CHAPTER 5 – REMOTE SENSING & GIS

5.1 Introduction

Remotely sensed data, such as satellite images, are measurements of reflected solar radiation, energy emitted by the earth itself or energy emitted by radar systems that is reflected by the earth.

The remotely-sensed data used in this study was in the form of aerial photographs, aster data and TM bands. The aerial photographs used were taken in 1987 and 2002. The ASTER data was collected in 2001. The 1:50 000 topographic map of Carltonville (2627AD) published in 1991 was used to ground truth the information found on the remotely sensed data. The different types of remotely sensed data as well as the topographic map were imported into ILWIS and were processed to create maps for further analysis.

5.2 Aerial Photographs

The aerial photographs were scanned and saved as BITMAPS. They were then imported into ILWIS and georeferenced to the scanned topographic map for ease of location. This was achieved by image-to-image registration. This technique is useful for combining images of different dates and different sensor systems. To execute this process one image is selected as a reference (with known coordinates) and another image is matched to the reference image, in this case, the topographic map was the reference to which the aerial photos were matched. The reference image is called the Master image and the map to be referenced is known as the Slave image. The slave image is resampled to the master image. This requires the availability of objects identifiable on both images. The slave image will inherit the coordinate/reference system after registration.

Once the aerial photos were georeferenced the tailings dams on the aerial photographs were digitized on-screen. This entailed creating a segment map and ensuring the correct coordinate system was used (the master image's coordinate system). The cursor was used to draw the perimeter of each tailings dam to determine determine the area occupied by each dam. Once the perimeter of each dam has been drawn the segments are checked for intersections, dead ends and self overlaps. If none are found then the segments are polygonised. The polygon map is created. A histogram showing the perimeter and the area of each of the digitized tailings dams is displayed.

Table 5.1 Area in m^2 occupied by tailings dams in 1987 and 2002

Tailings Dam	**Area to the nearest thousand (1987)**	**Area to the nearest thousand (2002)**
North Mine dam 3		1,903,000
North Mine dam 5a	434,000	413,000
North Mine dam 5b	381,000	389,000
North Mine dam 7a	852,000	785,000
North Mine dam 7b	832,000	922,000
South Mine dam 1a	1,000,000	900,000
South Mine dam 1b	1,688,000	1,515,000

Only North Mine dam 5b and North Mine dam 7b increased in size between 1987 and 2002. North Mine dam 5b increased from 381,000 in 1987 to 389,000 in 2002, while North Mine dam 7b increased from 832,000 in 1987 to 922,000 in 2002. North Mine dam 5a decreased by 21,000 from 434,000 in 1987 to 413,000 in 2002. South Mine dam 1a decreased by 100,000 from 1,000,000 in 1987 to 900,000 in 2002. North Mine dam 7a decreased from 852,000 in 1987 to 785,000 in 2002.

Although the plantation covers a large area, a section of the plantation was selected to monitor the change in size (see Figure 5.1). The selected sections of the plantation covered a total area of 798 ha in 1991. In 2002 the total area covered by the same sections of the plantation was 846 ha. The area covered by the bare area between the plantation and the tailings dam was also measured and was found to have decreased from 852 ha (1991) to 833 ha (2002). To make sure that the decrease was not due to increase in area occupied by the tailings dam, the change in the tailings dam was also measured and was found to have decreased from 1000 ha to 974 ha in the same period. The two sections of the plantation digitized have both increased in size (the location of the sections of the plantation, the bare area within the plantation and the tailings dam referred to above are shown in figure 5.1).

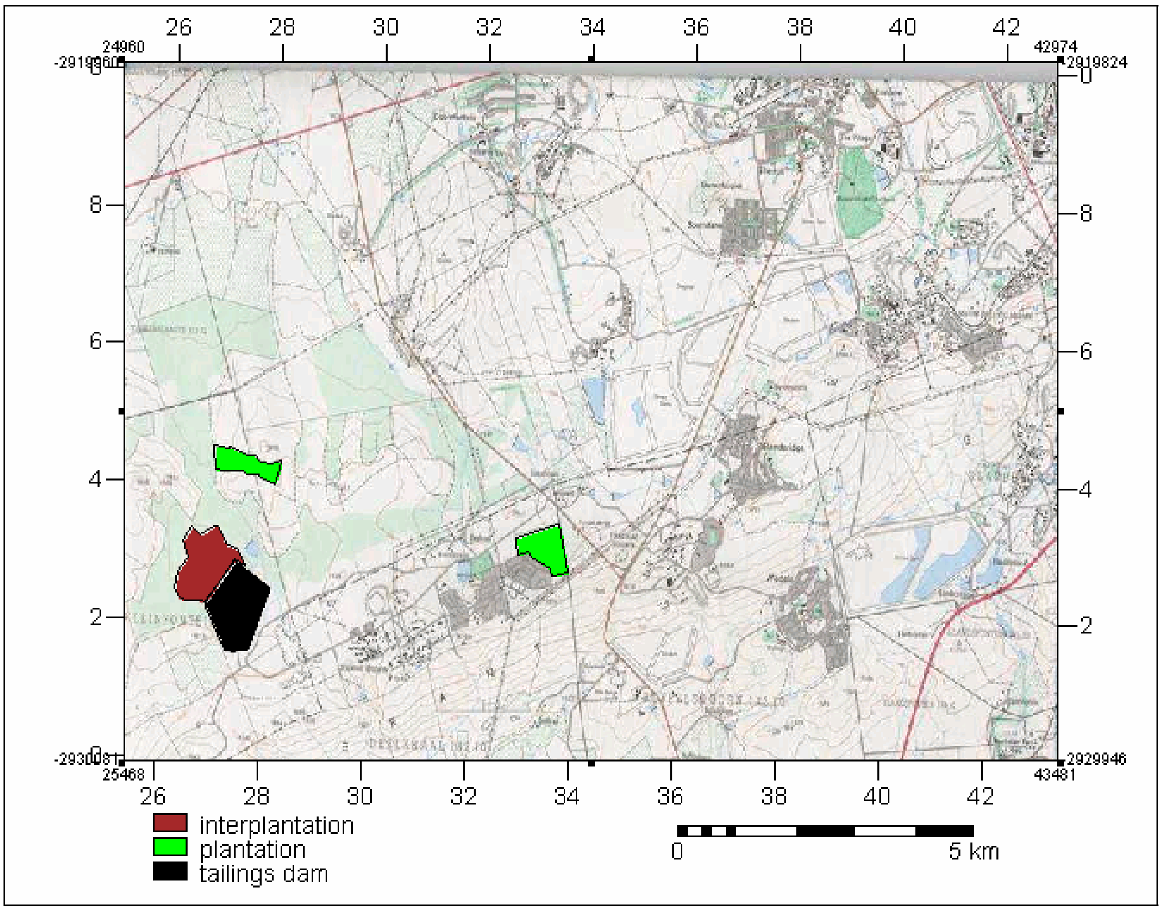
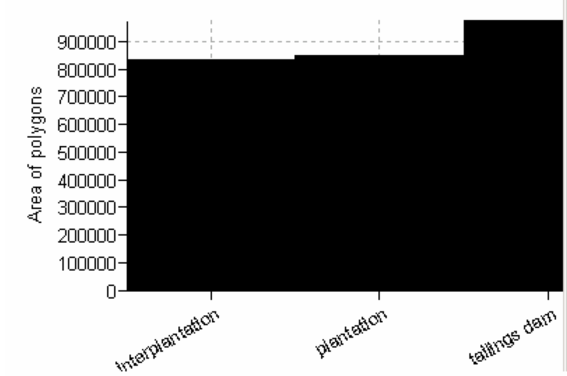


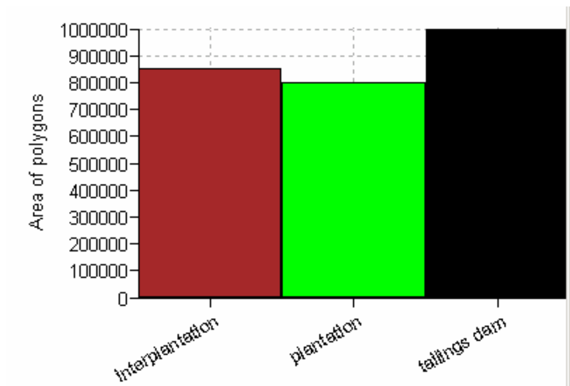
Figure 5.1 Location of sections of the plantation, tailings dam & bare area between plantation & plantation

The big plantation was digitized from the colour composite as well as the Thermal Infrared (TIR) 1 taken in 2002. In 2002 (when the TIR was taken) the tree distribution covers a smaller area than in the colour composite created from bands. From the time the TM bands were taken to 2002 (when the TIR were taken) the big plantation has decreased in size.



	NrPol	Perimeter	Area
interplantation	1	3949.25	833169.00
plantation	2	6216.28	846381.93
tailings dam	1	3730.77	973613.64

Digitised from aerial photograph taken in 2002



	NrPol	Perimeter	Area
interplantation	1	4193.45	851842.17
plantation	2	6252.68	797754.40
tailings dam	1	3822.56	999691.76

Digitised from a topographic map developed in 1991

Figure 5.2 Changes in sections of the plantation between 1991 and 2002

Topographic Map

The topographic map was scanned and then imported into ILWIS. An LO coordinate (with the following coordinates: min & max X of 30000 and 45000 and min and max Y coordinates of –2930000 and –2920000, Projection: Transverse Mercator, Central Meridian: 27˚, Ellipsoid: Clarke 1880) system was created for the map. The map was used to digitize the different land uses found in the West Rand Region (plantation, roads, rail, tailings dams, built-up area, and mine dumps).

Table 5.2 Area occupied by the tailings dams in 1991

Tailings Dam	**Area in m^2 (rounded off to the nearest 10)**
Elandsrand dam 1a	495461
Elandsrand dam 1b	359950
South Mine dam 1a	1042137
South Mine dam 1b	1587260
North Mine dam 7a	788347
North Mine dam 7b	877106
North Mine dam 5a	389555
North Mine dam 5b	411448
North Mine dam 3	1949950

5.3 Landsat Thematic Mapper (TM)

Landsat Thematic Mapper (TM) is a sensor system on board Landsat 4 that was launched in 1982. It is a scanning optical-mechanical sensor that records energy in the visible, reflective-infrared, middle-infrared, thermal infrared regions of the spectrum. TM data have a ground-projected IFOV of 30 m x 30 m for the six of the seven bands. The thermal-infrared band 6 has a spatial resolution of 120 m x 120 m. TM bands make use of the dominant factors controlling leaf reflectance, such as pigmentation, leaf and canopy structure and moisture content (Jensen, 1996).

Data are collected primarily by satellite and aircraft systems in conjunction with localised ground-based surveys and measurements. Table 5.3 below shows the Thematic Mapper Spectral bands of satellite images. The data are then processed by computer or optical techniques to extract information of value. An image consists of an array of pixels (picture elements) or grid cells, which are ordered in rows and columns. Each pixel has a digital number that represents the intensity of the received signal reflected or emitted by a given area of the earth surface.

Table 5.3 Thematic Mapper Spectral Bands (Lillesand & Keifer, 1994)

Band	wavelength (um)	nominal spectral location	principal application
1	0.45 - 0.52	blue	soil/vegetation discrimination
2	0.52 - 0.60	green	Measures green reflectance & assesses vegetation vigor
3	0.63 - 0.69	Red	aids in plant species differentiation
4	0.76 - 0.90	near infrared	determines vegetation vigour and biomass content
5	1.55 - 1.75	mid infrared	indicates soil & vegetation moisture content
6	10.4 - 12.5	thermal infrared	vegetation stress analysis, soil moisture discrimination
7	2.08 - 2.35	mid infrared	discrimination of mineral and rock types

The seven TM bands were georeferenced to the topographic map (in the same way that the aerial photographs were georeferenced, see Section 5.2). A submap makes it possible to select an area of interest in a map and save it as a new map. This is especially useful when only a part of larger map will be used in analysis. To create a submap you first have to select minimum and maximum coordinates which covers the area of interest.

The tailings dams on the submaps were digitized similarly to the ones found on the aerial photographs. Their areas were also determined from histogram.

5.3.1 Normalised Difference Vegetation Index (NDVI)

Various mathematical combinations of satellite bands have been found to be sensitive indicators of the presence and condition of green vegetation. These band combinations are called vegetation indices. Two such indices are the simple vegetation index (VI) and the normalised difference vegetation index (NDVI). The NDVI as a normalised index is preferred over the VI because the NDVI compensates for changes in illumination conditions, surface slope and aspect (Lillesand & Keifer, 1994).

The NDVI relates the near-infrared (NIR) and visible reflectance of earth surface features. Vegetated areas generally yield high values for the index because of their relatively high near-infrared reflectance and low visible reflectance. In contrast water has larger visible reflectance than near-infrared reflectance. Thus it yields negative index values. Rock and bare soil areas have similar reflectances in the two bands and result in vegetation indices near zero. Figure 5.3 shows the NDVI of the West Rand Region. It was created by combining TM bands 3 and 4.

An NDVI is generated with a map calculator using the following equation:

NDVI = NIR - red/ NIR + red

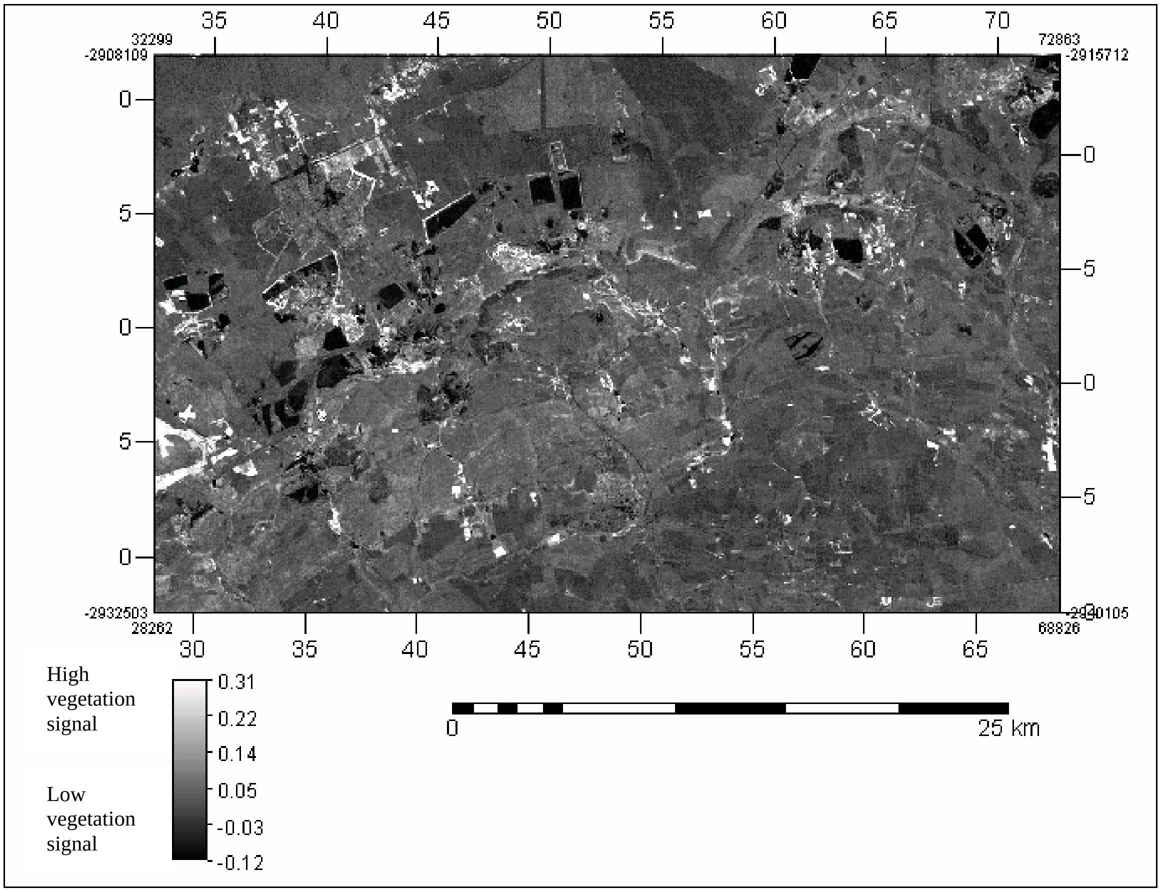


Figure 5.3 NDVI of the West Rand Region

The West Rand Region is grassland; during winter months the area is dry and therefore the vegetation signal is low. The low vegetation is shown by the small percentage of the NDVI which appears white (representing vegetation), and the rest of the map is dominated by a dark colour which characterizes soil, rocks and man-made surfaces. The plantation appears whiter than the vegetated areas showing denser foliage. A number of reasons could be responsible for the sparse vegetation, the most likely being the naturally poor soils. The soils would however still be able to sustain shrubs. Lack of shrubs suggests that there is one or more reasons, besides the edaphic factor, that brought scarcity of vegetation. The rainfall is not low enough to justify the lack of vegetation. The pollution from mining activities and clearing of vegetation (to accommodate mining-related activities) are the most likely causes of lack of vegetation.

5.3.2 Colour composite

Optical combination of spectral images from the blue, green and red portions of the spectrum results in a ‘true’ colour display. Projection of positives taken in the green, red and the photographic infrared results in a ‘false’ colour display (Lillesand & Kiefer, 1994). In a False Colour Composite (FCC) the red colour is assigned to the near-infrared band, the green colour to the red visible band and the blue colour to the green visible band. The green vegetation will appear reddish, the water bluish and the bare soil in shades of brown and grey. Combining bands 4, 3 and 2 created the false colour composite (Figure 5.4). The map confirms the scarcity of vegetation shown by the NDVI. The vegetation is restricted to the gentle slopes.

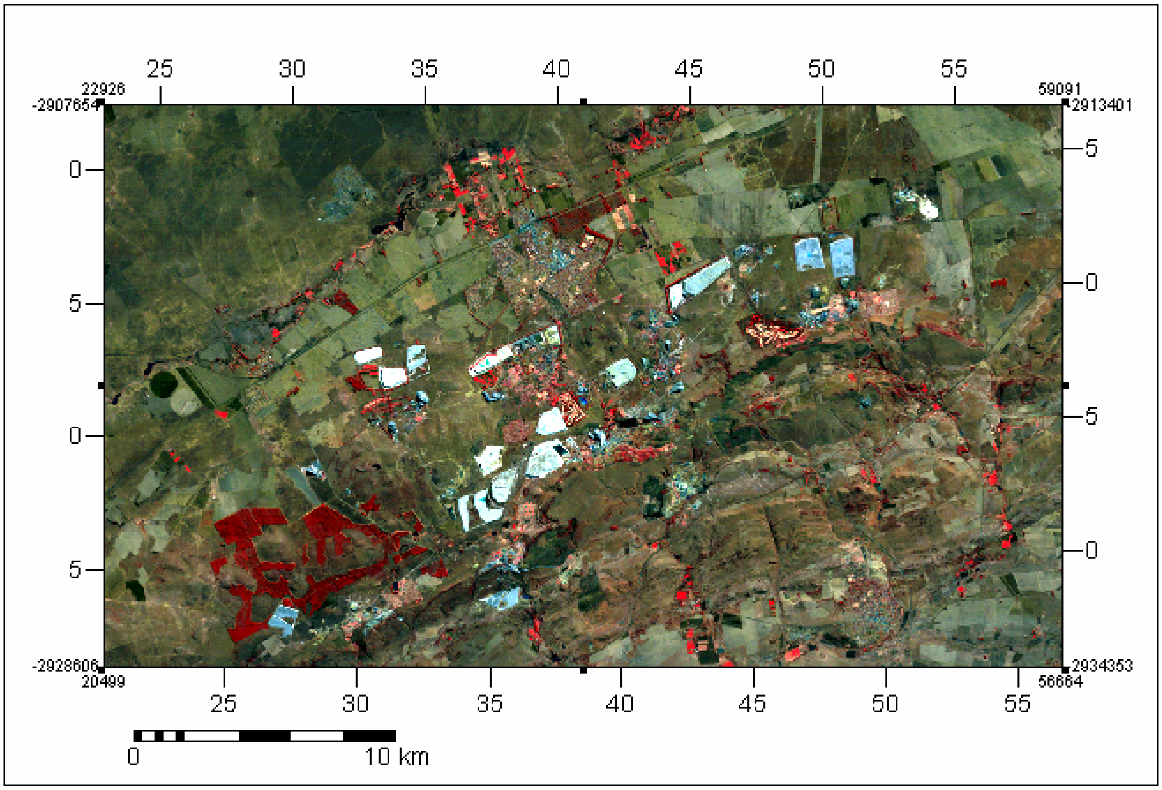


Figure 5.4 A Colour Composite of the West Rand Region

5.3.3 Classification of Satellite Images

The reflection values in an image depend on local characteristics of the earth's surface. In order to extract information from the image data, the relationship between the reflection values and the land characteristics has to be established. This is achieved by a process called Classification. Image classification is used to infer land use classes from the reflectance spectrum of the surface. It can either be supervised or unsupervised. In supervised classification the computer is 'trained' to assign a class label to a limited number of pixels. The computer is then able to identify other pixels similar to the few that have been assigned a class and then groups all the similar pixels to that class.

In supervised classification the classes to be used are pre-defined. In order to do this the study area has to be known; ground truthing, either through field work or reference to a map, has to be undertaken. If the ground truth is available training samples (small areas or pixels) are selected on a map and the corresponding class names are entered. A sample set has to be created in which all data relating to the input bands (map list) and cover classes (domain codes) and background image for selecting the training area is stored. The selection of the training areas is performed on a colour composite. The colour composite is created as discussed in section 5.3.2. Once the colour composite has been created the sample set is created (see Appendix 3 for the procedure).

The classes can be plotted in distinct colours in a feature space. A feature space gives a visual overview of the separation of classes of training pixels; it enables a judgement of whether the classes can really be spectrally distinguished and whether each class corresponds to only one spectral cluster. The feature space is a graph in which the reflectance values of one band are plotted against the values of another. To create the graph see the procedure in Appendix 3).

The training samples created above are used to create an output map where each pixel is assigned a class label, according to the feature space partitioning. There are different techniques used to classify images - Box Classifier, The Minimum Distance Classifier, the Mahalanobis Distance Classifier and Maximum Likelihood Classifier. In this study the Box Classifier method was used. This method uses class ranges determined by the reflectance values from the training set and the output is rectangular spaces or boxes; hence the name. Having sampled a representative amount of pixels in each class, the mean reflectance values of the class are used, together with standard deviation of the sample and a multiplication factor, to determine the extent of the box. The boundaries of the box are defined by the product of the standard deviation and the multiplication factor. A pixel that does not fall within a box is not classified. If the pixel falls within two or more overlapping boxes it is classified according to the smallest box. To perform Box Classifier technique, refer to Appendix 3 for the procedure.

In unsupervised classification, also known as Clustering, there is no prior knowledge of about the land cover classes. The computer groups similar reflectance values together and assigns class numbers to these groups. The output map results in each pixel being assigned to one of the classes.

Figure 5.5 shows that some features can easily be overlooked if unsupervised classification is used. The mine dumps cannot be seen on the unsupervised map.

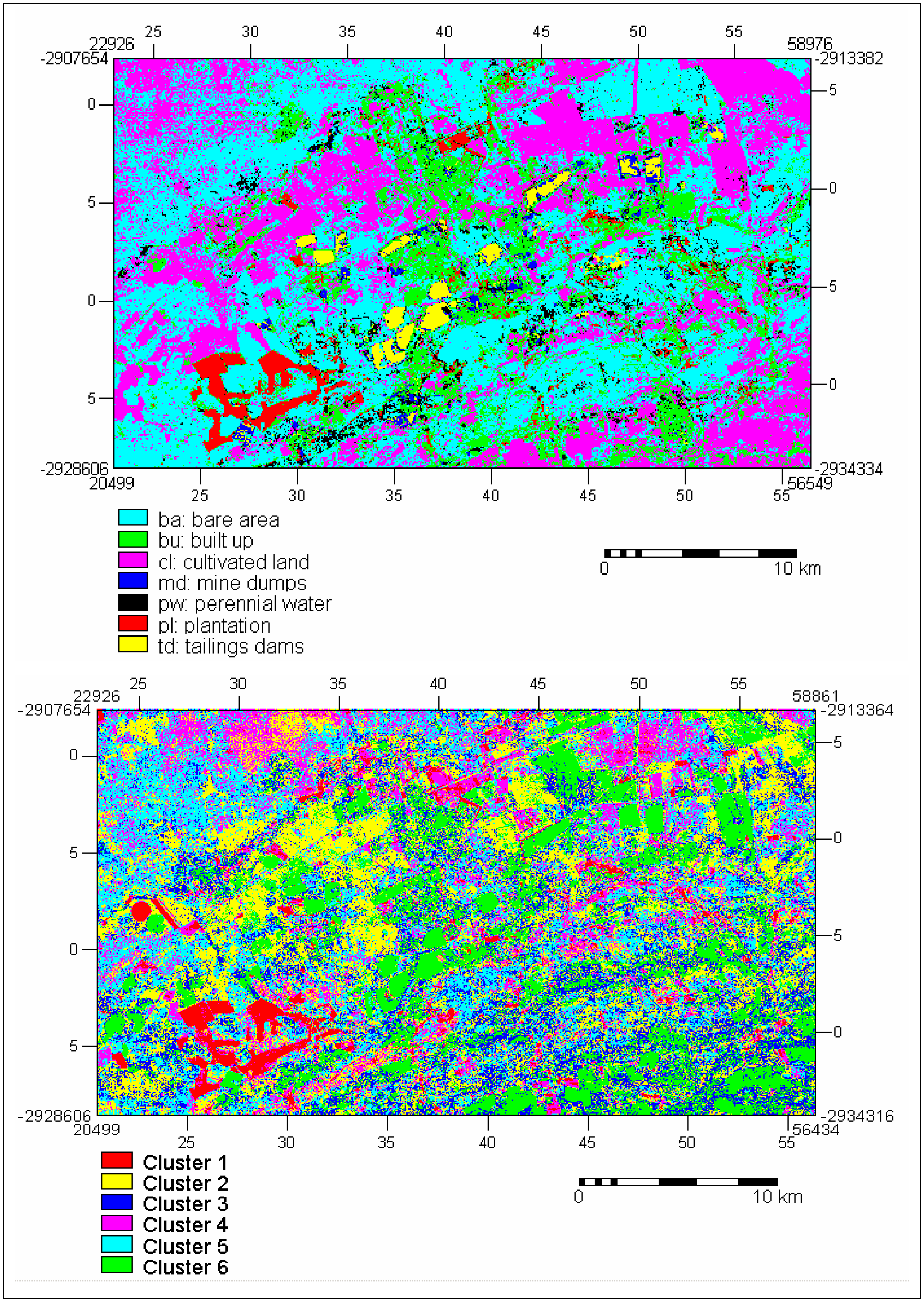


Figure 5.5 Comparison of supervised & unsupervised classification of the study area based on TM data

5.3.5 Tassled Cap (TC) Transforms

Tassled Cap transform enables the extraction of particular class formation from combining multiple bands into a lesser number of features (Crist *et al*, 1986, in Limpitlaw, 2003). In the TM images vegetation and soil data in the six reflective bands occupy three dimensions in the TC transform, namely, Brightness, Greenness and Wetness. Brightness measures overall reflectance from weighted sum of all six bands. Greenness measures the presence and density of green vegetation. It is a contrast between near infrared and visible reflectance. Wetness measures soil moisture content, vegetation density and other scene characteristics. Wetness is a contrast between short wave infrared and visible near infrared.

Tassled Cap images are created through the following process:

- Double click Map Calculation in the Operations List.
- Use the Tassled Cap transformation coefficients for TM (tabled below) to multiply the TM bands.

Table 5.4 Tassled Cap Transformation Coefficients for TM (Crist *et al*, 1986 in Limpitlaw, 2003)

	TM1	TM2	TM3	TM4	TM5	TM7	Additive Term
Brightness	0.2909	0.2493	0.4806	0.5568	0.4438	0.1706	10.3695
Greenness	-0.2728	-0.2174	-0.5508	0.7221	0.0733	-0.1648	-0.7310
Wetness	0.1446	0.1761	0.3322	0.3396	-0.6210	-0.4186	-3.3828

- Once the three maps have been created (Brightness, Greenness & Wetness),
- Apply the formula (**Wetness*+127.6451)/195.1086*255**) to convert the image domain from Value to Image.
- Create a colour composite using the brightness map (created above) as the red band, greenness map as the green band and wetness map as the blue band.

- The Colour Composite image discriminated well between various land classes and was used to define a sample set for supervised classification, as shown in Figure 5.5.

The physical land cover categories which were used in the classification of TC map were Bare areas, plantation, mine dumps, built-up area, cultivated area, perennial water and tailings dams. The plantation is represented by the red areas on the classified map. The plantation is mainly found in one area (to the west of the mining activities) with smaller clusters scattered randomly in the Carltonville area. Mine dumps are represented in blue on the classified map. The tailings dams are coloured yellow. Both the mine dumps and the tailings dams are predominantly found in bare areas. The bare areas, represented by blue patches, occupy the largest area. The built-up area is represented by green colour and is randomly distributed throughout the study area with some built-up areas being close to both the tailings dams and mine dumps. The area occupied by both the tailings dams and mine dumps is significant and therefore determines the land use in the West Rand Region (refer to Figure 5.5 below).

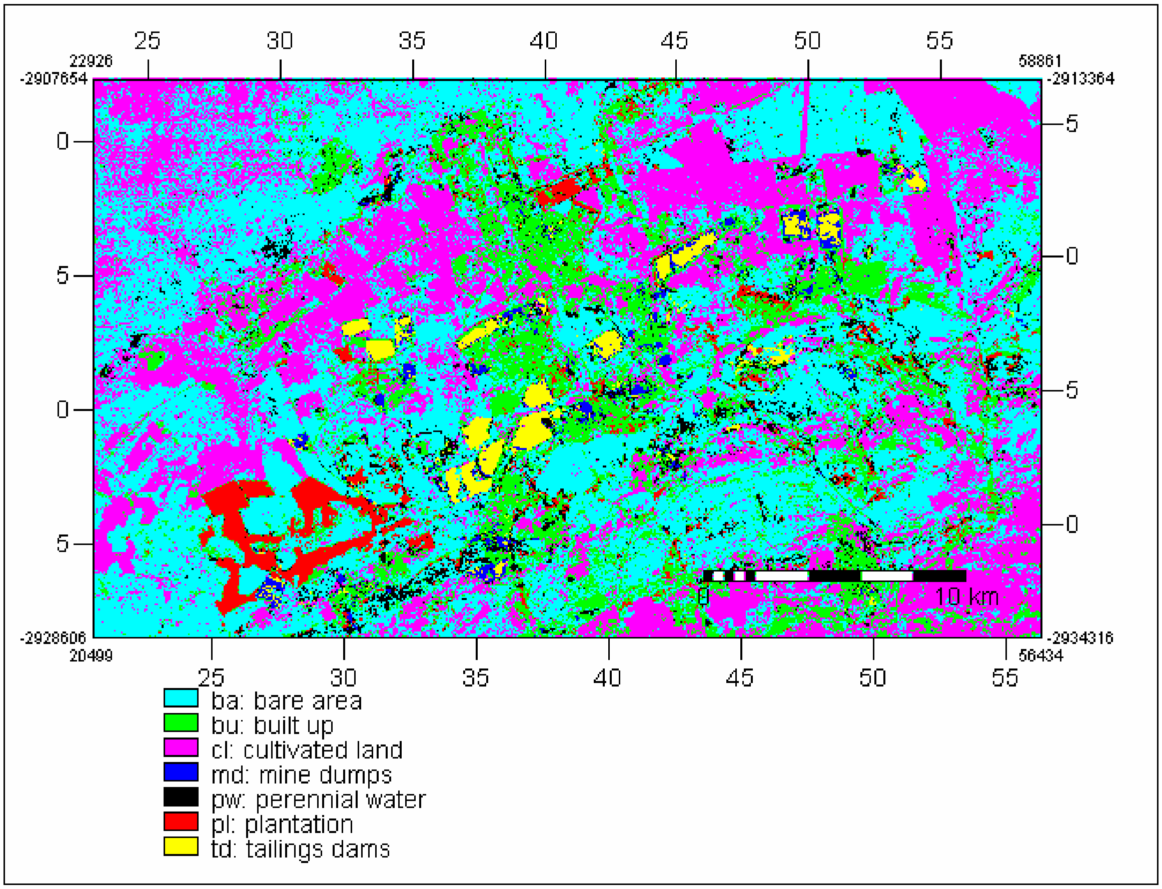


Figure 5.6 TC Classified (Maximum Likelihood Classifier)

The TC map above was filtered using the Majority filter to enhance the features thus making it clear to distinguish the different land use classes, as shown in Figure 5.6.

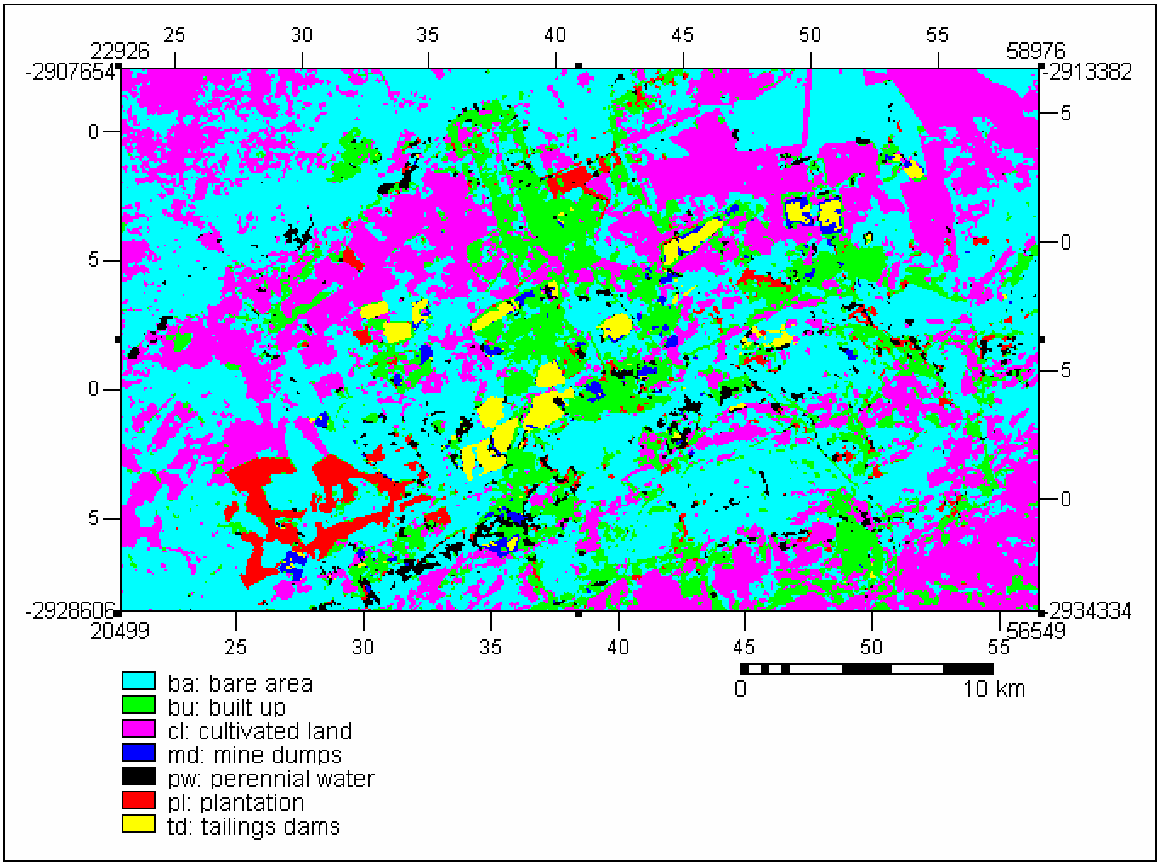


Figure 5.7 Filtered TC image

TC greenness map shows that the study area is not dominated by lush, verdant vegetation. This is clearly shown by the negative vegetation index values over more than 80% of the total surface area. The positive vegetation index is seen at the plantation area, the cultivated area and the golf course, the total area of which constitutes less than 20% of the total surface area. There is no direct correlation between areas of high greenness values and drainage lines. The rivers are mainly located to the south of the tailings dams and not close to the plantation or cultivated land. Approximately 60% of the study area scored high values for wetness; this clearly shows the extent of tailings dams (the tailings dams and the plantation are the wettest land covers). The cultivated land does not reflect high wetness values. This suggests that the cultivation was either not in good health (especially if it was winter) when the TM bands were taken or the quality of the vegetation was poor due to deteriorating/poor conditions for optimum plant growth. The brightness map shows the lowest reflective values over the plantation area and medium values over the cultivated land. The tailings dams are the brightest due to the fact that water reflects back more light than vegetation and bare soil.

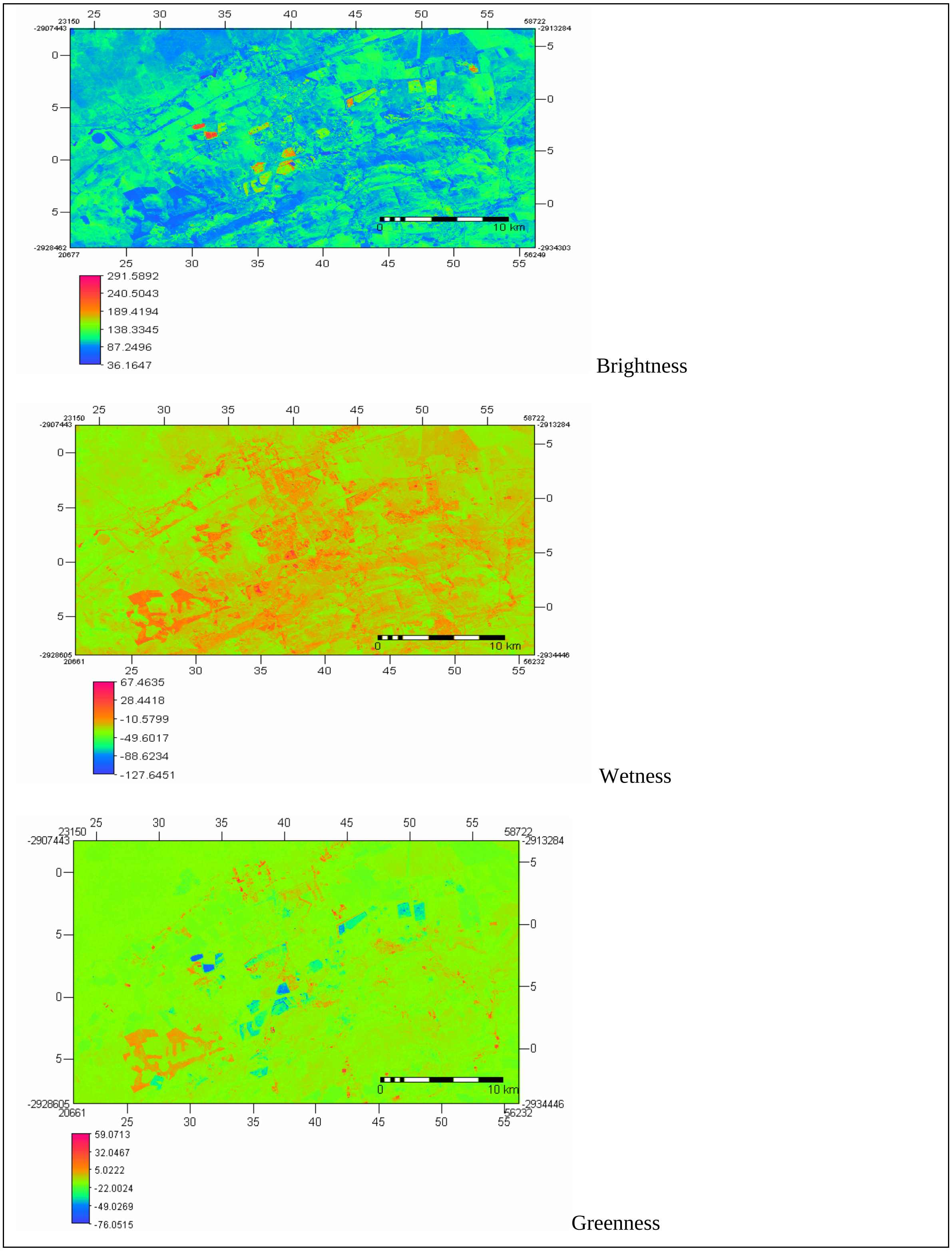


Figure 5.8 TC components (brightness, wetness & greenness)

5.3.4 Principal Components

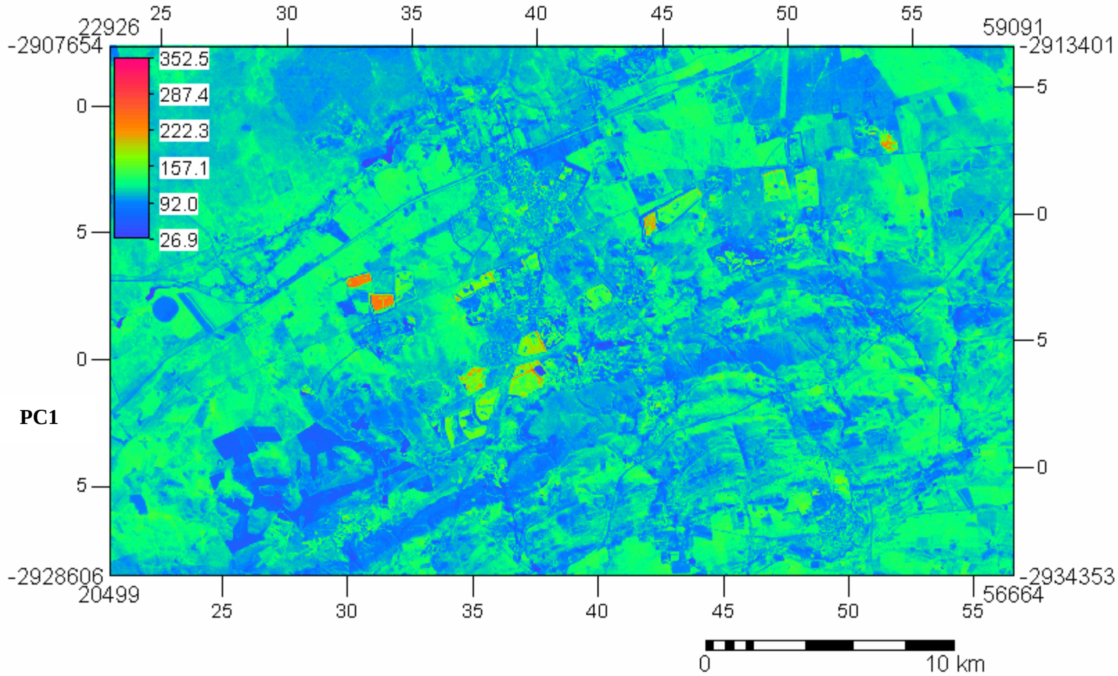
Principal Component Analysis (PCA) operation is mathematical method to uncover relationships among many variables (as found in a set of raster maps in a map list) and to reduce the amount of data needed to define the relationships. With Principal Component Analysis each variable is transformed into a linear combination of orthogonal common components (output raster maps) with decreasing variation. The linear transformation assumes the components will explain all of the variance in each variable. Hence each component (output raster map) carries different information which is uncorrelated with other components (ILWIS, 1997). The output raster maps are listed in decreasing order of variance. This enables a reduction of output maps because the last number of transformed maps has little or no variation left (may be virtually constant maps). The 'last' components thus do not add significance and may hence be discarded.

Principal Component Analysis (PCA) can be applied to compact redundant data in the TM bands into fewer layers. Seven TM bands were used and therefore seven principal components were created. The eigenvalues for the seven principal components created were as follows:

Table 5.4 Eigenvalues of the Principal Components

	TM1	**TM2**	**TM3**	**TM4**	**TM5**	**TM6**	**TM7**
PC1	0.285	0.204	0.354	0.238	0.708	0.051	0.437
PC2	0.597	0.325	0.342	0.338	-0.391	-0.181	-0.348
PC3	0.411	0.141	0.071	-0.820	-0.160	-0.059	0.323
PC4	0.198	-0.020	-0.222	-0.280	0.564	-0.254	-0.671
PC5	-0.288	-0.004	0.170	0.014	-0.021	-0.924	0.185
PC6	-0.439	0.123	0.756	-0.279	0.036	0.208	-0.315
PC7	0.281	-0.904	0.321	0.016	-0.014	-0.025	-0.005

All the bands have a positive eigenvalue in principal component 1; therefore this PC explains the intensity difference of the input bands. Figure 5.8 below shows the decreasing order of variance between PC1 and PC7. The differences in the seven bands are most pronounced in PC1 and least detectable in PC7. PC7 is blurred as a result of lack of variation in variables in TM bands 1 to 7.



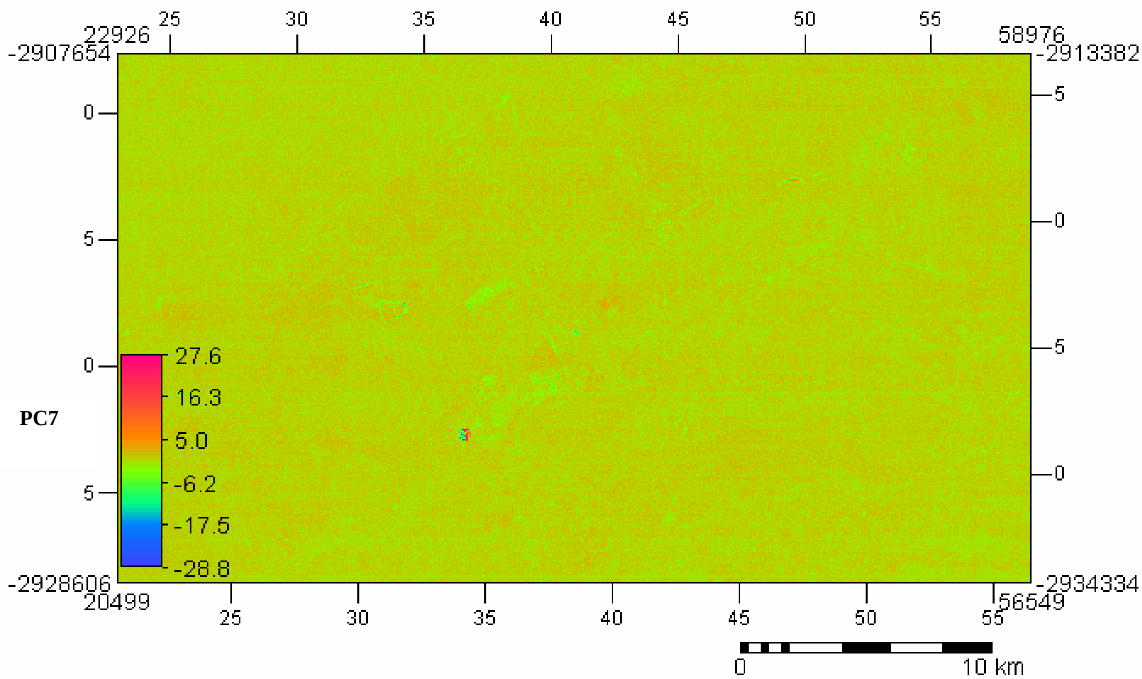


Figure 5.9 Principal Component 1 & 7 showing decreasing variance between the TM bands

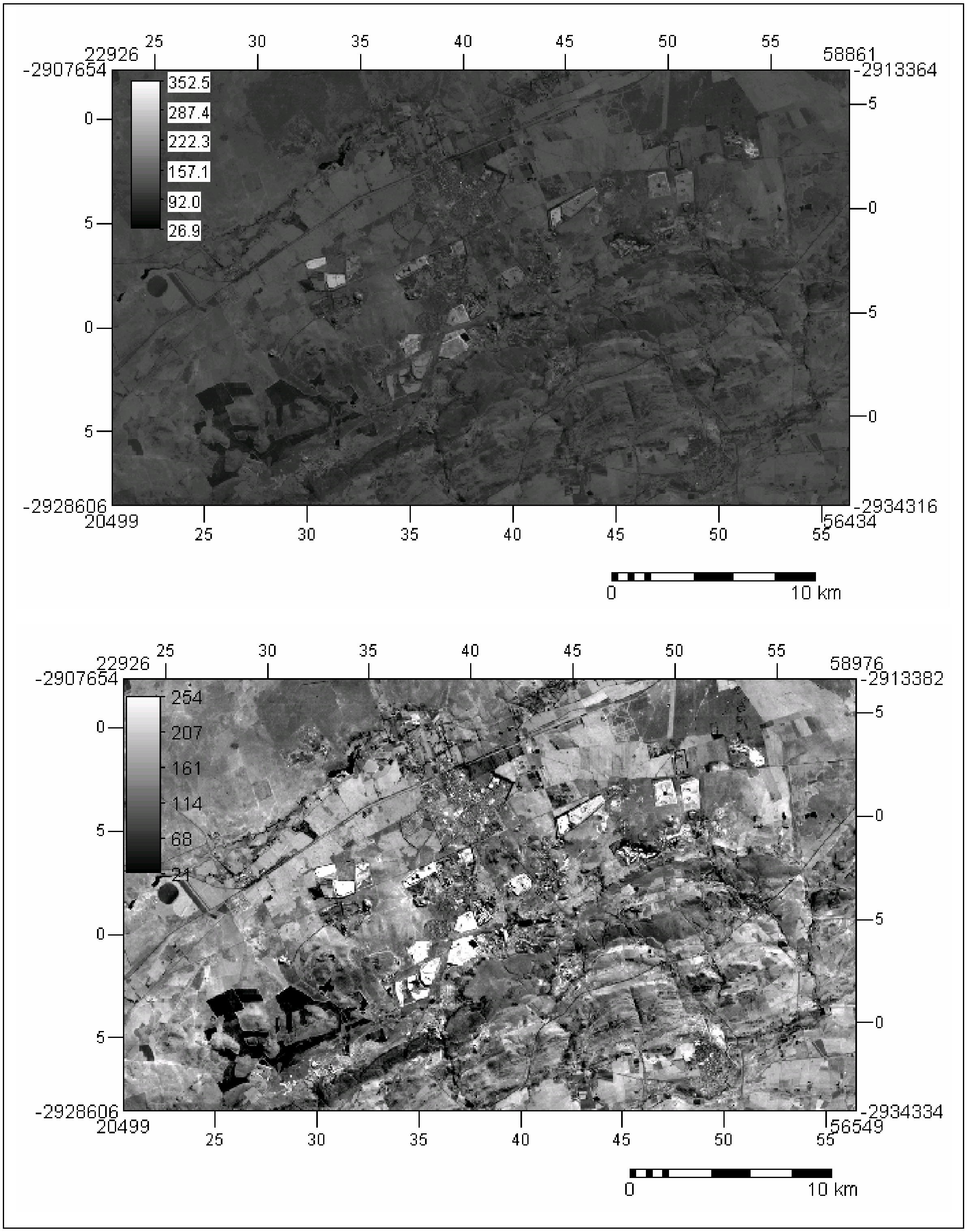


Figure 5.10 Principal Component 1 & the Stretched Principal Component 1 (displayed in grey)

Figure 5.10 above shows the effect of stretching maps. The map was stretched by selecting Image Processing from the Operations menu of ILWIS' main window. PC1 was selected as the Raster Map; Linear Stretching was used as the stretching method with a Percentage equal to 1. The stretched PC1 shows features on the map more clearly than PC1. Stretching is especially helpful where the area being assessed is not well-known and therefore some features/changes can easily be overlooked. In the above maps it is easy to miss the tailings dam next to the plantation in the original PC1 map but the dam is easily seen in the stretched PC1 map. The roads (especially N12 south east of the study area) are easy to recognise in the stretched map.

5.4 Advanced Spaceborne Thermal Emission & Reflection Radiometer (ASTER)

The objective for using ASTER data is to improve understanding of the local and regional-scale processes occurring on or near the surface of the earth and lower atmosphere, including surface-atmospheric interactions. ASTER data is applicable to investigations relating to land surface climatology, monitoring volcanoes, hazards monitoring, carbon cycle in the marine ecosystems, geology & soils, aerosols & clouds, hydrology and flood monitoring (NASA's Science Mission Directorate, 2004).

Terra, the polar orbiting satellite of NASA's Earth Observing System (EOS) program was launched on the 18th of December 1999 to map and study the manifestations of global change within the earth's systems. ASTER, one of the five instrument sensor systems on-board Terra, was built by a consortium of Japanese government, industry and research groups. It has three spectral bands in the visible near infrared (VNIR), six bands in the short-wave infrared (SWIR), and five bands in the thermal infrared (TIR) regions with 15, 30 and 90 metre ground resolution respectively. This combination of a wide spectrum coverage and high spatial resolution enables ASTER to differentiate a wide range of surface materials (USGS, 2003).

Table 5.5 Areal extent of the tailings dams in 2001

Tailings Dam	Area (to the nearest 000)
North Mine dam 3	1,853,000
North Mine dam 5a	364,000
North Mine dam 5b	323,000
North Mine dam 7a	732,000
North Mine dam 7b	793,000
South Mine dam 1a	978,000
South Mine dam 1b	1,785,000
Elandsrand dam 1a	605,000
Elandsrand dam 1b	435,000

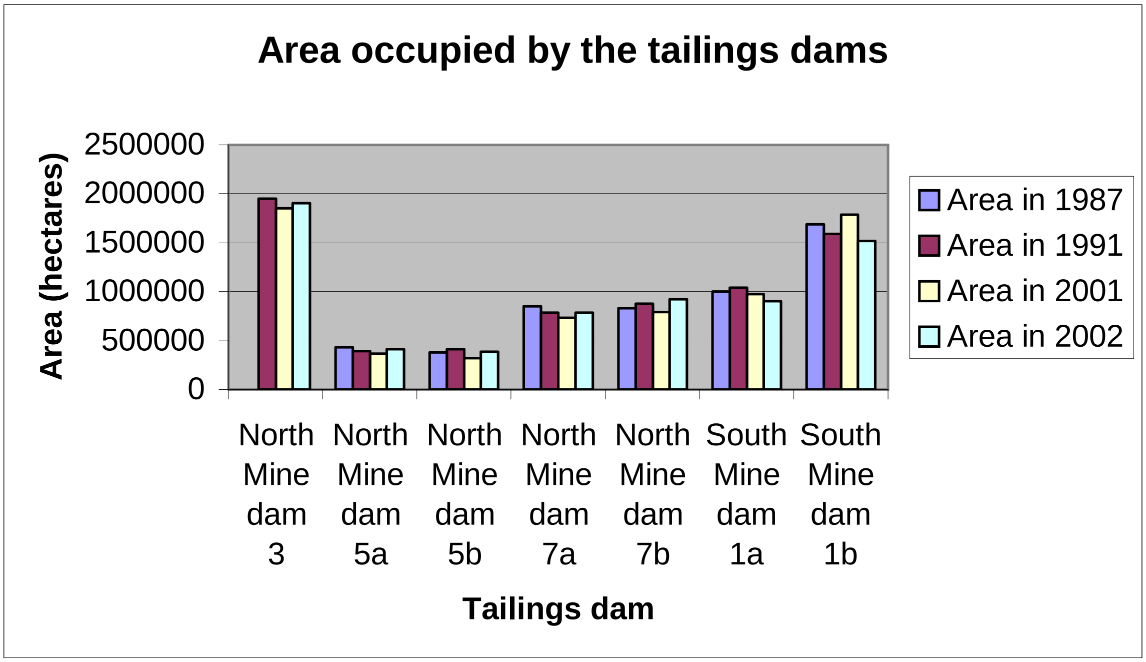


Figure 5.11 Area occupied by Tailings Dams in 1987, 1991, 2001 & 2002

Although the dams show fluctuating changes in their sizes the trend seems to increasing (judged by the 2002 sizes). Only the South Mines dams show a decrease in the sizes of the dams in 2002.

5.5 Discussion

The differences in the methods of classification (supervised and unsupervised) and processing (stretching) emphasize the need to undertake ground truthing in order to effectively analyse remotely sensed data. The mine dumps and their potential impacts on the environment could be overlooked if the satellite data was analysed by unsupervised classification only.

The changes in the sizes of the dams over the period 1987 to 2002 are not significant (refer to Table 5.6). The size of South Mine dam 1a seems to have been decreasing post 1996. This coincides with the vegetation programme that was introduced in 1996. This is in line with past evidence which shows that the dams viewed from space appear smaller if vegetation has been established on the dam slopes. As the South mine dams become older the increase in their sizes is more vertical than horizontal, hence their size seems to have decreased in 2002. It is not clear why the sizes of North mine dams seem to have decreased in 2001 only to increase again in 2002. One reason could be the accuracy of the remote sensing instruments used. Further monitoring of the changes in size of the dams needs to be undertaken. This will enable one to understand the reasons for the changes.

Table 5.6 Area occupied by the tailings dams between 1987 and 2002

Tailings Dam	Aerial photos (1987)	Topomap (1991)	ASTER (2001)	Aerial photos (2002)
North Mine dam 3		1,949,950	1,853,299	1,902,821
North Mine dam 5a	433,507	389,555	363,853	413,066
North Mine dam 5b	381,242	411,448	323,307	388,948
North Mine dam 7a	851,677	788,347	732,493	785,255
North Mine dam 7b	831,786	877,106	792,980	922,154
South Mine dam 1a	1,000,053	1,042,137	978,163	900,200
South Mine dam 1b	1,687,917	1,587,260	1,785,348	1,515,094

5.6 Conclusion

Smaller sections of the plantation have increased in size while the big section of the plantation has decreased. The sections that have increased are situated on the far west and south west of the North mine dam 7 while the section which has decreased in size is located west of the North mine dam 7. The size of this section has been negatively affected by its closer (compared to the sections that have increased in size) proximity to the North mine dam 7.

The NDVI, the colour composite and the tassled cap images confirm natural lack of vegetation (pre-mining the area was covered by scattered trees and shrubs. The mining activities have had limited negative impact on the vegetation cover.

There have been insignificant changes in the sizes of the tailings dams during the study period. The tailings dams occupy a significant portion of the West Rand area. There is considerable risk of pollution from these dams and the effectiveness of their rehabilitation will determine future land use in the area.