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MAPPING THE STATUS OF MINING WASTE USING LANDSAT DATA IN THE RUSTENBURG REGION

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ABSTRACT:

The Rustenburg region, located in the North West Province of South Africa has been subjected to several decades of intensive mining. Landsat images spanning a period of 29 years were used to analyse changes in the mining waste status. NDVI, MNDWI images and TC were used to evaluate vegetation and water coverage of the mining waste and its surroundings. From 1973 to 2002, the extent of the mine tailings area increased from 411 to 2614 ha (640%). This study has shown that Landsat medium resolution satellite images proved to be an efficient tool and cost effective way of mapping the status of mine wastes.

INTRODUCTION

The Rustenburg region lies on the edge of the Bushveld Igneous Complex (BIC), one of the most heavily mineralised regions in the whole world. The two largest platinum mines in the region are located on land owned by the Royal Bafokeng people. Minerals mined in the area include platinum, chrome, marble, tin, lead and granite. Despite the region being an industrial and mining area, agricultural activities also contribute greatly to the economy of the region. Mining and mineral processing of in the area is characterised by large open pits, deep shafts and large volume of waste. Environmental management constitutes the control of those activities that are potentially damaging to the environment, and rehabilitating land degraded due to human activities. Mining activities and the waste products they produce can have significant effects on the surrounding environment, ranging from localized surface and ground water contamination, to the damaging effects of airborne pollutants on the regional ecosystem.

Mapping the environmental impacts of mining, during production and after closure, requires comprehensive monitoring and assessment of changes in environmental variables over both time and space (Limpitlaw, 2006). Data collection and analysis that is timely, accurate and comprehensive is required for efficient environmental management. Such data can be expensive to acquire. A cost effective way is to augment surface sampling is with remotely sensed data. Remotely sensed data enable a synoptic view and provide a wide coverage of a relatively good consistent and reliable data (Limpitlaw and Woldai, 2000; Rathore and Wright 1993).

Due to the high temporal and spatial dynamics of mining areas, mining companies have carried out analyses based on the analogue and digital interpretation of multi-temporal aerial photographs since the 1970s. With the launching of the Landsat Satellite 1972, researchers began to use satellite data for monitoring mining activities in different parts of the world (Anderson, 1977). The distribution and rate of change in land use of which mine waste deposits is a key factor in a mining area need to be investigated. This helps to establish a link between changes detected between land covers and the drivers behind these changes. The aim of this study is to provide information on the location, extent and changes in the area occupied by mine waste deposits using medium resolution imaging devices, in the Rustenburg, district, Northwest Province of South Africa.

Study area

The study area was chosen based on the geology of the area, which is dominated by igneous rock formations. Most of the operating platinum mines are located on the Rustenburg layered suite of the Bushveld complex, close to Rustenburg town The area forms part of the Crocodile River Catchment with its main rivers being the Hex, Elands and Sterkstroom rivers. The Hex River is a major supply of water in the region. As the water drains northward, the pollutant loads increases, principally due to organic contaminants from sewage arising from the growth of informal settlements in the area. Artificial water diversions occur throughout the catchment, constructed for agricultural, industrial and mining purposes. The area consists of a relatively flat landscape intersected by drainage lines, bounded on the southern margin by a low mountain range, Magaliesberg (Which forms the Magaliesberg Protected Environment (Figure 1).

DATA AND METHODOLOGY

Landsat MSS (Multi Spectral Scanner), Landsat TM (Thematic Mapper), and Landsat ETM+ (Enhanced Thematic Mapper) images were acquired for the periods 1972 to 2002 (Table 1). All of the images chosen for processing were collected in winter season to enhance spectral separability, yet minimise spectral similarity due to excessive surface wetness during the summer period when everything appears green.

Figure 1: Rustenburg regional locality map: The Magelisberg protected environment shown in green in the south of the map. [Source: Ecological and Environmental Consultants]

Table 1: Landsat scenes accessed for this study.

Year	Sensor	Path	Row	Acquisition date	Resolu-tion
1973	MSS	183	78	1973/04/10	57 m
1989	TM	171	78	1989/08/30	30 m
1998	TM	171	78	1998/07/06	30 m
2002	ETM+	171	78	2002/07/23	30 m

Image pre-processing

Prior to any digital processing, all the images were radiometrically normalised (Hall et al., 1991). This is done by rescaling the raw digital data transmitted from the satellite to calibrated digital data, which have the same post-calibration dynamic range for all scenes processed on the ground for a specific period of time (Alford and Baker, 1983; Abrams et al., 1985).

The calibration is given by the following expression at satellite spectral radiance

$$L\lambda = Bias + (Gain \times DN) \qquad (1)$$

Gains and biases for each band l are calculated from the lower (Lmin) and upper (Lmax) limits of the post-calibration spectral radiance range.

$$Gain = L\max\lambda/254 - L\min\lambda/255$$

$$Bias = L\min\lambda \qquad (2)$$

Equations (2) were used to solve equation (1).

The values of Lmax and Lmin can be obtained from the header file, which accompanies the data.

The spectral radiance was now converted to exo-atmospheric reflectance using equation (3)

$$\rho = \prod . L . d^2 / \{ESUN . \cos(SZ)\} \qquad (3)$$

where $\rho =$ unitless planetary reflectance at the satellite (this takes values in the range 0 to 1) ;
L = spectral radiance at sensor aperture in mW cm^{-2} $ster^{-1}$ mm^{-1};
d^2 = the square of the Earth-Sun distance in astronomical units, equal to $(1 - 0.01674 \cos(0.9856 (JD - 4)))^2$;
JD is the Julian Day (day number of the year) of the image acquisition;
ESUN = mean solar exo-atmospheric irradiance in (mW cm^{-2} mm^{-1}); and
SZ = sun zenith angle in radians when the scene was recorded (Markham and Barker, 1986).

After the radiometric normalisation process, all the images were geometrically corrected. The image acquired in 2002 was geo-referenced to the UTM coordinate system, zone 35 South based on 1:50,000 scale digital topographic maps using 18 control points on the map. The other images were registered through an image-to-image registration tie down algorithm with the 2002 scene. All image data processing was carried out using TNT MIPS 7.0® image processing system. The 1973 and 2002 scenes were each resampled to 60 m resolution for accurate comparison using the nearest neighbour 3x3 pixel method and the study area was then extracted from each of the images.

The Normalised Difference Vegetation (NDVI) was used to measure the presence of vegetation on the mine waste. This involves the combination of bands consisting of red and near infrared (NIR) wavelengths (Lyon et al., 1998).

$$NDVI = (NIR - Red) / (NIR + Red) \qquad (4)$$

The Normalised Difference Water Index (NDWI) was used to detect whether the mine waste has any water content in them. The NDWI makes use of reflected near-infrared radiation and visible green light to enhance open water features while eliminating the presence of soil and terrestrial vegetation features (Hanqiu, 2006; McFeeters, 1996).

The NDWI is expressed as follows (McFeeters 1996):

$$NDWI = (Green - NIR) / (Green + NIR) \qquad (5)$$

where Green is a green band (TM band 2), and NIR is a near infrared band (TM band 4).

These band combinations maximize reflectance of water by using green band wavelenths; minimize the low reflectance of NIR by water features and take advantage of the high reflectance of NIR by vegetation and soil features. As a result, water features have positive values, thus are enhanced, while vegetation and soil usually have zero or negative values, and are therefore suppressed (McFeeters 1996).

Hanqiu (2006) developed a modification of the (NDWI) to enhance open water features in remotely sensed imagery because in the NDWI-image built up area also gives a positive value like water. Based on the assumption he proposed that, the Middle Infrared radiation (MIR) be substituted for the NIR band. This is expressed as follows:

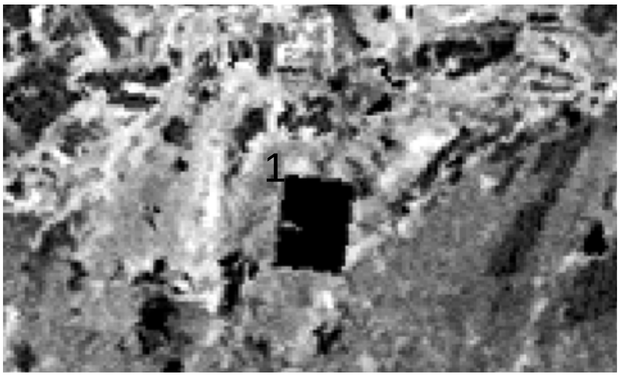
$$MNDWI = (Green - MIR) / (Green + MIR) \quad (6)$$

Although this method is commonly used to delineate open waters, it was also found useful in monitoring mine waste with water bodies on the surface where the water bodies appear. This is interpreted to mean that the mine wastes were being sprayed with water to prevent wind blown dust and it shows also the return water ponds associated with it.

The Tasselled Cap (TC) transformation is also useful to compare data from different sensors since we are comparing. The TC transform is based on the principle that combining multiple bands into lesser features reduces the overall data volume and enhances the ability to extract particular types of scne class information (Crist et al., 1986). Colour composite (CC) images were then created using the Tasseled Cap components with greenness in the green channel, wetness component in the blue component and the brightness in the red channel. For the identification of mine waste, the colour composite of band 731 proved useful and the features were digitized on screen.

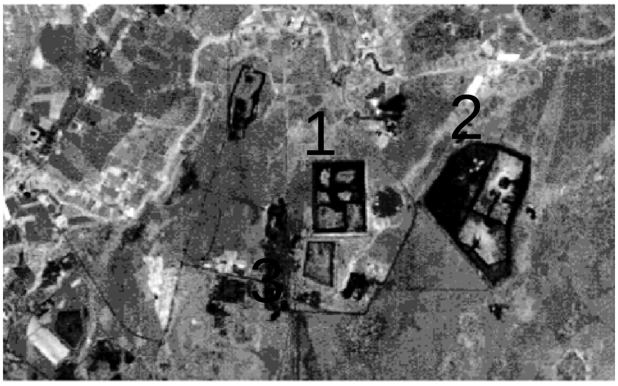
RESULTS AND DISCUSSION

In the NDVI images in figure 2, vegetation appears bright in the image that was generated using this combination. Soil, rocks and man made objects appear dark while water bodies and mine waste appear black since they lack any vegetation. Figure 2 shows an NDVI time series images of mine waste at the Paadekraal mining area.



1973 NDVI

1989 NDVI



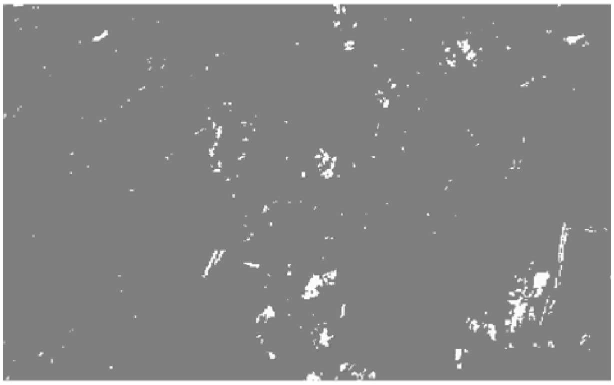
2002 NDVI

1998TM NDVI

Figure 2: Time series NDVI images of the Paadekraal mining area in Rustenburg

The False Colour Composite (FCC) and NDWI of TM 1998 are shown in figure 3. Mine waste can be clearly identified and the bright white patch indicates the presence of water on the surface of the mine waste and the return water ponds.

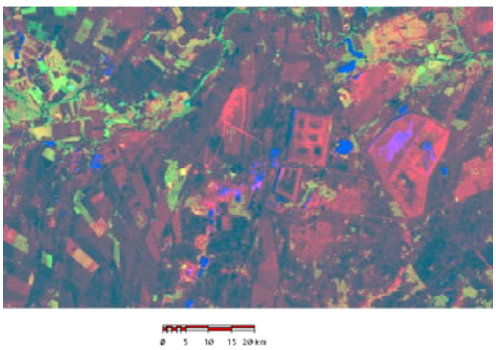
FCC of 2002



MNDWI

Figure 3: False Colour Composite and MNDWI image of 2002

The TC transform of 1998 is shown in figure 4. Vegetation and water bodies can be identified in this image. The mine waste appears in red colour, vegetated areas around the mine waste appears green, water appears blue and soil and mine waste with moisture content appears dark.



TC transform of 1998

Figure 4: Tasselled Cap transformation of 1998

The mine waste deposits were digitized on the different images and 1973 image was compared to the 2002 image. The area of each digitized polygon was calculated and added together. The total area covered by waste in 1973 was approximately 411 hectares and it increased to 2614 hectares. The change in area covered by the mine waste is shown in figure 5. The brownish part is the area covered by mine waste in 1973, while the orange part is the increased surface area covered by mine waste in 2002.

CONCLUSION

This study has shown that Landsat medium resolution satellite images can provide quantitative information on the location, extent and changes in the area occupied by mine waste deposits from the primarily platinum mining industry in the Rustenburg district, Northwest Province of South Africa. From 1973 to 2002, the extent of the mine tailings area increased from 411 to 2614 ha (640%). This study has demonstrated that remote sensing analysis provides a cost effective and rapid way of implementing an inventory of mining waste across a large mining region. The state of mine waste can be established and upgraded regularly.

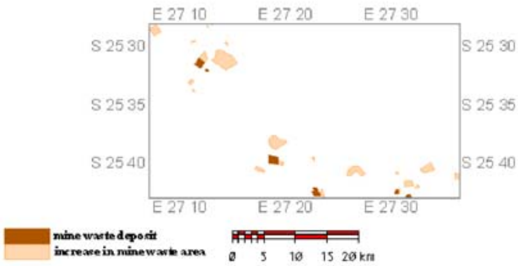


Figure 5: Change in surface area of mine waste 1973-2002

The inventory and other environmental information acquired in the region will help in the environmental management of mining impacts. The time series analysis and change detection of the status of mine dumps in the region shows that the mines in the area are monitoring their mining waste in order to reduce their impacts on the environment. This could be seen through more vegetation on the waste and the moisture content of the waste. The mines in the area will be able to manage the rehabilitation of mine waste through proper timely monitoring of their status through image analysis. The provision of regional-scale information assists regulators and planning authorities in directing scarce resources to critical areas within their jurisdiction.

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