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A Spatio-Temporal Based Estimation of Vegetation Changes in the Tarkwa Mining Area of Ghana

[1]B. Kumi-Boateng, [1]D. Mireku-Gyimah and [2]A.A. Duker
[1]University of Mines and Technology, P.O. Box 237, Tarkwa, Ghana
[2]Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

Abstract: The Tarkwa Mining Area (TMA) falls in the rainfall belt of Ghana with evergreen Equatorial forest vegetation. TMA has witnessed clearance of large tracts of vegetation to make room for mining and settlements. Destruction of vegetation has exacerbated since surface mining was introduced in the area in the 1980s. However, the actual extent of vegetation change since 1980 to date has not been assessed and quantified. This study uses Remote Sensing (RS) and Geographic Information Systems (GIS) techniques to estimate the changes in vegetation in the area. Temporal satellite images for four different years and 250 ground reference points were classified using maximum likelihood algorithm. The impact of mining on vegetation composition was also estimated using distant gradient. Phytosociological analysis was also carried out to determine the species density, dominance index and diversity index. The results revealed five dominant land use/cover types. Vegetated areas in the TMA lost 932.92 km^2 whereas settlements and mining areas gained 932.93 km^2 of land. A phytosociological analysis of the TMA revealed that the number of herbaceous species colonizing the mined areas was much higher than the number colonizing the unmined areas. The study concluded that the rate of changes in the various land-use/cover types in the TMA is alarming and if the current trend of development continues, there could be an imbalance in the ecosystem of the TMA.

Key words: Distant gradient, mining, phytosociological, tarkwa, vegetation

INTRODUCTION

Vegetation supports critical functions in the biosphere, at all possible spatial scales. It regulates the flow of numerous biogeochemical cycles, most critically those of water, carbon, and nitrogen; it is also of great importance in local and global energy balances. Such cycles are important not only for global patterns of vegetation but also for those of climate. Vegetation also strongly affects soil characteristics, including soil volume, chemistry and texture, which feed back to affect various vegetational characteristics, including productivity and structure. Even though vegetation has a high biological importance, it is often under intense human pressure in mining areas especially where surface mining and illegal small scale mining (*Galamsey*) activities are prevalent. Mining activities impact negatively on the environment and the severity of the impact depends on methods used and whether the mine is large or small (Bell *et al*., 2001). Mining causes massive damage to landscapes, flora and the fauna through the clearing of the top soil to make room for surface mining (Fyles *et al*., 1985). The indiscriminate and unscientific mining methods by the *Galamsey* operators, absence of post mining treatment and management of mined areas are making the fragile ecosystems more vulnerable to environmental degradation. Therefore, urgent and effective action for revegetation and conservation is required to monitor and sustain vegetation condition.

The Tarkwa Mining Area (TMA) is one of the areas in Ghana where rapid changes in vegetation status are taking place as a result of surface mining activities and population growth. These changes could also be attributed to climate change, changing hydrologic regimes, vegetation redistributions and potential agricultural failures on massive scale. Clearing of the vegetation in TMA required to make room for mining has resulted in large scale denudation of forest cover, erosion of top soil, degradation of agricultural lands as well as the conversion of original lush green landscape into mine spoils. These changes may lead to very serious consequences such as deterioration of the land, environmental damage, famine and/or other unanticipated and undesirable effects (Lunetta, 1999).

Studies related to the floristic composition of mining areas have been conducted by several researchers in different parts of the world (Conwell, 1971; Game *et al.*, 1982; Fyles *et al.*, 1985; Prasad, 1989; Pandey, 1993). An understanding of the process of change detection as a result of the impact of mining on the environment, particularly, on vegetation characteristics is a prerequisite. The process of change detection forms an important part

Corresponding Author: B. Kumi-Boateng, University of Mines and Technology, P.O. Box 237, Tarkwa, Ghana

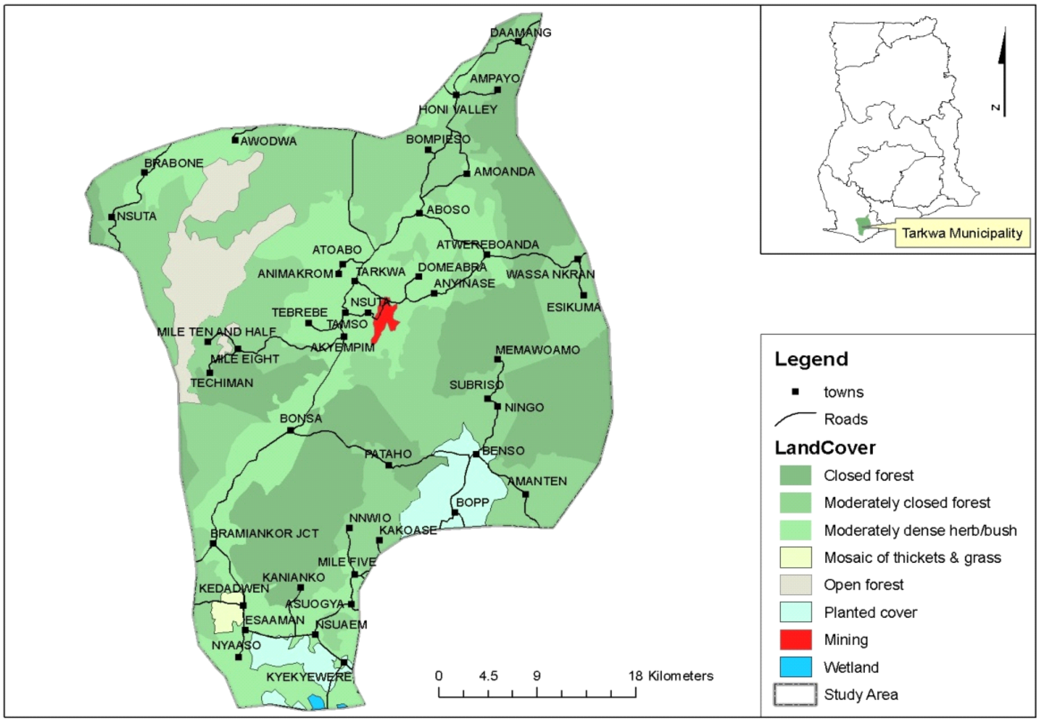

Fig. 1: Tarkwa Mining Area (TMA)

of the process by which plans on the use of natural resources can be reviewed and up-dated. Change detection provides the basis for coordinated policies and strategies to guide development at local authority level and within the framework of selecting short-term actions to provide solutions for immediate problems (Sarma, 2002). Change detection may also reveal the spatial pattern of development in the area. Depending on whether it is positive or negative, it will enable planners to modify strategies accordingly. Additionally, change detection may identify areas where particular types of change should be encouraged or discouraged (Lambin *et al.*, 2001). However, no known research has been conducted in the TMA to quantitatively assess the changes taking place on vegetation as a result of mining activities. This paper, therefore, seeks to assess the impact of mining on vegetation in the TMA using Remote Sensing (RS) and Geographic Information System (GIS) techniques. Questions envisaged to be answered are:

- What has changed?
- Where and when did the change occur?
- How can ecosystem failures be averted?

Study area: The study area is the Tarkwa-Nsuaem Municipality and its environs in the Western Region of Ghana (Fig. 1). For the purpose of this study, it shall be referred to as the Tarkwa Mining Area (TMA). TMA has nearly a century of gold mining history and has the largest concentration of mines in a single area on the continent of Africa, with virtually all the six new gold mines operating surface mines (Akabzaa and Darimani, 2001). TMA was the focus of attention for the earliest European prospectors and promoters who first entered the hinterlands of the Gold Coast Colony in the late 1870s just after the region had been declared a British colony (Griffis *et al.*, 2002). It eventually became an important gold producing area and an administrative centre for the mining industry. Underground mining was carried out for over 100 years during which about 7 million ounces of gold were produced. However, from the late 1960s to the late 1980s, production had dropped dramatically due to a variety of problems. Revival of gold mining started in the late 1980s when attention was focused on the open-pit potential of the area (Griffis *et al.*, 2002). TMA is located between latitudes; 4º0′ 0″ N and 5º40′0″ N and longitudes; 1º45′0″ W and 2º1′0″ W. The area is estimated to have a total land area of 3 783.64 km^2 with Tarkwa having a population of 40 397 as of 2005 (Kumi-Boateng *et al.*, 2010).

TMA lies within the South-Western Equatorial Zone. It therefore has fairly uniform temperature, ranging between 26ºC in August and 30ºC in March. It has a mean annual rainfall of 187.83 cm with a double maximum rainfall starting from March and September as the main

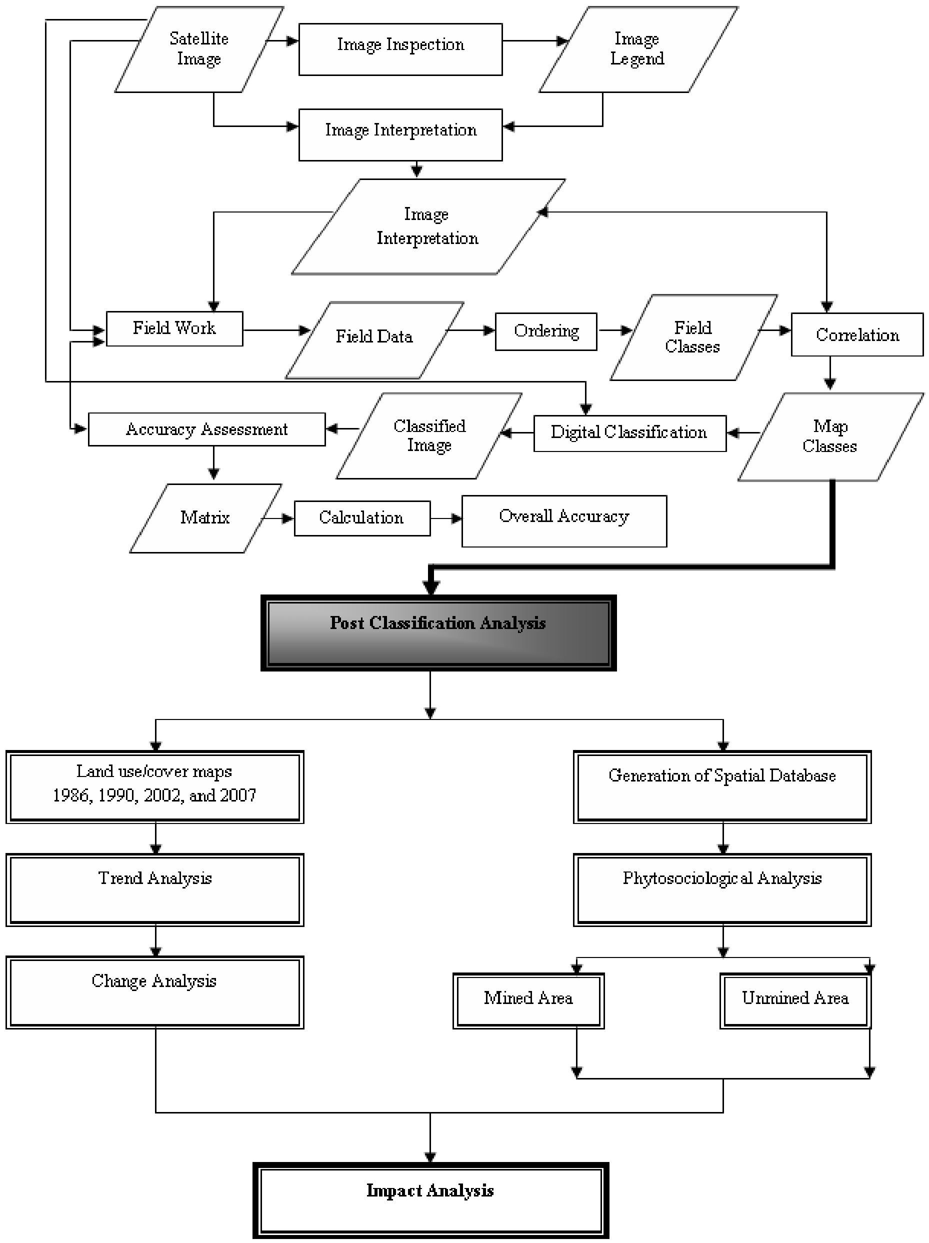

Fig. : Flow chart of research methodology

rainfall season and October to February as the dry season. The TMA falls within the rainfall belt with evergreen Equitorial vegetation. The height of trees ranges between 15 and 40 m high and have wide crowns. The forest is full of climbers and lianas, which are able to reach into the upper tree layer. Economic trees include mahogany, wawa, odum, sapele among others (Anon, 2010). In recent times, most part of the rich forest has been reduced to secondary forest through increased human activity. Human activities such as, excessive opening pit mining, farming and indiscriminate lumbering have impacted negatively on the natural vegetation. The TMA however, can still boast of large forest reserves like the Bonsa Reserves (209.79 km^2), Ekumfi Reserve (72.52 km^2) and Neung Reserve (157.84 km^2).

MATERIALS AND METHODS

Materials: In order to estimate the spatial distribution pattern of land use/land cover in the TMA, Landsat TM images of 1986 and 2002 and ASTER images of 1990 and 2007 were used together with ground observations.

Topographic map of the area obtained from the Mapping and Survey Division of Ghana were also used. A secondary data on the vegetation composition in the study area was obtained from the Forestry Commission of Ghana. Digital Image Processing (DIP) was done using ERDAS IMAGINE software, and ILWIS to prepare the land use/land cover maps. Land use/land cover data were interpreted and digitized from the digital images into ESRI shape files in the Ghana National Grid (GNG) coordinate system. Statistical analyses were done using R software and the Analysis Toolpak function of Microsoft Excel.

Methods employed in the image classification: The methods employed in the spatio-temporal estimation of vegetation changes in the TMA included image pre-processing, interpretation of the Landsat (1986 and 2002) and ASTER (1990 and 2007) satellite images; field data collection; classification; accuracy assessment as well as post classification analysis. The methodology applied in DIP and the estimation of mining impacts on vegetation status is as shown in Fig. 2.

Image pre-processing:

Geometric correction: Geometric correction procedure is used to register each pixel to real world coordinates. The four (4) images were geometrically corrected to the local coordinate system (GNG) using ERDAS Imagine and ArcGIS. The 2007 image was georeferenced with forty-five (45) pairs of well distributed tie points. The tie points were picked at road intersections and river confluence from the road and river digital maps respectively and subsequently co-registered to 1986 image using 2nd order polynomial transformation coefficients to correct the data sets that are distorted in several ways at once. Tutu Benefoh (2008), Yuan *et al.* (2005) and Attua and Laing (2001) used 40, 35 and 30 pairs of ground control points to georeference landsat TM and Spot images respectively in their respective studies. The forty-five (45) well distributed points used in this study was meant to increase the accuracy of the georeferencing. Root Mean Square Error (RMSE) could be defined as the deviation between Ground Control Points (GCP) and geographic locations as predicted by fitted-polynomial and their actual locations (Shalaby and Tateishi, 2007).

RMSE between the geo-located images of 0.25 pixel, was recorded and accepted as the positional accuracy of the transformation of this study. This error margin was accepted for the study because it is within 0.5 pixel recommended by Osei and Zhou (2004). Tutu Benefoh (2008), Shalaby and Tateishi (2007) and Yuan *et al.* (2005) accepted 0.2 pixel, 0.4 pixel, 0.25 pixel RMSE respectively in their respective studies. It is also instructive to indicate that, different levels of errors were accepted in different studies based on the spatial resolution of the image. The two (2) ASTER images were resampled to 30×30 m pixel size using the nearest neighbour resampling method in order to have the same pixel size for the Landsat and Aster images and also to preserve the original ASTER image radiometry since it had a pixel size of 15×15 m pixel. Tutu Benefoh (2008), Serra *et al.* (2003), Asubonteng (2007) and Yuan *et al.* (2005) used similar resampling methods in their respective studies. The nearest neighbour resampling method assigns the DN value of the closest original pixel to the new pixel without being changed and retaining all spectral information, which makes the resampled image efficient in classification (Kerle *et al.*, 2004).

Radiometric correction: Dealing with multi-date image dataset requires that images obtained by sensors of different times are comparable in terms of radiometric characteristics (Mas, 1999). Radiometric correction techniques such as image enhancement, normalisation and calibration are applied to multi-date satellite images in order to increase visual discriminations between features as well as increase the amount of information to improve interpretability (Bektas and Goksel, 2003). In this study, radiometric correction processes such as haze reduction and band co-linearity analysis were done on the 1986, 1990, 2002 and 2007 images to reduce band correlation. The images were further subset to fit the study area using ERDAS IMAGINE.

Interpretation: A visual interpretation of the four images of TMA for the years 1986, 1990, 2002 and 2007 at a scale of 1: 30 000 were carried out. A preliminary legend was established in terms of the image characteristics, by identifying homogeneous areas in terms of the tone or colour, pattern, texture, shape, size and location or situation of the image. The visually interpreted image formed the basis for the field work design and observations.

Field data collection: The purpose of the field survey was to observe what the different image characteristics are in reality. A total of 250 field points were observed (10-02-2010 to 19-04-2010) using a hand-held Global Positioning System (GPS) to check the correctness of the mapping unit boundaries delineated on the interpreted image and to collect additional information on land use/land cover which could not be obtained from the image. In order to minimize the time spent on the field, the points were selected and mapped based on a stratified clustered representative sampling where an equal number of sample points were allocated to each preliminary legend unit (irrespective of the size of the unit and number of polygons that belong to the unit). The field data were then ordered to define the five field classes (closed cover, open cover, shrub/herbaceous, mining areas and settlement). Theses classes were then correlated with the initial interpreted image to generate the land use/land cover map of the TMA (Fig. 2).

Classification: Supervised classification was used to classify the individual images into the various land cover classes. Lillesand and Kiefer (1994) described supervised classification as based on statistics inherent in the dataset, and divided the approach into three basic steps namely the training stage, the classification stage and the output stage. With the help of the various reference datasets, consultation with the local people and personal knowledge about the study area, training samples representing the various land cover classes were digitised on the individual images using the AOI tool and named accordingly in the signature editor of Erdas Imagine. In evaluating the training samples, feature spaces were plotted to ascertain the distribution of the individual pixels in the images. The next step was the classification stage which was performed using the Maximum Likelihood algorithm. This algorithm classifies images according to the variance and covariance of the spectral response patterns of a pixel. An assumption is made that in order to apply this algorithm, the distribution of the pixels forming training data should be normally distributed. The individual images were classified into five different land cover classes: closed cover, open cover, shrubs/herbaceous, mining areas and settlement. These classes were chosen based on the Anderson classification scheme (Anderson *et al.*, 1976).

Accuracy assessment: In this study, the accuracy assessment was carried out using 250 points obtained from the five land use/land cover types of the study area. These points were determined using selective sampling method to ensure an adequate representation of the different land use/land cover types within the TMA. Mining and waterlogged areas were not used for the accuracy assessment due to lack of accessibility. In order to increase the accuracy of the land use/land cover mapping of the four images, ancillary data from visual image interpretation were integrated into the initial image classification results. A visual interpretation of the images was done using on-screen digitizing. The resulting polygons of the cover types were rasterised and incorporated into the classified land use/land cover spectral classes.

Methods employed in the post classification analysis:

Change analysis: Post-classification change analysis method was used to assess change in the various land-use/cover types over the period of study (1986-2007). This technique was used because it readily provides a change matrix and where different transfers from one land-use/cover type to another can be visually appreciated. Several studies including those of Tutu Benefoh (2008), Sedego (2007), Shalaby and Tateishi (2007), Asubonteng (2007) and Vasconcelos *et al*. (2002) used post-classification change detection method, which resulted in a change matrix.

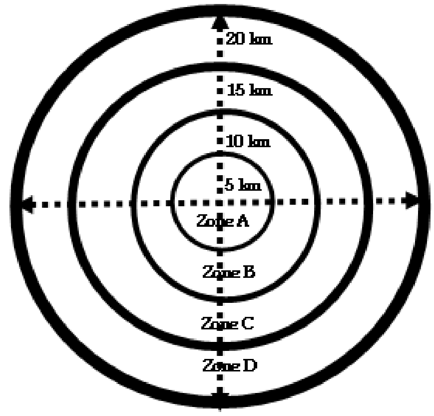

Fig. 3: Conceptual model of mining impact zones

Phytosociological analysis: The community characteristics of vegetation composition in the TMA were studied. In order to estimate the impact of mining on vegetation composition, distant gradient analysis was carried out. From the centre of the study area, structure and composition of vegetation is observed in four different zones. The radius of the first circle i.e., Zone A is 5 km. The distance from the periphery of the first circle to the periphery of the second circle is also 5 km and is considered as Zone B. Likewise, Zone C and Zone D are delineated (Fig. 3). In each circle 24 sample plots each for trees, shrubs and herbs were laid. Each sample plot was supported by 3 replicas. The total number of sample plots for trees, shrubs and herbs came to 72 each in each zone. The overall number of sample plots for tree, shrub and herb species was 288 each in the TMA, i.e., in all the four zones. The vegetation characteristics of the mined areas were compared with that of adjacent undisturbed vegetation referred to here as unmined areas.

The total number of quadrats laid in the unmined area was 10. For tree component a quadrat of 10 m × 10 m size was laid while for the shrub species it was 5 m × 5 m. For the herbaceous species the size of the quadrat was 1 m × 1 m. The species found in the quadrats were identified with the help of the officer in-charge of the forestry commission in Tarkwa. The plants having Canopy Based Height (CBH)>15 cm was considered as tree, stem diameter 5-15 cm at basal level was considered as shrubs and stem diameter <5 cm at basal level was considered as herbs. Quantitative community characteristics such as frequency, density, basal area and Important Value Index

(IVI) of each component were determined by following the methods as outlined by Misra (1968) and Muller-Dombois and Ellenberg (1974):

Frequency (%)	= NQS/TQ × 100
Density	= TIS/TQ
Basal Cover	= Density × ABIS
Abundance	= TIS/NQS
Simpson Dominance Index	= (ni/N)2

where,

NQS	= Number of quadrats of occurrence of a species
TQ	= Total number of quadrats studied
TIS	= Total number of individual species
ABIS	= Average basal area of individual species
Ni	= Importance value index
N	= Total importance value of all species
Pi	= Relative abundance of species

The Shannon-weaver index of general diversity was calculated as: $H' = -\Sigma \text{ Pi} \times \ln(\text{Pi})$.

RESULTS AND DISCUSSION

Results: Land use/cover distribution between 1986 and 2007: The classification yielded four land use/land cover maps from the satellite images of 1986, 1990, 2002 and 2007 of the study area. The classified land use/land cover maps of TMA for the years 1986 and 1990, 2002 and 2007 are shown in Fig. 4 and 5, respectively. The classification categorized the area into five (5) main land use/land cover types as detailed in Table 1.

According to the 1986 land use/land cover thematic map (Fig. 4a), closed canopy are predominantly found in the north-eastern and south-western portions of the study area where human activities are relatively less intense whilst open canopy is scattered across the landscape. Mining areas occurs mostly in the central portion of TMA as patches.

Shrubs/Herbs are common in the southern and northern part and around towns and frequently associated with settlements. In the 1990 land use/cover map, the size of both the closed and open canopy have reduced with mining areas increasing in patches across the TMA (Fig. 4b). The 2002 land use/land cover map showed closed canopy mainly in the south-eastern portions of the study area whereas open canopy spreads across the entire landscape as patches except the middle and south-western portions that have been taken over by shrubs/herbs. Mining areas have increased predominantly in the central part of the study area as patches (Fig. 4c). A careful perusal of the 2007 classification depicts closed canopy as a large homogenous patch in the south and east of the study area. Open canopy spreads across the entire study area and has thus taken over areas previously occupied by closed canopy in 1986, 1990 and 2002 classification. Mining areas has increased as large strips in the central as well as the fringes of the study area. Shrubs/Herbs are scattered across the landscape but predominant around settlements shown in Fig. 4d.

Table 2 shows that closed and open canopies forms the major land use/land cover representing 52.54% and 44.37% of the study area respectively in 1986. It is followed by shrubs/herbs (2.72%) and mining areas (less than 1%). In 1990 the area experienced some amount of change in land use/cover.

Open canopy formed the major land use/land cover occupying 52.79% and closed canopy reduced to 37.11% of the study area. Shrubs/herbs accounted for 8.78% whilst mining areas increased to 0.86% of the area. The classification for 2007 revealed a considerable amount of change in the cover types. Closed canopy reduced to

Table 1: Description of main land use/land cover types in the TMA

Cover type	Description
Closed canopy	Rain-forest with three layers of multiple species obstructing sunlight from reaching the floor.
Open canopy	No-shade, secondary re-growth, other trees with no overhead canopy, crop farm with mixture of crops, fallow re-growth.
Shrubs/herbaceous	Grass cover and fallow vegetation which dry up in the dry season exposing partly the soil cover, freshly cleared/planted areas of fallowed and access road corridors.
Mining areas	Areas where both small scale and large scale mining activities are taken place
Settlement	Areas of intensive infrastructure with much of the land covered by structures such as towns, buildings, barren lands etc.

Table 2: Land use/land cover areas for the period under study

	Areas in square kilometres							
Cover type	1986	%	1990	%	2002	%	2007	%
Closed	1987.91	52.54	1404.02	37.11	342.83	9.06	125.15	3.31
Open	1678.68	44.36	1997.24	52.79	893.90	23.63	758.85	20.06
Shrubs/herbs	102.77	2.72	332.20	8.78	2342.41	61.91	1952.43	51.60
Mining	8.00	0.21	32.62	0.86	105.08	2.78	513.11	13.56
Settlement	6.28	0.17	17.56	0.46	99.42	2.63	434.10	11.47
Total area	3783.64	100.00	3783.64	100.00	3783.64	100.00	3783.64	100.00

Table 3: Land use/cover change between 1986 and 2007

	Changes between (km^2):					
Cover type	1986-1990	%	1986-2002	%	1986-2007	%
Closed canopy	- 583.88	- 15.43	- 1645.07	- 43.48	- 1862.75	- 49.23
Open canopy	318.56	8.42	- 784.78	- 20.74	- 919.83	- 24.31
Shrubs/herbs	229.43	6.06	2239.64	59.19	1849.66	48.89
Mining areas	24.62	0.65	97.08	2.57	505.11	13.35
Settlement	11.28	0.30	93.14	2.46	427.82	11.31
Total area						3783.64

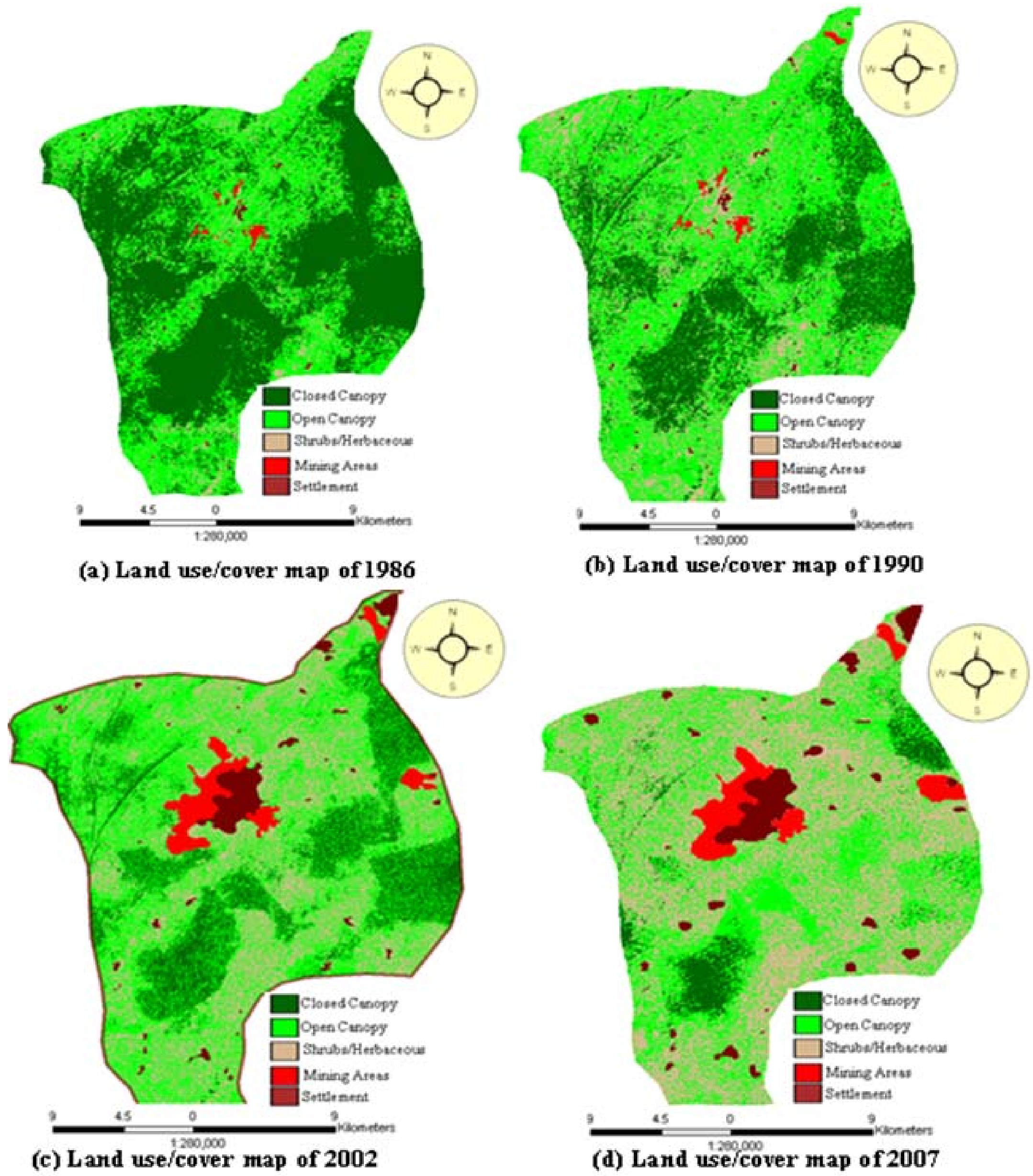

Fig. 4a-d: Land use/cover map of TMA (1986-2007)

3.31% with mining areas increasing to 13.56% of the area. Shrubs/herbs obtained the major cover representing 51.60% and settlement gaining 11.47% of the area under consideration.

Accuracy assessment: The accuracy of the classified 2007 image was assessed using 250 reference points to obtain error matrix and kappa statistics of 72.5%, and 0.72 respectively. The integration of the classified image with ancillary GIS data (visual interpretation data) increased the accuracy of the classification to 86.80% and a kappa of 0.86. However, the accuracy of the 1986, 1990 and 2002 could not be statistically assessed but was ascertained with the use of local knowledge and validated with information on the land use/cover map of 1974 acquired from the Survey and Mapping Agency of Ghana.

Land use/cover changes between 1986 and 2007: Comparison of 1986 land use/cover types and that of 1990, 2002 and 2007 land-use/cover (Table 3) showed different levels of change in the cover types due to conversions between land-use/cover types. Figure 5 indicates the extent of change among land-use/cover types. Generally, all the five (5) land-use/cover types experienced change in size from 1986 to 2007.

Table 3 shows that closed and open canopies decreased in size whereas shrubs/herbaceous, mining areas, and settlements increased over the 21 years. Closed canopy and shrubs/herbs experienced the most negative and positive changes respectively. While closed canopy lost a substantial area of 1 862.75 km^2, which is about 49.23% of the previous extent of closed canopy, shrubs/herbaceous increased to 1 849.66 km^2 representing 48.89% of the existing shrubs/herbaceous cover in1986.

Mining areas increased by 505.11 km^2 representing 13.35% of the study area from 8.00 km^2 in 1986 to 513.11 km^2 in 2007. Settlement gained a total area of 427.82 km^2 accounting for 11.31% of the area in 2007.

In order to estimate the mining areas in the future, a deterministic correlation coefficient (R^2) was determined between mining and the other four land use/cover against the years under consideration.

Over the 21 year period, the size of mining areas and closed canopy extended over several orders of magnitude. There was a strong relation between mining and the years under study ($R^2 = 0.92$) as well as closed canopy and the years of study ($R^2 = 0.81$) culminating in the following models:

$$\text{Mining Areas} = 2.3\times10^{150}e^{0.1734\text{Year}} \quad (1)$$
$$\text{Closed Canopy} = 2\times10^{114}e^{-0.128\text{Year}} \quad (2)$$

There was a strong deterministic correlation coefficient between open canopy and the years under consideration ($R^2 = 0.98$) with this model:

$$\text{Open Canopy} = 0.6926\text{Year}^3-1405.9674\text{Year}^2-4.3038\times10^4 \quad (3)$$

Shrubs/herbs cover showed a strong deterministic correlation coefficient, R^2 of 1 with the following equation:

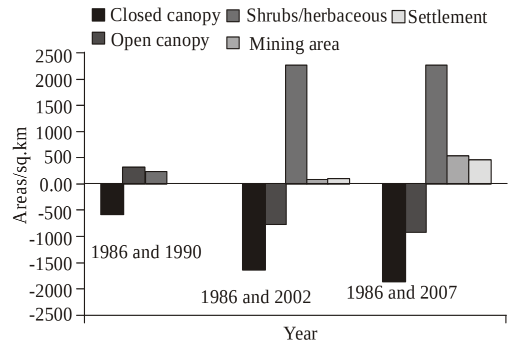

Fig. 5: Land use/cover changes from 1986 to 2007

$$\text{Shrubs/herbs} = -1.0.156\text{Year}^3 + 2061.668\text{Year}^2 - 0.6859\text{Year} + 1389.30 \quad (4)$$

Land use/cover transfers in the TMA: To understand the land use dynamics related to vegetation and mining, land use/cover changes between 1986 and 1990, 1986 and 2002 as well as 1986 and 2007 were determined. Eleven (11) classes of changes i.e., closed canopy to open canopy, closed canopy to shrubs, closed canopy to mining areas, closed canopy to settlement, open canopy to shrubs, open canopy to mining areas, open canopy to settlement, shrubs to settlement, no change and others were considered (Table 4).

It was found from the change analysis that there was impact of mining on different land uses, which were directly or indirectly related to vegetation. About 378 km^2 of closed canopy of the study area were transferred to open canopy between 1986 and 1990. This rate of transfer was not maintained in the proceeding years. During that same period about 24 km^2 of closed canopy was converted to mining areas. Between 1986 and 2007, a total of 229.07 km^2 of various land-use/cover types were transferred to mining areas.

Phytosociological analysis:

Floristic composition: The floristic composition of the TMA extended over several magnitudes in the mined and unmined areas. In the Zone A of the mined areas, tree, shrubs and herbs recorded an average of 15, 30, 51 species where as the unmined areas had an average of 51, 32 and 28 species.

At the peripheral (i.e, Zone D) of the mined areas, the tree and shrub species increased (Table 5).

Density: The tree density in the mined areas ranged between 523 and 797 stems per ha while in the unmined area it was 1974 stems per ha (Table 6). There was not much variation in the shrub density but density of herbaceous species was higher in the mined areas (179-342 individual/m^2) than the unmined area (132 individual/m^2).

Table 4: Land use/cover transfers in TMA

	Transfers between (km^2):					
Transfer type	1986-1990	%	1986-2002	%	1986-2007	%
Closed to open	378.25	10.00	187.46	4.95	62.04	1.64
Closed to shrubs	96.18	2.54	81.45	2.15	204.19	5.40
Closed to mining	24.39	0.64	96.17	2.54	172.84	4.57
Closed to settlement	8.54	0.23	85.37	2.26	103.72	2.74
Open to shrubs	202.97	5.36	114.08	3.02	99.02	2.62
Open to mining	3.90	0.10	5.39	0.14	52.05	1.38
Open to settlement	2.15	0.06	4.08	0.11	15.66	0.41
Shrubs to mining	0.68	0.02	2.87	0.08	4.18	0.11
Shrubs to settlement	1.73	0.05	2.24	0.06	5.09	0.13
Other changes	575.60	15.21	515.28	13.62	475.60	12.57
No change	2489.25	65.79	2689.25	71.08	2589.25	68.43
Total area	3783.64	100.00	3783.64	100.00	3783.64	100.00

Table 5: Floristic composition

	Mined areas				
Composition	Zone A	Zone B	Zone C	Zone D	Unmined areas All zones
Trees					
No. of species	15	13	17	22	51
No. of family	10	11	13	18	42
Shrubs					
No. of species	30	23	28	34	32
No. of family	23	20	26	33	23
Herbaceous					
No. of species	51	47	43	38	28
No. of family	37	40	29	38	20

Table 6: Density of vegetation affected by mining in the various zones

	Mined areas				
Vegetation type	Zone A	Zone B	Zone C	Zone D	Unmined areas All zones
Trees	523	615	673	797	1974
Shrubs	6	4	4	4	4
Herbaceous	311	342	332	179	132

Table 7: Simpson dominance index of vegetation types

	Mined areas				
Vegetation type	Zone A	Zone B	Zone C	Zone D	Unmined areas All zones
Trees	0.893	0.876	0.697	0.676	0.056
Shrubs	0.124	0.127	0.018	0.143	0.079
Herbaceous	0.045	0.229	0.198	0.238	0.093

Table 8: Shannon-weaver diversity index of vegetation in control and mined areas

	Mined areas				
Vegetation type	Zone A	Zone B	Zone C	Zone D	Unmined areas All zones
Trees	0.343	0.475	0.542	0.858	2.795
Shrubs	2.843	2.516	2.691	2.569	3.163
Herbaceous	3.853	2.949	2.788	2.471	2.679

Pattern vegetation dominance: In order to estimate the vegetation pattern in the TMA, the Simpson's dominance index was determined for tree, shrub and herbaceous species. The Zone A of the mining areas recorded a

Simpson index of 0.893, 0.124 and 0.045 for tree, shrub and herbaceous species respectively while that of the unmined areas had 0.056, 0.079 as well as 0.093 respectively (Table 7).

A dominance curve for the mined and unmined areas was determined for the TMA and a broken-stick series (Fig. 9) modle was observed in the mened arear.

Vegetation diversity: Shannon-Weaver diversity was determined for the various vegetation types under study. Herbaceous species had a diversity index of 3.853, 2.949, 2.788 and 2.471 in Zone A, Zone B, Zone C and Zone D respectively as against 2.679 in the unmined areas of the TMA (Table 8).

Density-diameter distribution: The density-diameter of tree distribution in both mined and unmined areas of TMA were estimated. The tree species of girth classes <14, 36-55 and >96 cm recorded an average density-

Table 9: Density-diameter distribution in both mined and unmined areas

	Frequency Mined areas (Frequency)				
Girth (cm)	Zone A	Zone B	Zone C	Zone D	Unmined areas All Zones
<14	4	12	125	5	708
15-35	48	35	88	54	150
36-55	201	87	132	304	50
56-75	172	185	75	262	43
76-95	103	100	62	51	25
>96	53	50	4	24	34

Table 10: Basal area of tree distribution

Vegetation	Mined areas (m^2/ha)				Unmined areas
Type	Zone A	Zone B	Zone C	Zone D	All zones
Trees	25.06	27.18	22.36	34.38	23.94

diameter of 4 in Zone A, 304 in Zone D and 4 in Zone C respectively in the mined areas. The unmined areas had 708 in Zone A, 50 in Zone D and 34 in Zone C of girth classes <14, 36-55 and >96cm, respectively (Table 9).

Basal cover: The basal area of tree distribution in the TMA was estimated and ranged from 22.36 m^2/ha to 34.38 m2/ha in the mined areas whilst that of the unmined areas had an average of 23.94 m^2/ha (Table 10).

The basal area in both mined and unmined areas showed no trend and was almost equally distributed (Fig. 10).

DISCUSSION

Land use/cover dynamics in the TMA: In order to estimate the actual land use/cover dynamics in the TMA, the state of the environment in 1986 (the selected base year) was established to put the changes occurring into a proper perspective. The aerial extent of each land use/cover class in the different years i.e., 1986, 1990, 2002 and 2007 was analysed to determine an overview of the level of changes (Fig. 4). It was found that most of the area had lost considerable amount of both closed and open canopies shrinking from 52.54 to 3.31% and 44.37 to 20.06%, respectively while mining areas had increased from 0.21 to 13.56% and that of settlement from 0.17 to 11.47% of the total area (Table 2). By the end of 2007, the TMA had been dominated by shrubs/herbaceous cover (51.60%) signifying a total failure of the ecosystem sustaining itself in terms of both closed and open canopies. The TMA experienced a total change of about 32%, indicating the stress that has taken place on the landscape over 21 years period. Between 1986 and 1990 as well as 1986 and 2002, changes occurred in about 34% and 29% of the total area respectively. About 173 km^2 of the closed canopy were converted into mining areas during the 21 year period under study. The change of open canopy to mining recorded a considerable size of 52.05 km^2. During the years 1986 and 2002, mining areas gained a total of 104 km^2 from closed canopy, open canopy and shrubs, representing 3% of the total area under consideration. During this same period a total of 450.45 km^2 of closed canopy was converted to mining, shrubs and open canopy (Table 4). This can be attributed to a number of factors such as mining, construction of new houses and roads (i.e, urbanisation) as the population of TMA increases, farming and fuel wood collection. Mining activities in the study area have been identified as one of the major driving forces causing rapid land use/cover changes. Mining areas in the TMA have increased sharply from 8.00 km^2 (0.21%) in 1986 to 513.11 km^2 (13.56%) in 2007, an increase of about sixty four (64) times. An increase in mining operations will demand manpower and development of infrastructure in the mine sites; Table 4 reveal that mining areas increased at the expense of closed and open canopies. This suggests that both closed and open canopies were targeted to accommodate these facilities. During this period a considerable portion of the closed and open canopies were converted to settlements, roads, farms and shrubs. It was detected that the impact of mining on shrubs and existing non-forest areas of TMA was not severe between the period understudy. The clearing of the top soil to make room for mining over the years has created conditions favorable for shrubs capable of growing in the hash edaphic condition. This confirms the studies conducted by Adu-Poku (2010), Sarma (2005), Prakash and Gupta (1998) and Rathore and Wright (1993) who concluded that the upsurge of mining activities and the changes in land use/cover types were correlated to each other. Within the period 1986 and 2007, settlement increased from 6.28 km^2 (0.17%) to 434.10 km^2 (11.47%) thus establishing urbanisation as one of the driving forces behind the alteration of land use/cover in the TMA. This confirmed the suggestion that the Earth's land surface is affected rapidly by the presence of human beings and their activities (De Sherbinin, 2002). The population of TMA as of 1984 was 22 107 and shot up to 30 631 in 2000 (Anonymous, 2002), an increase of about 37%. Again between 1986 and 1996 there was an upsurge of gold mining and this led to an increase in gold production from an annual total of 11 339.809 kg in 1987 to 34 019.428 kg by 1996 (Adu-Poku, 2010). This resulted in an increase in urbanisation as many people came to live in Tarkwa in search of employment in the booming mining sector. The effect of this is clearly seen in the sharp increase in settlement areas between the period of 1986 and 2007. It was revealed (Table 4) that settlements increased by 124.47 km^2 (3.28%) at the expense of closed canopy, open canopy and shrubs/herbs. These land cover conversions are an indication of influx of people seeking new space and claiming vegetated areas close to settlements for developmental purposes (such as construction of road, building of houses and industries, and cutting down of trees for fuel wood in the case of those living in the hinterlands). The dislocated farmers by both large and small scale miners in their quest for new space to farm turn to available vegetated areas. Field visits within the TMA showed that deforestation had been caused by timber companies and illegal chainsaw operators. Bushfires also contributed to the conversion of forest reserves into shrubs/herbs. Between 1983 and 1986 most of the forest reserves in Ghana suffered severely as a result of drought and countrywide burning all across the land. During these period farmlands, foodstuffs, forest reserves etc from north to south and west to east got burnt. Most of the closed canopies were thus converted into shrubs/herbs. This explains why shrubs/herbs increased from 102.77 km^2 in 1986 to 2 342.41 km^2 in 2002 (Table 2). However, between 1986 and 2007 shrubs/herbs decreased marginally compared with the period between 1986 and 2002. In the gap of 21 years, shrubs/herbs, which could as well be farm lands might have been replaced by trees or open canopies or forb regrowth coupled with increased settlement expansion and mining activities.

Impact of mining on vegetation composition: There were variations in the composition of plant in the mined and unmined areas. The tree species showed a drastic reduction in their number in all zones of the mined areas (i.e., 13-22) while that of the unmined areas experienced an increase (i.e, 51). In the unmined area 51 tree species belonging to 42 families were registered. Fifteen (15) tree species belonging to 10 families, 13 tree species belonging to 11 families, 17 tree species belonging to 13 families, and 22 tree species belonging to 18 families were recorded in the mined areas of Zone A, Zone B, Zone C and Zone D respectively (Table 5). It was apparent from the study that the number of tree and shrub species was more in the peripheral zone than the inner zones. There was not much variation in the number in first three zones of the area. The shrub species did not show much variation in the unmined and all the zones of the mined areas. In the unmined area, a total of 32 shrub species belonging to 23 families were found. Shrubs were represented by 30, 23, 28 and 34 species from 23, 20, 26 and 33 families in Zone A, Zone B, Zone C and Zone D respectively. There was remarkable increase in the number of herbaceous species in the mined areas. In the unmined area, the total number of ground species (herbs) was 28 belonging to 20 families. In the mined areas herbs layer was composed of 51 species and 37 families in the Zone A, 47 species belonging to and 40 families in the Zone B, 43 species from 29 families in Zone C, and 38 species belonging to 38 families in Zone D (Table 5). Since the mined and unmined areas had similar climatic, edaphic and physiographic features, the differences in species composition could be attributed to the mining activities. This is in agreement with the findings of Adu-Poku (2010), Sarma (2005), Das Gupta (1999), Baig (1992) and Singh and Jha (1987). Sarma (2002), while studying the impact of coal mining on the vegetation characteristics of the Nokrek Biosphere Reserve of Meghalaya outlined that the composition of vegetation reduced in the mined areas with that of the adjacent unmined areas. Lyngdoh *et al*. (1992) reported less number of species in the mine spoils of different ages to that of the unmined areas. However, if mining operators will adhere strictly to their reclamation policy the floristic composition may, with time, increase in their species richness as underscored by Iverson and Wali (1982) in their study.

The unmined area had greater tree density compared to that of the mined areas (Table 6) because of the low levels of pH (acidic pH) in the soil, moisture stress and nutrient property of litter. The mined areas recorded some levels of tree density due to the species ability to tolerate low nutrient levels and low moisture conditions and probably the adaptations to the harsh physical nature of the substrate. Low nutrient habitats are usually colonized by species with relatively low growth rates. These adaptations enable colonizing species to maximize the nutrient uptake and ensure high nutrient use efficiency in low nutrient environments. The studies of Baig (1992), Lyngdoh *et al*. (1992), Das Gupta (1999) and Sarma's (2002) lend support to the present findings that certain species are able to grow in areas of low nutrient levels and low moisture conditions. Bradshaw and Chadwick (1980) working on colliery spoils reported that the number of species colonizing on the mined areas was influenced by its pH.

The dominance was different for tree, shrub and herb component in mined and the unmined area of the study area. In terms of Simpson dominance index, herbaceous species dominant (0.045) in the mining areas of Zone A, followed by the shrubs (0.124) with tree species (0.893) having least dominance effect (Table 7). However, in the unmined areas tree species (0.056) dominates in all the

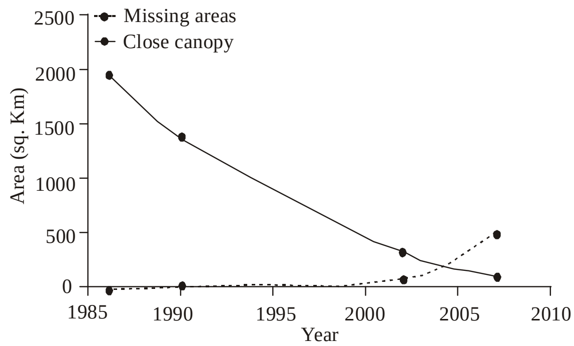

Fig. 6: A graph of mining areas and closed canopy against year

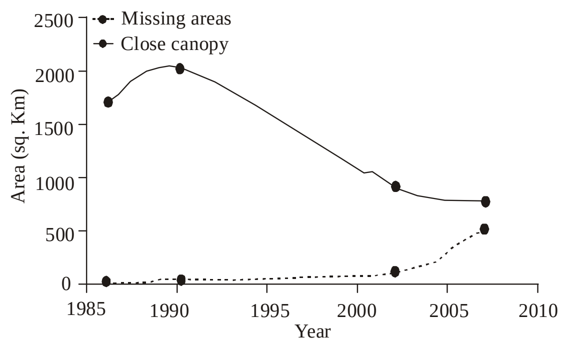

Fig. 7: A graph of mining areas and open canopy against year

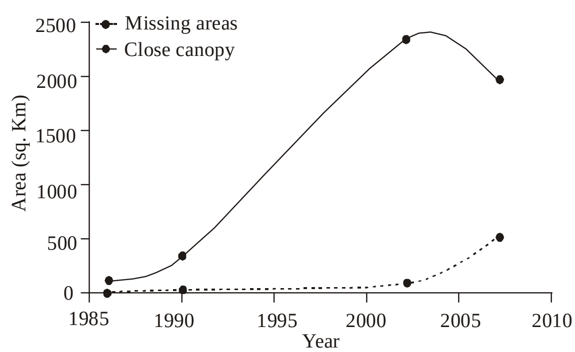

Fig. 8: A graph of mining areas and shrubs/herbaceous against year

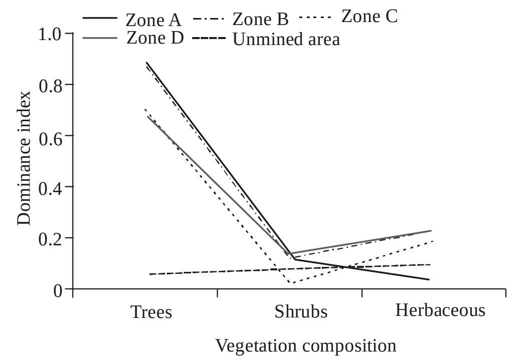

Fig. 9: Vegetation dominance curve

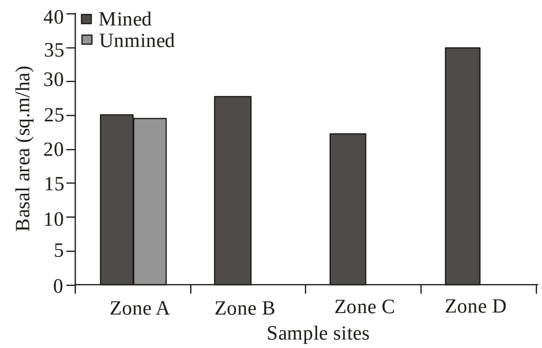

Fig. 10: Basal area of trees

zones followed by shrubs (0.079) and herbaceous (0.093). Dominance-diversity curves (Fig. 9) have been used to interpret the dominance of vegetation types in the TMA in relation to resource apportionment and niche space (Whittakker, 1975). The curve in the unmined areas falls between 0 and 0.2 suggesting more species richness apportionment among that section of the TMA. The curves for the mined areas in all the four zones resemble the broken-stick series model (Poole, 1974). This could be attributed to the lesser number of species occurring in these areas and also represent a stress environment where conditions are not favourable for vegetation growth. Species diversity was low on these stands, but the species that grow here appear to have developed tolerance that enables them to grow in such an environment.

Shannon-Weaver diversity index for tree and shrub species were less in the mined areas as compared to that of the unmined area. Diversity in tree species was drastically reduced in the mined areas in all the zones. There were not many differences in the diversity of ground vegetation both in mined and unmined areas (Table 8). The diversity index for herbaceous species increased with mining suggesting that mining operation enhanced the colonization of certain species in the newly created habitats. This confirms the findings of Sarma (2005), Das Gupta (1999) and Lyngdoh (1995).

The trees of medium girth class (26-55cm) dominate in the mined areas in all the zones. In the unmined areas the trees with low girth class (<14 cm) had the maximum individuals (Table 9). In the unmined areas, it was detected that the density of young and middle sized trees were higher than the older tree, indicating stable tree population structure. Such a tree population structure is normal and suggests that the vegetation is growing and would continue to exist. However, in the mined areas, the tree density in all the girth classes was extremely low and did not follow any standard density diameter population curve (Rao *et al.*, 1990). This has been due to rampant and random clearing of the vegetation for mining and has subsequently led to a drastic change in tree population structure.

In spite of the high population density in the unmined areas, it was detected that the basal area was low and this could be attributed to the trees dominated by small girth sizes. The higher basal area in the mined areas could be attributed to the existence of bigger trees and causing no damage to these trees during mining. This indicates the removal of younger trees during mining, making re-generation difficult. Similar trend was also observed by Parthasarathi and Karthikeyan (1997) in India, Newbery *et al*. (1992) in Malayasia and Paijmans (1970) in New Guinea for various disturbed vegetation stands.

Implications for the ecosystem: Ecosystem disturbance may be defined as an event or series of events that alters the relationship of organisms and their habitat in time and space. Mining is a major contributor to the ecosystem disturbance in the TMA. The mining areas and the other land use/cover types correlated well with the period under study. Through out the period under study, the changes that occurred in mining areas had a semblance of an exponential function (Fig. 6) while that of closed canopy experienced an exponential change culminating in Eq. (1) and Eq. 2, respectively. open canopy over the period underwent a change typical of a polynomial function of order 3 (Fig. 7) with the model shown in Eq. (3). Shrubs/herbs changed drastically, the rate of change being very strong ($R^2 = 0.96$) and indicating another polynomial (Fig. 8) of order 3 with a mathematical model shown in Eq. (4). Over the 21 years study period, vegetated areas in the TMA lost 932.92 km^2 where as non-vegetated areas (settlements and mining areas) gained 932.93 km^2 of land. This raises concern about the ill-controlled growth rate in the non-vegetated areas against the vegetated areas in the TMA. Kumi-Boateng *et al.* (2010) observed a similar trend in their study. They concluded that the main driving forces accounting for this trend could be attributed to the large surface and small scale mining activities where large tract of vegetation cover are cleared to pave way for mining as well as the increasing number of communities springing up without proper planning. The rate of changes in the various land use/cover types in the TMA is alarming and if the current situation is allowed to persist, by 2030, mining areas and shrubs/herbs would have increased to 1,710.00 and 2,781.68 km^2, respectively while closed and open canopies would have decreased to 8.41, and 360.50 km^2, respectively and this could lead to an imbalance in the ecosystem of the TMA.

CONCLUSION

- The classified land use/cover maps of TMA for the four years yielded five main land use/cover types (closed canopy, open canopy, mining areas and settlements) with an overall accuracy of 86.80% and a kappa statistic of 0.86. TMA experienced a total change of about 32%, indicating the stress that has taken place on the landscape during 21 years of time. About 173 km^2 of the closed canopy were converted into mining areas during this period. The change of open canopy to mining recorded a considerable size of 52.05 km^2. During the years 1986 and 2002, mining areas gained a total of 104 km^2 from closed canopy, open canopy and shrubs representing 3% of the total area under consideration. During this same period a total of 450.45 km^2 of closed canopy was converted to mining, shrubs and open canopy. The driving forces accounting for the land use/cover dynamics includes mining, construction of new houses and roads and population growth of TMA.
- Due to the extensive mining activities, large areas of TMA have been turned into degraded land, creating unfavourable habitat conditions for plants and animals. Mining activities coupled with urbanization has caused massive damage to the landscape and biological communities. It was found that the number of tree and shrub species decreased due to mining. The unfavourable habitat conditions prevailing in the mined areas have reduced the chances of regeneration of many a species, thereby reducing the number of species in the mined areas. Although the number of trees and shrubs decreased, the number of herbaceous species colonizing the mined areas was found to be higher in unmined areas. Similar observations were made by several researchers in the mining areas in different parts of the world (Conwell, 1971; Fyles *et al*., 1985; Game *et al*., 1982; Singh and Jha, 1987; Jha and Singh, 1990). The density of tree species decreased considerably in the mined areas. The density of the shrub species did not vary much. Lyngdoh (1995), Das Gupta (1999) in Jaintia Hills, and Sarma (2002) in Garo Hills district had similar observations. This could be due to the better ability of herbs to adapt to the disturbed sites. Some herbaceous species invaded the newly created habitats.
- Over the 21 years study period, vegetated areas in the TMA lost 932.92 km^2 whereas non-vegetated areas (settlements and mining areas) gained 932.93 km^2 of land. Finally, the rate of changes in the various land use/cover types in the TMA is alarming and if the current development continues, by 2030, mining areas and shrubs/herbaceous would have increased to 1,710.00, and 2,781.68 km^2, respectively while closed and open canopies would have decreased to 8.41 and 360.50 km^2, respectively and this could change the balance in the ecosystem of the TMA.

REFERENCES

Adu-Poku, I., 2010. Land-Cover Change Monitoring in Obuasi Using a Remote Sensing and GIS Approach. *MSc Thesis*, University of Glasgow, UK, pp: 78.

Akabzaa, T. and A. Darimani, 2001. Impact of Mining Sector Investment in Ghana: A study of the Tarkwa Mining Region, (Unpublished), pp: 71.

Anderson, J.R., E.E. Hardy, J.T. Roach and W.E. Witmer, 1976. A land use and land cover classification system for use with remote sensing data, USGS professional paper 964, Reston, Virginia, U.S. Geological Survey, pp: 23.

Anonymous, 2002. 2000 Population and Housing Census, Special Report on Urban Localities. Ghana Statistical Service, pp: 215.

Anon, 2010. Tarkwa-Nsueam Municipality. Retrieved from: www.ghanadistricts.com, (Accessed on: February 13, 2011).

Asubonteng, O.K., 2007. Identification of Land-use/cover Transfer Hotspots in Ejisu-Juaben District, Ghana. MSc Thesis, International Institute for Geo-information Science and Earth Observation ,Enschede, Netherlands, pp: 57.

Attua, E.M. and E. Laing, 2001. Land-cover mapping of the Densu Basin: Interpretations from multi-spectral imagery. Bull. Ghana Geograph. Assoc. 33: 1-8.

Baig, M.N., 1992. Natural revegetation of coal mine spoils in the rocky mountains of Alberta and significant for species selection in land restoration. Mountain Res. Dev., 12(3): 285-300.

Bektas, F. and C. Goksel, 2003. Remote Sensing and GIS Integration for Land Cover Analysis, A case study: Gokceada Isaland, (Unpublished), pp: 125.

Bell, F.G., S.E.T. Bullock, T.F.J. Halbich and P. Lindsey, 2001. Environmental Impacts Associated with an Abandoned mine in the Witbank Coalfield, South Africa. Int. J. Coal Geo., 45: 195-216.

Bradshaw, A.D. and M.J. Chadwick, 1980. The Restoration of Land, Blackwell Scientific Publication, Oxford. England, pp: 241.

Conwell, S.M., 1971. Anthracite mining spoils in Pennsylvania. I. spoil classification and plant cover studies. J. Appl. Ecol. 8: 401-409.

Das Gupta, S., 1999. Studies on vegetal and microbiological processes in coal mining affected areas, Shillong. Ph.D. Thesis, India, North-Eastern Hill University, pp: 228.

De Sherbinin, A., 2002. Land-Use and Land-Cover Change: A CIESIN Thematic Guide, Palisades New York, Center for International Earth Science Information Network of Columbia University, pp: 126.

Fyles, F.W., I.H. Fyles and M.A.M. Bell, 1985. Vegetation and soil development on coal mine spoil at high elevation in Canadian Rockies. J. Appl. Ecol., 22: 239-248.

Game, M.J., E. Carrel and T. Hotrabhavandra, 1982. Patch dynamics of plant succession on abandoned surface coal mines: A case history approach. J. Appl. Ecol., 16: 1-15.

Griffis, R., J. Kwasi, B. Agezo, F.L. and F.K. Akosah, 2002. Gold Deposits of Ghana. Minerals Commission, Ghana, pp: 438.

Jha, A.K. and J.S. Singh, 1990. Revegetation of Mine Spoils: Review and Case Study. Environmental Management of Mining Operations, Ashish Publishing House, New Delhi, pp: 326.

Iverson, L.R. and M.K. Wali, 1982. Buried, viable seeds and their relation to revegetation after surface mining. J. Range Manage., 35(5): 648-652.

Kerle, N., L.L.F. Janssen and G.C. Huurneman, 2004. Principles of Remote sensing ITC Educational Textbook Series, ITC, Enschede, Netherlands, pp: 250.

Kumi-Boateng, B., C.B. Boye and Y. Issaka, 2010. Land Use/Land Cover Mapping Using Remote Sensing for Urban Development-A Case Study of Tarkwa and Its Environs", Proceedings of ASPRS 2010 Conference on Opportunities for Emerging Geo-Spatial Technologies, San Diego-Califonia, 26-30 April, 2010, San Diego, California-USA, pp: 1-11.

Lambin, E.F., B.L. Turner, S.B. Agbola and A. Angelsen, 2001. The Causes of Land-use and Land-cover change; moving beyond the Myths. Global Environ. Change, 11: 261-269.

Lillesand, T.M. and R. Kiefer, 1994. Remote Sensing and Image Interpretation. John Villey and Sons Inc, New York, pp: 613.

Lunetta, R.S., 1999. Applications, Project Formulation and Analytical Approach. In: Lunetta, R.S. and C.D. Elvidge, (Eds.), Remote Sensing Change Detection: Environmental Monitoring Methods and Applications. Taylor & Francis, London, UK, pp: 1-19.

Lyngdoh, T., 1995. Community dynamics and edaphic changes in relation to coal mining in Jaintia Hills, Meghalaya. Unpublished Ph.D. Thesis, North-Eastern Hill University, Shillong, India, pp: 250.

Lyngdoh, T., R.S. Tripathi and A.K. Das, 1992. Vegetation dynamics on coal mine spoils of Jaintia Hills in Meghalaya (North-East India) undergoing natural recovery. Act. Oecologia, 13(6): 767-775.

Mas, J.F., 1999. Monitoring Land-cover changes: A comparison of change detection techniques. Int. J. Remote Sens. 20(1): 139-152.

Misra, R., 1968. Ecology Work Book. Oxford & IBH Publication, New Delhi, pp: 610.

Muller-Dombois, D. and H. Ellenberg, 1974. Aims and Methods of Vegetation Ecology. John Wiley & Sons, New York, pp: 320.

Newbery, D.M., E.J.F. Canpbell, Y.F. Lee, C.E. Ridsdale and M.J. Still, 1992. Primary lowland dipterocarpus forest at danum valley, Sabah, Malaysia: Structure, relative abundance and family composition. Proceedings of the transactions of Ropyal Society, London, pp: 127-139.

Osei, E.M. and Y.X. Zhou, 2004. Land cover change detection in west Jilin using ETM+ images. J. Geosci. Res. N.E. Asia, 7(1): 74-84.

Paijmans, K., 1970. An analysis of four tropical rain forest sites in Guinea. J. Ecol. 58: 77-356.

Pandey, H.N., 1993. Studies on Environmental Impact of Coal Mining in Jaintia Hills District. North Eastern Hill University, Shillong, pp: 521.

Parthasarathi, N. and J. Karthikeyan, 1997. Biodiversity and population density of woody species in a tropical evergreen forest in Courtallum Reserve Forest, Western Ghats, India. Trop. Ecol. 38(2): 297-306.

Poole, R.W., 1974. An Introduction to Quantitative Ecology. Mc Graw Hill, Kogakusha Tokyo, pp: 741.

Prakash, A. and R.K. Gupta, 1998. Land-use mapping and change detection in a coal mining area-a case study in the Jharia coal field, India. Inter. J. Remote Sens. 19(3): 391-410.

Prasad, R., 1989. Removal of forest cover through mining and technology for retrieval. J. Tropical Forestry, 5: 109-116.

Rao, P., S.K. Barik, H.N. Pandey and R.S. Tripathi, 1990. Community composition and tree population structure in a sub-tropical broad-leaved forest along a disturbance gradient. Veg., 88: 151-162.

Rathore, C.S. and R. Wright, 1993. Monitoring environmental impacts of surface coal mining. Int. J. Remote Sens. 14: 1021-1042.

Sarma, K., 2002. Coal mining and its impact on environment of Nokrek Biosphere Reserve, Meghalaya Shillong. Ph.D. Thesis, North-Eastern Hill University, pp: 182.

Sarma, K., 2005. Impact of coal mining on vegetation: A case study in Jaintia hills district of Meghalaya, India. MS.c. Thesis, International Institute for Geo-information Science and Earth Observation, pp: 85.

Sedego, C.A., 2007. Assessing the impact of urban expansion and land-cover within the landscape of Kumasi metropolitan Area, Ghana. MS.c. Thesis, International Institute for Geo-information Science and Earth Observation, Enschede, pp: 51.

Serra, P., X. Pons and D. Sauri, 2003. Post-classification change detection with data from different sensors: Some accuracy considerations. Inter. J. Remote Sens. 24(16): 3311-3340.

Shalaby, A. and R. Tateishi, 2007. Remote sensing and GIS for mapping and monitoring land cover and land-use changes in the Northwestern coastal zone of Egypt. Appl. Geog. 27: 28-41.

Singh, J.S. and A.K. Jha, 1987. Ecological aspects of reclamation and revegetation of coal mine spoils", Proceedings of National Workshop on Environmental Management of Mining Operations in India- A status paper, India, Department of Mining Engineering, B.H.U. Vanarasi, pp: 73-86.

Tutu Benefoh, D., 2008. Assessing the effects of land-use/cover change on ecosystem services in Ejisu-Juaben District, Ghana: The case study of carbon sequestration. MS.c. Thesis, International Institute for Geo-information Science and Earth Observation, Enschede, pp: 88.

Vasconcelos, M.J.P., J.C.M. Biai, A. Araujo and M.A. Diniz, 2002. Land cover change in two protected areas of Guinea-Bissau (1956-1998). Appl. Geogr. 22: 139-156.

Whittakker, R.H., 1975. Communities and Ecosystems. Mc Milan Publishing Company, New York, pp: 548.

Yuan, F., E. Kali and J. Sawaya, 2005. Land cover classification and change analysis of the twin cities (Minnesota) metropolitan area by Multi-temporal landsat remote sensing. Remote Sens. Environ., 98: 317-328.