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Expansion of Subsistence Agriculture in North-Central Namibia: 1973 to 1997.

A pilot study of rapid land cover area estimation using remote sensing.

M.Sc. Applied Remote Sensing

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ABSTRACT

Human population growth and the expansion of related activities with environmental impact, is of interest to Governments as well as the private sector in countries around the world. Political independence in March of 1990 has brought peace, stability and economic growth to Namibia. Subsequent expansion of subsistence based as well as small-scale commercial agricultural activities in the north-central regions of the country are obvious, but quantitative information on rates of expansion and spatial extents are not available. This study focused on the communally owned portion of Oshikoto region in northern Namibia. It illustrates a rapid and reliable method for estimating crop areas for current and historical time frames, and provides a useful indication of changes in the spatial extent of these activities through time. The methodology can be applied to the remaining regions of Oshana, Omusati and Ohangwena, in order to obtain a contextual view of these changes. Direct expansion estimates of areas under subsistence agriculture were derived from satellite data for 1973, 1987 and 1997, using classical statistical methods. These data were validated against aerial photographs, which are available for selected areas. Results were tabulated and put into spatial context, by linking data for individual sample segments to their geographical positions in a GIS. Change during both the 1973 to 1987 and 1987 to 1997 periods was in the form of an increase in the area under agricultural practice, and no abandonment was observed in the sample data. Expansion of agricultural activities between 1973 and 1987 was relatively minor, with a spatial distribution proximal to major towns and roads. The post-independence period between 1987 and 1997 saw much greater expansion, not only locally, but also into relatively remote parts of the region.

Acknowledgments

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Table of Contents

List of Tables and Figures

1. Introduction

1.1. Rationale

1.1.1. Perspective overview.

Namibia is a large country with a small population. It is almost $3^1/_2$ times the size of the United Kingdom, but the population is 36 times smaller. The density of 2 people per square kilometre belies the fact that human settlement is highly clustered, with the majority of the population residing in the northern parts of the country. The land tenure in these densely populated areas is predominantly communal, while subsistence agriculture and animal husbandry are the main forms of land use. The importance of natural resources is emphasised by the fact that more than a quarter of the population lives on just over one percent of the land, within the Omusati, Ohangwena, Oshana and Oshikoto regions (Ashley, 1996, in Tarr, 1996).

Namibia won political independence from South Africa in March of 1990. This ended 23 years of war, and brought peace and stability to Namibia. The north-central regions of the country were particularly affected, and post-war growth in both the economic and agricultural sectors are obvious. However, quantitative information on rates of expansion as well as past and present spatial extents of subsistence agriculture in particular, is not available. This information is essential for strategic planning, and may serve to focus private sector and non-governmental organisation activities.

1.1.2. This work.

This study was conducted within the framework of the Northern Namibia Environmental Project (NNEP). The NNEP is a project of the Namibian Ministry of Environment and Tourism, and is co-funded by the British Department for International Development (DfiD). The purpose of the NNEP is to promote information based and participatory planning processes, for sustainable environmental management in Northern Namibia (NNEP project document, 1999). NNEP activities are largely confined to the four administrative regions of Omusati, Ohangwena, Oshana and Oshikoto (Figure 1.1).

1.1.3. Study area.

Oshikoto region lies between latitudes 17º 41' and 19º 32' S, and longitudes 15º 50' and 18º 13' E. The vegetation is a combination of savanna and woodland (Geiss, 1971), on soil types which range from weakly developed, shallow calcerous soils in the south, to a mixture of arenosols in the north of the area (Harmse, H.J. von M. in Werger, 1978). Rain falls during the summer months of October to April, and is highly variable. Rainfall increases steadily eastwards, and at the eastern edge of the study area (Grootfontein) averages more than 500 mm per annum (Botha, 1997).

The total size of the Oshikoto region is 38669 km^2. However, the fact that the Etosha National Park and privately owned commercial farms in the south of the region were not considered in this study, reduced the size of the study area to 18426 km^2.

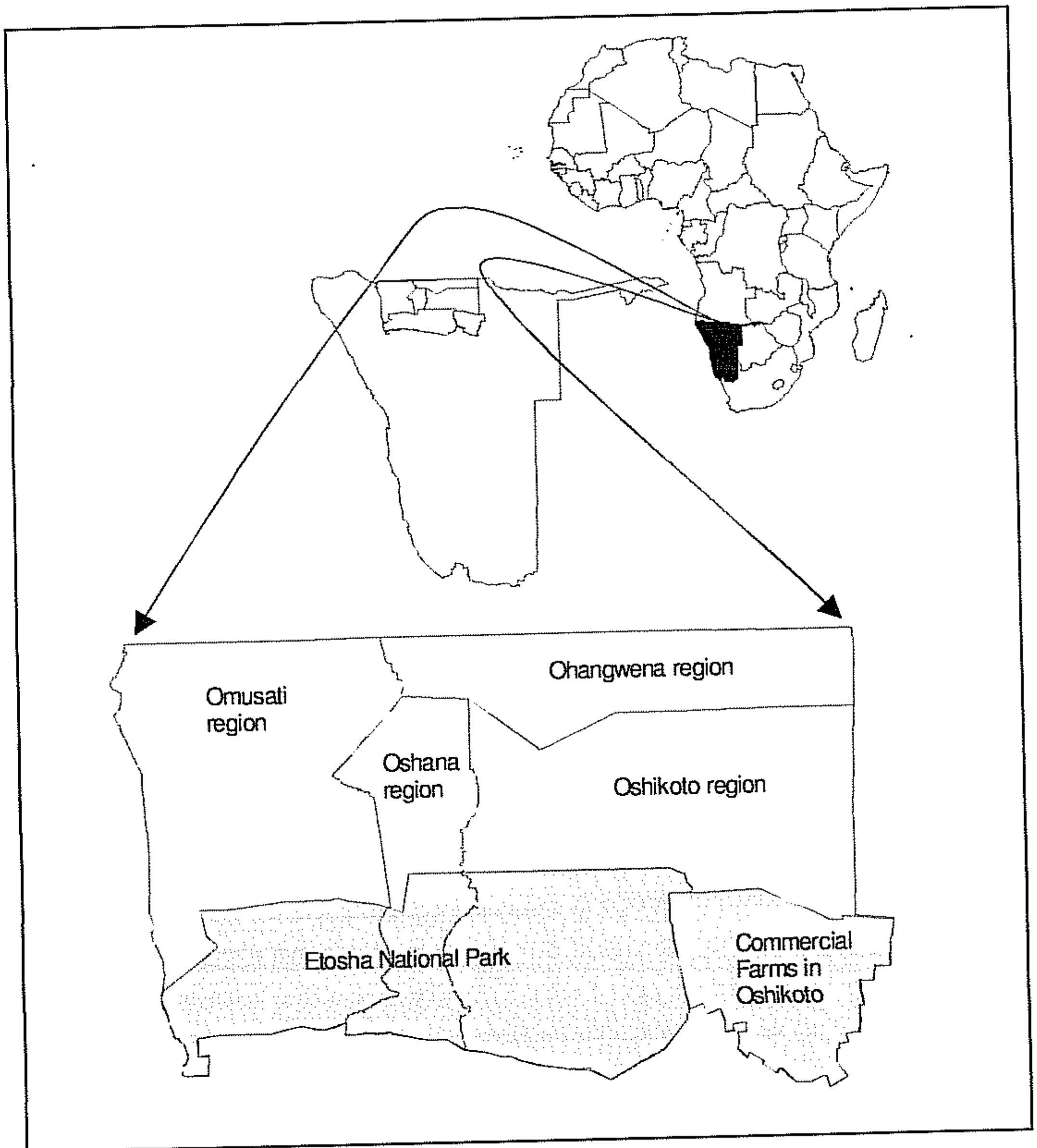

Figure 1.1 The geographic position of Namibia and the study area within it. The shaded areas of Etosha National Park and the commercial farms were not considered in this study.

1.2. *Area estimation with remote sensing*

1.2.1. Overview of methodology.

Crop area estimation with remote sensing has been used operationally in the U.S.A. for almost 10 years (Deppe, 1998), while its application in Europe was investigated as part of the Monitoring Agriculture with Remote Sensing program (Taylor and Eva, 1991). Studies were also carried out in Spain (González-Alonso et al, 1997), Australia (Daubin and Beach, 1981 in Deppe, 1988), Canada (Ryerson et al., 1985) and Lybia (Latham et al 1983).

The basic methodology relies on direct expansion of area estimates obtained from an area frame sampling scheme. The land area under investigation is divided into regular shaped grid cells of fixed size. This establishes the sampling frame. Smaller, regular shaped, fixed-size areas, are selected at random within this grid. These form the sample segments. The number and size of these segments determine the sample fraction. This is commonly between 1 and 2 percent of the total area which is being surveyed. The proportion of each crop within each segment is determined. The mean proportion for each crop for all segments, is taken as the estimator for that particular crop, and is used to obtain the direct expansion estimate.

The methodology as described in the above-mentioned literature, relies on ground survey to determine crop types and aerial cover for each crop in every segment. The study reported on here, applied visual interpretation techniques to satellite imagery, in order to determine these parameters.

1.3. *Aims and objectives*

1.3.1. Scope.

This research focuses on one of four geographical regions. It serves as a pilot study to develop a methodology, which can be applied to the neighbouring areas, in order to produce a synthesis of spatial and aerial change in land cover over time. This work originally set out to develop a rapid and reliable method for estimating the areal extent of several land cover types for current and historical time frames. This information is of use at local, regional and national level, and would enable decision makers to gain a clear understanding of the rates of environmental change over time, as well as which cover types are being impacted by expansions in subsistence agriculture. However, analysis of changes related to natural vegetation cover types was abandoned due to practical constraints (see section 2.5.1), and the focus narrowed to just two classes namely agriculture and non-agriculture.

1.3.2. Objectives and outputs.

The specific objectives of this research are:

1) To establish procedures for area estimation based on area frame sampling of contemporary and historical satellite images.
2) To estimate areas under agriculture for each date of imagery.
3) To indicate the spatial extent of temporal change in agricultural areas.
4) To evaluate the reliability of the methodology.
5) To make recommendations relating to it's application to the remaining regions.

Outputs are contained in this document, and contain tables of values, as well as maps.

2. Area estimation

2.1. Satellite data

2.1.1. Data source.

Digital image coverage of Oshikoto region requires 4 Landsat Thematic Mapper images. These (for 1997) were supplied by the North-Central Region Environmental Profiles Project, as were the aerial photographs for 1996. The Landsat Multi-Spectral Scanner datasets for 1987 were acquired from the Satellite Applications Centre (SAC) in South Africa, while the 1973 data were obtained directly from the Eros Data Centre at Sioux Falls in the U.S.A.

2.1.2. Data quality.

The 1997 TM data were supplied geometrically corrected to the local Datum (Schwarzeck) and an Albers Equal Area projection. The geometric accuracy of these data were evaluated against independent ground control points. Accuracy was generally within 100 metres. These scenes were used as the base to which the MSS data were matched.

The MSS data for 1987 were supplied by the SAC, with geometric corrections applied in both the along scan and across track directions based on spacecraft orbital and attitude information. The SAC processing therefore resulted in images, which had been corrected, and the orientation changed to align it with a map projection. Severe striping caused by post-launch drift in one of the six sensors was evident in the data. This could not be corrected using the data supplied, since the geocoding process had turned the horizontal scan lines into a series of steps. The data were replaced with "system corrected only" datasets. These images had geometric corrections applied in the along scan direction only, and had not been fitted to a map projection. It was then possible to apply radiometric restoration procedures prior to geocorrection (see section 2.2.3).

No sensor striping was evident in the MSS data for 1973.

It was not clear what radiometric processing had been applied to the TM data prior to delivery. However, truncated histograms in the near infrared (0.7 to 1.3 µm) band were interpreted as indicators of severe radiometric alteration of the original values.

A small proportion of the pixels in one image from 1987 suffered from cloud contamination, despite the fact that all images had been given a 100% cloud free vote by the SAC. This did not affect the sample segments.

2.2. *Satellite data pre-processing*

2.2.1. Spatial resolution

The Landsat TM scenes were supplied with a pixel size of 30 metres, whereas the Landsat MSS data had been resampled to 57 metres. Segments from the same sources (TM and MSS) were resampled to two different pixel sizes[1] by two different interpolation methods[2] were compared and evaluated (Figure 2.1). Results indicated severe reduction in feature definition even when resampling the 57 metre MSS data to 100 metre pixels (Figure 2.1c). Feature degradation was even worse for the TM data. Atkinson and Curran (1997) describe objective methods for choosing a suitable spatial resolution, but these were considered inappropriate for this study. All datasets were therefore resampled to a pixel size of 25 m using cubic convolution interpolation as described in Richards (1995, P.60). The decision to resample from 30 m to 25 metres in the case of the TM data, was taken so as to facilitate the fitting of a grid with sides in multiples of 100 metres. This decision dictated the size of the MSS pixels, which were resampled to the same size as the TM data so as to compare like with like.

The full scenes were subset to coincide with the boundaries of the geographic region of interest, and the number of spectral bands reduced to three selected bands per scene (see section 2.4), in order to reduce the size of the datasets.

[1] 25 metres and 100 metres
[2] Nearest neighbour and Cubic convolution

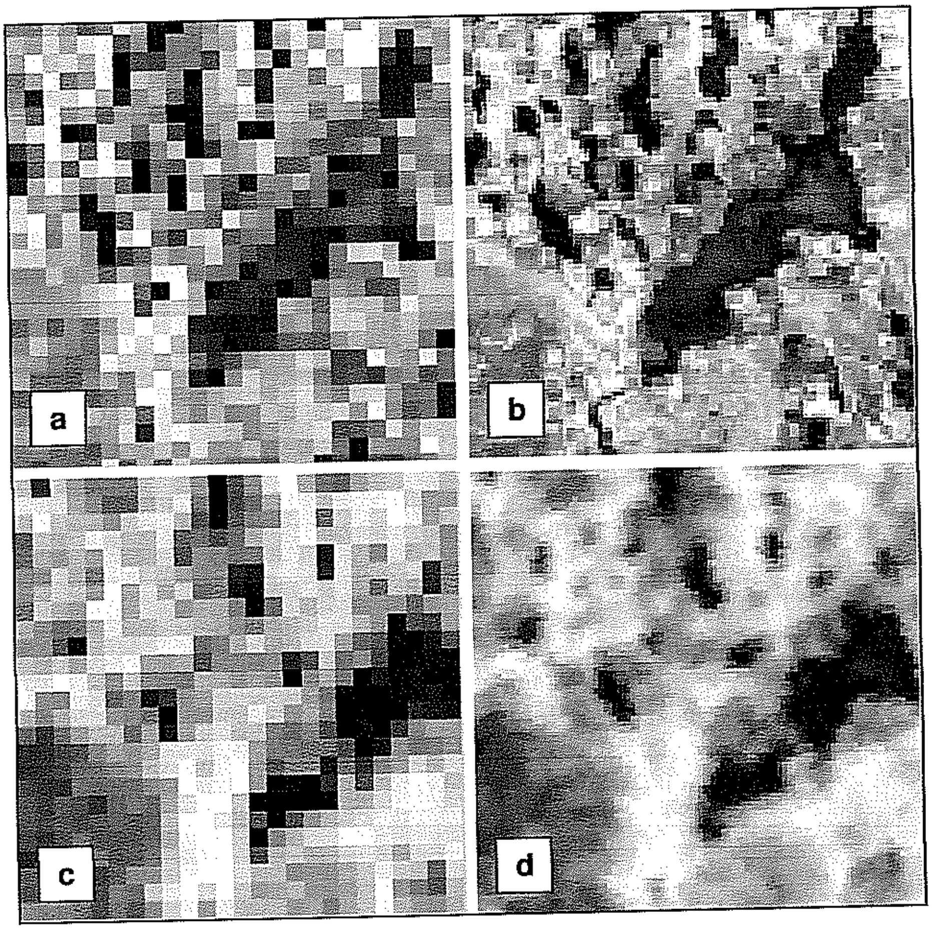

Figure 2.1 Comparison between sample segments resampled to different pixel sizes. Segment a is Landsat TM data at 100 metres; segment b shows the same segment with 25 m pixels. Segment c is Landsat MSS data at 100 metres; segment d shows the same segment with 25m pixels.

2.2.2. Geometric correction

Image to image, MSS to TM co-registration was carried out using first order polynomials and nearest neighbour resampling. A suitable number of well distributed ground control points and RMS errors of < 1.0 resulted in sub-pixel geometric accuracy, although localised misregistration of up to 3 pixels (75 metres) in the vicinity of some GCP's was evident in one set of data.

2.2.3. Radiometric correction.

The Landsat MSS data for 1987 suffered from severe sensor striping (Figure 2.2.a). Destriping procedures followed those described in Lillesand and Kiefer (1994, P. 537). Mean and standard deviation values extracted from the histograms for individual sensors for each band are given in Table 2.1.

Overall Image :	Mean	: 138.16	SD	: 31.23
Detector 1 :	Mean	: 127.83	SD	: 27.99
Detector 2 :	Mean	: 140.19	SD	: 31.26
Detector 3 :	Mean	: 136.93	SD	: 30.05
Detector 4 :	Mean	: 145.45	SD	: 32.74
Detector 5 :	Mean	: 145.52	SD	: 32.26
Detector 6 :	Mean	: 133.06	SD	: 28.83

Table 2.1 Histogram values for individual sensors in a Landsat MSS scene before radiometric restoration.

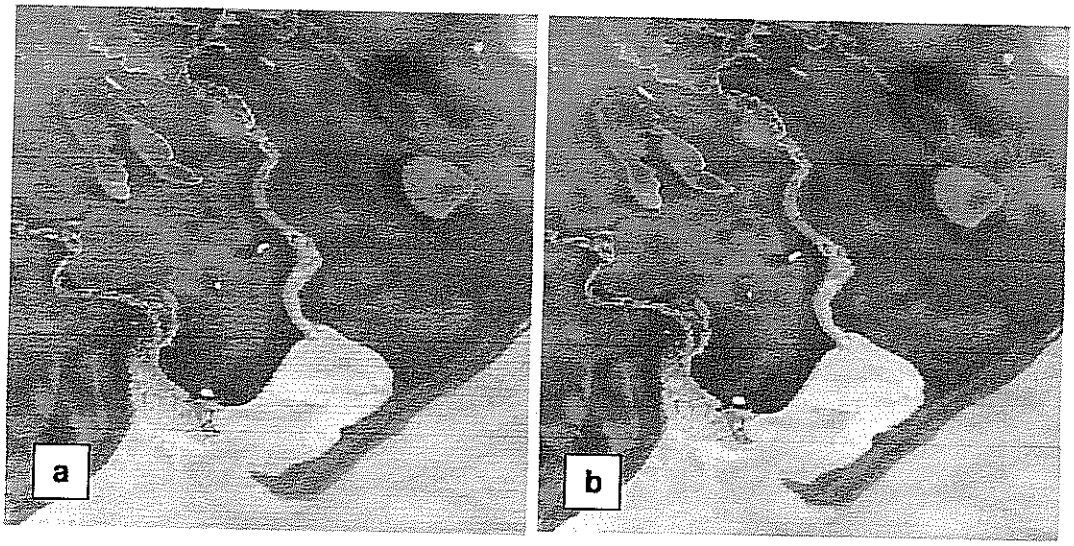

Figure 2.2 A section of a Landsat MSS scene from 1987, showing severe sensor striping in image (a), and the same image after radiometric restoration (b).

Idrisi software was used to apply greyscale correction factors to reduce the variation between successive scan lines. Statistics for the de-striped image is given in Table 2.2. No further radiometric corrections were applied to the data.

Overall Image :	Mean	: 138.16	SD	: 31.15
Detector 1 :	Mean	: 138.11	SD	: 31.03
Detector 2 :	Mean	: 138.22	SD	: 31.11
Detector 3 :	Mean	: 138.20	SD	: 31.28
Detector 4 :	Mean	: 138.13	SD	: 31.31
Detector 5 :	Mean	: 138.11	SD	: 31.31
Detector 6 :	Mean	: 138.21	SD	: 30.84

Table 2.2 Histogram values for individual sensors in a Landsat MSS scene after radiometric restoration.

2.3. *Sampling scheme*

This study followed the methodology as outlined in section 1.2.1. The finite population was defined by a regular grid over the study area. A systematically aligned, random sample was used to select one sample segment from each grid cell. This was repeated to produce 3 replicates.

2.3.1. Statistical design.

A regular grid based on northing and easting and measuring 25 km. per side, was produced to cover the area of interest. This resulted in 45 grid cells covering the study area (Figure 2.3).

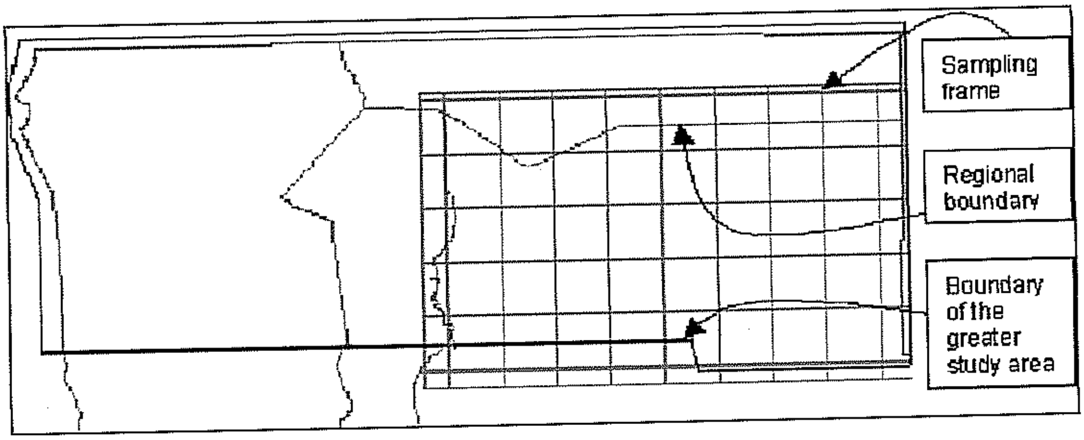

Figure 2.3 The sampling frame, based on a 25 x 25 km grid over the study area.

Each grid cell was sub-divided into 2.5 x 2.5 km. segments, which were numbered sequentially from 1 to 100, starting with 1 in the top left cell. The random number generation function in Microsoft Excel was used to produce one number between 1 and 100, which was taken as the cell address for the sample segment. This process was repeated to produce three repetitions (Figure 2.4). No stratification was applied.

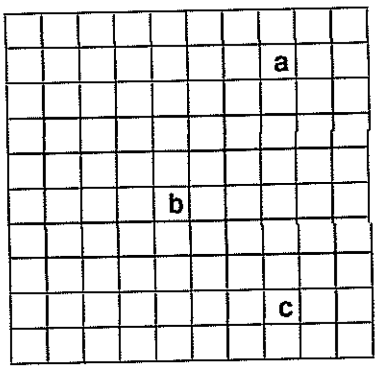

Figure 2.4 The sampling frame, showing 100 sub-divisions of one grid cell from the 25 x 25 km area frame. The letters a, b and c correspond to random cell addresses, and were used to define repititions 1,2 and 3 respectively.

The positioning of sample segments within the defining frame of the study area (Figure 2.5), resulted in 26 segments for repetition one, 33 segments for repetition two, and 26 segments for repetition three. This corresponds to sample fractions of 0.9%, 1.1% and 0.9% respectively.

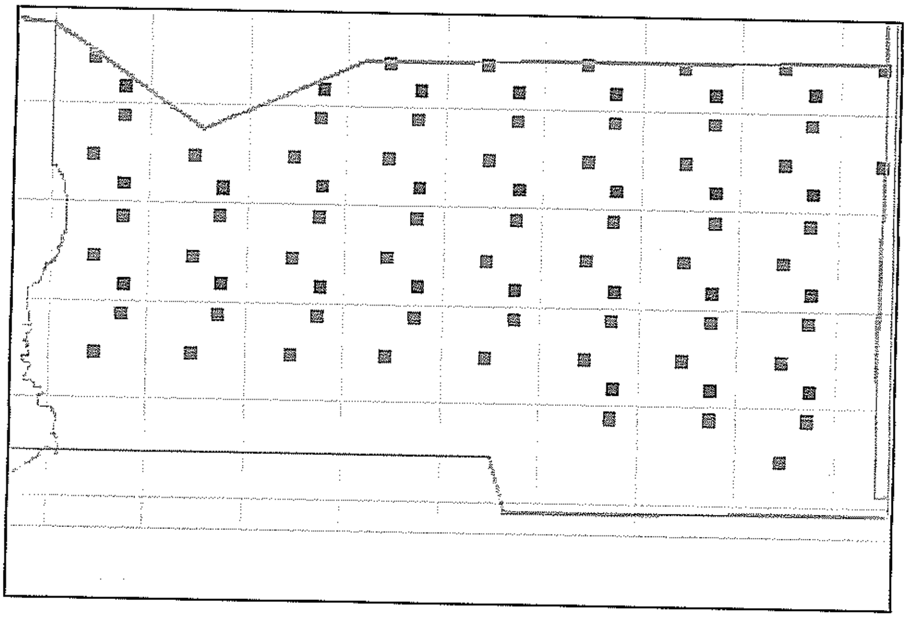

Figure 2.5 Area frame sampling scheme, showing the distribution of sample segments. Red, green and blue squares represent repetitions 1, 2 and 3 respectively.

2.4. Production of imagettes

Sample segments were subset from the individual Landsat TM and MSS scenes according to the area frame sample scheme outlined in section 2.3.1. This resulted in 255 geo-referenced imagettes (85 for each of the three dates of imagery). Each imagette covered an area of 2.5 x 2.5 km on the ground, and contained three spectral bands corresponding to the green, red and near-infrared parts of the electromagnetic spectrum. This corresponds to bands 2,3,4 for the TM data, and bands 1,2,4 for the MSS data.

2.5. Data interpretation

2.5.1. Classification decision rule.

Visual interpretation techniques were applied to a sample of the 1997 data. These results were subjected to field validation, in order to refine the classification decision rules. This was done by drawing a randomly selected 10% sample from the total population of sample segments for 1997. These were displayed as false colour composite images and printed onto A4 sheets at a scale of 1:15000. Boundaries of land cover types were delineated on acetate overlays prior to the field survey, and each parcel was assigned to one of five classes: agriculture; woodland; grassland; mixed woodland/grassland, and other. The field survey showed that natural vegetation types, although readily distinguishable on the imagery, could not be labelled with any degree of accuracy by visual interpretation. Classification of natural vegetation was therefore abandoned, as field validation of the historical data would not be possible.

The only land cover type of interest that could be identified and labelled accurately through visual interpretation, was agriculture. This consisted of land used for subsistence dry-land crop cultivation. Peripheral areas between the fields and newly erected steel-wire fences could not be distinguished from natural vegetation, and is therefore not included in the definition of agricultural areas.

2.5.2. Classification methodology

Sample segments were displayed as false colour composite images, with the near infrared band assigned to red, the red band assigned to green, and the green band assigned to blue. This band combination highlighted areas under cultivation, which showed up as bright areas in the image. Decorrelation stretches were applied to the MSS data to bring the colour saturation closer to that of the TM imagettes.

Boundaries of agricultural areas in the 1997 imagette were determined by visual interpretation, and defined through on-screen digitising. The corresponding imagette for 1987 was then displayed alongside, and the vector layer derived from the 1997 imagette overlaid on it. Areas covered by the 1997 vector polygons were examined to determine whether changes had occurred. Changes to polygon boundaries were made, or entire polygons were deleted, based on the interpretation of the 1987 imagette. This was repeated for the corresponding 1973 imagette. In cases where a particular farming area had not changed shape or size between dates, but mis-registration between imagettes caused a poor polygon fit, the whole polygon was shifted without altering the shape. This ensured that changes that were detected, were due to observed differences rather than inconsistent digitising. Inter-dependant image analysis also meant that the datasets for 1987 and 1973 which were derived from lower spatial resolution MSS data, could be interpreted in the light of information gained from the relatively high-resolution TM data.

ER Mapper software was used to calculate area sizes for the polygons defined in each segment. These figures were imported into Microsoft Excel spreadsheet for further analysis.

2.6. *Data analysis*

2.6.1. Statistical calculations.

The area under agricultural practice and the standard error of the estimate, was calculated by direct expansion according to formulae given by Gallego & Delincé (1991a). The estimator for the class is its mean proportion for the sample segments contained within the whole study area. This is given by:

$$\bar{y}_c = \frac{1}{n}\sum_{i=1}^{n} y_{ic} \qquad (1)$$

where n is the number of sample segments, and Y_{ic} is the proportion for class c in the i^{th} sample segment. The total area Z covered by class c is given by:

$$Z_c = D\bar{y}_c \qquad (2)$$

where D is the size of the whole area. The standard error $S.E._{Zc}$ given by:

$$S.E._{Zc} = D\sqrt{\left[(1-\frac{n}{N})\frac{1}{n(n-1)}\sum_{i=1}^{n}(y_{ic}-\bar{y}_c)^2\right]} \qquad (3)$$

where N is the total population of sample segments within the area from which the sample was drawn. The percentage relative standard error of the estimate was calculated from:

$$\%R.S.E_{Zc} = \frac{S.E._{(Zc)}}{Zc}\times 100 \qquad (4)$$

Data from corresponding imagettes for the different dates, were treated as paired observations over time. Individual change values were obtained for each imagette, and total change estimated by direct expansion as explained above. The statistical significance of these observed changes was tested with a two-tailed t-test for matched samples as described in Fowler and Cohen (1993, P. 176).

2.7. *Classification accuracy assessment*

Aerial photographs which were available for the whole area for 1996, and for a portion of the area only for 1970, were used as surrogate ground data against which to validate the results of the visual interpretation. Imagettes which corresponded to the satellite image derived sample segments, were subset from scanned geocoded airphotos. A grid of points based on 10 seconds of latitude and longitude, was overlaid on the airphoto imagette. This produced either 64 or 72 systematic random points per imagette, spaced at 300 metre intervals. The land cover under each point was determined through visual interpretation, and scored as either agriculture or other. This was done for all airphoto imagettes, and the procedure repeated on the 1997 TM derived imagettes. These data were then tabulated in a confusion matrix (Table 3.1) in order to assess the accuracy of the interpretation. The same procedure was followed to produce a confusion matrix (Table 3.2) for the 1973 Landsat MSS derived data.

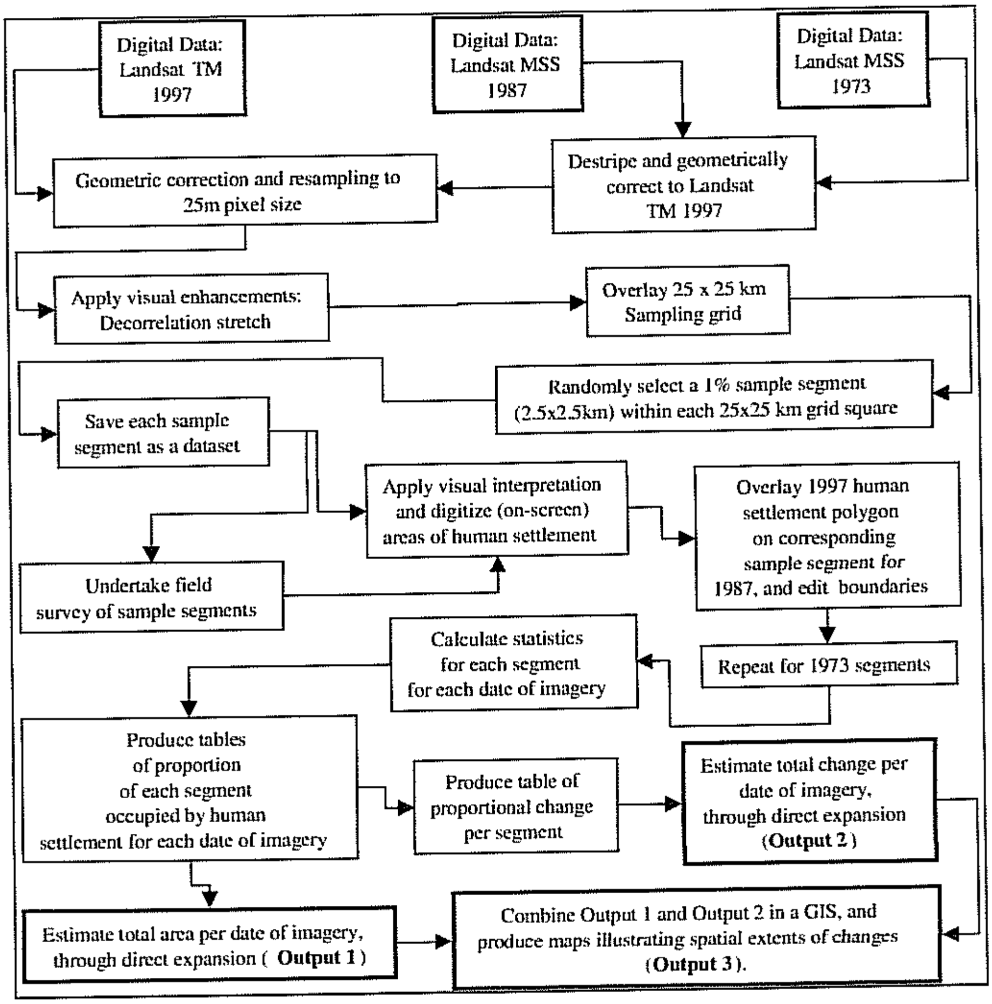

Figure 2.6 Flow diagram of methodology, from digital inputs to tabular and map outputs.

3. Results.

3.1. *Establishing the methodology*

Agricultural areas for contemporary as well as historical dates could be classified by visual interpretation, with an overall average mapping accuracy of 70.9%. These results were obtained from the confusion matrixes which are presented in Table 3.1 (1997) and Table 3.2 (1973).

		"Ground" i.e. Airphoto		
		Agric	Other	Total
Thematic	Agric	**274**	42	316
	Other	91	**1729**	1820
	Total	365	1771	*2136*

Table 3.1 Confusion matrix for the 1997 data, based on comparison between visual interpreted results from 1997 Landsat TM imagery (Thematic) and 1996 aireal photographs (Ground data).

		"Ground" i.e. Airphoto		
		Agric	Other	Total
Thematic	Agric	**15**	7	22
	Other	13	**605**	618
	Total	28	612	*640*

Table 3.1 Confusion matrix for the 1973 data, based on a comparison between visual interpreted results from 1973 Landsat MSS imagery (Thematic) and 1970 aireal photographs (Ground data).

3.2. *Area estimates and change*

Direct expansion estimates for areas under agricultural are presented in Table 3.3. No abandonment of agricultural land was observed, and in all cases transition was from natural habitat to agriculture.

	% of total area occupied by agricultural land	Area occupied by agricultural land (hectares)	% Relative Standard Error of the Estimate	% Change in agricultural area between dates	% Relative Standard Error of the Change estimate	Annual rate of change from natural area to agriculture	Overall accuracy of the mapping and classification
1973	1.3 %	23387	28.7				60.9 %
1987	2.9 %	53405	21.3	+ 1.6 %	1973 to 1987: 26.3 %	1973 to 1987: + 6.1 % per annum	Not determined
1997	7.6 %	140302	20.2	+ 4.7 %	1987 to 1997: 24.3 %	1987 to 1997: + 10.1 % per annum	80.9 %

Table 3.3 Direct expansion estimates of agricultural areas (subsistence dry-land crops)

The expansion of dry-land cropping activities between 1973 and 1987 was relatively minor and confined to areas close to the major centres of Oshakati and Ondangwa, although some expansion occurred along the main road between these centres and the south. During this period (1973 –1987) the agricultural area approximately doubled in size. Greater changes are evident in the period between 1987 and 1997 (Figure 3.1), when agricultural activities expanded at a rate of 10.1 % per annum, resulting in an almost threefold increase in the land area under agriculture. Observed differences in area estimates between image dates were highly significant (Student's t-test: P(T>=t) = 0.0001).

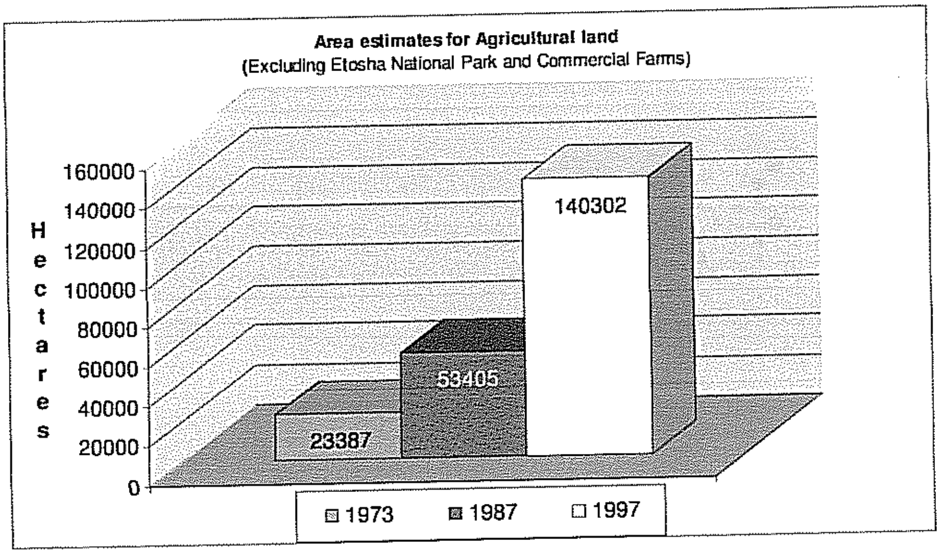

Figure 3.2 Direct expansion estimates of agricultural areas (subsistence dry-land crops).

3.3. Spatial distribution of area estimates

The spatial distribution of agricultural practices for each date is presented in Figure 3.2, and shows the amount of land occupied by agricultural areas in individual sample segments. Each segment is represented by a coloured dot at its geographic location on the map. Dot sizes are proportional to the percentage of the segment that is under agricultural practice.

Agricultural activities expanded not only locally, but also in a northeastern *direction* away from the major centres. This is evidenced in an increase in the agricultural proportion of a particular segment over time (Figure 3.3), as well as an increase in the number of segments containing

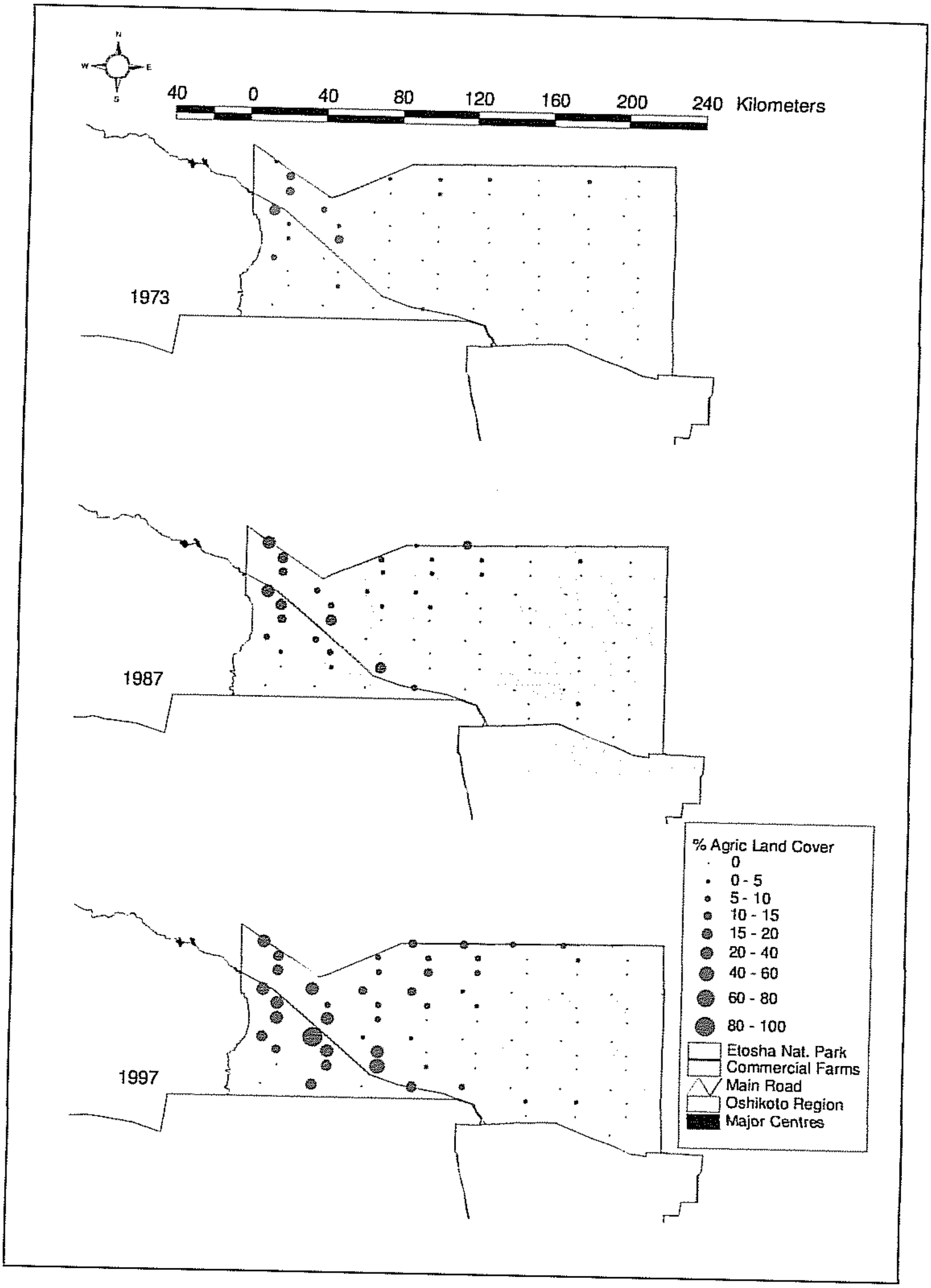

Figure 3.2 Spatial distribution of sample segments, classified according to the percentage land under agriculture in each segment. Major centres are the towns of Oshakati, Ongwediva and Ondangwa.

agricultural land. These data should be viewed in the context of changes which have taken place across the entire north-central Namibian region, but the results are consistent with the distribution of arable soils, and also follow expansion of local infrastructure such as health facilities, water points and roads.

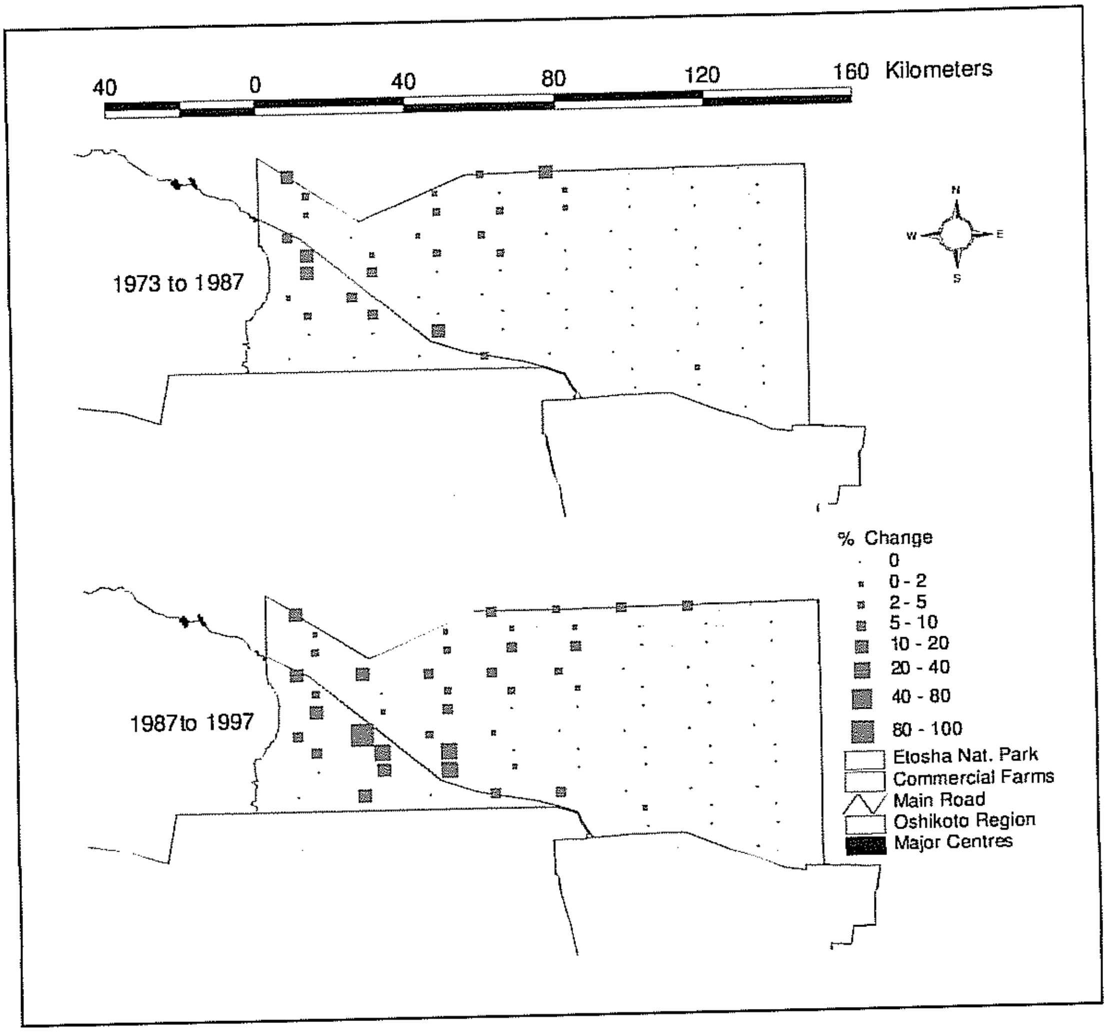

Figure 3.3 Expansion of agricultural areas between 1973 and 1987, and between 1987 and 1997, classified according to the percentage change in the agricultural area in each sample segment.

4. Discussion

4.1. Precision of the area estimates

The design of the sampling strategy allowed independent area estimates to be derived for sample fractions of approximately 1,2 & 3 %. Results for these estimates (Figure 4.1) show very little variation in the area estimate for a particular date, regardless of the sample fraction. It does however indicate that a sample fraction of > 2 % is required if an acceptable level of reliability is to be attached to the estimate for the respective dates. Area estimates for 1973 for instance, vary by only 11.3 % between the 1% and 3 % sample fraction results, but the corresponding relative standard error decreases by 42 %. Changes between dates were significant even for the 1 % sampling fraction (Student's t-test: P(T>=t) = 0.04).

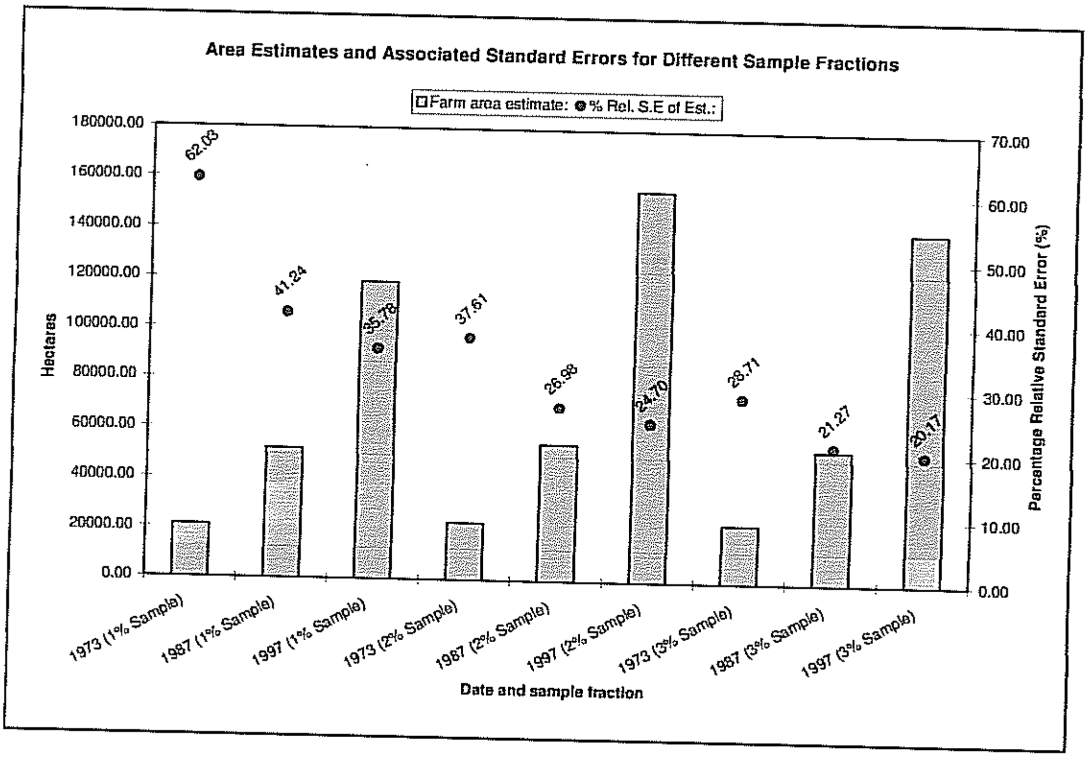

Figure 4.1 Direct expansion estimates and associated % Relative Standard Error of the area estimate for different sample fractions.

4.2. *Visual interpretation and classification.*

Visual interpretation as an approach to image classification is generally more successful than traditional digital processing techniques, particularly where the image interpreter's knowledge and experience allows interpretation of feature size and association (Mas and Ramirez, 1996). Overall classification accuracy for the 1997 data was 80.9 %, while the 1973 data produced results with an overall accuracy of 60.9 %. No validation data was available for 1987, but it is reasonable to expect that the accuracy would lie within this range.

Analysis of the results presented in Table 3.1 (P.13) show a user accuracy of 86.7 %, and a producer accuracy of 75.1 % for the 1997 data. This corresponds to errors of commission of 13.3 % and errors of omission of 24.9 %

Results for the 1973 data as presented in Table 3.2 (P.13) show a user accuracy of 68.2 % and a producer accuracy of 53.6 %. This corresponds to errors of commission of 31.8 % and errors of omission of 46.4 %. This decrease in interpretation accuracy is related to differences in image acquisition dates between the years, and is discussed in section 4.3.

4.3. Temporal differences of the datasets.

Data from two different seasons were used in the analysis. The 1997 and 1987 imagery was acquired by the satellites during April and May. This represents the end of the growing season in northern Namibia, and resulted in imagery with easily identifiable crop lands due to their high reflectance properties in the near infrared (0.7 to 1.3 μm) part of the electromagnetic spectrum. The 1973 data was imaged by the satellite sensors during various times of the year, and included no data acquired during the growing season. This resulted in images which appeared very different to the 1997 and 1987 data. A time series of false colour composite images from the same sample segment is shown in Figure 4.2. Similarities between the two wet season datasets (a and b) are clear, while their relationship with the dry season image (c) is less obvious. Areas under agriculture show up as bright red areas in segments a and b, and as pale pink areas in segment c. Visual interpretation based on inter-dependent image analysis allowed these differences to be taken into consideration, but it remained the single most important factor affecting classification accuracy.

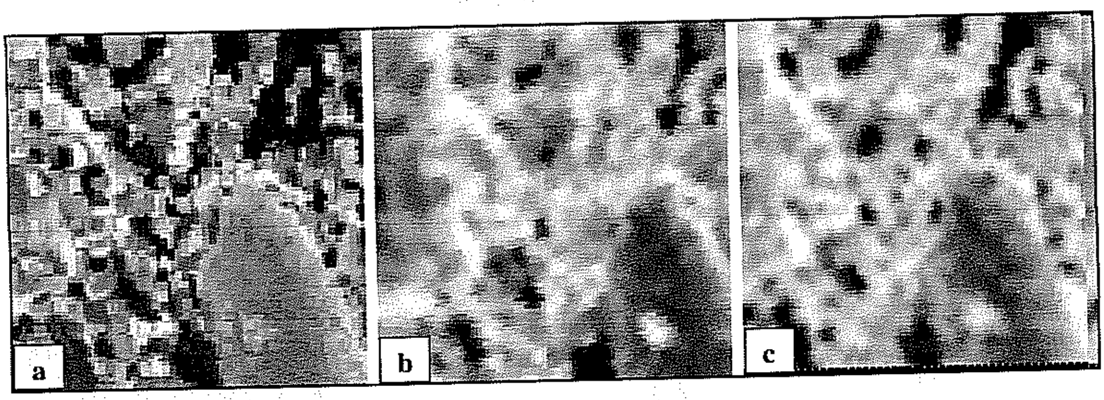

Figure 4.2 False colour composite imagettes of one sample segment over time. a - 1997 Landsat TM; b – 1987 Landsat MSS; c – 1973 Landsat MSS

The tendency was to interpret the pink regions in Figure 4.2c as the extent of the agricultural area. This approach worked well when applied to the wet season imagery of 1987 and 1997, and resulted in classification accuracy for crop areas with an omission error of 24.9 %. The commission error for the same data (1997) was 13.3 %. In contrast, omission and commission errors for the 1973 data were 46.4 and 31.8 % respectively. The reason for the large increase in the omission error lies not in the fact that agricultural areas could not be identified on the satellite images, but rather that the extent of the area covered could not be determined accurately. This is illustrated in Figure 4.3, where the red and pink portions of the colour composite image would be interpreted as agricultural areas. Comparison with the aerial photograph on the left however, shows that each field enclosed with a brush fence occupies a much greater area.

4.4. Spatial differences of the datasets.

Data from two different sensors were used in the analysis. Sample segments for 1997 were subset from imagery acquired from the Landsat Thematic Mapper. These data are collected using a 30-m ground resolution cell. Sample segments for 1987 and 1973 were subset from data acquired by the Landsat Multispectral Scanner. These data were collected from MSS sensors onboard Landsat 1 and 5, using a ground cell of approximately 79 and 82 meters respectively. This amounts to a reduction in spatial resolution of about 7 times as compared to the Thematic Mapper data. However, sharply contrasting spectral reflectance between adjacent land cover types will allow linear features as narrow as a few meters to be distinguished (Lillesand and Kiefer, 1994, P. 445). This can be observed in Figure 4.2, where small features which are visible in the TM derived image (segment a), have been retained in the MSS derived images (segments b and c).

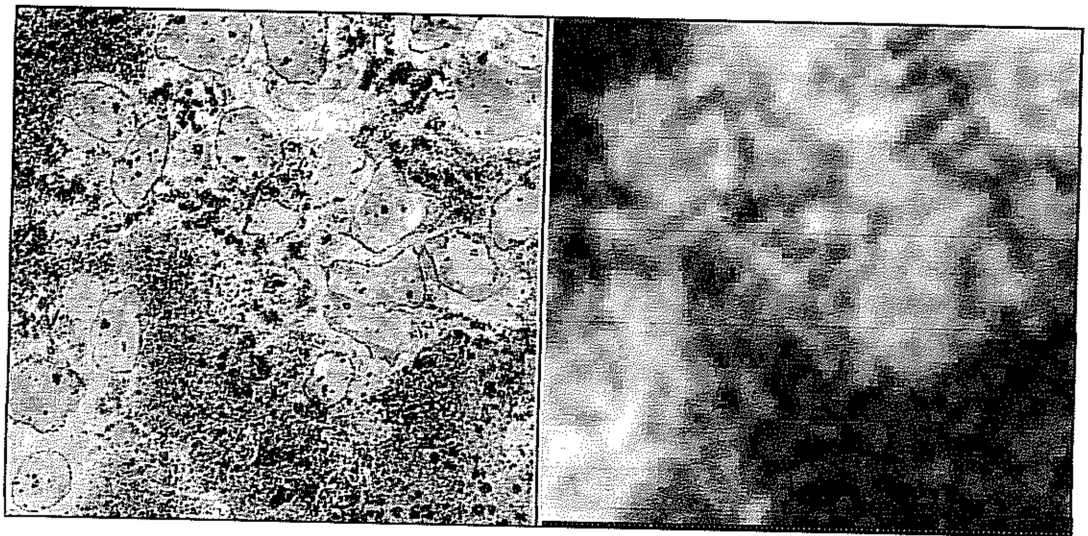

Figure 4.3 Aerial photograph (1970) and false colour composite Landsat MSS image (1973) of one sample segment.

4.5. *Radiometric and spectral differences of the datasets.*

The analog-to-digital signal conversion process performed by the Landsat Thematic Mapper sensors results in an 8 bit dataset (256 digital numbers), while Landsat MSS sensors perform their quantisation across a range of only 64 digital numbers, resulting in a 6 bit dataset. This difference in radiometric precision did not play a major role in the detectability of features, since the radiometric differences between land cover types of interest were sufficiently large.

Datasets were displayed as false colour composite images, using wavebands with nominal spectral locations corresponding to the near infrared, red and green regions of the electromagnetic spectrum. Differences exist between the spectral bandwidths across the TM and MSS sensors. These differences are negligible in the green bands, where the TM sensor spans the range from 0.52 to 0.60 μm compared to 0.50 to 0.60 μm for the corresponding MSS bands. The same is true for the red bands, with the TM sensor recording in the range between 0.63 and 0.69 μm compared to 0.60 to 0.70 μm for the corresponding MSS bands. However, in the near-infrared bands, the MSS sensor records data over a much wider bandwidth (0.80 to 1.1 μm) compared to the much narrower bandwidth of 0.76 to 0.90 μm of the TM sensor. Visual comparison of datasets for the same time of year but from different sensors (Figure 4.2, segments a and b), show very little difference as a result of this wider bandwidth on the MSS sensor.

5. Recommendations

5.1. *Sampling scheme*

It is recommended that data from all 4 regions be treated as a single 3 % sample. This pilot study focused on Oshikoto region. Three more regions (Oshana, Ohangwena and Omusati) need to be processed. Treating these regions as a unit along with Oshikoto will increase the total number of samples for each date to 238. This should decrease the standard error and therefore the confidence interval of the estimate.

Decreasing the sample segment size is not recommended. Although this would increase the number of samples, it would also increase the time required to travel between them in the field. Furthermore, a dramatic increase in the sample size is required in order to reduce the confidence interval by an appreciable extent (Fowler and Cohen, 1993, P. 100).

Stratification in order to reduce the number of segments without agricultural activities should be explored. Several objective methods for stratification of the 1997 data are available. Buffering could be performed using road networks, villages, water points etc. However, corresponding data for 1987 or 1973 was not available and should be sought. Alternatively, the satellite images could serve as a basis for strata delineation, as pointed out by Gallego and Delincé (1991b).

5.2. Classification

The use of confusion matrix results to correct area estimates is not recommended. Prisley and Smith (1987) describe methods whereby land cover area estimates may be corrected from confusion matrixes. However, major biases may be introduced through the use of inappropriate methods, as illustrated by Buckland and Elston (1994). The fact that validation points for 1973 could not be selected from the whole study area due to the absence of airphoto coverage, is sufficient to bias any corrections based on that confusion matrix. It is also not possible to correct estimates for 1987 by this method, as no surrogate ground data exists. Adjustments to the 1973 figures based on omission errors of 46.4 %, is likely to result in estimates which are higher than those of 1987, particularly since the increase in area under agriculture between the two dates is only 1.6 %.

6. Conclusions

Output 1: Establishing procedures for area estimation based on area frame sampling of contemporary and historical satellite images. Shortcomings in the procedure were identified. The methodology could not be applied to natural vegetation types, and therefore focused on agricultural areas which were clearly identifiable. Procedures were established whereby these areas could be classified, mapped and assessed for accuracy.

Output 2: Estimating areas under agriculture for each date of imagery. Estimates with reasonably narrow confidence intervals, could be derived using classical direct expansion methods as applied to agricultural areas in other parts of the world.

Output 3: Indicating the spatial extent of temporal change in agricultural areas. The spatial extent of agricultural activities could be visualised by linking tabulated results and geographical locations of each sample segment.

Output 4: Evaluating the reliability of the methodology. The methodology produced reliable results. Overall average mapping accuracy was 70.9 %, which produced area estimates with an average percentage relative standard error of 23.4 %.

Output 5: Recommendations relating to its application to the remaining regions. These recommendations are contained in section 5.

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