nang Rong, Thailand. In D. Liverman, E.F. Moran, R.R. Rindfuss, & P.C. Stern (Eds). *People and Pixels. Linking Remote Sensing and Social Science* (121-144). Washington, D.C: National Academy Press.

Entwisle, B., Walsh, D.J., Rindfuss, R.R., & VanWey L.K. (2005). Population and upland crop production in Nang Rong, Thailand. *Population and Environment* 26(6), 449-470.

Estes, J.E., Jensen, J.R., & Simonett, D.S. (1980). Impacts of Remote Sensing on U.S Geography. *Remote Sensing of Environment,* 10, 43-80.

Evans, T.P., & Moran, E.F. (2002). Spatial integration of social and biophysical factors related to landscape change. *Population and Development Review*, Supplement to Vol. 28.

FAO. (2000). *Global Forest Resources Assessment*. FRA Working Paper No. 19.

Faust, K., Entwisle, B., Rindfuss, R.R., Walsh, S.J., & Sawangdee, Y. (1997). *Spatial Arrangement of Social and Economic Networks among Villages in Nang Rong, Thailand.* Paper Presented at the Annual Meeting of the Sunbelt Social Network Conference, San Diego, California.

Flora, L.H., Bilsborrow, R., & Ona, A. (2004). *Demography, Household Economics, and Land and Resource Use of Five Indigenous Populations of the Northern Ecuadorian Amazon: A Summary of Ethnographic Research*. Occasional Paper, Chapel Hill, NC: Carolina Population Center.

Frizzelle, B.G., Walsh S.J., Mena, C.F., & Erlien, C.M. (2005). *Land use change patterns of colonists and indigenous groups in the northern Ecuadorian Amazon: A comparison of Landsat TM spectral and spatial analysis.* Proceedings of American Society for Photogrammetry and Remote Sensing, Baltimore, Maryland.

Geist, H., & Lambin, E.F. (2002). Proximate causes and underlying driving forces of tropical deforestation. *Bioscience*, 52(2), 143-150.

Geoghegan, J., Pritchard, L., Ogneva-Himmelberger, Y., Chowdhury, R.R., Sanderson, S., & Turner II, B.L. (1998). Socializing the pixel and pixelizing the social in land-use and land-cover change. In D. Liverman, E.F. Moran, R.R. Rindfuss, & P.C. Stern (Eds). *People and Pixels. Linking Remote Sensing and Social Science* (pp. 51-69). Washington, D.C: National Academy Press.

Ghana Statistical Service. (1989). *1984 Population Census of Ghana. Special Report on Localities by Local Authorities*. Accra: Eddy Williams Ltd.

Ghana Statistical Service and Macro International Inc. (1999). *Ghana Demographic and Health Survey, 1998*. Calverton, Maryland.

Ghana Statistical Service. (2002). *2000 Population and Housing Census. Summary Report on Final Results*. Accra: Medialite Co. Ltd.

Ghana Statistical Service. (2004). *Ghana Demographic and Health Survey, 2003*. Calverton, Maryland.

Guyer, J., & Lambin, E.F. (1993). Land use in the urban hinterland: Ethnography and Remote Sensing in the study of African intensification. *American Anthropologist,* 95 (4), 839-859.

Jensen, J.R., & Cowen, D.C. (1999). Remote Sensing of urban/suburban infrastructure and socio-economic attributes. *Photogrammetric Engineering and Remote Sensing*, 65 (5), 611-622.

Kakane, V.C.K., & Hooijer, A. (1999). Rainfall calibration for Ghana: the TAMSAT method. In P.W.K. Yankson & M.S. Rasmussen (Eds.), *Remote Sensing and Geographic Information Systems (GIS) in Ghana: Research, Applications and Collaborations* (pp. 31-37). Legon: Media Design.

Kok, K. & Veldkamp, A. (2000). Using the CLUE framework to model changes in land use on multiple scales. In B.A.M. Bouman et al., (Eds). *Tools for land use analysis on different scales. With case studies for Costa Rica* (pp. 35-63) Dordrecht: Kluwer Academic Publishers.

Koning de, G.H.J., Verburg, P.H., Veldkamp, A., & Fresco, L.O. (1999). Multi-scale modelling of land use change dynamics in Ecuador. *Agricultural Systems* 61(2), 77-93.

Kufogbe, S.K. (1999). A remote sensing perspective on land use and environmental change in the Afram plains of Ghana using SPOT-XS images. In P.W.K. Yankson & M.S. Rasmussen (Eds.), *Remote Sensing and Geographic Information Systems (GIS) in Ghana: Research, Applications and Collaborations* (pp. 38-46). Legon: Media Design.

Kyem, P.A.K. (1989). Remote sensing and disaster management: the case of earthquake hazard of Accra. In G.T. Agyepong et al. (Eds.), *Remote Sensing in Ghana* (pp. 45-48). Department of Geography and Resource Development, University of Ghana Legon, Environmental Protection Council in collaboration with National Remote Sensing Committee.

Lambin E.F., & Ehrlich, D., (1997). Land-cover changes in sub-Saharan Africa (1982-1991): Application of a change index based on remotely-sensed surface temperature and vegetation indices at a continental scale. *Remote Sensing of Environment*, 61(2), 181-200.

Lambin, E.F., Baulies, X., Bockstael, N., Fischer, G., Krug, T., Leemans, R., Moran, E.F., Rindfuss, R.R., Skole, D., Turner II, B.L., & Vogel, C. (1999). *Land use and land cover change (LUCC): implementation strategy*. IGBP Report no.48/IHDP Report no. 10, ICBP, Stockholm.

Lambin, E.F., Geist, H., & Lepers, E., (2003). Dynamics of land use and cover change in tropical regions. *Annual Review of Environment and Resources*, 28, 205-241.

Lambin, E.F. and Geist, H., (2003). Regional differences in tropical deforestation. *Environment*, 45(6), 22-36.

Leddy, R., & Mathur, P. (2002). Estimating Local Population in West Africa with Lights, Infrastructure, Other. *Paper presented at the 2002 ESRI International User's Conference*, 8-12 July, San Diego, California.

Liu, J.G. (2001). Integrating ecology with human demography, behaviour, and socioeconomics: Needs and approaches. *Ecological Modeling*, 140(1-2), 1-8.

Mayhew, S. (1997). *A Dictionary of Geography*. New York: Oxford University Press,

Mena, C.F., Barbieri, A., Walsh, S.J., Erlien, C.M., Holf, F.L., & Bilsborrow, R.E. (2006). Pressure on the Cuyabeno Wildlife reserve: Development and land use/cover change in the northern Ecuadorian Amazon. *World Development*, 34(10), 1831-1849.

Mensah, F.K., & Nyamekye, A. (1999). The use of remote sensing for road map updating: a pilot study for the Greater Accra region. In P.W.K. Yankson & M.S. Rasmussen (Eds.), *Remote Sensing and Geographic Information Systems (GIS) in Ghana: Research, Applications and Collaborations* (pp. 50-53). Legon: Media Design.

Mertens, B., & Lambin, E.F. (1997). Spatial modelling of deforestation in Southern Cameroon. *Applied Geography*, 17(2), 143-162.

Mertens B., & Lambin, E.F. (2000). Land-cover change trajectories in southern Cameroon. *Annals of the Association of American Geographers*, 90 (3), 467-494.

Mertens, B., Sunderlin, W.D., Ousseynou N., & Lambin, E.F. (2000). Impact of macroeconomic change on deforestation in South Cameroon: Integration of household survey and Remotely-Sensed data. *World Development*, 28(6), 983-999.

Messina, J.P., & Walsh, S.J. (2005). Dynamic spatial simulation modeling of the population-environment matrix in the Ecuadorian Amazon. *Environment and Planning B*, 32(6), 835-856.

Messina, J.P., Walsh, S.J., Mena, C.F., and Delamater, P.L. (2006). Land tenure and deforestation patterns in the Ecuadorian Amazon: Conflicts in land conservation in a frontier setting. *Applied Geography*, 26, 113-128.

Meyer, W.B. (1995). Past and present land use and land cover in the United States of America. *Consequences*, 1 (1), 25-33.

Millington, A., Al-Hussein, S., & Dutton, R. (1999). Population dynamics, socioeconomic change and land colonisation in Northern Jordan, with special reference to the Badia research and development project area. *Applied Geography*, 19(4), 363-84.

Moran, E.F., & Brondizio, E. (1998). Land use change after deforestation in Amazonia. In D. Liverman, E.F. Moran, R.R. Rindfuss, & P.C. Stern (Eds). *People and Pixels. Linking Remote Sensing and Social Science* (pp. 94-120). Washington, D.C: National Academy Press.

Moran, E., Brondizio, E., & VanWey, L. (2005). Population and environment in Amazonia: Landscape and household dynamics. In B. Entwisle, & P. Stern, (Eds.). *Population, Land Use, and Environment* (pp. 106-134). Washington, D.C.: The National Academies Press.

Pan, W., Walsh, S., Bilsborrow, R., Frizzelle, B., Erlien, C., & Baquero, F. (2004). Farm-level models of spatial patterns of land use and land cover dynamics in the Ecuadorian Amazon. *Agriculture, Ecosystems, and Environment,* 101, 117-134.

Parker, D.C., Manson, S.M., Janssen, M.A., Hoffmann, M.J., & Deadman, P. (2003). Multi-agent system models for the simulation of land-use and land-cover change: A review. *Annals of the Association of American Geographers*, 93(2), 314-337.

Perz, S.G. (2002). The changing social contexts of deforestation in the Brazilian Amazon. *Social Science Quarterly*, 83(1), 35-52.

Petit, C., & Lambin, E.F. (2001). Integration of multi-source remote sensing data for land cover change detection. *International Journal of Geographical Information Science*, 15(8), 785-803.

Pfaff, A. (1997). *Spatial Perspectives on Deforestation in the Brazilian Amazon: First Results and a Spatial Research Agenda.* Paper Presented in Conference on Research Transformations in Environmental Economics. Policy Design in Responses to Global Change, Durham, N.C., May, 5-6.

Population Reference Bureau. (2006). *Population Data Sheet*. Washington, D.C.

Quattrochi, D.A., & Goodchild, M.F. (Eds.). (1997). *Scale in Remote Sensing and GIS*. New York: Lewis Publishers.

Rahman, M.M., & Csaplovics, E. (1999). *Assessing Tropical Deforestation in Southern Chittagong, Bangladesh Using Remote Sensing*. Institute of International Forestry and Forest Products, Dresden University of Technology, Germany.

Reining, P. (1979). Challenging desertification in West Africa: Insights from Landsat in carrying capacity, cultivation and settlement sites in Upper Volta and Niger. Ohio: Ohio University Press.

Rindfuss, R., & Stern, P. (1998). Linking remote sensing and social science: the need and the challenges. In D. Liverman, E.F. Moran, R.R. Rindfuss, & P.C. Stern (Eds). *People* *and Pixels. Linking Remote Sensing and Social Science* (pp. 1-27). Washington, D.C: National Academy Press.

Rindfuss, R., Entwisle, B., Walsh, S.J., Prasartkul, P., Sawangdee, Y., Crawford, T.W., & Reade, T. (2002). Continuous and discrete: where they have met in Nang Rong, Thailand. In S.J. Walsh & K. Crews-Meyer (Eds.). *Linking People, Place and Policy: A GIScience Approach*, Kluwer Academic Press, Boston.

Serneels S.S.M., & Lambin, E.F., (2001a). Land-cover changes around a major East African wildlife reserve: the Mara ecosystem. *International Journal of Remote Sensing*, 22(17): 3397-3420.

Serneels S.S.M., & Lambin, E.F. (2001b). Proximate causes of land-use changes in Narok District, Kenya. *Agriculture, Ecosystems and Environment*, 85(1-3), 65-82.

Sever, T.L. (1998). Validating prehistoric and current social phenomenon upon the landscape of the Peten, Guatemala. In D. Liverman, E.F. Moran, R.R. Rindfuss, & P.C. Stern (Eds). *People and Pixels. Linking Remote Sensing and Social Science* (pp. 145-163). Washington, D.C: National Academy Press.

Skole, D.L., & Tucker, C.J. (1993). Tropical deforestation, fragmented habitats, and adversely affected habitat in the Brazilian Amazon: 1978-1988. *Science,* 260, 1905-1910.

Stephenne, N., & Lambin, E.F. (2001). A dynamic simulation model of land-use changes in the African Sahel (SALU). *Agriculture, Ecosystems and Environment*, 85 (1-3), 145-162 .

Stephenne, N., & Lambin, E.F. (2005). Scenarios of land-use change in Sudano-Sahelian countries of Africa to better understand driving forces. *GeoJournal*, 61, 365-379.

Sunderlin, W.D., Angelsen, A., Resosudarmo, D.P., Dermawan, A., & Rianto, E. (2001). Economic crisis, small farmer well-being, and forest cover change in Indonesia. *World Development*, 29(5), 767-782.

Tang, W., Malanson, G.P., & Walsh, S.J. (2004). Model for land use change in Thailand. *Asian Surveying and Mapping*, 2, 1-3.

USDA Forest Service. (1989). *Interim Resource Inventory Glossary*. Washington, D.C.

Veldkamp, A., & Fresco, L.O. (1997). Reconstructing land use drivers and their spatial scale dependence for Costa Rica, 1973 and 1984. *Agricultural Systems*, 55, 19-43.

Veldkamp, A., & Lambin, E.F. (2001). Predicting land use change. *Agriculture, Ecosystems and Environment*. 85 (1-3), 1-6.

Verburg, P.H., Veldkamp, A., & Fresco, L.O. (1999a). Simulation of changes in the spatial pattern of land use in China. *Applied Geography,* 19(3), 213-235.

Verburg, P.H., Veldkamp, A., & Bouma, J. (1999b). Land use change under conditions of high population pressure: The case of Java. *Global Environmental Change*, 9(4), 303-312.

Verburg, P. H., & Chen, Y. Q. (2000). Multiscale characterization of land-use patterns in China. *Ecosystems* 3, 369-385.

Walsh, S.J., Entwisle, B., Rindfuss, R.R., Shao, Y., Weiss, D.J., McDaniel, P.M., & Pullen, R.E. (2003). *Characterizing land use/land cover change in northeast Thailand and analyzing the causes and consequences of landscape dynamics*. Proceedings; 30th International Symposium on Remote Sensing of Environment, Honolulu, Hawaii.

Walsh, S.J., & Welsh, W.F. (2003). Approaches for linking people, place and environment for human dimensions research. *Geocarto International*, 18(3), 51-61.

Walsh, S.J., Rindfuss, R.R., Prasartkul, P., Entwisle, B., & Chamratrithirong, A. (2005). Population Change and Landscape Dynamics: Nang Rong Studies. In B. Entwisle & P.C. Stern (Eds.). *Population, Land Use, and Environment: Research Directions*. Washington, DC: National Academy Press.

Walsh, S.J., Entwisle, B., Rindfuss, R.R., & Page, P.H. (2006). Spatial simulation modeling of land use/land cover change scenarios in northeastern Thailand: A cellular automata approach. *Journal of Land Use Science,* 1(1), 5-28.