MAPPING MINING WASTE AND ENVIRONMENTAL IMPACTS IN ZAMBIA WITH LANDSAT

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1. Introduction

Copper-bearing sediments are preserved in the 800 km long Lufilian Arc on the central African plateau, forming one of the great mineralised regions of the world. The southern portion of this region falls within Zambia and is known as the Zambian Copperbelt, where mining can be traced back to 350 AD (Holmes, 2001). Large-scale copper production commenced in the 1930s and has been the key driver of the Zambian economy.

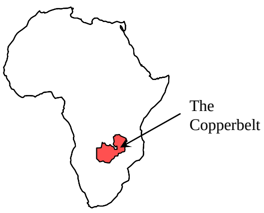

Figure 1. Location of Zambia and the Copperbelt.

Mining companies in the Copperbelt were nationalised in 1969 and were later amalgamated into Zambia Consolidated Copper Mines (ZCCM)[1]. ZCCM operated five mining divisions and one electrical distribution division, and was a fully integrated mining and metallurgical company. Across the Copperbelt, approximately 30 Mt of copper has been produced (Lungu, 1998) and significant qualities of waste rock have been disposed of at surface.

Mining and minerals processing in the Copperbelt has been characterised by large open pits, deep shafts, large volume waste disposal, large volumes of water pumped from underground and substantial pyrometallurgical processing. Many significant environmental impacts have resulted: surface subsidence, air pollution from smelters, siltation of rivers, pollution of land and water resources, land sterilisation and habitat destruction. The spatial extent and temporal dynamics of these impacts are not well understood. This paper describes methods applied to map mine wastes in the Copperbelt to determine environmental changes over time.

2. Understanding the spatial dynamics of environmental degradation

Environmental management consists of controlling those activities that are potentially damaging to the environment, and rehabilitating land that has been degraded by earlier activities. For this management to be effective, data collection and analysis must be timely, accurate and sufficient (Barandela, 1997; Mather, 1988). Two datasets are particularly important (Mather, 1988): a) the present distribution of land cover and terrain types, and, b) measures of the direction and rate of change of these distributions.

Baseline conditions characterising an environment at a point in time must be established before changes in the state of that environment can be monitored. Remote sensing is a powerful and proven tool in environmental studies (Loveson & Dhar, 1995) and can be used to determine current and past states of the environment. Remotely sensed data enable a synoptic view and provide global coverage, as well as having the advantage of relatively good consistency and repeatability (Limpitlaw & Woldai, 2000; Mather, 1988).

The distribution and rate of change in key land use classes, of which mine waste deposits are a prime example, must be determined. This facilitates the measurement of change in anthropogenic surfaces and thus investigates possible linkage between such changes and the changes detected in land cover. Using a combination of data sets, including panchromatic aerial photographs (1968, 1984 and 1990), a Landsat Multispectral Scanner image (MSS) (1972), Landsat Thematic Mapper images (TM) (1984 and 1998) and a Landsat Enhanced Thematic Mapper image (ETM) (2000), changes in the area occupied by various types of mine

[1] ZCCM has recently been privatised.

infrastructure have been identified. The area occupied by mine infrastructure before 1960 was digitised from 1:50,000 topographic maps published by the Northern Rhodesian and Zambian Surveyors General. These maps are based on aerial photographic missions flown between 1947 and 1957.

The task of mapping key land use classes is confounded by the lack of a comprehensive environmental survey for the Copperbelt and inaccuracies in maps and mine data. Many old dumps are not indicated on government topographic maps and mine data tables may reflect incorrect areas for known dumps. Table 1 shows the differences in areas derived from generalised outlines of the Mindola dump shown on the government topocadastral map and those derived using remote sensing (RS). The reported area in a mine plan is also included.

Table 1. Reported and measured areas of mine waste deposits in the former Nkana Division of ZCCM.

Mine Waste Deposit	*Area Reported in Mine Plans* (ha)*	*Area Digitised from Topocadastral Map (ha)*	*Area Measured using ETM image (ha)*
Mindola West 15A	7,091.9	659.5	674.3
Mindola 15 East	1,300.0	not shown	411.6

* Mineral Resource Inventory, Nkana Division, ZCCM (unpublished).

3. Mapping Mine Waste

To provide information on dump status, location and extent, medium resolution satellite data was referenced to the local coordinate system and processed. Dumps identified were verified through field assessments and by aerial photographic analysis. Images acquired by Landsat were found to adequately map dumps of a range of sizes and materials. Using a time series of Landsat images, vegetation cover and increases in dump area were mapped.

Tasselled Cap (TC) transforms yielded good land cover classification results for the Copperbelt. The TC transform is based on the principle that combining multiple bands into a lesser number of features reduces the overall data volume and enhances the processor's ability to extract particular types of scene class information (Crist *et al*., 1986). This transformation is particularly useful in this investigation, as MSS and TM datasets have to be compared. Crist and Cicone (1984) found that TM TC features provide a direct association with MSS TC features, as the greenness and brightness features were identical in all aspects except dynamic range and signal-to-noise ratio. Colour composite (CC) images were created using wetness component in the blue channel, the greenness in the green channel and the brightness component in the red channel. For classification of broad changes in vegetation assemblages around mine sites these images were subjected to supervised classification. For the identification of mine waste deposits, the colour composite was analysed and features were digitised on-screen.

Detecting Changes in area covered by mine waste

Differences in the resolution of sensing instruments, as well as registration errors, result in some waste deposits appearing different in successive images, when little or no change has occurred. This reduces the accuracy of change detection. Changes in the surface condition of some waste deposits also contribute to erroneous detection of change. For example, the waste rock dump adjacent to the Konkola[2] plant area appears smaller in later images due to increasing vegetation cover (planned or un-planned). This apparent change is detected in successive TC CCs created for the 1972, 1984, 1998 and 2000 data sets. Areas covered by tailings and waste rock appear to decrease in the last two images, even though the waste deposit area has not changed.

To overcome the detection of spurious changes in the area covered by mine waste dumps, it is assumed that, unless reprocessed, these dumps do not decrease in size. Dump dimensions in subsequent years are therefore digitised over the boundary segments captured in the first year

[2] A mine in the north of the Copperbelt near the border with the Democratic Republic of Congo.

for which data is available. This reduces the risk of misclassifying old, inactive portions of dumps, which may be covered by vegetation.

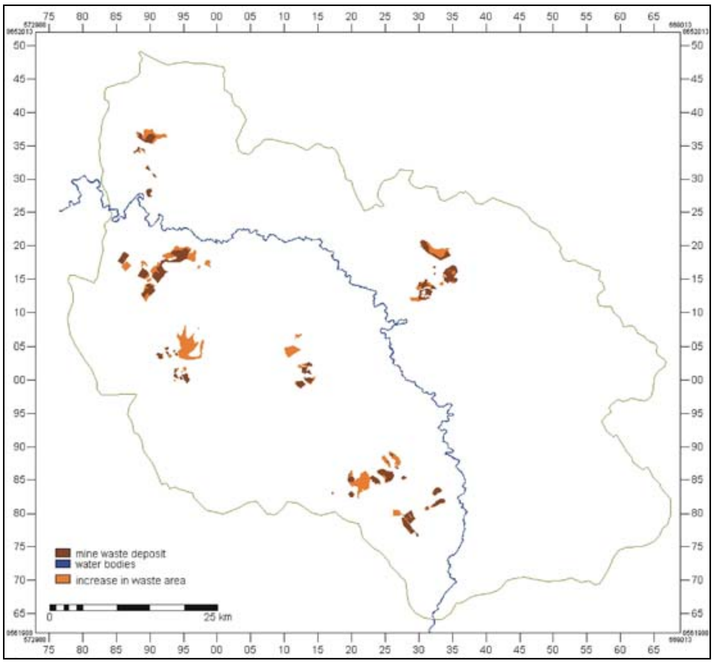

Figure 2. Change in the area covered by mine waste 1972-2000.

4. Results

Mine waste deposits identified in the 1972 MSS image were compared with those in the 2000 ETM image. The change in area covered by the dumps is shown in Figure 2. The deposits shown in this figure occur in the north of the Copperbelt in a portion of the Kafue River catchment (shown by the polygon outline). By the year 2000, mine waste deposits covered 8,350 ha, up from 4,289 ha in 1972. This excludes the area covered by the water bodies associated with the deposits.

5. Conclusion

This provides a rapid and cost effective way of establishing a dump inventory over a large, mature mining region. The inventory and related environmental information is very useful in environmental impact assessments and provides a means of evaluating changes in land cover and land use classes over time. This data was compared with changes in vegetation assemblages and used to show that mining-derived land cover conversion was not the principal driver of change in the Zambian Copperbelt (see Limpitlaw, 2003).

6. References

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