Land Use Change Detection as an Initial Stage in Environmental Impact Assessment on the Zambian Copperbelt

Proceedings: 28th ISRSE: Information for Sustainable Development, *Cape Town, 27-31 March, 2000*

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Abstract - Copper has been exploited in Zambia for much of this century. As population pressure on the natural resource base in the Copperbelt has increased, environmental impacts arising from mining and other industries have become less acceptable.

An assessment of environmental impacts must measure changes in natural resources. Developing countries lack the extensive environmental databases required for comprehensive environmental impact assessment. In Zambia, up-to-date maps are scarce and so recourse is made to satellite remote sensing. Land use classes are identified using a combination of published maps, aerial photography, satellite images acquired by Landsat and field verification. Through edge-enhancement, the generation of false colour composites and supervised classification, land use classes are quantified for images acquired in 1972, 1984 1989, 1997 and 1998.

Trends in the data are interpreted and the implications for the environment are discussed.

INTRODUCTION

Globally changes in land use are increasingly altering land cover. These changes occur mainly in the tropics (Houghton, 1994, in Lambin, 1997) and have implications for the sustainability of socio-economic development as they affect climate, soils, water, vegetation and biodiversity (Mather & Sdasyuk, 1991, in Lambin, 1997).

Most changes in terrestrial ecosystems arise from anthropogenic land cover conversion, land degradation or land use intensification (Lambin, 1997). The most widespread example of land cover conversion is tropical deforestation. To assess the environmental impacts arising from man's activities two questions are important:

1. Which locations are affected by land cover changes?
2. At what rate do land cover changes progress?

This paper provides answers to these questions and thus input into an assessment of environmental impact. It is concerned with identifying areas undergoing change near the city of Kitwe in the Zambian Copperbelt.

DETECTION OF CHANGE

In environmental studies, "change" implies an alteration in the surface components of a landscape. Common types of change detectable on remotely sensed (RS) imagery are associated with vegetation clearance, urban expansion, changing water levels in surface water bodies, vegetation regeneration after disturbance and soil disturbances resulting from mining, landslides and overgrazing (Milne, 1988).

Changes can be abrupt or gradual. If abrupt, the alteration of the surface is complete and usually marked by clear boundaries. Such changes are easily detected on RS imagery. Subtle changes, such as the gradual deterioration of vegetation resulting from overgrazing, occur without distinct boundaries and are far more difficult to detect.

The principal value of generating change maps is that they allow identification of the locations of high magnitude changes. This results in the concentration of monitoring and modelling efforts in the "hot spots" (Lambin, 1997).

Land cover maps produced using RS data are a significant source of information for monitoring change in land use and land cover across large areas (Aspinall & Hill, 1997). These changes are detected by comparing images acquired at different times (Singh, 1989 in Bruzzone & Serpico, 1997).

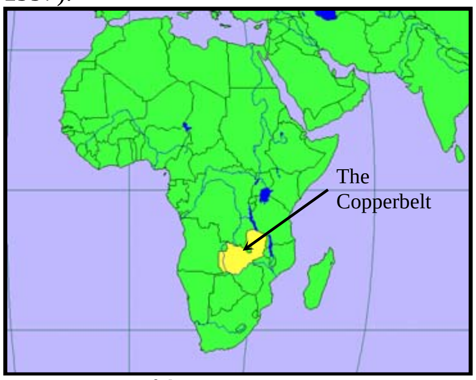

Fig. 1 Location of the AOI

Most change detection techniques can be grouped into two classes: 1) spectral classification of input data; and 2) radiometric change between acquisition dates (Johnson & Kasischke, 1998). The former include procedures which a) assess change based on classification and subsequent comparison of results from different dates, or b) assess change based on direct two-date classification. Radiometric techniques include: a) band differencing, b) transformed band differencing, such as vegetation indices, c) ratioing, d) regression, e) principal components and f) multispectral change vector magnitude and direction (Johnson & Kasischke, 1998). Both classes are applied in this paper.

LAND USE CHANGE IN KITWE: CHANGE ANALYSIS USING MAPS AND TM FALSE COLOUR COMPOSITES

Kitwe lies near the centre of the copper mining complex that has driven Zambia's economy since 1930. The earliest data available for this study is a topographic map produced from aerial photographic missions flown in 1957. This map was digitised and the areas of preselected land use classes were recorded. Two Landsat Thematic Mapper (TM) data sets were used: one from 1989 and the second from 1998. A Landsat Multi Spectral Scanner (MSS) data set acquired in 1972 was used to provide information between 1957 and 1984. Not all the land cover classes could be extracted from this data set as the precision of MSS data is appreciably lower than that of TM. The satellite data sets were haze corrected using the improved dark-object subtraction technique (Chavez, 1988) and edge-enhanced to improve discrimination between land cover types. These five data sets were then compared to assess trends on land cover classes over the last forty years.

Some land cover and land use classes are amenable to assessment by supervised classification. Others are more problematic. Small land use classes with many mixed pixels which cannot be separated on spectral characteristics alone, but also require ancillary information for their classification, have been digitised on-screen using aerial photographs from 1968, 1984 and 1990 for verification. This group includes urban areas, mine surface infrastructure and other anthropogenic surfaces.

A second group that is not readily classified using supervised classification techniques includes natural land covers such as the Miombo woodland in the area of interest (AOI) and agricultural land. While both these land covers can be classified using known areas as training sets, calibration of classification parameters, to make comparison between years meaningful, is onerous. For this reason, these land cover classes have been assessed by generating multi-temporal false colour composite images (FCCs).

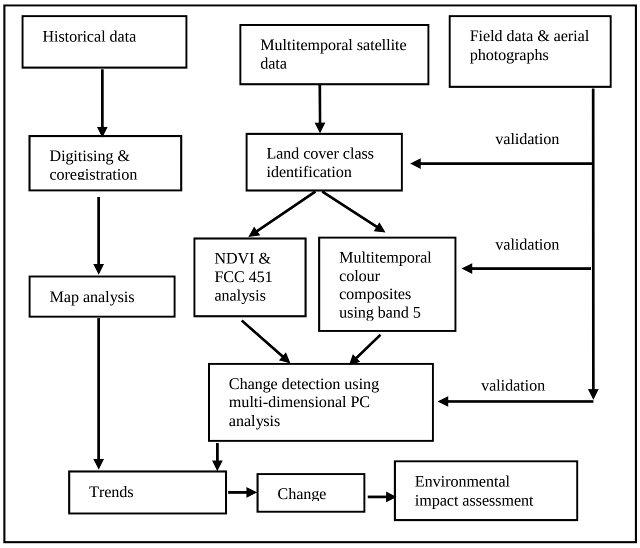

Fig. 2 Methodology

TRENDS IN ANTHROPOGENIC SURFACES

Concentrated informal settlements have high building density, small buildings and the absence of observable street patterns. On the band 4 5 1 FCC, these areas appear light-grey/white. Urban areas have similar spectral characteristics to concentrated informal settlements, but exhibit higher spectral variation (possibly due to the presence of gardens and parks). Regular street patterns are observable in these areas.

Informal settlers are vulnerable to water pollution and land degradation by mining as they rely on direct exploitation of these resources. In turn they degrade both land and water by over-exploitation and lack of sanitation.

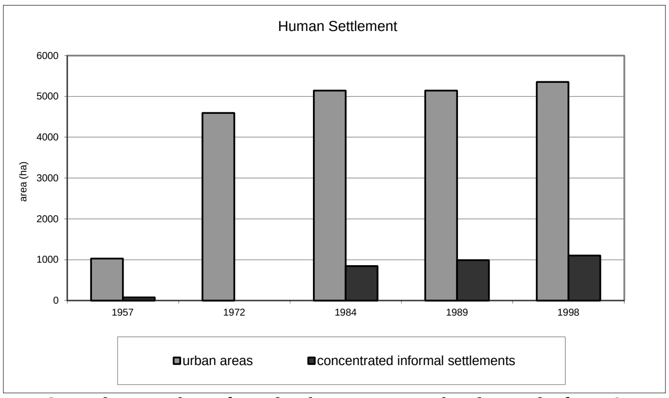

Fig. 3. Little growth in formal urban areas can be detected after 1972. During this period most population growth appears to have occured in informal settlements. MSS data is too coarse to detect informal settlements and so no data is available for 1972.

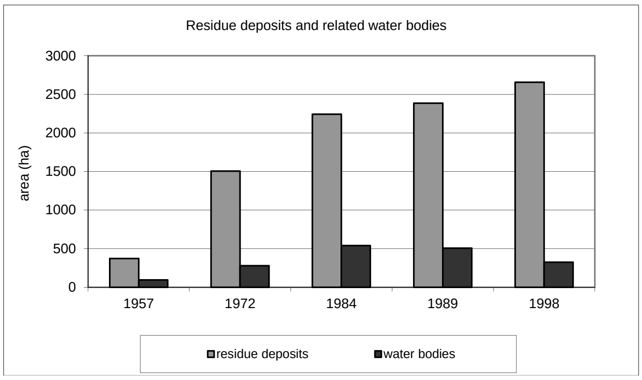

Fig. 4. In 1957 water bodies were only related to tailings if they occurred direclty on the tailings as ponds. With the introduction of valley dams in the 1960's, lakes were created by tailings dykes. As these lakes were backfilled with tailings, water surface areas diminshed as the tailings increased.

In excavations, dry, hard surfaces result in high reflectance values. Excavations can often only be separated from other anthropogenic surfaces, such as residue deposits, by referring to collateral data. After 1989, no increase in area in surface excavations is detected, probably due to exhaustion of near-surface reserves. No reduction in area is observed and therefore no rehabilitation has occurred.

Disturbed land forms a class of anthropogenic surfaces which are not excavations, residue deposits or settlements and appear blue on the FCC. Ancillary data suggests that mine surface infrastructure such as metallurgical plants and shafts occur in these areas. The maximum area covered by this class occurs in 1984, after which it declines. Other unidentified land uses also occur within this class.

Plantations show up as areas of deep red colour and rough texture on the FCC. These areas correlate well with exotic softwood plantations defined on the 1984 topographic map.

Mine residue deposits occur as bright areas of characteristic shape easily identified on the FCC and equally easily verified with collateral data. Spillage sometimes makes the separation of individual dumps difficult.

Water bodies are clearly delineated blue-black areas on the FCC. This water is associated with residue deposits, either in ponds on top of ring dyke tailings deposits or in lakes formed when valley dam tailings impoundments are established.

To assess changes in the natural woodland cover and the increase in agricultural areas, a FCC using band 5 from 1984, 1989 and 1997 was used. This image showed changes in vegetated areas clearly. Band 5 is useful for vegetation and soil moisture studies (USGS, 1997).

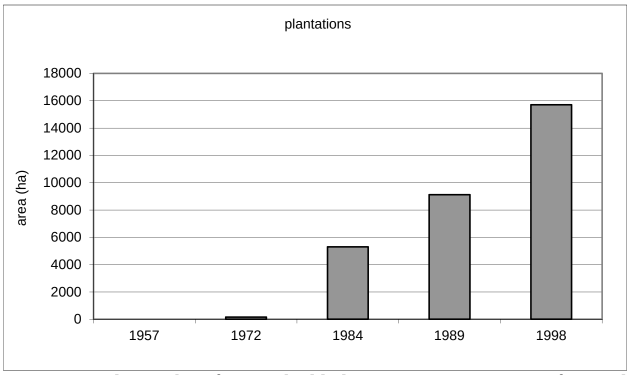

Fig. 5. Rapid growth in forestry had led to increasing amounts of natural woodland being converted into exotic softwood plantations.

MULTI-TEMPORAL FCC ANALYSIS

Initially, the 1984, 1989 and 1998 TM data sets were used in FCC analysis. The 1998 image was acquired at the end of the dry season and the other images at the end of the rainy season. This difference had little effect on detecting anthropogenic surfaces, but became significant is assessing natural vegetation cover. Therefore, an FCC of the years 1984, 1989 and 1997 was used, reducing seasonal effects.

The Copperbelt is situated in the Miombo woodland biome, characterised by scattered trees and grass. Woodland is the category least affected by human activities. Observable in virgin areas as exaggerated drainage patterns, dambos are natural wetlands occurring in the Miombo. They are linear features associated with watercourses and are generally absent in urban areas. Dambo conservation is a priority.

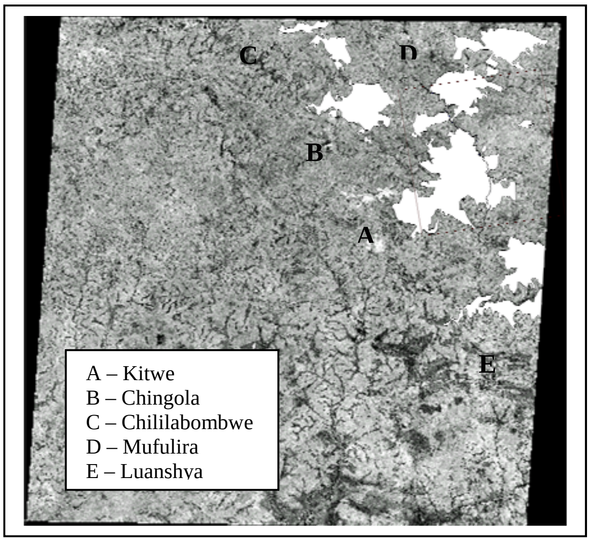

Fig. 7. Deforestation around Copperbelt towns digitsed using 1972 MSS data. The deforested polygons are superimposed over MSS band 7 data. The AOI is indicated in the north orientated square and the Kafue River is shown as the black line crossing the Kitwe polygon in the AOI.

Agricultural areas appear as light blue-green areas of high variation characterised by mixed pixels largely corresponding to known occurrences of peasant farming, small settlements, deforested land and erosion. The increase in area of this land cover at the expense of Miombo woodland was assessed using multitemporal FCCs. The 1972 MSS image was used to digitise spreading centres of deforestation. Each of the towns in the Copperbelt have acted as settlement nuclei from which agricultural activities have radiated.

CLASSIFIED VEGETATION CHANGE MAP

Normalised difference vegetation index (NDVI) images were generated for each year. The map of changes in woodland and agricultural surfaces between 1984 and 1989 was produced by examining each pixel of the 1984 NDVI image and the 1989 NDVI. An “increase” label was assigned where the NDVI value was larger in 1989, than in 1984, and a “decrease” label in the opposite case. To reduce the effect of noise, a label was only assigned if the difference between the values was greater than 30. The equation used was as follows (ndvi84ri and ndvi89ri are the NDVI images):

iff(ndvi84ri>ndvi89ri+30,"decrease 84-89",
iff(ndvi84ri+30<ndvi89ri,"increase 84-89", "stable 84-89"))

This process was carried out for the 1989 and 1997 NDVI images as well and both change maps were subjected to a majority filter to remove speckle and insignificant areal changes. The resultant maps were combined to produce a map showing changes for the full period of examination (ctveg89m and ctveg84m are the majority filtered maps):
iff(ctveg89m="stable 89-97",ctveg84m,ctveg89m)

The resultant map was subjected to a majority filter.

ANALYSIS AND IMPLICATIONS FOR THE ENVIRONMENT

In the forty-year period investigated here, the zone of deforestation around Kitwe has increased dramatically and has merged with that of neighbouring Mufulira. Natural land cover near the Copperbelt cities has largely been converted into sparsely vegetated (high reflectance) agricultural areas. With the high intensity rainfall events common here and the poor nutrient levels in the latteritic soils, permanent land degradation is likely.

Within Kitwe, most mining-related land uses increased significantly in the 1970’s and early 80’s during the boom years for the copper industry. Since the decline of world commodity prices, mining infrastructure has ceased growing in area. The same trend occurs in urban areas.

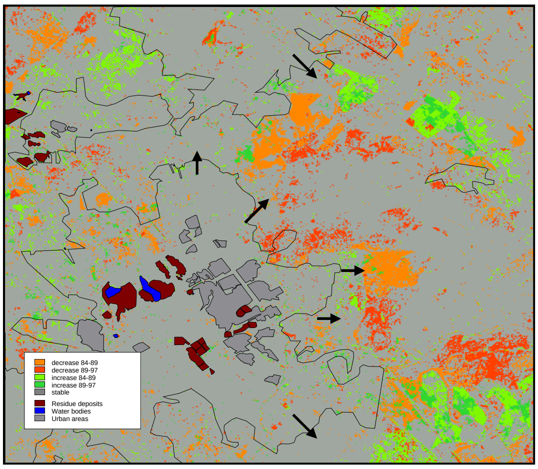

Fig. 8. Digitised temporal deforestation fronts traced on multitemporal FCCs and then superimposed over classified vegetation change areas. Arrows show direction of front movement. Changes in vegetation in the AOI 1984-1997: black = 1984-1989 decrease. Dark grey = 1989-1997 decrease. Light grey = 1984-1989 increase and grey = 1989-1997 increase. Kitwe is shown in grey polygons and the Kafue River appears in black.

Population growth has not stabilised, however, as seen in the increasing extent of informal settlements. With little funding available for urban development and service provision, increasing numbers of people live without sanitation or access to clean water. This combined with the presence of mine pollution has led to an unacceptable impact on the community.

Simple techniques applied to RS data have uncovered land use trends in areas surrounding Kitwe and within the city, that threaten the long term sustainability of human habitation in the area.

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