LAND-USE/COVER MAPPING AND CHANGE DETECTION IN THE RUSTENBURG MINING REGION USING LANDSAT IMAGES

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Abstract

Several decades of intensive mining have taken place in the Rustenburg region, located in the North West Province of South Africa. The platinum boom of the late 90s has seen new surface and underground operations opening up in this area. To assess land-use/cover and environmental impacts, remotely sensed data in the form of Landsat images were analysed. The post-classification change detection method was used to detect land-use/cover changes in the various images. Landsat ETM$^+$ 2002 was used as the reference image. Significant and extensive changes in the land-use/cover patterns occurred in the last three decades: vegetation has undergone a general decrease, and woodland and grassland have been changed to cultivated land. Open mining areas increased due to expansion of mining activities. High urban expansion due to influx of job seekers has lead to an increase in the built up area, formal and informal. Consequently, the landscape became highly disturbed due to increased mining, agriculture and urban development.

Keywords: Mining; Land-use/cover; Landsat; ETM$^+$; Rustenburg

INTRODUCTION

Rustenburg region lies on the edge of the Bushveld Igneous Complex, which is one of the most heavily mineralized and diverse mineral producing districts in the world. The region consists of the Bojanala District and the Rustenburg local municipality area, which accounts for a significant part of the economy of the North West Province, South Africa. Due to its rich mineral resources, there is an increase in the pressure on the natural environment in terms of large-scale industrialisation. Several decades of intensive mining for chrome, vanadium, tin, lead, marble, granite and slate have taken place in the region. The platinum boom of the late 90s has seen new surface and underground operations opening up in this area, leading to a high intensity of mining. The two biggest platinum mines in the world are situated within 14 km of Rustenburg, while further large and smaller platinum mines are being developed in the area.

The exploitation of Rustenburg's riches has led to a significant population increase due to influx of job seekers. This has led to a problem of growing informal settlements around the mines, whose residents suffer deteriorating social and physical conditions, including a lack of essential services, crime and disease (1).

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 (2). With the launching of the Landsat Satellite 1972, researchers began to use satellite data for monitoring mining activities in different parts of the world. This helps by reducing the need for conventional time consuming and expensive field sampling methods, which is the traditional method of monitoring mining pollution (3), (4). The objectives of this paper is to evaluate the broad land use/cover changes over three decades in the Rustenburg region using digital analysis of Landsat MSS, TM and ETM$^+$ images.

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 (5). 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 and the Magaliesberg Protected Environment (Figure 1).

DATA AND METHODS

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). Although these scenes were acquired with different sensors the classification results can be compared to identify changes in land use/cover. Most 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 [*Source: Ecological and Environmental Consultants* (6)]

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
1997	TM	171	78	1997/12/03	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 (7). Digital numbers were converted in exo-atmosphere reflectance values in order to compensate for variations in the sensor radiometric responses over time and for variations in the natural conditions of solar irradiance and solar angles. 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 using the nearest neighbour 3x3 pixel method and the study area was then extracted from each of the images.

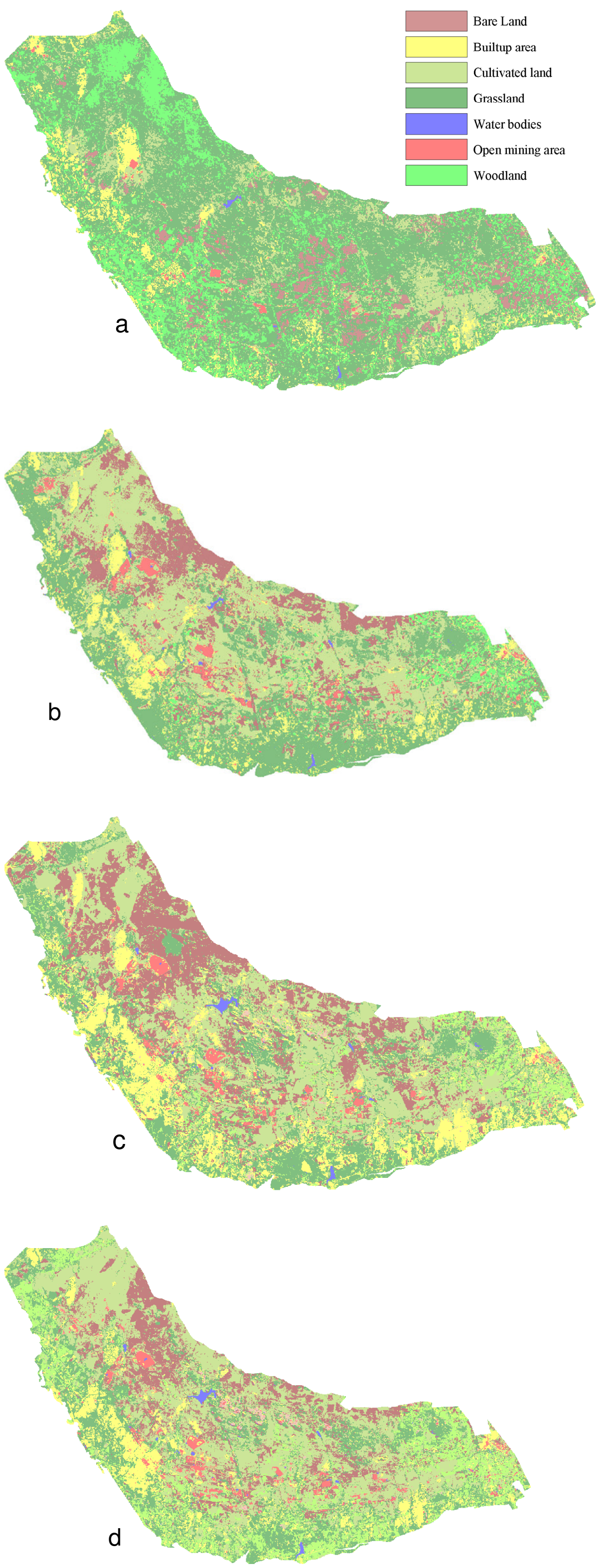
Image processing and band combinations

False colour composites (FCC) were generated using band combinations of RGB = 4:3:2 for the MSS73 image and RGB = 7:4:1 and 5:4:2 for the TM89, TM97, TM98 and ETM+02 images for visual interpretation of temporal images in land use and land cover. Three different band ratios were generated to identify different classes on the images. Band ratios 3:1, 7:8, 4:3 proved useful for the identification of bare land, water bodies and vegetation respectively. The three ratios were combined as an RGB in the order of soil, vegetation and water bodies. The leaf area index helped in identifying the (evergreen) vegetated areas in the MSS73 image while the traditional method of NDVI and Tasselled Cap (TC) transformations helped in identifying different classes in the TM89, TM97, TM98 and ETM+02 images. Training classes were created from the images using the supervised classification method and they were then classified using maximum likelihood classifier and filtered using the modal method to reduce noise. The classified maps were verified through the 1:50 000 topographic maps and field checks and the land use/cover classes were defined in line with the Land Cover Classification System (LCCS) (8). Tailing dams, open cast mines and rock dumps were classified as open mining area, while dams, rivers and return water ponds were classified as water bodies. Classified images for each scene are shown in Figure 3.

Change detection analysis comprises a wide range of methods to identify, describe and quantify changes between images of the same scene at different times (9). In this study *Post-classification* change detection is the method used to determine the difference between independently classified images from each of the different scenes acquired. It is a method in which *from* and *to* classes can be quantified for each changed pixel. All the scenes were compared to the 2002 image. The TM 97 (summer) image was also compared to the TM 98 (winter) image to detect changes between the summer and winter seasons.

RESULT AND DISCUSSION

Land use/cover classes were observed to have changed significantly. Changes are normally quantified per pixel counts, areas or percentages. The different classes were represented as different colours in each image, making it easy to identify not only where changes have taken place, but also the class into which the pixel changed. The change detection statistics of the study area for three decades of the study area are presented in Table 2.



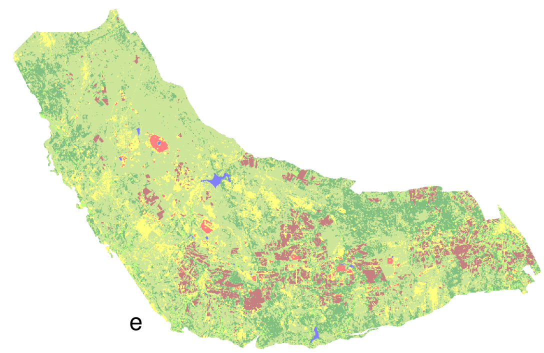


Figure 3: Classified images for: (a) 1973; (b) 1989; (c) 1998; (d) 2002, all winter; and (e) 1997 (summer image)

Table 2: Change detection (%) for the period 1973-2002 (Diagonal represents unchanged fraction of each class)

Changed from:	Grass-land	Culti-vated land	Wood-land	Bare land	Built-up	Open mining areas	Water bodies
Grassland	23.5	34.7	13.6	0.2	8.5	2.3	0.4
Cultivated land	17.9	0.5	9.6	19.1	9.0	11.1	0.0
Woodland	24.4	30.1	18.4	14.2	10.6	1.3	0.2
Bare land	12.1	47.5	20.4	16.0	5.4	3.0	0.3
Built-up	23.3	13.3	13.2	1.7	45.6	1.4	0.1
Open mining areas	0.2	25.3	0.1	0.1	6.3	34.9	1.9

The statistics in Table 2 shows that *open mining areas*, which consist of tailing dams and opencast mines, increased significantly, including taking 11% of the 1973 cultivated land, because of the expansion of platinum mining activities. This can be seen in Figure 3 where the orange (mining) patches increased over the years. Much of the *grassland* and *woodland* changed to *cultivated land* over the three decades. This is because of development of intensive agriculture in the area. Small scale agriculture was also carried out by most of the residents in the informal settlements over the years. Large fractions *grassland* and *cultivated land* became *built-up areas*. High urban expansion during the three decades has led to a significant increase in the *built-up* areas. The apparent decease in built up area is due to urban forest establish over the last two decade – object-based rather than pixel-based analysis would help resolve such ambiguities. Some water bodies appeared over the years as a result of dam construction and return water ponds for tailings dams.

Land use/cover changes for the different years are represented in Figure 4. Establishment of trees/wood plantations increased between 1973 and 1989, declined between 1989 and 1998, and increased again between 1998 and 2002. There was an increase in overall agricultural activity, probably due to subsistence and mechanised farming, and in bare land areas between 1989 and 1998. The *Cultivated land* class was highly dynamic, with only 0.5% of original 1973 agricultural land remaining in this class in 2002. The 1997 summer image showed that all the bare land areas in the 1998 scene were mostly cultivated and grassland, instead of classifying it as a barren land. There was less rainfall in 1998 compared to the two previous years. This means that the bare land could have occurred as result of overgrazing, or fallow land being prepared for the next planting season. Urban expansion occurred between 1989 and 1998 due to accommodate workers for the rapidly expanding mining sector. The loss of almost 20 000 hectares of cultivated land is accounted for by the total space consumed by the built-up areas. The built up area continued to expand during the period 1998 to 2002, although at a slower rate. More growth in cultivated land at the expense of grassland occurred during this later period, reflecting an expansion of formal and informal agriculture.

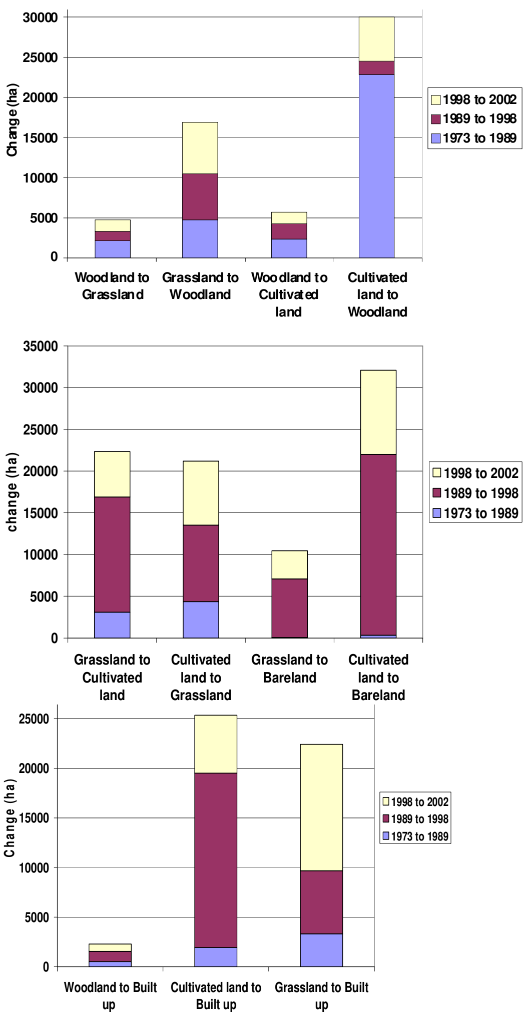


Figure 4: Land use/cover changes in different years

CONCLUSIONS

Rustenburg and its environs are the location of the world's richest platinum deposits. Results presented here show rapid alteration from a primarily agriculture area to an urbanised-industrial landscape, driven by expansion of mining and associated industries. However, as the climate and soil are favourable for agriculture, further natural grassland and woodland have been developed for formal agriculture. A significant increase in population has fuelled an urbanisation expansion rate of ~2.5% a^{-1}. Urbanisation observed includes informal settlements, not controlled by local authorities or mine mangers. Overall, natural areas are shown to be reducing and under pressure.

In this study, analysis of land cover/use changes over three decades has revealed a highly dynamic interchange of land use, driven by competition for land between urbanisation, agriculture and mining. By providing an integrated regional vantage point, extending over multiple decades, this RS study has highlighted changes and cumulative impacts of changes that are not apparent to decision makers in diverse agricultural, mining and urban planning departments. The unique perspectives of such RS applications can assist in macro-planning decisions that will for example preserve land for biodiversity and food production, while allowing orderly urban and mining developments.

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