SUSTAINABLE LAND-USE EVALUATION ON STEEP LANDSCAPES AND FLOOD PLAINS IN THE NEW JUABEN DISTRICT OF GHANA: A GIS APPROACH.

***Opoku Pabi[1], Attua, E. M[2]**

1 Research Consultant, Box LG 511, Legon, Ghana.
2 Department of Geography and Resource Development, Box LG 59, University of Ghana, Legon.

*Corresponding Author: **opabi@yahoo.com**

ABSTRACT

Specific criteria are stipulated and recommendations made for sustainable management of landscapes in Ghana. Yet, evaluation is scarcely conducted to determine whether real performance of land-use strategies are meeting expected standards of sustainability. The paper reports on an evaluation study conducted on a landscape with various levels of slopes and flood plains. The study sought to demonstrate the application of information technology in achieving the objectives of sustainable land-use management. Landscape of the area was modeled in a Geographic Information System (GIS) environment. Slope was derived from digital elevation model (DEM) and spatially analyzed with land-use/cover information generated from satellite data. The performance of existing land-use was compared with expected land-use performance criteria for steep landscapes and flood plains. Steep slopes and areas within 100 m of the Densu River have been denuded of forest vegetation. Rather than making only a marginal use of geo-information technology in generating data, we must leverage its inherent analytical potentials that enable innovative, creative and enhanced management decisions for sustainable land resource use. Continually monitoring and evaluating the performance of land-resource utilization will provide feedback information necessary for directing resource use on sustainable trajectories.

Introduction

Tree-dominated vegetation cover plays a critical role in hydrological processes of mountain ecosystems (Buttle *et al*, 2000). They minimise soil erosion as they serve as important protective cover. Research shows that land-use disturbances affect the infiltration of water into the soil as they cause soil compaction or diminishes porosity that leads to increase runoff and peak flow during rainfall events, and possibly increases flooding (Kaimowitz, 2004). Worldwide, many watershed studies indicate that water yield increases when forests are harvested (Bates, 2000). High erosion rates are associated with overuse of land in the upper basin, especially, where there is farming on steep hillsides (Swallow *et al*, 2005). Deforestation on steep slopes due to poor agricultural practices leads to excessive nutrient loading, which causes severe eutrophication and anoxic conditions (Walsh *et al*, 2004).

Conscious of the critical roles played by vegetation ecosystems on steep landscapes and watersheds, their vulnerability and sensitivity to anthropogenic disturbances, Ghana has evolved environmental and land-use policy frameworks to protect these fragile and sensitive but important ecosystems. Generally, farming within these landscapes without applying measures that protect them from total exposure to the elements is prohibited under the policy. Specifically, it is against the national policy to farm within 100 m of water bodies without appropriate strategies to prevent the total destruction of forest cover (Ministry of Lands and Forestry, 1999). Steep slope is also considered a critical indicator of terrain vulnerability to erosive agents (Price, 1993). Slope is an adopted diagnostic feature for terrain vulnerability to erosion and unsustainable land use (Ministry of Lands and Forestry, 1999). Therefore, it is against the national land-use policy to undertake land-uses activities on steep slope landscapes that result in complete vegetation denudation (Ministry of Lands and Forestry, 1999).

Like most developing economies, agriculture and other land-based economic sectors are crucial for economic development in Ghana. According to the Ghana Statistical Service, 49.2% of the work force in Ghana depended on agricultural and related sectors from the late 1990s to 2000 (Ghana Statistical Service, 2002). Investigations on land-use impacts in Ghana (Osman, 2000; Gyasi and Uitto, 1997), however, have revealed significant transformations of the dense woody vegetation cover into shades of fallow and degraded lands (Pabi and Attua, 2005; Pabi, 2007). Pabi (2007) has observed deforestation on flood plains of important rivers due to agricultural land-use. In the year 2000, an estimated 220,000 km^2 of land in Ghana was affected by erosion due to poor land-use practices (FAO/AGL, 2000).

Whereas the above indications of disturbances of ecosystems in Ghana raise fundamental questions about the efficacy of land and environmental resource use, they are not suggestive of a definite unsustainability or otherwise of land resource uses, since the levels of observed resource utilization impacts and efficiency are not measured against recognized and definite sustainable resource utilization performance standards. For lack of substantive evaluation programmes, no clear feedback information on the performance trajectory of land use, and the level of achievement of sustainable resource utilization objectives could be determined.

Sustainable resource use is a multi-dimensional concept, which involves combining technologies, policies and activities to integrate socio-economic principles with environmental concerns to simultaneously maintain or enhance production services, reduce the level of production risk, protect the potential of natural resources and prevent the degradation of soil and water quality (Dumanski, 1993). It is dynamic in that what is sustainable in one area may not be in another, and also what was sustainable at one time may no longer be sustainable today. This emphasizes the need for regular assessment to ascertain whether the sustainability of resource use is proceeding on a sustainable trajectory. The prime aim of sustainability evaluation is to identify impacts, such that positive effects may be enhanced, and action taken to counter negative ones, either through the application of appropriate policy alternatives, or through parallel mitigation and enhancement measures.

The enormity of the task of data acquisition, resource modeling and spatial computation is demanding for landscape studies. However, geo-information technology offers functionalities that address these challenges. In Ghana, though, there have been very limited applications of geo-information technology in the analysis of sustainable land and environmental resource use issues (eg. Pabi and Attua, 2005; Pabi, 2007). The limited deployment of geo-information technology has been for inventorying of resources (Therefore, the study sought to demonstrate the application of this technology in addressing sustainable development management issue of land resource use evaluation. Geographic information system provides unique set of analytical capabilities and functions that address problems with spatial dimensions. Consequently, the study leveraged extensively these functionalities in the study.

Methodology

Study area

The study area (Fig 1) is sandwiched between latitude $0^{o}.10'$ W and $0^{o}.24'$ W, and longitude $5^{o}.55'$ N and $6^{o}.15'$ N. It is located in the upper section of the Densu River Basin. Though the New Juaben District was the primary focus of the study, portions of neighbouring districts - Yilo Krobo, Akuapem North, Suhum Kraboa Coaltar, and East Akim Districts, that interface directly with the New Juaben were included. Of a total land area of 110 km square, about 27.0 % was built-up, making it one of the most built-up districts in Ghana in 1996 (Ministry of Local Government, 1996). The New Juabeng District is particularly heavily urbanized, with acute land shortage for agriculture land uses. This is acknowledged as a major developmental constraint in the District (Ministry of Local Government, 1996). In 1996, about 90.0 % of the population lived in urban centers. By 1984, the population was 92,482, which increased to 136,768 by 2000 (Ghana Statistical Service, 2002).

The Voltáian scarp is an important geological feature of the northern section of the region. This consists of chalk and coarse sandstone with some clay shales interstratified (Junner and Hirst, 1946). The plateau overlooking Koforidua and trending a northwest direction forms an imposing feature in the region. It peaks at about 200 m. From Koforidua towards the western section of the area, the terrain is low-lying and flat with gentle undulations and occasionally low hills rising abruptly above the generally low elevation. With progressive and intense land-use pressure, the originally dense forest vegetation has been transformed into fallows of different ages and cropping fields, practically losing its pristine status. Only isolated patches of the original vegetation exist in the most inaccessible areas such as summits of relatively highlands and river banks (Adu and Asiamah, 1992). A baseline survey conducted in 1996 on occupations in the area indicated that 60.0 % were engaged in farming (Ministry of Local Government, 1996)

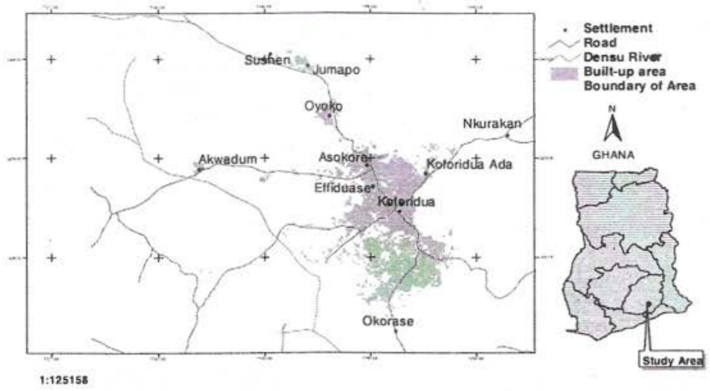


Figure 1: Location of the Study Area

Evaluation of the use of steep slope lands

A typical evaluation study involves a series of standard management procedures: (1) adoption of standards of performance for sustainable land resource utilization, (2) data gathering on actual performance of land resource utilization and (3) comparison of the standards and the actual performance (Cole, 1996). A good knowledge of the conditions of land and environmental resources and their uses are important for evaluating sustainable utilization (Lillesand and Kiefer, 1994). Collins and Rhind (1997) have argued for a consistent and readily available framework data for scientific monitoring and modeling of resources. Estes *et al.* (1995) have recommended ten relevant core data sets, including topographic features.

For sustainable use of steep slopes, land-use policy in Ghana prohibits the use of slopes >30° (Ministry of Lands and Forestry, 1999). In this study, the FAO (1985) slope classification scheme that was used for the national agriculture land suitability scheme was adopted. This provides appropriate details for the intended analyses in the study. Besides, it has the same unit of measurement (percentage) as the one used in the study. Slope suitability for annual crops of cassava and maize, which are extensively cultivated in the area, and whose cultivation may cause greater damage to fragile ecosystems was considered. The slope suitability classes of the crops are shown in Table 1.

TABLE 1 Slope suitability for maize and cassava

Maize	Cassava
0-8 %: suitable	0-8 %: suitable
8-16 %: suitable or marginally suitable	8-16 %: marginally suitable
16-30 %: marginally suitable or not suitable	>16 %; not suitable
>30 %: not suitable	

Source: Soil Research Institute of Ghana (SRI, CSIR), Accra

Elevation Sampling for Digital Elevation Modelling (DEM) and Slope Modelling

Slope is a derivative of DEM, hence the need for the construction of a digital elevation model. In the study, elevation was used as the voxel for the DEM generation. The project could not afford the purchase of a digital contour, so a 'progressive sampling' method by Makarovic (1984) was adopted, and manually adapted for carrying out the, normally, automated tasks. The technique allows for objective sampling of terrain with varying complexity, as is the case in the study area. In this case, highly varied topographic terrains were comprehensively sampled than less varied ones.

First, the boundary of the area of interest was marked out on a topographic map with a scale of 1:50,000, and a contour interval of 50 ft. Lines of varying intervals (depending on the closeness of contours) were drawn parallel to the latitudes across a topographic sheet. Points of intersection between the horizontal and the contour lines were then marked out. Due to the practical difficulty of estimating elevation measurements between adjacent contours, sampling of elevation points were restricted to the points of intersections only. A total of 1605 points were marked for the elevation modeling. The sampled points were digitized on an electronic digitizing board configured to ArcInfo 3.5.1, and the coverage registered to the Ghana topographical map. In ArcView 3.2 environment, the coverage was converted into a point shape file and elevation data entered into an attribute table. The attribute table was converted into an Excel format for subsequent use in the Surfer 7.02 package.

Spatial interpolation by Kriging and variogram techniques for DEM and slope modeling

Normally, it is impossible to make exhaustive sampling for continuous spatial environmental phenomena under investigations. This necessitated the use of spatial interpolation to estimate values for areas not sampled (Franke and Nielson, 1991 and Watson, 1992). Petrie and Kennie (1990) identify two broad categories of geo-statistical interpolation techniques: global and the local. The global interpolation function suppresses local variations. Therefore, it was considered inappropriate for the study since the scale of analyses required the computation of local variations. The local techniques are based on the assumption that each point influences the resulting surface only up to a certain definite distance. Appropriately, two local methods namely Kriging (Houlding, 1994) and Triangular Tessellation or Triangular Irregular Network–based technique (TIN) (Nielson, 1993) were used in the study. These quantitative interpolating methods have been found to be suitable for computer contouring algorithms (Lam, 1990; Burrough, 1986).

Kriging is a local geo-statistical estimation technique synonymous with "optimal prediction" (Journel and Huijbregts, 1978). Kriging interpolation procedure allows for the computation of statistical significance of the surface and uncertainty of the predicted values to be calculated. This is expressed in a variogram that shows how the average difference between values at points change with distance between the points. Semi-variance may be defined as half the expected squared difference between the random variables Z (x) and Z (x + h) at a particular lag h. The variogram defined as a parameter of the random variable, is then the function that relates semi-variance to lag h (1).

$$y(h) = \frac{1}{2} E[Z(x) - Z(x+h)]^2 \qquad (1)$$

The sample or experimental variogram - $y(h)$, can be estimated for $p(h)$ pairs of observations, $z(x_\iota + h)$, $\iota = 1, 2, 3\ldots, p(h)$ by equation (2) below:

$$y(h) = \frac{1}{2} p(h) \sum Z(x_i) - Z(x_i - h)^2 \qquad (2)$$

The attribute data of elevation and coordinate (feet) were used to generate the experimental variogram with forty (40) lags in Surfer. Experimental variograms are, invariably, discontinuous and do not meet the conditionality of non-negative variance (Cressie, 1993). To achieve a continuous model of the experimental variogram, the power functional model (r=0.508: r is an exponent) (Pannatier, 1996), was fitted to the experimental variogram since they strongly matched. The interpolated elevation surface was converted to the DEM. A slope surface was constructed as a derivative of the DEM and measured in percentage.

Land-Use/Cover Analysis from Remote Sensing

The Landsat ETM+ satellite data of 2000 was used for this study. The spatial resolution of 30×30 m for the multi-spectral bands, 1-5 and 7 are particularly suitable for the study since they are capable of detecting the typically, small-sized farms of peasant farmers prevalent in the area.

Enhancement, Interpretation and Classification of satellite imagery

The image bands were geometrically corrected and referenced to the digital topographic map of Ghana. Bands 3, 4 and 5 were subjected to contrast-stretch enhancement procedure to optimize information content and interpretation of the false color image. This was appropriately used since the spectral distribution was Gaussian (Jensen, 1996). In the enhanced image, thicker vegetation appeared dark green, with lighter vegetation cover appearing light green. Young or short fallows/annual crops appeared greenish yellow or yellow, with built-up/exposed or bare ground appearing reddish and purple respectively.

The classification process started with initial exploration and identification of possible distinct cover classes using an unsupervised classification algorithm called Iterative Self-Organizing Data Analysis Technique (ISODATA) (Jain, 1989). Coupled with previously acquired *in situ* information, a combined functional and structural (land-use/cover) classification scheme that fits local conditions and the objectives of the study was designed to guide characterization of the land-use/cover types. The adopted land-use/cover classification scheme was made up of following five (5) broad categories:

- Built-up/exposed (exp) areas: constructed features such as buildings and roads;

- Forest-farms (for-farm): patches of dense forest or tree crop farms or a mixture of the two;
- Long fallow (longfall): dense and high thicket with a number of trees of different sizes;
- Short fallow (shfall)/annual crop farms (anncrop): young fallows or annual food-crop farms or a mixture of them, usually with widely spaced isolated trees;
- Degraded lands (deg): comparatively short vegetation of grass and other herbs, invariably associated with highlands with a history of intensive cultivation and bush burning.

Training areas were selected for the various land-use/cover classes. The selection procedure carefully considered homogeneous representative areas for the various land-use/cover categories based on color, size, shape, and context properties (Richards, 1993 and Lam, 1990). These were on-screen digitized as polygon shapes. Training statistics of the spectral the values were generated for the five land-use/cover classes. Separability matrix of Jeffries-Matusita, which has a continuous scale of 0 - 1.44, was generated for the training areas to determine the degree of separation or similarity between them. Maximum Likelihood classifier algorithm, a supervise classification technique, was used to classify the image.

Field verification and evaluation of classification accuracy

Samples collected from the vegetation ground truthing were a valuable source of test reference information since these were randomly collected, photographed, adequately characterized floristically, extensively distributed throughout all the cover types and geo-referenced with GPS. As earlier mentioned, a field verification survey carried out after the unsupervised classification yielded important information that improved the subsequent supervised classification. The pixels used to train the Maximum Likelihood algorithm were not used as test samples. This was to ensure that the reference information was as independent or unbiased as possible.

Statistically, classifications schemes with few categories, such as that adopted for this study do not demand the use of many test samples for error calculation. However, the high level of within cover variability necessitated the use of a relatively high number of test samples of 150 for the analysis. The test sample data were converted into a point shape, rasterised and used for a pixel-by-pixel comparison with the classified image, and accuracy computed using Kappa statistical technique (Carstensen, 1987), which measures the level of agreement between two images captured in different periods. An accuracy of 90.5% was considered appropriate within the associated constraints.

Protection of the Densu Flood Plain and land-use conflict

A layer of three (3) contiguous buffers at distances of 100 m, 200 m and 300 m from the river were constructed around the segment of the Densu River that lie within the study area. This was followed by Boolean analysis of the buffer and the land-use/cover layers. Map query was conducted on the two maps to identify land-use/cover types that fall within the various buffer corridors. Another map query was also carried out to identify segments within the 100 m buffers that have forest-farms.

Results

Topographic Models

There was a wide range of elevation, with the minimum and maximum being 107.94m and 318.99m respectively. The experimental variogram indicated a strong relationship between changes in separation distance and altitude and at the same time showed little variability, for which reason no correction by smoothing was applied. There were no definite range and sill. The fit of the power model to the experimental variogram was a near perfect one and is as shown in Figure 2

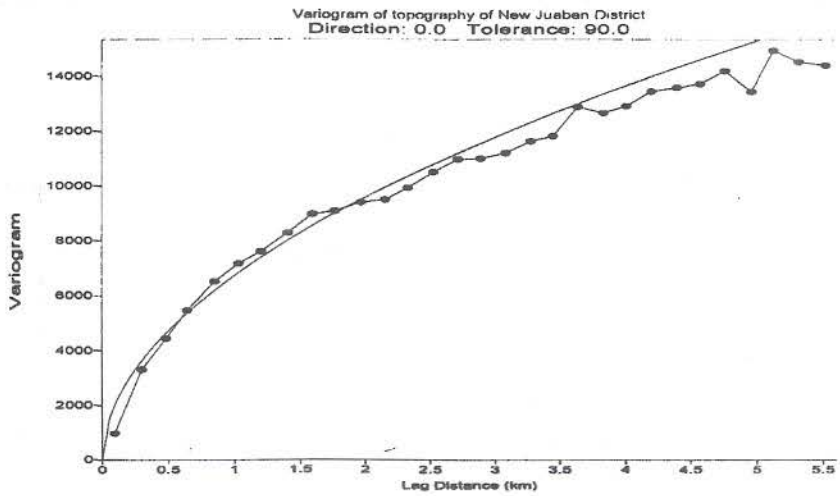


Fig. 2. Experimental Variogram fitted with the power model

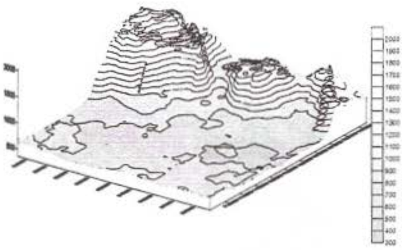


Fig.3. Elevation contour draped

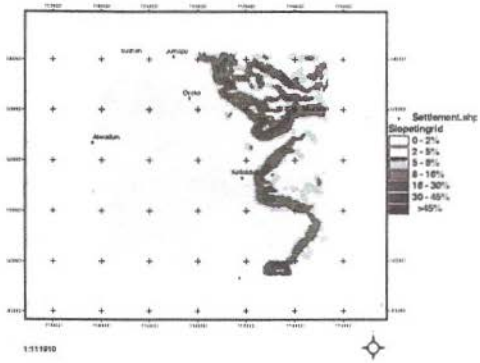


Figure 3 below indicates the DEM from which slope was derived. Steep slopes were commonly associated with the mountainous areas (Fig 4).

Table 2. Proportional coverage of slope classes

Slope (%)	Percentage (%)
0-2	22.321
2-5	58.208
5-8	6.871
8-16	9.765
16-30	2.638
0-45	1.960
>45	0.000

Of the total land surface, about 80.0% ranged between the slope categories of 0-2% and 2-5%. Only 4.59% of the area was relatively steep (16% - 45%)(Fig 4 and Table 2). The steep slopes were located in the mountainous areas, with the gentle slopes located in the flat and undulating zones.

Figure 5 is a representation of the land-use/cover of the area in the year 2000.

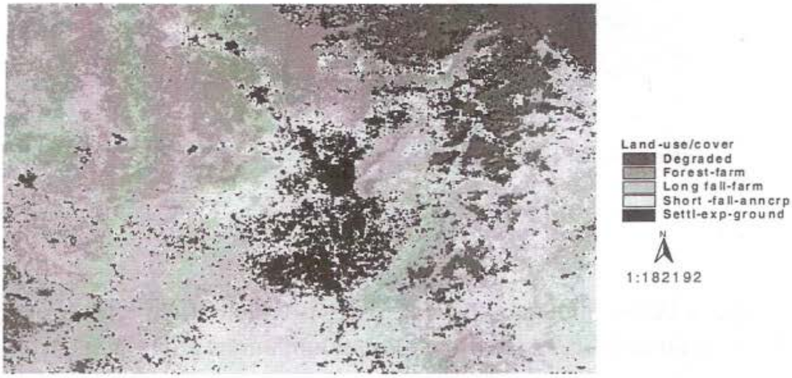


Fig. 5. Land-use/cover of 2000

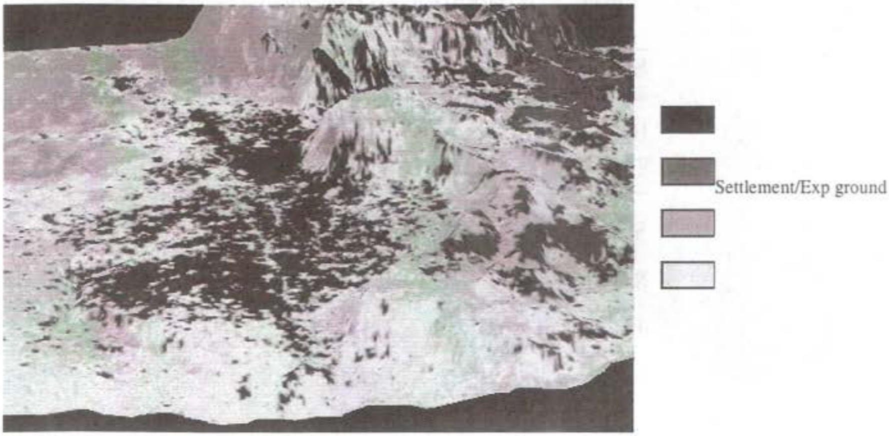


Fig. 6. Land-use/cover draped over DEM

Different proportions of the 2000 land-use/cover types were distributed within all the various slope classes (Figs 6 and 7). Forest-farms, short fallow and long fallow farms dominated the gentle slope classes. However, at the steeper slopes (> 16%), the proportion of long fallow, short fallow and annual crop farms largely dominated with a decrease in the amount of forest-farms. Short fallow-annual crops dominated the steepest slopes. There were some built-up and exposed areas also within the steep slopes (>16%). Even within very steep slopes above 30%, there were fallows and annual crop cultivation (fig. 8).

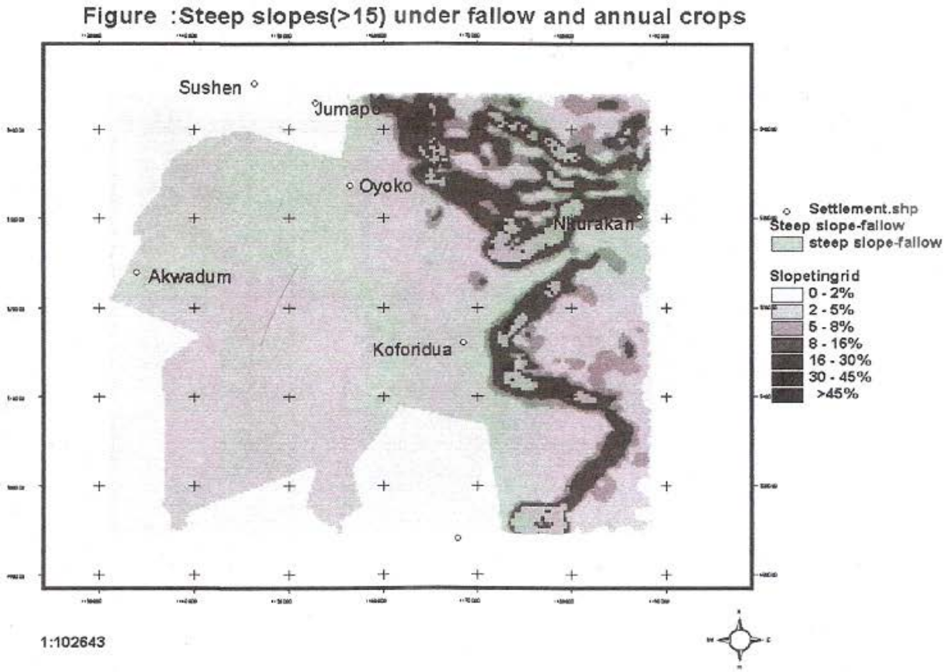


Fig. 8. Intensive cultivated areas and short fallows within steep slopes (>30%)

Land-use/cover within the flood plain of the Densu River.

There was no appreciable difference in the relative compositions of land-use/cover in the series of buffers created at the various distances from the Densu River in the year 2000 (Fig 9). However, within the buffers, long fallow constituted the highest proportion of the land-use/cover, with forest-farms and short fallow/annual crops following in that order.

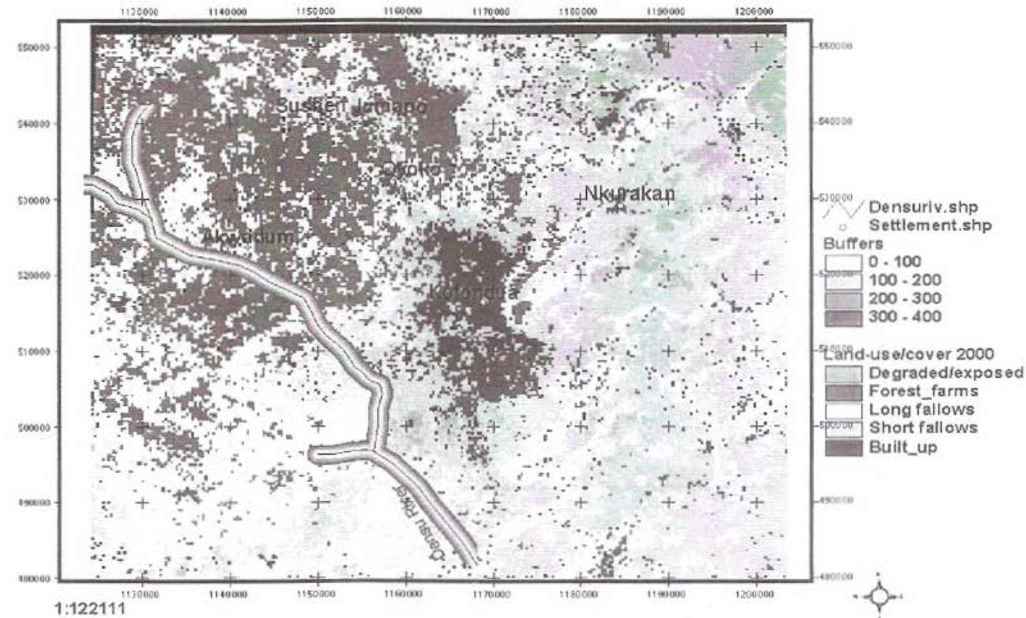
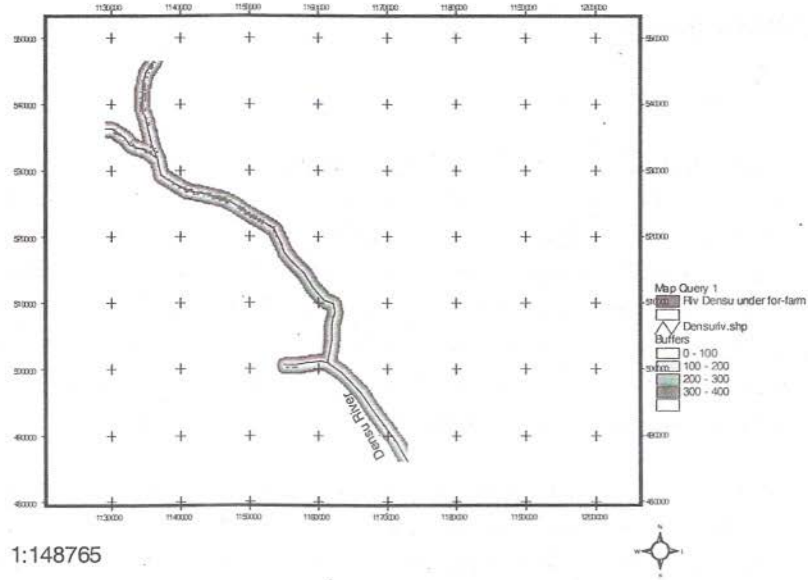


Fig. 9. Buffers around the Densu River in the 2000 land cover

Figure 10 shows isolated areas along the river covered with forest-farms. Some built-up/exposed areas were also located within all the buffers as illustrated by figure 11.



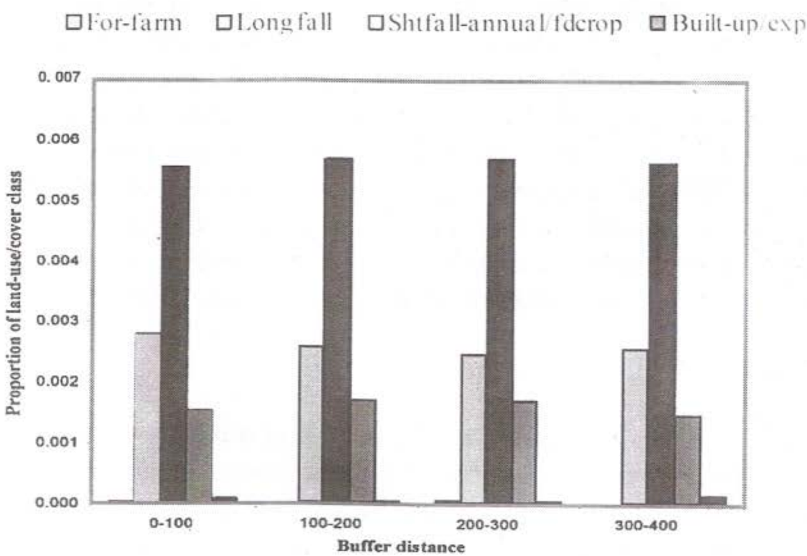


Fig. 11. Land-use/cover classes within four buffers at different distances away from the Densu River

Discussion

Slope Surface model

High magnitudes of both the standard deviation and the range of the elevation data set reflected extremes in heterogeneity of the topography of the area. The enhanced fit between the experimental variogram and the power model obtained suggests a better predictive capability of elevation by the experimental variogram model. However, it appears the predictive capacity may be greater at higher than lower elevations. Non-stationarity may also exist between elevation and distance at certain localities due to the presence of valleys in the area.

Theoretically, variograms are supposed to have zero semivariance at a lag distance of zero (Cornford, 1999). The non-zero semivariance or nugget variance/effect found in the study implies that more than spatial separation accounted for the total variation in elevation. Possibly, random errors might have been introduced during the processing of the aerial photographs for the topographic maps. Digitizing of the maps may also have contributed some amount of random errors. Local variations inherent in the topography of the area may also explain the presence of the nugget effect. There could have been a sill if more samples were collected or the experimental variogram estimated beyond 5.5 km range. Curran and Dungan (1989) have shown that the square root of the nugget variation can be a useful estimate of standard deviation of terrain elevation.Topographic variability has been studied using variograms (Isaaks and Srivastava, 1989; Curran and Atkinson, 1998).

Sustainable use of steep landscapes

Though a greater proportion of the area investigated was gentle rolling, appreciable amount fell within the slope range unsuitable for various forms of land-use activities. To ensure a sustainable management of these marginal lands, Lal (1986) has recommended that steep and rocky terrains are better left as protected forest reserves. It has been established that clearing of vegetation on steep landscape creates favorable conditions for water and wind erosion (Jankauskas, 1994; Lobb *et al*., 1995). For croplands, they recommended the use of gentle slopes (<5%) with deep good soils, which are input responsive. Contrary to above suggestions, steep terrains in the mountainous regions of the New Juaben and neighbouring districts were heavily deforested through farming, bush burning and to a limited extent, constructional purposes. Food cropping on the steep slopes does not employ effective farming practices that minimize erosion hazards.

Apparently, land resource utilization has not been carried out in a manner that promoted sustainable land and environmental resources use management in the sensitive ecosystems. Sustainable management of land and environmental resources utilization in the topographically marginal terrains should be seen in the context of their vulnerability to land degradative processes, and their roles in ecological processes.

Sustainable use of flood plains

The presence of only narrow patches of isolated clusters of tree cover that along the flood plains evidenced the existence of some dense forest vegetation along the river in the past. The transformation of the forest cover into fallows and progressive adoption of intensive annual cropping systems on the flood plains may have similarly contributed to the persistent flash floods and drying-ups during the rainy and dry seasons, respectively, of the Densu River in recent years. Erosion on bare grounds of the watershed may have been responsible for the siltation of the reservoir on the river that provides potable water to Koforidua and the neighboring communities. Gash and Stedard (1977) have found that disturbances of vegetation cover over watersheds cause disruptions of hydrological regimes.

Prior to the formulation of the national land-use policy strategies that prohibits land use within 100m of water bodies, there were local and traditional arrangements that sought to protect vegetation ecosystems in the immediate vicinity of rivers and streams. For their importance and sensitivity to disturbances, it has been suggested that watersheds and flood plains be protected by sound ecological measures (Golly, 1993; Hedin and Likens, 1996). Having noticed the negative effect of deforestation on the sustained water provision for the communities, some District Assemblies have initiated programs to re-afforest sections of the floodplain of the Densu River. However, the coverage is not extensive enough to be effective in protecting the entire river. A more comprehensive inter-district measure could be an effective and a better option.

Conclusion

The successful application of GIS and remote sensing techniques in this evaluation process makes a strong case for the need of applying these information technologies in achieving sustainable resource use objectives. Geo-information technologies applications provide the opportunity to make this possible. Continuous use of these technologies will improve their effective applications in sustainable land-use management.

Obviously, current status of land use and the vegetation cover in the Densu Basin can scarcely promote sustained water flow of the river, and the provision of water for both human use and aquatic communities. Denudation of vegetation from the riverbanks and steep slopes of the highlands clearly indicates that the long-term capacity of these natural systems to sustain the provision of ecological services is being undermined. Much has to be done to protect them if they are to continue to deliver these important ecological services.

Land-use monitoring and evaluation should be seen as an important component of sustainable land resource use management strategy and accordingly incorporated into these systems. The use of land and environmental resources must be constantly evaluated to ascertain the trajectory of the sustainability of resource use regimes. If this management approach were adopted, it would allow for possible adjustment and redirection of land-use strategies that are unsustainable. Where possible, a modification in the standards of land-use may ensure that sustainable land resource use is achieved.

References

Bates N.S. (2000). Hydrologic effects of forest harvesting on headwater watersheds in the West Virginia. Thesis, B.S. Engineering. Princeton University.

Buttle J. M. Creed I. F. and Pomeroy J .W. (2000). Advances in Canadian forest hydrology, 1995–1998. *Hydrological Processes*. 14(9):1551–1578.

Cornford D. (1999). Using variograms to evaluate a model for the spatial prediction of minimum air temperature. *In Advances of Remote Sensing and GIS Analysis*. P. M.

Curran P.J. and Atkinson P.M. (1998). Geostatistics and remote sensing. *Progress in physical geography*, 21, 61-78

Curran P.J. and Dugan J. K. (1989). Estimation of signal to noise: A new procedure applied to AVIRIS data. *IEEE Transaction of Geoscience and Remote sensing*, 27,620-628.

Cressie N. (1993). *Statistics for spatial data*. Willey, New York.

Dumanski J. (1993). *Sustainable land management for the 21st Century. Volume 1: Workshop Summary. Compiled on behalf of the Organizing Committee.* Proceedings of the International Workshop on Sustainable Land Management for the 21st Century: University of Lethbridge, Canada, June 20-26, 50 pp

FAO (1985). *Guidelines: land evaluation for irrigated agriculture*. FAO of the United Nations, Rome.

FAO (1995). *Planning for sustainable use of land resources*. FAO development series 1, FAO, Rome.

FAO/AGL (2000). *Management of degraded soils in Southern and Eastern Africa (MADS-SEA-Network). Land and plant nutrition management service of FAO*. FAO, Rome.

Franke R. and Nielson G. (1991). *Scattered data interpolation and applications: a tutorial and survey. In Hegen H. and Roller D. (Eds). Geometric modeling : Methods and application.* Springer, Berlin, 131-60.

Ghana Statistical Service (2002). *Population census of Ghana. Demographic and economic statistics*. Ghana Statistical Service, Accra.

Gyasi E. and Uitto J. I. (1997). *Environment, Biodiversity and Agricultural Change in West Africa.* UNU Press, Tokyo.

Houlding S. (1994) . *Three dimensional geoscience modeling*. Springer, Berlin.

Isaaks E.H. and Srivastava R.M. (1989). *Applied Geostatistics.* Oxford University Press, Oxford

Jankauskas B. (1994). *Soil erosion and agrarian control measures. The work of doctor habilitatis* (English summary). 80-102.

Journel A. G. and Huijbregts C. J. (1978). *Mining Geostatistics*. Academic Press, London.

Kaimowitz, D. (2004). Useful myths and intractable truths: the politics of the link between forest and water in Central America. In: Bonnell, M. Brijnzeel L. A (eds). *Forest-Water-People in the Humid Tropics*. Cambrdge University Press, Cambridge.

Lobb D. A., Kanchanoski R. G. and Miller M. H. (1995). Tillage translocation and tillage erosion on shoulder slope landscape sloping measures using 135Cs as a tracer can. *Journal of Soil Sci*, 2111-218.

Lam N. S. (1990). Description and measurement of Landsat TM images using fractals. *Photogrammetric Engineering and remote sensing*. 56, 187-95.

Makarovic B. (1984). Structures for Geo-information and their application in selective sampling for digital terrain models. *ITC Journal*, 1984, 285-95.

Ministry of Local Government and Rural Development (1996). *A medium term development plan for New Juaben Municipality (1996-2000)*. Kessie-Taigo and Associates, Accra.

Osman A. A. (2000). *Land use and cover change patterns in the Densu Basin: Implications for wood fuel resources in Ghana* (Unpublished thesis). University of Ghana, Accra.

Pabi O. (2007). Understanding land-use/covcer change process for land and environmental resources use polices in Ghana. *Geojournal*, 68, 369-383.

Pannatier Y. (1996). *VarioWin - Software for Spatial Data Analysis in 2D*. Springer-Verlag, New York, 91 pp.

Petrie G. and Kennie T. J. M. (1990). *Terrain modeling in surveying and civil engineering*. Caithness, Whittles.

Price K. P. (1993). Detection of soil erosion within Pinyon-Juniper woodlands using Thematic Mapper (TM) Data, *Remote Sensing of Environment*, 45, 233-248.

Swallow B., Onyango L. and Meinzen-Dick R. (2005). *Hydronomics and terranomics in the Nyando Basin of WesternKenya*. International workshop on 'African Water Laws: Plural Legislative Frameworks for Rural Water Management in Africa', 26-28 January 2005, Gauteng, South Africa

Walsh M., Shephered K. and Verchot L. (2004). Identification of sediment sources and sinks in the Nyado River Basin. In D. Swallow, J. Mburu L. Onyango and A. Njui (eds). *Proceedings of a workshop on Reversing Environmental and Agriculture Decline in the Nyando River Basin, ICRAF*: Nairobi, Kenya, pp. 27-32.