EROSION HAZARD MAPPING: MODELLING THE VEGETATIVE COVER

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ABSTRACT

Soil loss Estimation Model for Southern Africa (SLEMSA) has been used as method to determine the erosion hazard in member countries of Southern African Development Community (SADC). The vegetation cover sub-model, however, is based on the development of crops as a result of rain. An average vegetative cover, based on the development of crops through the rainy season, is used for the rainfall interception sub-model. This vegetative cover estimate is not applicable in Namibia, as (i) the initial rainfalls of the season, when the vegetative cover is at its lowest, often has the highest intensity and causes the most damage; (ii) cropping is only marginally possible in about 10 % of the country, and (iii) the Zimbabwean crop growth models are not applicable to Namibia.

A method has been devised to correlate the cover of the natural vegetation to the Normalized Differentiated Vegetation Index (NDVI) value from a National Oceanographic and Atmospheric Agency (NOAA) image. The fitted regression line was applied to another NOAA NDVI image of October, representing the stage where the vegetation offers the least cover to the soil (before the onset of the rainy season). In this way an estimate of the lowest vegetative cover was obtained for the country.

Overall, the vegetation cover map produced is felt to be a good first approximation of the minimum vegetation cover in the country. However, the map can be refined by doing some detailed studies in the methodology, as well as collecting additional cover data. Different methods should however be investigated.

INTRODUCTION

As part of the SADC Erosion Hazard Mapping project, an estimate had to be obtained of the vegetative cover of Namibia. SLEMSA (Stocking, 1987) proposes the measurement of the vegetative cover by using standard crop growth models, predicting the estimated vegetative cover of the crop growth through the season. The algorithm is dependent on the type of crop, and the rainfall. It has been developed and extensively tested in Zimbabwe by Elwell & Wendelaar (1977) (as cited in Stocking, 1988).

Three problems present themselves with this approach:

(i) In Namibia, the initial rains of the season often have the highest intensity, and result in the most damage through erosion.

(ii) Very little crops are planted in Namibia (approximately 10 % of the country, under marginal conditions).

(iii) Virtually no suitable data on crop growth is available for Namibia. Due to the low rainfall in Namibia, the Zimbabwean models can not be applied locally.

A completely different approach has thus been followed:

The Namibian Weather Bureau is in the possession of a NOAA receiving station. An NDVI image is processed and made available to the Early Warning/Food Security Unit on a 10-daily basis. The NOAA NDVI images are often composites of various images, selected for being cloud-free. These NDVI images are stored on computer tape and can be easily accessed.

The NDVI is a "greenness" index, depicting the activity of the vegetation. All that was needed, was to correlate the vegetative cover to the intensity of the NDVI. For this purpose a field survey of the vegetative cover on various sample sites all over the country was taken within a ten-day time limit (i.e. a "decade"), to coincide with the decade in which a NOAA image was collected and composed by the Weather Bureau.

For the purpose of mapping the vegetative cover, a NDVI image from the driest time of the year was used, in order to depict the minimum cover, or a worst case scenario. It was decided to follow this approach of minimum vegetative cover rather than an estimate of the average vegetative cover due to the following reasons:

i) The initial rains create the worst erosion,

ii) The rainfall is erratic, and often the vegetative cover can be expected to be far lower than the average (as often as 5 years out of 10 years, in some areas even more).

iii) Wind erosion is not included in the SLEMSA model. The strong winds responsible for much of the erosion problems are normally occurring during the dry season from July to October/November.

METHODS AND RESULTS

i) Survey methodology

A sighting frame has been developed for the use with the Elwell/Stocking model, with which the cover at various stages of development can be estimated (Stocking, 1988). This sighting frame works on a similar principle as the descending point frame (Mueller-Dombois & Ellenberg, 1974), except that instead of a descending point or pin, only a visual inspection is made whether a plant or part thereof is intercepting the path of a raindrop.

Because of the principle on which the survey is based, however, it was found that the construction and use of such frames was not feasible. As large amounts of data needed to be collected over a relatively large plot, and numerous plots needed to be collected during a short period of time, it was decided to replace the sighting frame method by a simple stave point method using an aluminium rod of 6 mm diameter and 2.50 m length. These were available as standard products at local hardware stores for less than N$ 10.00 each.

The length of the rod had two advantages: The length made it possible to model the line of fall of a raindrop upwards into the tree layer relatively accurate. The length also meant that the stave was acting like a spring, making it impossible to place the point onto the earth subjectively.

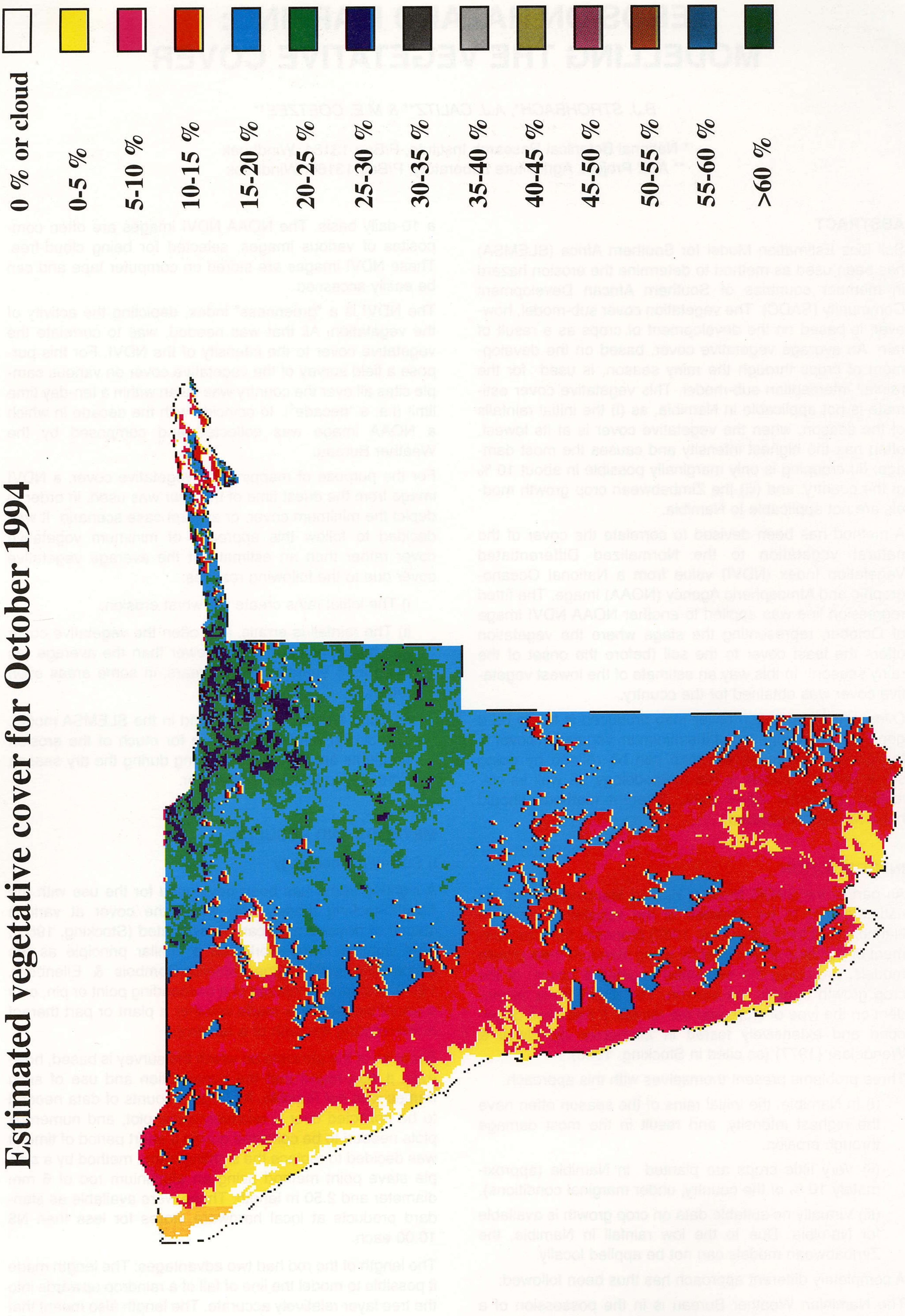

Figure 4: Estimated vegetation cover of Namibia for October 1994.

The thickness of the stave is important in accessing the cover. Mentis (1981) showed that the basal cover measurement is dependant on the thickness/diameter of the point used in sampling basal cover. A similar problem was experienced with the survey - some staff were equipped only with a broomstick. Samples were later verified, and a discrepancy of between 20 and 100 % found between the aluminium rod and the broomstick. The discrepancy was linked to the structure of the vegetation rather than the actual cover - finer grass tended to "intercept" the thicker broomstick, but not the aluminium rod. In the final analysis the data collected by broomstick was omitted.

ii) Field survey

An initial survey was done using two teams during the 2nd decade of February 1994 (i.e. 11-20 February 1994). Due to problems with cloud cover which could not be excluded from the NOAA image, it was decided to repeat the sampling during the 2nd decade of August 1994, now using 6 teams.

Plots were identified in a systematic manner all over the country. Because of limited time and manpower, it was decided that each team was to follow a route along the major roads, covering as much as possible distance within one day. Plots were thus selected every 40 or 50 km, depending on the route taken. An important criterium was that the plots should be of a (visually) uniform landscape for at least 1 km radius from the point sampled. This was necessary as the pixel size of the NOAA image is roughly 1 km x 1 km.

The rod was placed onto the ground every 2nd step, and it was noted wether the rod intercepted a part of a plant or not

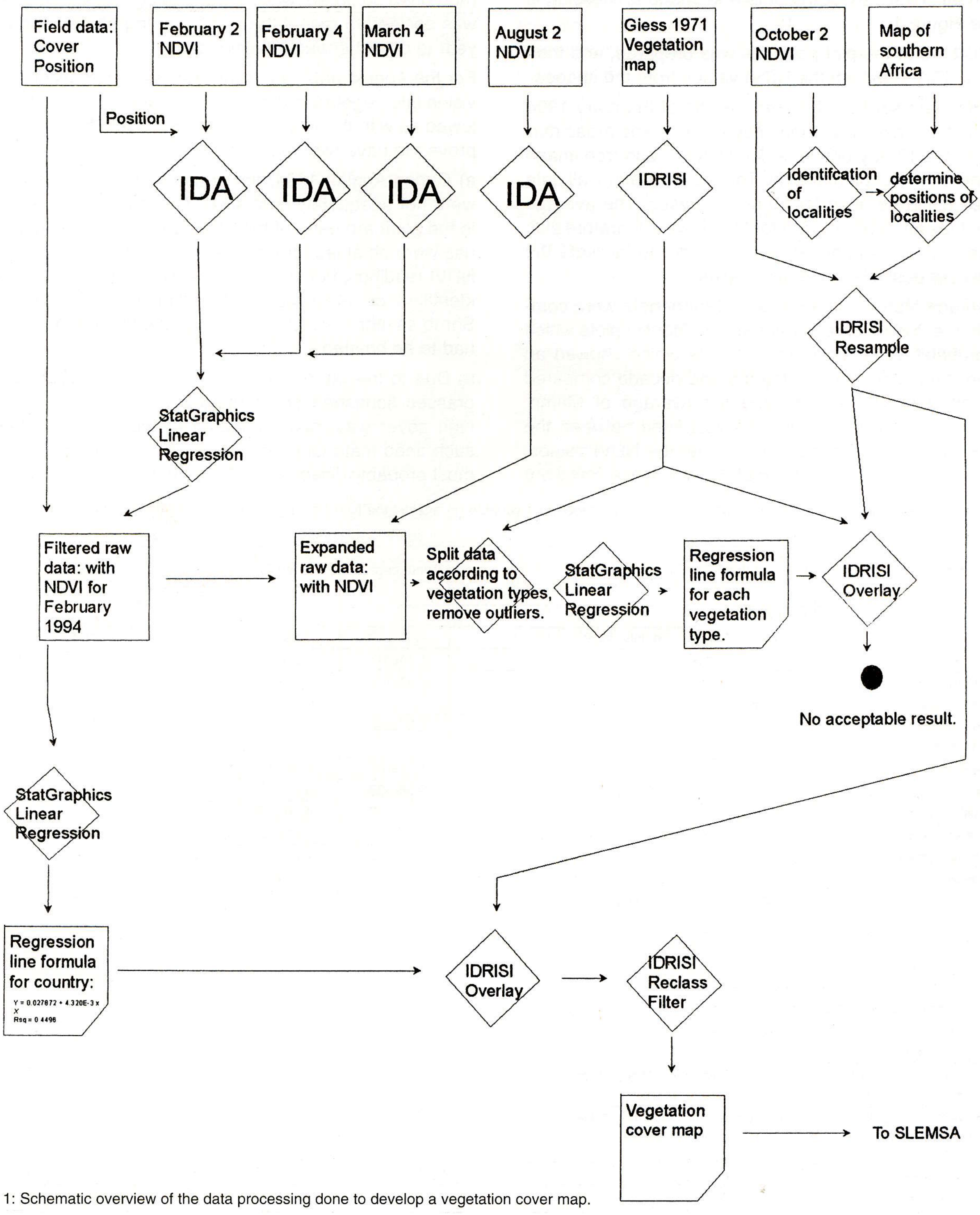

Figure 1: Schematic overview of the data processing done to develop a vegetation cover map.

(i.e. wether a raindrop would be intercepted along this path or not). This measurement was repeated 150 times or more per plot. The measurement was done indiscriminately whether the plant part "intercepting the rain drop" was dead or not, as it was assumed that even dead plant material will contribute to the plant cover and thus protect the soil.

Additional data collected at each sample site was the position by way of a GPS reading, as well as a soil sample to determine the soil colour (Munsell colour) and the soil acidity (Coetzee, 1994). A basic description of the relevant vegetation was also included.

In total, 259 plots were sampled during February, and an additional 418 plots during August.

iii) Data processing

A schematic overview of the data and image processing is given in Figure 1.

An ASCII file of the plot positions was prepared, and then used with IDA to extract the NDVI values from the images.

The initial data set from the 2nd decade of February 1994 proved to have extensive cloud cover over some areas during the entire 10 day period. A completely cloud-free image could therefore not be made up. This meant that not all data collected could be used for further analyses. The average NDVI values for February and for March were therefore also extracted by the Weather Bureau, in order to facilitate the extraction of possible clouded samples.

The average March and average February data were compared to the 2nd decade of February to identify plots which were probably cloud covered, i.e. plots which showed an extreme low NDVI cover during the 2nd decade compared to the average of February and the average of March. Eventually a linear regression line was fitted between the 2nd decade and the corresponding average NDVI values. All sample sites falling below the 95 % confidence limit were regarded as partially clouded and excluded from the data set (Figure 2). 38 plots were in this way excluded, which represent roughly 15 % of the total data from the 2nd decade of February.

A linear regression line was fitted, using the cover as independent, and the NDVI value as dependant variable. For the statistical analysis Statgraphics (Statistical Graphics Corporation 1991) was used. A R^2 value of 0,5180 was achieved, which can be regarded as a reasonable fit. The statistics of the fitted regression lines are given in Table 1.

When plotting the NDVI values against the cover values (Figure 3), it was found that distinct groupings according to the vegetation type could be identified. This prompted the splitting of the data set into various vegetation type subgroups, using the Giess vegetation map (1971) as base. The data for some individual types was however so few, (and often so green, without any low cover samples), that it was decided to repeat the survey during a drier time of the year to collect enough additional data.

For the August data, a similar process of extraction, subdivision into vegetation units and regression analysis was followed as with the February data. However, the August data proved to have two serious flaws:

a) During August 1994, the sensors of the NOAA satellite were not adequately controlled. This meant that especially in the southern parts of the country extreme high NDVI values were obtained for large areas. Samples with such high NDVI readings, but low cover measurements, were visually identified on the graphs and eliminated. For the Dwarf Shrub savanna, which was worst affected, the August data had to be omitted.

b) Due to the rather good rainy season, especially annual grasses flourished and formed a dense canopy cover. A high cover was thus measured on such plots. However, such dead material does not give a NDVI reading, and will most probably disappear before the next rainy season, thus

Table 1: Linear regression analysis of the vegetative cover as independent variable (x) against the NDVI as dependent variable (y) (Regression formula: y = a + bx).

Vegetation type	Data set used	Intercept (a)	Slope (b)	Correlation Coefficient	Standard Error	R^2
Northern Namib	No data					
Central Namib	February & August (4 points only!)	-3.24e-04	2.16e-03	0.9428	0.0107	88.89%
Southern Namib	February & August	1.14e-01	1.01e-03	0.01733	0.0575	0.03%
Winter Rainfall Area (succulent steppe)	February & August, excluding outliers	9.41e-02	1.27e-03	0.4594	0.0341	21.11%
Escarpment zone (desert transition)	February & August	7.57e-02	1.58e-03	0.441	0.0543	19.45%
Mopane Savanna	February data only	1.52e-01	1.72e-03	0.5477	0.0372	30.00%
Karstveld & Mountain savanna	February & August, excluding outliers (Total: 4 points!)	9.26e-02	3.95e-03	0.9832	0.0357	96.66%
Thornbush savanna	February & August, excluding outliers	9.77e-02	4.66e-03	0.8525	0.05	72.67%
Highland savanna	February & August, excluding outliers	7.97e-02	2.41e-03	0.7488	0.0363	56.08%
Dwarf shrub savanna	February data only	2.22e-02	2.91e-03	0.6951	0.0366	48.32%
Saline desert	February & August, excluding outliers (Total: 5 points!)	1.17e-01	7.93e-03	0.6901	0.0145	47.62%
Northern Kalahari (forest savanna and woodland)	February & August, excluding outliers	5.51e-02	6.16e-03	0,6569	0.1078	43.15%
Central Kalahari (camelthorn savanna)	February & August, excluding outliers (Total: 3 points!)	1.21e-01	1.75e-03	0.9917	0.0124	98.35%
Southern Kalahari (mixed tree and shrub savanna)	February & August	2.81e-01	-1.96e-03	-0.3182	0.1087	10.13%
All desert types, including escarpment zone	February & August	8.55e-02	1.02e-03	0.3904	0.0408	15.24%
Northern Kalahari, Thornbush savanna & Karstveld combined	February & August, excluding outliers	8.78e-02	5.23e-03	0.7901	0.0823	62.43%
Mopane savanna, Highland savanna, central and southern Kalahari combined	February & August, excluding outliers	1.65e-01	2.04e-04	0.0685	0.0549	0.47%
All types combined	February & August	1.68e-01	7.67e-05	0.01665	0.1114	0.03%
All types combined	February data only	6.68e-02	4.74e-03	0.7197	0.091	51.80%

not protecting the soil during the first rain storms of the season. It was thus decided to eliminate data from the August survey which, upon visual inspection, showed a high cover value combined with a low NDVI. Such cases were common in the Northern Kalahari, Karstveld and Thornbush savanna types in the north-eastern parts of the country.

It was found that several data sets were unacceptably small (less than 10 sample points). Because of this, several data sets were lumped together. In this way the following groups were identified:

All deserts and semi-deserts (Northern, Central and Southern Namib, the Winter Rainfall Succulent Steppe, the Escarpment Zone (desert transition) and the Saline Desert).

The drier savannas (the Mopane Savanna, the Highland Savanna, the Central and Southern Kalahari).

The wetter savannas (the Northern Kalahari, the Karstveld and the Thornbush Savanna).

The Dwarf Shrub Savanna.

Linear regression lines were fitted on each of these data sets. The results of the linear regressions are displayed in Table 1.

iv) Image processing

A NOAA NDVI image for October 1994 was obtained from the Etosha Ecological Institute. Other than the NDVI images from the Weather Bureau, this image was not cropped to show only the Namibian part of the image, nor was it georeferenced. The image was converted with IDA software

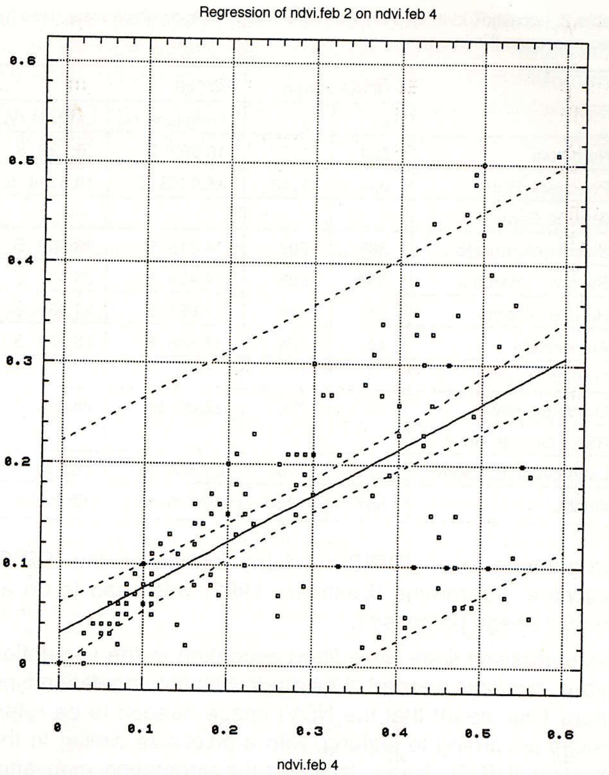

Figure 2: Correlation between the NDVI values of the 2nd decade of February 1994 (ndvi.feb_2) and the average NDVI values for February 1994 (ndvi.feb_4). All samples below the 95 % confidence limit were regarded as "clouded" and removed from the data set.

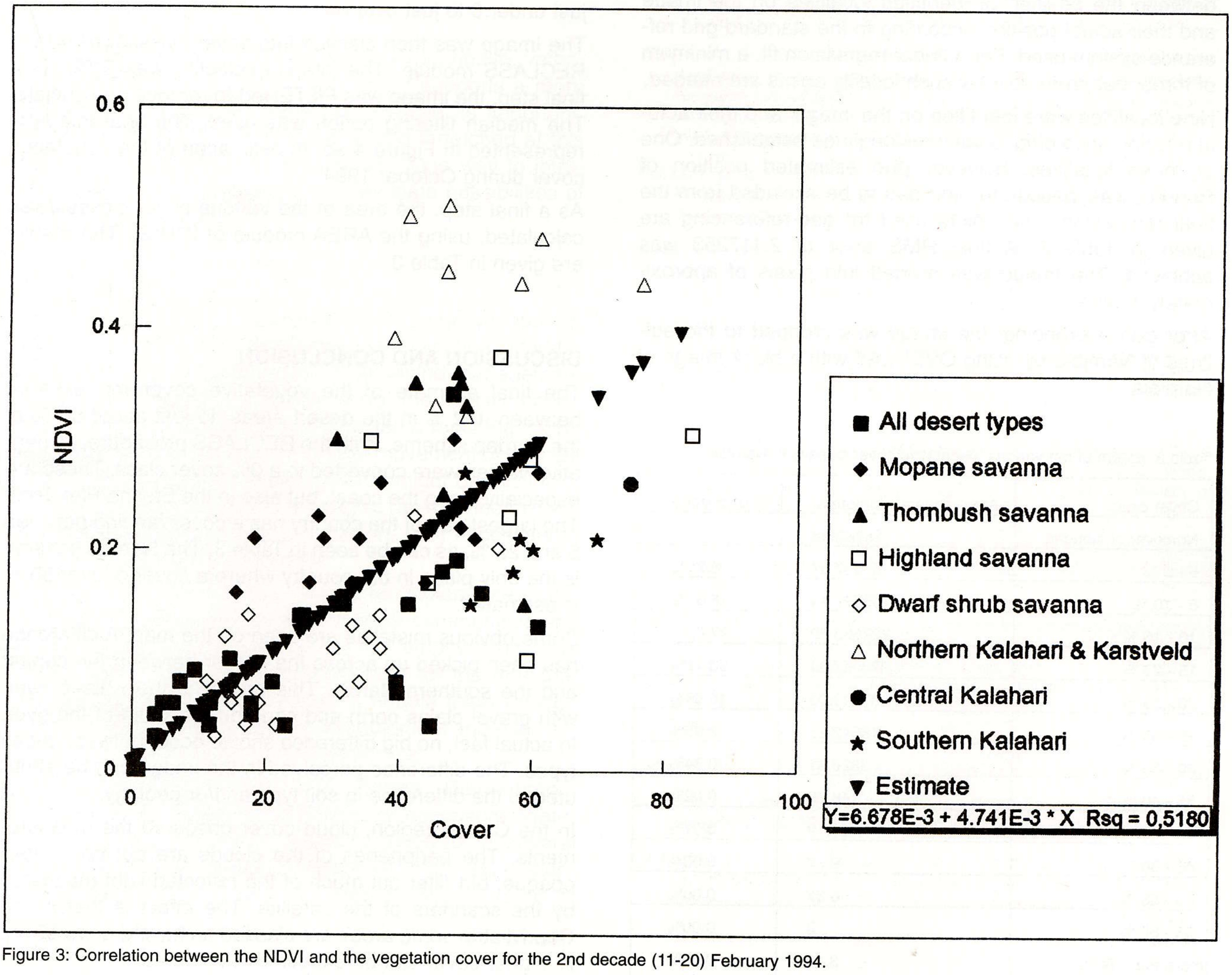

Figure 3: Correlation between the NDVI and the vegetation cover for the 2nd decade (11-20) February 1994.

Table 2: Localities identified on the NOAA NDVI image, which were used to geo-reference the image.

	NOAA image		Actual	
	x	y	Longitude (x)	Latitude (y)
Namutoni	594	1157	16.933° E	18.796° S
Poacher's Point	554	1178	16.5308° E	18.6154° S
(Etosha Pan)				
Swartbank, Kuiseb	387	703	14.815° E	23.352° S
Sandwich Harbour	349	698	14.459° E	23.407° S
Hardap scheme	692	586	17.867° E	24.533° S
Aussenkehr -	641	166	17.388° E	28.723° S
Orange River				
Grobblershoop,	1101	150	22.00° E	28.910° S
RSA - Orange River				
Lake Linyanti, Caprivi	1261	1187	23.566° E	18.490° S
Rundu*	867	1250	19.716° E	17.954° S

programme to an IDRISI-readable format, as the IDRISI software programme (Eastman, 1992) was used to do all further image processing.

As regression lines were fitted according to the vegetation types, overlays needed to be made with the vegetation type map. This meant that the NDVI image needed to be referenced according to lat/long, with a pixel size similar to the existing IDRISI image depicting the vegetation map after Giess (1971). For the purpose of geo-referencing, the RESAMPLE module of IDRISI (Eastman, 1992) was used. RESAMPLE does a rubber sheet transformation of an image according to a regression fit. The regression is done between the position of identified localities on the image and their actual position according to the standard grid reference system used. For a linear regression fit, a minimum of three, but preferably six such locality points are needed.

Nine localities were identified on the image, and their actual position according to latitude/ longitude established. One of these localities, however (the estimated position of Rundu), was inaccurate, and had to be excluded from the final regression. The points used for geo-referencing are given in Table 2. A final RMS error of 2.117253 was achieved. The image was divided into pixels of approximately 1' size.

After geo-referencing, the image was cropped to the outlines of Namibia by using OVERLAY with a blank image of Namibia.

Table 3: Extent of the various vegetative cover classes in Namibia

Cover class	Area (square kilometres)	% of country
No cover or clouded	25743.48	
0 - 5 %	51457.07	6.25%
5 - 10 %	135997.44	16.52%
10 - 15 %	222563.79	27.04%
15 - 20 %	273057.34	33.17%
20 - 25 %	87749.09	10.66%
25 - 30 %	18542.25	2.25%
30 - 35 %	2826.41	0.34%
35 - 40 %	146.28	0.02%
40 - 45 %	61.19	0.01%
45 - 50 %	9.77	0.00%
50 - 55 %	6.37	0.00%
55 - 60 %	0	0.00%
more than 60 %	3.12	0.00%

In order to apply the regression line (y = a + bx) to the NDVI, two copies of the Giess vegetation map were prepared using the ASSIGN module. In the first copy (called "A"), each vegetation unit was assigned the relevant "a" (or intercept) value, and in the second copy (called "B"), each vegetation was assigned the relevant "b" (or slope) value. As the NDVI values in the image represented the "y" value, the formula was changed to read x = (y-a)/b. OVERLAY was run twice - the first time image "A" was subtracted from the NDVI image to create a temporary image, while during the second run of OVERLAY, the temporary image was divided through the "B" image to create an image with vegetation cover values.

Upon inspection it was found that the operation was unsuccessful, as the "cover" values ranged between -120 % to 20 %. Huge differences were found between adjoining vegetation types, often being that the type in a lower rainfall area had a higher cover than the type in the higher rainfall area - ALONG THE COMMON BORDER. This operation was not further perused, discarding thus all regression lines for individual vegetation types.

The common regression line determined from all February data was thus used in another attempt. Two blank copies were again made of the image. In the first copy (again called the "A" image) all pixels were assigned the value of the intercept ("a" in the formula), the second ("B") image was assigned the value of the slope ("b" in the formula). OVERLAY was again run twice - once to deduct image "A" from the NDVI, and the second time to divide the result by image "B". Good results were obtained this time, with values (representing the % vegetation cover) ranging between just under 0 to just over 60.

The image was then classed into cover classes, using the RECLASS module. The interval selected was 5 %. As a final step, the image was FILTERed to remove any outliers. The median filtering option was used. The final image is represented in Figure 4 as an estimation of the vegetation cover during October 1994.

As a final step, the area of the various cover classes was calculated, using the AREA module of IDRISI. The results are given in Table 3.

DISCUSSION AND CONCLUSION

The final estimate of the vegetative cover ranges from between -0.2 % in the desert areas, to just about 60 % at the Hardap scheme. With the RECLASS procedure, all negative values were converted to a 0% cover class. These are especially along the coast, but also in the Etosha Pan itself. The largest part of the country has a cover ranging between 5 and 25 %, as can be seen in Table 3. The Hardap scheme is the only place in the country where a cover of over 60 % is estimated.

Some obvious mistakes are seen on the map: A difference has been picked up across the border between the central and the southern Namib. This border is the Kuiseb river, with gravel plains north and sand dunes south of the river. In actual fact, no big difference should occur between these types. The difference perceived in the image can be attributed to the difference in soil type and/or geology.

In the Caprivi region, cloud cover obscured the measurements. The peripheries of the clouds are not completely opaque, but filter out much of the reflected light measured by the scanners of the satellite. The effect is that in the Caprivi strip some areas are classed as having a low cover. A higher cover can be expected in this area.

The fact that the data collected during August 1994 proved to be unusable, demonstrates that this method can be refined. Especially while sampling the cover, dead material should not be considered as being part of the vegetative cover. The sampling during February was advantageous, as virtually no dead material was left from the previous season, and the actual cover was actively growing. Problems with cloud cover are unfortunate, but can be excluded with repetition.

An average cover map, as well as an average minimum cover map, can also be derived by this method, simply by averaging the NDVI images over a number of years and seasons.

Refinement according to vegetation types is warranted, if considering the fact that there is a difference between the central and southern Namib, and that the slope of the regression lines of the "wetter" savanna types are often steeper than the lines of the desert and "drier" savanna types. It is considered to determine an average vegetative cover for each vegetation type with future vegetation type descriptions. This would be an alternative method to map the vegetative cover to the method presently employed.

Overall, the vegetation cover map produced is felt to be a good first approximation of the minimum vegetation cover in the country. However, the map can be refined by doing some detailed studies in the methodology, as well as collecting additional cover data. Different methods are also to be investigated.

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