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South African National Land-Cover Change Map

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Abstract

Globally, countries face a changing environment due to population growth, increase in agricultural production, increasing demand on natural resources, climate change and resultant degradation of the natural environment. One means of monitoring this changing scenario is through land-cover change mapping. Modern Earth Observation (EO) technologies, especially those EO datasets comprising a multi-year data archive, lend themselves to land-cover change studies. This project used a practical and cost-effective approach for monitoring land-cover change at a national scale over time using EO data. The primary objective of this study was to determine the extent of transformed landscape change within South Africa over a 10-year period between 1994 and 2005. The project used three generalised land-cover datasets (for 1994, 2000 and 2005) and quantified the change between these assessment years. The land-cover change was based on five classes: Urban, Mining, Forestry, Cultivation and Other. The standardised five class land-cover datasets representing the three assessment years were compared within a uniform national grid, based on 500 m x 500 m cells. The land-cover allocated to each cell in each year represented the spatially dominant land-cover within that cell, as determined from the original land-cover datasets. Various spatial modelling procedures were used to ensure compilation of comparable and standardised land-cover class allocations to each cell for each year, prior to any year-on-year change analyses. The results indicate that at a national level there has been a total increase of 1.2% in transformed land specifically associated with Urban, Cultivation, Plantation Forestry and Mining. This represents an increase from 14.5% transformed land in 1994 to 15.7% in 2005 across South Africa.

1. Introduction

Globally, countries face a changing environment due to population growth, increase in agricultural production, increasing demand on natural resources, climate change and resultant degradation of the natural environment (Martino & Zommers, 2007). One means of monitoring this changing scenario is through land-cover change mapping. Modern Earth Observation (EO) technologies, especially those EO datasets comprising a multi-year data archive, lend themselves to land-cover change studies (Schoeman *et al*., 2010) South Africa has over recent years experienced significant changes in policy, legislation and service delivery. The FAO contracted the ARC-ISCW to prepare a national land-cover change map to quantitatively assess the impacts these developments have had on land-cover. This project used a practical and cost-effective approach for monitoring land-cover change at a national scale over time using EO data.

2. Objective

The primary objective of the study was to determine the extent of transformed landscape change within South Africa over a 10-year period between 1994 and 2005. In order to achieve this objective, the project used three generalised land-cover datasets (for 1994, 2000 and 2005) and quantified the change between these assessment years. The Land-cover change was based on five land-cover classes (Table 1).

Table 1: Definitions of the five land-cover classes on which land-cover change has been based

Land-cover class	Class definition
Urban	Human settlements, both rural and urban
Mining	Areas covered by mining and related mining activities, also includes mine dumps
Forestry and plantations	All forestry and plantations including woodlots and clear fell areas (excludes indigenous natural forests)
Cultivation	All areas used for agricultural activities, including old fields and subsistence agriculture
Other	All other areas not covered by those listed above

3. Materials

3.1 Data Sources

Land-cover data for the three assessment years was sourced from a combination of existing datasets and data generated specifically for the FAO land-cover change assessment. The 1994 land-cover data was extracted from the existing 1994 South African National Land-Cover Dataset (NLC 94) (Fairbanks *et al.*, 2000). The 2000 land-cover data was extracted from the existing South African National Land-Cover 2000 Dataset (NLC 2000) (Van den Berg *et al.*, 2008). The 2005 land-cover data was generated from a combination of provincial land-cover datasets, captured from various satellite data acquired between 2005 and 2009, and from new land-cover data captured specifically for the FAO project from historical 2005 Landsat imagery.

All existing land-cover datasets contained sufficient levels of land-cover detail to enable standardised re-formatting into the required four basic change assessment land-cover types, namely: urban / built-up, cultivated, mines, and (forest) plantation. All new land-cover datasets were only mapped in terms of the required four change assessment land-cover classes.

3.1.1 National Land-Cover 1994

The NLC 94 data was mapped manually from 1:250 000 scale hardcopy Landsat image maps, based on imagery acquired in 1994-1995. The original land-cover data was captured as a digital vector dataset with a minimum mapping unit of 25 ha, and contained 31 land-cover classes

(Fairbanks *et al.*, 2000). The original land-cover class detail was simplified into the required four change assessment class legend format, with all excluded original land-cover classes being amalgamated into a new “other / background” class. The final map accuracy of the NLC 94 dataset (averaged over the three geographical production phases) was 79.4% (78.5-80.4% at the 90% confidence limits), with a kappa index of 74.8 (Fairbanks *et al.*, 2000).

3.1.2 National Land-Cover 2000

The NLC 2000 data was generated from digital Landsat imagery, acquired primarily from 2000-2001. The original land-cover data was captured as a digital raster dataset with a minimum mapping unit of 2 ha, and contained 45 land-cover classes (Van den Berg *et al*., 2008). The original land-cover class detail was simplified into the required four change assessment class legend format, with all excluded original land-cover classes being amalgamated into a new “other / background” class. The final map accuracy for NLC 2000 was 65.8% (65.10-66.52% at the 90% confidence limits), with a kappa index of 57 (Van den Berg *et al*., 2008).

3.1.3 “Five Class” National Land-Cover 2005

The 2005 land-cover data was derived from a combination of existing provincial land-cover datasets (which had been generated from suitably dated satellite imagery), and new land-cover data mapped specifically for this project, off historical Landsat imagery *circa* 2005.

The existing provincial land-cover datasets were all generated independently using SPOT satellite data and contained comparable levels of detailed land-cover information. These datasets included detailed coverage of Gauteng, KwaZulu-Natal, significant parts of the Western and Northern Cape, and North West Province, as well as nationally all urban / built-up areas. Permission to use and extract relevant land-cover class information from these datasets was granted by Cape Nature, Ezemvelo KZN Wildlife, Eskom, GeoTerraImage Pty Ltd, and North West Department of Agriculture, Conservation and Environment.

Areas where no suitable 2005 land-cover data existed were mapped using conventional digital classification techniques from archival 2005 Landsat imagery, as part of the data preparation activities for this project. These datasets were only generated in terms of the required four basic land-cover change assessment classes, and not as full detail land-cover legends. New five class land-cover data were generated for the Mpumalanga, Eastern Cape and Limpopo provinces. The reported mapping accuracies for these existing datasets were between 80% and 83%.

The original land-cover class detail in these existing land-cover datasets was simplified into the required four change assessment class legend format, with all excluded original land-cover classes being amalgamated into a new “other / background” class.

4. Methodology

The basic approach taken for the land-cover change assessment was to compare the standardised five class land-cover datasets representing the three assessment years (i.e. 1995, 2000 and 2005), within a uniform national grid based on 500 m x 500 m cells. The land-cover allocated to each cell in each year represented the spatially dominant land-cover within that cell, as determined from the original 1994, 2000 and 2005 datasets. Various spatial modelling procedures, as described below, were used to ensure compilation of comparable and standardised land-cover class allocations to each cell for each year, prior to any year-on-year change analyses. A 500 m x 500 m cell size was chosen since this is the same as the 25 ha theoretical minimum mapping unit associated with the original NLC1995 land-cover dataset, and as such represented the coarsest level of mapping detail in the input datasets. All other input datasets were thus spatially downgraded to this coarsest level.

4.1 Workflow

The flowchart in Figure 1 illustrates the overall workflow that was followed in order to convert the individual 1995, 2000 and 2005 national land-cover datasets into standardised five class legend format, and code the cells within the 500 m x 500 m national grid structure, on which all change assessments were based.

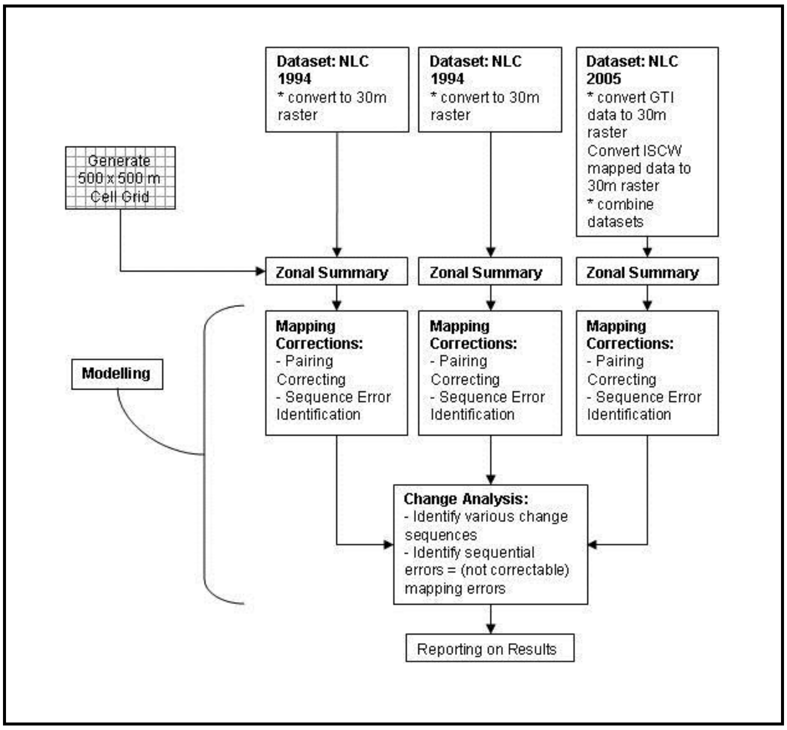

Figure 1: The overall workflow followed to convert the individual national land-cover datasets into a standardised five class legend format within the 500 m x 500 m national grid structure.

4.2 Process Description

4.2.1 Base Grid

A national vector grid frame, based on 500 m x 500 m cells and covering all of South Africa, was created as the base template. All cells were given national and provincial name attributes to assist with final results reporting and analysis on a sub-national level. Boundary cells were clipped according to the definitive national boundary and thus are not necessarily complete 500 m x 500 m square cell structures.

4.2.2 Conversion to Standardised Land-Cover Datasets

Prior to encoding of the 500 m x 500 m national base grid, each of the individual national land-cover datasets for 1995, 2000 and 2005 were initially converted into comparable 30 m raster national datasets, based on the five class basic land-cover legend format to be used in the change analysis. This approach was done to ensure, as far as possible, that comparable results would be achieved, year-on-year, when spatially summarising the original land-cover to the required 500 m x 500 m cell format.

4.2.3 Zonal Attributes

Encoding of the individual 500 m x 500 m cells with the appropriate land-cover for each year was achieved using a “zonal majority” modelling process. This process generated an attribute code for each cell based on the spatially dominant land-cover class located within that cell extent. Due to the physical size of the datasets being processed in this manner, it was necessary to sub-divide the country into a series of non-overlapping data clips, which were processed individually before being re-combined into a single national coverage.

4.2.4 Final Annual Land-Cover Datasets

The land-cover codes for each year are represented as different attributes for each cell within the same base grid template, rather than generating separate grid templates for each assessment year (Figure 2). Similarly, all change assessment results are reported as additional attributes within the same data coverage. This approach has been taken since it allows a single data coverage to be the final product deliverable, and facilitates transparency of results reporting.

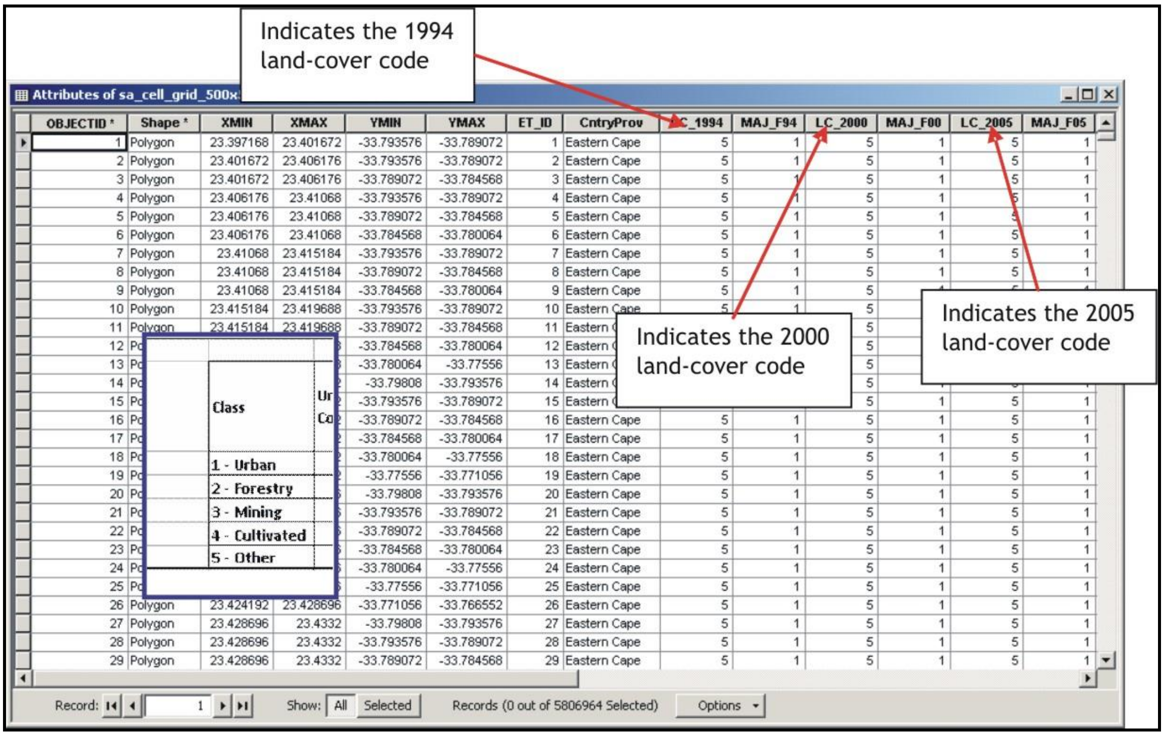

Figure 2: Example of the attribute table showing the three land-cover codes.

4.3 Temporal Land-Cover Change Modelling Issues

The accuracy of (land-cover) change modelling is directly dependent on the accuracy of the input data between which any changes are to be determined. As indicated previously, a significant proportion of the input land-cover data used in the FAO change assessment project was based on pre-existing land-cover data. In such cases, these datasets are known to have a certain error component in the original mapping content which could influence the accuracy and reliability of comparative change analyses.

In order to minimise, as far as possible, errors in change detection resulting from original land-cover data misclassifications in the individual year datasets, two systematic desktop assessment procedures were used to identify and correct any likely land-cover misclassifications based on the logic of the three year sequence of reported land-cover types within each specific grid cell. Whilst the limitations of such an approach are acknowledged, the approach allows a secondary level of individual year land-cover normalisation to be achieved prior to any year-on-year change analysis, with commensurate increases in the reliability and accuracy of final change assessment results. The two corrective modelling procedures were implemented within a single integrated modelling approach.

4.3.1 Land-Cover Change – Two-Date Sequence Logic Review

The first logic assessment was based on the likelihood of any two-date pair sequence of land-cover classes actually occurring in reality. These pair-based logic assumptions are illustrated in

Table 2. For example, it is quite possible for a forestry plantation to be cleared and replaced by an urban area, but highly unlikely that an urban area will be cleared for a forestry plantation. It is also highly unlikely for urban areas to be cleared for any of the other land-cover classes.

Forestry will most likely not be cleared for cultivation as this is usually located in areas where the slope is too steep for agricultural applications or the soil conditions are marginal. This also applies for changes to class "other".

Mining areas are not likely to be converted to either urban or plantation, even after rehabilitation, although a significant number of mines in the Mpumalanga Highveld are re-converted to either cultivated lands or grasslands (i.e. "other") as a result of local land-use and land-cover characteristics.

The reasoning followed in developing these rules is based on logical principles associated with drivers such as land-use economics and physical landscape criteria.

Table 2: Example of the two-date sequence

Change from code	**Change to code**	**Logical**
Urban	Forestry/Plantation	No
Urban	Mining/Quarries	No
Urban	Cultivation	No
Urban	Other	No

4.3.2 Land-Cover Change – Three-Date Sequence Logic Review

The second logic assessment was based on the likelihood of any three-date sequence of land-cover classes actually occurring in reality, taking into account the assumptions of the previous two-date logic, when seen as part of a longer three-date sequence.

For example, it is quite possible for a forestry plantation (first date) to be cleared and replaced by an urban area (second date), and that the urban area will remain on the third date. But it is highly unlikely that the urban area (second date) will be cleared for replanting as a forestry plantation again in the third year. In such a three-date sequence (i.e. plantation-urban-plantation) it is more likely that the second year "urban" code is a misclassification in the original land-cover dataset and should therefore be corrected to a second date "plantation" code (i.e. plantation-plantation-plantation).

Figure 3 illustrates the various year-on-year land-cover code sequences that could occur between the project legend classes and the corrective code sequences that could be logically applied to improve the initial accuracy of the three year land-cover datasets before change analysis. Note that in some instances, the logic of the three year sequence did not allow any corrective re-coding and in such cases these sequences were identified as "mapping errors" within the final change analysis.

1994		2000		2005	Likely		1994		2000		2005	Likely	
Forestry/Plantations	✓	Urban/Built-up	✓	Urban/Built-up	Y	2;1;1	Forestry/Plantations		Urban/Built-up		Urban/Built-up	Y	2;1;1
Forestry/Plantations	✓	Urban/Built-up	✗	Forestry/Plantations	X	2;2;2	Forestry/Plantations		Forestry/Plantations		Forestry/Plantations	X	2;2;2
Forestry/Plantations	✓	Urban/Built-up	✗	Mining/Quarries	N	mapping error	*Mapping Error*		*Mapping Error*		*Mapping Error*	N	0;0;0
Forestry/Plantations	✓	Urban/Built-up	✗	Cultivation	N	mapping error	*Mapping Error*		*Mapping Error*		*Mapping Error*	N	0;0;0
Forestry/Plantations	✓	Urban/Built-up	✗	Other	N	mapping error	*Mapping Error*		*Mapping Error*		*Mapping Error*	N	0;0;0
Forestry/Plantations	✓	Forestry/Plantations	✓	Urban/Built-up	Y	2;2;1	Forestry/Plantations		Forestry/Plantations		Urban/Built-up	Y	2;2;1
Forestry/Plantations	✓	Forestry/Plantations	✓	Forestry/Plantations	Y	2;2;2	Forestry/Plantations		Forestry/Plantations		Forestry/Plantations	Y	2;2;2
Forestry/Plantations	✓	Forestry/Plantations	✓	Mining/Quarries	Y	2;2;3	Forestry/Plantations		Forestry/Plantations		Mining/Quarries	Y	2;2;3
Forestry/Plantations	✓	Forestry/Plantations	✓	Cultivation	Y	2;2;4	Forestry/Plantations		Forestry/Plantations		Cultivation	Y	2;2;4
Forestry/Plantations	✓	Forestry/Plantations	✗	Other	Y	2;2;2	Forestry/Plantations		Forestry/Plantations		Forestry/Plantations	Y	2;2;2
Forestry/Plantations	✓	Mining/Quarries	✗	Urban/Built-up	N	mapping error	*Mapping Error*		*Mapping Error*		*Mapping Error*	N	0;0;0
Forestry/Plantations	✓	Mining/Quarries	✗	Forestry/Plantations	X	2;2;2	Forestry/Plantations		Mining/Quarries		Forestry/Plantations	X	2;2;2
Forestry/Plantations	✓	Mining/Quarries	✓	Mining/Quarries	Y	2;3;3	Forestry/Plantations		Mining/Quarries		Mining/Quarries	Y	2;3;3
Forestry/Plantations	✓	Mining/Quarries	✓	Cultivation	Y	2;3;4	Forestry/Plantations		Mining/Quarries		Cultivation	Y	2;3;4
Forestry/Plantations	✓	Mining/Quarries	✓	Other	N	mapping error	*Mapping Error*		*Mapping Error*		*Mapping Error*	N	0;0;0
Forestry/Plantations	✗	Cultivation	✓	Urban/Built-up	N	mapping error	*Mapping Error*		*Mapping Error*		*Mapping Error*	N	0;0;0
Forestry/Plantations	✗	Cultivation	✓	Forestry/Plantations	X	2;2;2	Forestry/Plantations		Forestry/Plantations		Forestry/Plantations	X	2;2;2
Forestry/Plantations	✗	Cultivation	✓	Mining/Quarries	N	mapping error	*Mapping Error*		*Mapping Error*		*Mapping Error*	N	0;0;0
Forestry/Plantations	✗	Cultivation	✓	Cultivation	X	4;4;4	Cultivation		Cultivation		Cultivation	X	4;4;4
Forestry/Plantations	✗	Cultivation	✓	Other	N	mapping error	*Mapping Error*		*Mapping Error*		*Mapping Error*	N	0;0;0
Forestry/Plantations	✗	Other	✓	Urban/Built-up	N	mapping error	*Mapping Error*		*Mapping Error*		*Mapping Error*	N	0;0;0
Forestry/Plantations	✗	Other	✓	Forestry/Plantations	X	2;2;2	Forestry/Plantations		Forestry/Plantations		Forestry/Plantations	X	2;2;2
Forestry/Plantations	✗	Other	✓	Mining/Quarries	N	mapping error	*Mapping Error*		*Mapping Error*		*Mapping Error*	N	0;0;0
Forestry/Plantations	✗	Other	✓	Cultivation	N	mapping error	*Mapping Error*		*Mapping Error*		*Mapping Error*	N	0;0;0
Forestry/Plantations	✗	Other	✓	Other	X	5;5;5	Other		Other		Other	X	5;5;5

Figure 3: Example of the year-on-year land-cover code sequence. The three year columns on the left indicate the original three date land-cover sequences, whilst those on the right illustrate the corrected sequences. Red cells indicate land-cover sequences that could not be logically corrected and were thus labelled as "mapping error" in the final data results.

4.4 Modelling

4.4.1 Modelling Process

The two- and three-date logic rules were applied to each cell within the national grid template to correct, as far as possible, any land-cover misclassifications in the original land-cover datasets that were now represented in the 500 m x 500 m cell attributes (after zonal majority modelling).

4.4.2 Data Normalisation – Number of Changes made to Original Cell Values

As can be seen in Figure 4, in most cases the number of changed cell values within any three-date sequence, including non-correctable "mapping error" cells (per land-cover class, per year) was significantly less than 10%, with many being less than 2%, which indicates that although original mapping errors did exist, they are unlikely to have significantly affected the reliability of the change assessment results.

Mpumalanga	Year: 1994					
Class	Unchanged Count	Unchanged Percentage	Logically Corrected Count	Logically Corrected Percentage	Total Count	Total Percentage
1 - Urban	4278	86.1%	691	13.9%	4969	100%
2 - Forestry	28036	91.1%	2729	8.9%	30765	100%
3 - Mining	1914	98.5%	29	1.5%	1943	100%
4 - Cultivated	56336	99.8%	91	0.2%	56427	100%
5 - Other	245503	100%	244	0.1%	245747	100%

Year: 2000						
Class	Unchanged Count	Unchanged Percentage	Logically Corrected Count	Logically Corrected Percentage	Total Count	Total Percentage
1 - Urban	7207	99.4%	43	0.6%	7250	100%
2 - Forestry	29395	94.1%	1843	5.9%	31238	100%
3 - Mining	1562	94.8%	86	5.2%	1648	100%
4 - Cultivated	47834	99.6%	214	0.4%	48048	100%
5 - Other	246260	97.9%	5407	2.1%	251667	100%

Year: 2005						
Class	Unchanged Count	Unchanged Percentage	Logically Corrected Count	Logically Corrected Percentage	Total Count	Total Percentage
1 - Urban	11555	98.6%	167	1.4%	11722	100%
2 - Forestry	37062	99.8%	69	0.2%	37131	100%
3 - Mining	2860	97.8%	63	2.2%	2923	100%
4 - Cultivated	73929	99.2%	621	0.8%	74550	100%
5 - Other	212862	99.7%	662	0.3%	213524	100%

Year: 2000						
Class	Unaltered Count	Unaltered Percentage	Logically Corrected Count	Logically Corrected Percentage	Total Count	Total Percentage
1 - Urban	7207	99.4%	43	0.6%	7250	100%
2 - Forestry	29395	94.1%	1843	5.9%	31238	100%
3 - Mining	1562	94.8%	86	5.2%	1648	100%
4 - Cultivated	47834	99.6%	214	0.4%	48048	100%
5 - Other	246260	97.9%	5407	2.1%	251667	100%

Figure 4: Example of the data normalisation results table.

5. Results

5.1 Land-Cover Statistics per Assessment Year

The tables below illustrate the total areas (and percentages) of each of the mapped land-cover classes within each assessment year at a national level. Since all mapped classes are representative of transformed landscapes (i.e. changed from a natural state), these year-on-year statistics are also broadly indicative of the level of landscape transformation across South Africa. Table 3 illustrates the total area of transformation, as represented by a combination of all mapped land-cover classes across the entire country. Table 4 illustrates the area of transformation, as represented by each individual land-cover classes across the entire country.

Table 3: The number of cells and percentage of the total number of cells that have been classed as transformed on a national scale on each of the three dates

	Transformed (cell count)	Other (cell count)	*Mapping Error (cell count)	Percentage Transformed	Percentage Other	Percentage *Mapping Error	Total
1994	844 306	4 953 730	8 928	14.5%	85.3%	0.2%	100.0%
2000	770 412	5 027 624	8 928	13.3%	86.6%	0.2%	100.0%
2005	909 633	4 888 403	8 928	15.7%	84.2%	0.2%	100.0%

*Non-correctable mapping errors in final land-cover datasets after all possible logical corrections have been applied

Table 4: Breakdown of transformation per class for each of the three dates

	1994		2000		2005	
	Cell count	Percentage	Cell count	Percentage	Cell count	Percentage
1 - Urban	49 116	0.8%	86 469	1.5%	114 987	2.0%
2 - Forestry and Plantations	67 346	1.2%	83 540	1.4%	93 849	1.6%
3 - Mining and Quarries	7 321	0.1%	7 726	0.1%	9 779	0.2%
4 - Cultivated	720 523	12.4%	592 677	10.2%	691 018	11.9%
5 - Other	4 953 730	85.3%	5 027 624	86.6%	4 888 403	84.2%
All classes	5 798 036		5 798 036		5 798 036	
Mapping errors	8 928	0.2%	8 928	0.2%	8 928	0.2%
Total	5 806 964	100.0%	5 806 964	100.0%	5 806 964	100.0%

5.2 Change map

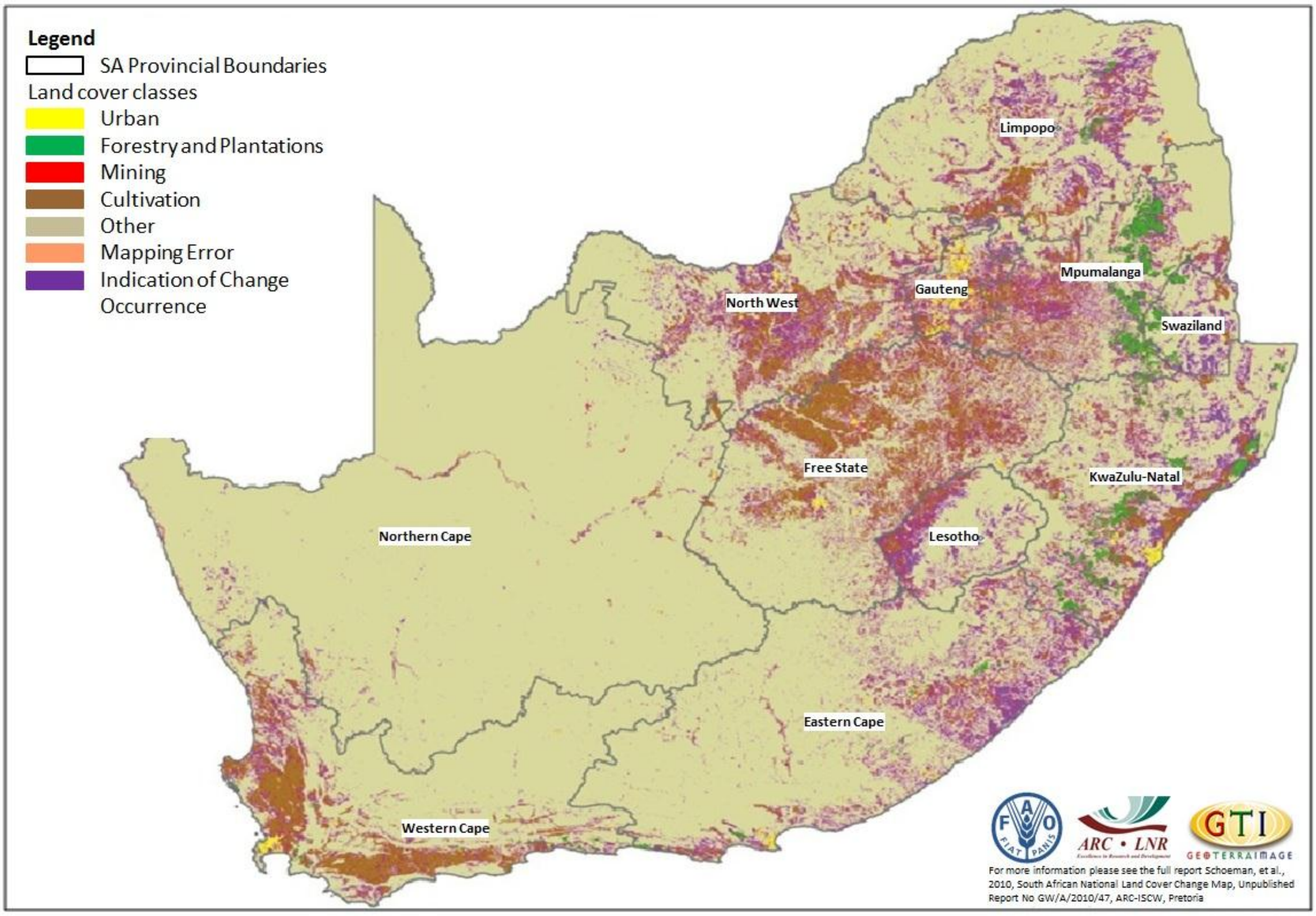

Figure 5: Final map showing areas of change between 1994 and 2005.

5.3 Comment on Accuracy of Change Assessment

The accuracy of land-cover change detection is directly linked to the accuracy of the input land-cover data being used to detect any change. Both the 1994 and 2000 land-cover datasets have previously been independently validated using comprehensive statistical sampling, as has a significant proportion of the 2005 land-cover data.

The assumption is that all the new land-cover data, created specifically for the FAO change project in order to complete the 2005 national data coverage, has been generated with comparable levels of mapping accuracy, since in many cases the same experienced remote sensing analysts have been used for this process as were involved in the previous NLC 94 and NLC 2000 mapping activities.

It is therefore assumed that the (logic-based) desktop corrective measures applied to the original land-cover data prior to change analysis should have corrected, where possible, the identified misclassifications, and so improved further the reliability of the change detection results.

6. Conclusions and Recommendations

In summary, the results indicate that at a national level there has been a total increase of 1.2% in transformed land specifically associated with Urban, Cultivation, Plantation Forestry and Mining. This represents an increase from 14.5% transformed land in 1994 to 15.7% in 2005 across South Africa (see Table 3).

On a national basis the areas of Urban, Forestry and Mining have all increased over the 10-year period whereas Cultivated areas have decreased. Urban has increased from 0.8% to 2%, Forestry from 1.2% to 1.6%, and Mining from 0.1% to 0.2%, while Cultivated has decreased from 12.4% to 11.9% (see Table 4). The spatial patterns do, however, vary geographically across provinces in South Africa.

Although the modelling procedures are considered sound and can form a framework for similar change assessments in future, it should be noted that the outputs are dependent on the quality, compatibility and accuracy of the input datasets. In this project it should be noted that the differences in the source datasets relating to mapping methodology, scale and classification systems used, will still have had an influence on the final project output. This is despite the corrective modelling procedures implemented.

Woodcock and Strahler (1987) discuss the difference between high resolution and low resolution imagery or spatial data and how the size and spatial relationship of the object of interest influence the variability within land-cover classes. In this study the reported increase in mining in Mpumalanga from 0.6% in 1994 to 0.9% in 2005, which represents a 50% increase in mining activity in the province, is possibly an under-estimation. This is the result of the fact that strip mining areas are generally not the dominant cover within a 500 m x 500 m cell due to their linear shape.

The dataset resulting from the process described can be considered a useful resource for further research. It is presented in a format that facilitates further research and analysis. The format of the dataset allows for ease of re-analysis and further interrogation. It is recommended that further research should include investigation into the transformed cover classes with the objective of identifying the drivers and type of change that has occurred, as well as the social, environmental and economical impacts of these changes over time.

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