

Chapter 12

Land Degradation in South Africa – A Degradation Index Derived from 10 Years of Net Primary Production Data

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Abstract Dry regions such as arid southern Africa are strained by unfavourable climatic conditions. Intensive land use as rangeland and for livestock farming leads to additional encroachment of these ecosystems. The consequence of this long-time stress is degradation in terms of loss of the vegetative cover and productivity. Albeit these are known facts there is still a lack of objectiveness in the long term assessment of degradation on a larger scale. We present a method of applying remote sensing time-series in a vegetation model that helps to fill this gap. The approach is based on time-series of the vegetative productivity computed by our vegetation model BETHY/DLR (Biosphere Energy Transfer Hydrology Model). The used data included SPOT-VGT LAI (Leaf area index) and ECMWF meteorology time-series for the period of 1999–2010. The trend-analysis of model output and climatic input results in a new land degradation index (LDI) that distinguishes between climatic and human-induced reduction of vegetative productivity.

12.1 Introduction

Arid or semi-arid areas are often affected by the process of land degradation, which is caused by different components from biophysical and socio-economic factors (Hoffman and Todd 2000). While the degradation of soils is mainly caused by wind and water erosion as well as soil acidification and salinization due to agricultural

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land use. The degradation of vegetative cover is driven by either human activity as logging, agriculture, fire or mono-culturing or meteorological factors as the reduction in precipitation or the variation of temperature. Main factors for the regional decrease in vegetative productivity include the intense livestock farming (Perkins and Thomas 1993; Dougill et al. 1999). The assessment of these processes has already been subject of several scientific investigations especially in African regions (Abel and Blaikie 1989; Ringrose et al. 1999; Stringer and Reed 2007; Wessels et al. 2004, 2008; Knauer et al. 2014).

Most of these activities have been carried out either on a regional scale for particular biomes or for a single snapshot of the state of the vegetation. The assessment of land degradation on a national to sub-continental scale based on long term time-series would be an intense benefit, which could be achieved by using the advancements of modern vegetation models driven by remote sensing data.

In principle land degradation is correlated with a loss of biological productivity due to soil erosion, salinization, crusting and loss of soil fertility. Moreover, the vegetation cover and especially its biodiversity and its density (Le Houérou 1996) are influenced, what can be intensified by excessive land use. The carbon reservoirs in biomass and soil are sensitive indicators of degradation and the change in climate and environmental conditions. Thus, the land biomass was defined as one of the essential climate variables with high impact on the requirements of the UNFCCC (United Nations Framework Convention on Climate Change) (GCOS 2003). Changes on this reservoir cause a crucial feedback on climate and the balance of greenhouse gases (GTOS 2009). Net primary productivity (NPP), as the exchange of carbon between vegetation and atmosphere was identified as key variable to observe the ecological functionality and the lasting degradation processes (CGER 2000).

One way of rating the status of land degradation is to interpret the perception of land owners or agricultural extension officers. This was done by Hoffman and Todd (2000) from a survey in the magisterial districts of South Africa. From this they could elaborate a map showing the incidence of land degradation for the whole country, with KwaZulu-Natal, Limpopo and the Northern and Eastern Cape being mostly affected.

Wessels et al. (2008) presented a quantitative method for assessing human induced land degradation using remote sensing data. The authors tested the local NPP Scaling (LNS) method, for which the growth season NDVI (Normalized Difference Vegetation Index) sum (Σ NDVI) is calculated as a substitute for the vegetative productivity for each pixel. This value is then normalized to the highest values (90th percentile) of Σ NDVI observed in all pixels within the same Land Capability Unit (LCU). They concluded that the LNS method is a valuable tool for mapping land degradation at a regional scale.

Instead of using NDVI sums the productivity of the plants derived from SVAT (Soil Vegetation Atmosphere Transfer) models can be used to analyze the influences of environmental circumstances on the photosynthetic reactions of the plants. The carbon exchange between atmosphere and vegetation is determined at leaf

level considering the energy and water balance. One model using this principle is BETHY/DLR (Biosphere Energy Transfer Hydrology Model) operated at the German Aerospace Center (DLR) (Knorr 1997; Knorr and Heimann 2001a, b; Wisskirchen 2005; Eisfelder et al. 2012, 2013). Meteorological and remote sensing based time-series are the drivers to compute the NPP in daily time steps. The analysis of the resulting time-series of NPP in arid and semi-arid areas is used to gather information about the process of land degradation. Additional analysis of climatic input parameters help to distinguish between climatic or human influences in this process.

12.2 The Study Area of Southern Africa

As region of interest for this study the area of southern Africa was chosen, including the countries Namibia, South Africa, Lesotho, Swaziland, Botswana, and Zimbabwe (see Fig. 12.1). The distribution of the Köppen-Geiger classification (Kottek et al. 2006) shows that the western part of the study area is categorized as steppe (BS) and desert (BW). The dry and hot climate of Namibia extends to Botswana and southern Zimbabwe and affects wide areas of the southern provinces in Mozambique. Warm-temperate climate zones (type C) can be found at the southern and southeastern coastal regions of South Africa, as well as at the higher altitudes of Lesotho and Swaziland in the east.

The classification of the different climates is based on the distribution of sums of precipitation and mean temperature (Tables 12.1 and 12.2). This climate classification from Kottek et al. (2006) is an update of the Köppen-Geiger classification (Köppen 1900; Geiger 1954) using monthly climate observations from meteorological stations provided by the Climatic Research Unit (CRU) of the University of East Anglia (Mitchell and Jones 2005) and a monthly precipitation data set provided by the Global Precipitation Climatology Centre (GPCC) (Beck et al. 2005). These datasets cover the period 1951–2000.

The climatic conditions of southern Africa can be seen in Fig. 12.2. Long time means are calculated from datasets of ECMWF (European Center for Medium Range Weather Forecasts) for the period 1989–2010. The combination of annual rainfall (Fig. 12.2a) and mean annual temperature (Fig. 12.2b) reflects the distribution of the Köppen-Geiger classification. Precipitation rates below 400 mm per year denote the western part of the region including the deserts Namib and Kalahari (<200 mm). Further east the precipitation rates increase more than 1,000 mm per year. The temperature shows a negative gradient from south to north with lowest temperatures below 10 °C in the higher altitudes of Lesotho and South Africa.

Variations of these climatic parameters will be used to assess the influence of climatic changes in the regional processes of land degradation. Thus a differentiation can be inferred whether a decreased vegetative productivity is affected by climate change or human influence.

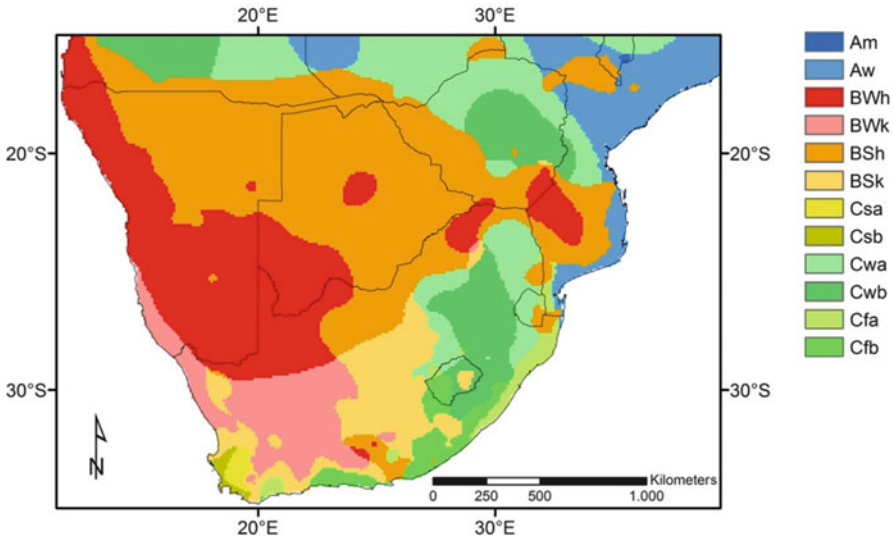


Fig. 12.1 Köppen-Geiger classification of climate types in the study area of southern Africa (For the description of the legend see Tables 12.1 and 12.2)

Table 12.1 Classification of main climates (A: equatorial, B: arid, C: warm temperate) considering characteristics of precipitation (*m* monsoonal, *S* steppe, *W* desert, *s* summer dry, *w* winter dry, *f* fully humid) for the study area following Köppen and Geiger (Köppen 1900; Geiger 1954; Kottke et al. 2006)

Climates	Description	Criteria
A	Equatorial	$T_{\min} \geq +18 \text{ }^\circ\text{C}$
Am	Monsoonal	$P_{\text{ann}} \geq 25(100 - P_{\min})$
Aw	Savanna	$P_{\min} < 60 \text{ mm}$ in winter
B	Arid	$P_{\text{ann}} < 10P_{\text{th}}$
BS	Steppe	$P_{\text{ann}} > 5 P_{\text{th}}$
BW	Desert	$P_{\text{ann}} \leq 5 P_{\text{th}}$
C	Warm temperate	$-3 \text{ }^\circ\text{C} < T_{\min} < +18 \text{ }^\circ\text{C}$
Cs	Warm summer dry	$P_{s,\min} < P_{w,\min}$, $P_{w,\max} > 3 P_{s,\min}$ and $P_{s,\min} < 40 \text{ mm}$
Cw	Warm winter dry	$P_{w,\min} < P_{s,\min}$ and $P_{s,\max} > 10 P_{w,\min}$
Cf	Fully humid	Neither Cs nor Cw

12.3 Method

12.3.1 NPP Time-Series from the Vegetation Model BETHY/DLR

We use the SVAT model BETHY/DLR to compute time-series of carbon uptake by vegetation (Knorr 1997; Roeckner et al. 2003). At the German Remote Sensing

Table 12.2 Division of temperature classes for the study area following Köppen and Geiger (Köppen 1900; Geiger 1954; Kottek et al. 2006)

Temperature classes	Description	Criteria
a	Hot summer	Mean temperature of warmest month higher than +22 °C
b	Warm summer	Mean temperature of warmest month lower than +22 °C, at least four months with mean temperature of +10 °C and higher
h	Hot arid	Mean annual temperature higher than +18 °C
k	Cold arid	Mean annual temperature lower than +18 °C

Data Center (DFD) of the DLR the model was modified by Wisskirchen (2005) for the use with time-series of meteorological and remotely sensed input data with higher resolution of up to 1 km. Now it is driven as BETHY/DLR on regional to national scales. The model mainly derives the carbon exchange between biosphere and atmosphere on basis of a photosynthetic parameterization. It also includes the water balance of the ecosystem considering precipitation, the soil water balance, uptake by the roots and the evapotranspiration of the plant.

The model needs meteorological and remote sensing based time series data. Air temperature at 2 m height, precipitation, wind speed at 10 m above ground and cloud cover are taken from the ECMWF. The daily mean of cloud cover over all three strata (high, medium and low) are used to calculate the fraction of photosynthetically active radiation (fPAR). The ECMWF provides the required data in a spatial resolution of $0.25^\circ \times 0.25^\circ$ (interpolated from station measurements) with a temporal resolution of every 6 h. The datasets are interpolated to time steps of 1 h. Leaf area index (LAI) and land cover (Global Land Cover, GLC2000) information are based on SPOT-VGT (Satellite Pour l'Observation de la Terre-Vegetation) and are used to describe the phenology. Since the model highly relies on LAI we need a long term, spatio-temporal continuous time-series of this parameter in model resolution. Here we use the product derived from SPOT-VGT satellite data, provided by Medias France for the years 1999–2003 and by Vito Belgium from 2004 onwards and reanalyze the data for gap filling using the method of harmonic analysis (Gessner et al. 2013).

Information on composition, stratification and thickness of the soils and their distribution are taken from the Harmonized World Soil Database (HWSD). This Dataset was created by the Food and Agriculture Organization (FAO) in collaboration with IIASA (International Institute for Applied Systems Analysis) (FAO et al. 2009). This data is aggregated from the digital soil map of the world from FAO-UNESCO, the European Soil Database (ESDB), the soil map of the Chinese Academy of Sciences and regional soil and terrain databases.

BETHY/DLR uses a two-flux scheme to approximate the radiation absorption in the canopy. A combined approach of Farquhar et al. (1980) and Collatz et al. (1992) describes the photosynthesis. Enzyme kinetics are parameterized on leaf level. For the special environment of southern Africa it is important to distinguish between C3 and C4 plants. C4 plants have different schemes of photosynthesis being better

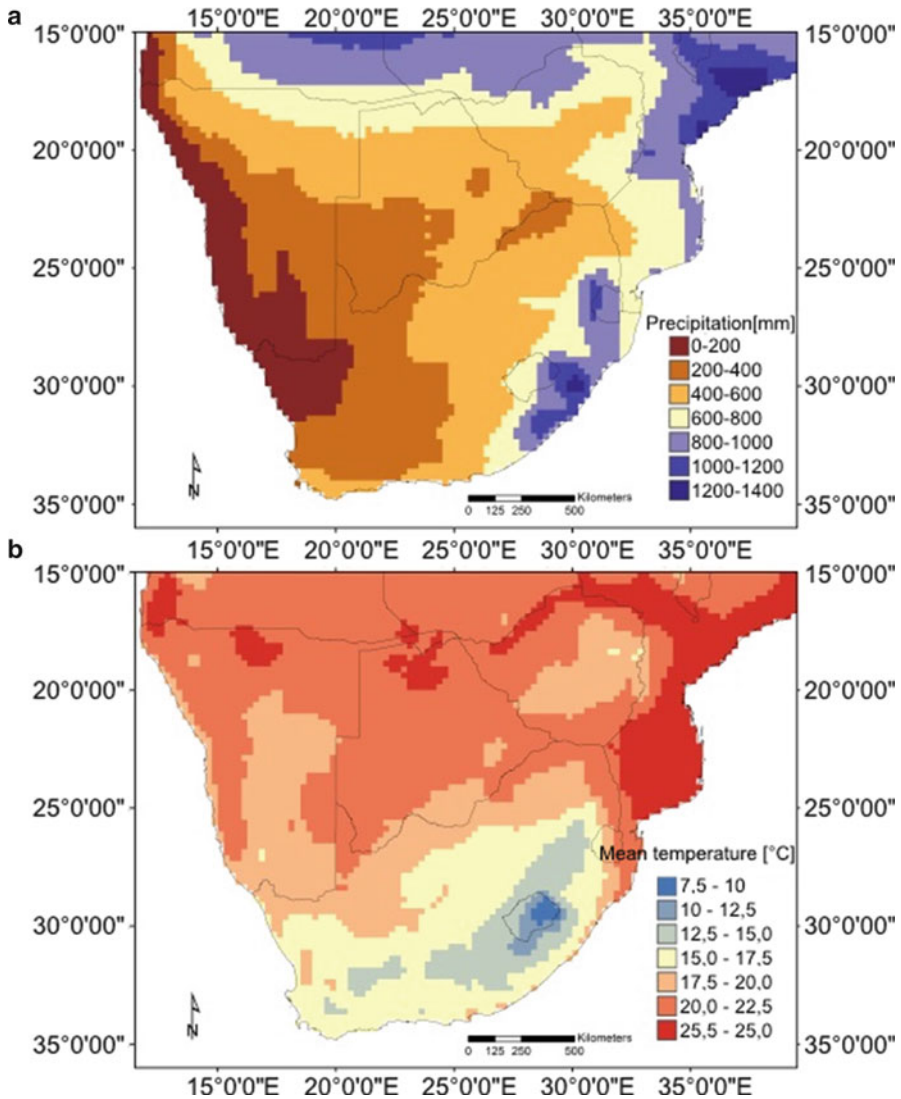


Fig. 12.2 Climatic conditions of the study area derived from time series of the ECMWF parameters precipitation (a) and temperature (b) calculated from the annual means of the period 1989–2010

adapted to dry and warm climate. The enzyme kinetics have significantly higher affinity for CO_2 than those of C_3 plants. In a second step the photosynthetic rate is extrapolated from leaf to canopy level, taking into account both the canopy structure as well as the interaction between soil, atmosphere and vegetation. Stomatal and canopy conductance, evapotranspiration and soil water balance are included.

The output is given by time-series of the Gross Primary Productivity (GPP) and the autotrophic respiration where the NPP can be calculated as the difference of these two values. The results are computed in daily time steps with the spatial resolution and projection of the land cover classification (1 km × 1 km, latitude – longitude projection with WGS84 (World Geodetic System 1984) datum).

12.3.2 NPP Variations from Annual Sums

The results of our SVAT model BETHY/DLR are used to analyze the time-series of the productivity of the plants for wide areas in the region of southern Africa. From this, variations caused by natural or anthropogenic influences can be identified. This can be done by analyzing the development of annual accumulated NPP values over the period of years 1999/2000–2009/2010. This leads to a variation of productivity for each individual pixel. To identify influences of climate anomalies this variation is weighted by variations in time-series of climatic variables (temperature and rainfall). Hence it can be distinguished if positive or negative variations in vegetative productivity can be traced back to human activities or variability in climatic conditions.

In a first step the annual NPP sums for the 11 vegetative periods (99/00 to 09/10) are calculated. The vegetative periods are defined with the beginning in July (from Julian day 182) and the end in June of the following year (to 181st day of year). Figure 12.3 shows the time-series of daily NPP values for a single pixel (blue line) as model output. The pixel represents a grassland covered area in the South African province Northern Cape close to the border to Botswana (26.67S 21.93E). The daily values of the annual period are summed up to a cumulative NPP (red circles). From these annual values a temporal variation in vegetative productivity can be derived (blue line), for which this example shows a distinct negative development. The slope of this variation represents the mean annual loss of productivity and has a value of $-1.4 \text{ gC m}^{-2}\text{a}^{-1}$ with a coefficient of determination of 0.67. So this pixel represents vegetation that has lost more than half (55 %) of its initial productivity ($27.7 \text{ gC m}^{-2}\text{a}^{-1}$ in 99/00) in a period of 11 years.

This relative variation of NPP is shown in Fig. 12.4 for the study region. Blue colors represent a positive variation of productivity, red represents a negative variation. For studies of land degradation the negative variations regions are to be analyzed. In the study area single regions become apparent where there are high negative variations of about 100 % loss of initial productivity. NPP values at saturation can occur where an initially positive NPP becomes negative during the modeling period. These values can be attributed to be based on soil types, with poor water storage properties within the soil. Other soil types allow for a maximum rooting depth of few millimeters which again leads to an insufficient amount of accumulated water to supply the vegetation.

One of these peculiar observations in the northwest of Lesotho represents the soil type Lithosol with a horizon thickness of 10 cm. This soil type can commonly be

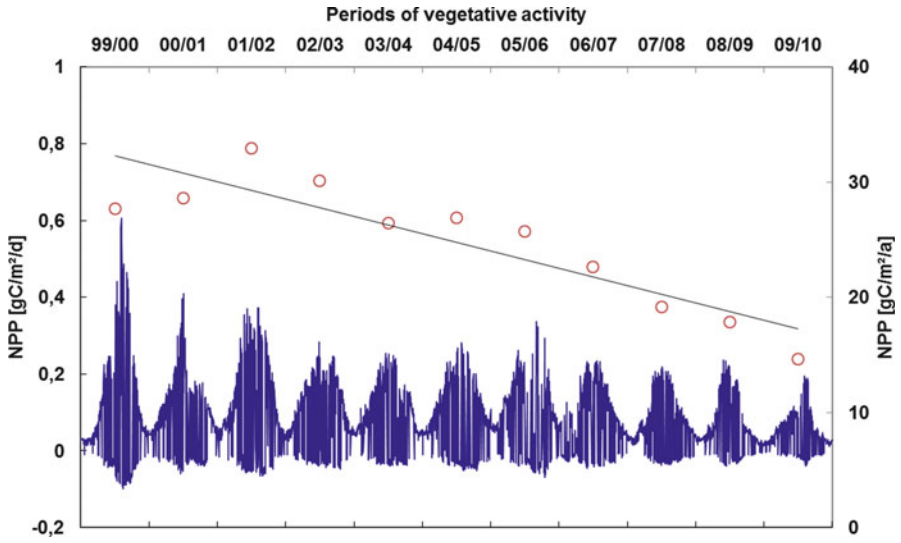


Fig. 12.3 Time-series of NPP from daily values (*blue line*) and annual sums (*red circles*) for the vegetative periods of 1999/2000–2009/2010

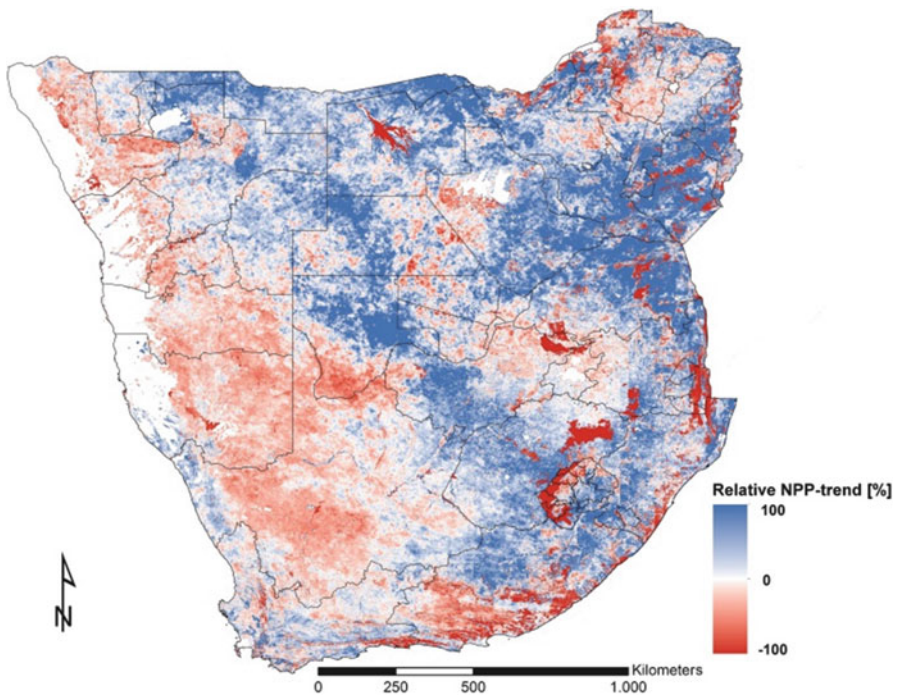


Fig. 12.4 Map of NPP-variations for the study area calculated from NPP sums of single vegetative periods

found in mountainous regions as thin layer on top of solid rocks. In contrast most of the soil types have a horizon thickness of 120 cm and more. From the soil water model the amount of water can be calculated, that can be used by the plant. Stress from insufficient water is simulated when only 25 % of this amount is left in the soil. For the Lithosol soil type the maximum amount is 2.4 cm water column, hence below 0.6 cm water column the plant experiences drought stress. Analyzing the precipitation rates of this pixel reveals a high variability over the modeling period with the amount of rain in the period 99/00–02/03 and 05/06 being up to 40 % higher than the mean value. The remaining periods show values of up to 30 % below mean where vegetation can experience stress almost the whole year. Hence the carbon assimilation is very low for these periods.

Other soils, e.g. Luvisols, have poor water storage properties with a high fraction of sand (>70 %), where water quickly percolates and gets unavailable for the vegetation. Additionally the density of vegetation cover defines the amount of water that is extracted from the soil. Translating the GLC2000 classes 2 and 3 (closed and open deciduous broadleaved forest) the fraction of cover is defined as 0.9 and 0.65 respectively. This leads to different variations in neighboring pixels when the fractional cover strongly varies on the same soil type with identical meteorological conditions. Exceeding the maximum water availability of the soil with having a denser vegetation cover can lead to negative variations, where the neighboring pixel is still getting enough water.

The negative development of the productivity is found in the dry grass- and shrubland areas in the west of the study area especially in Namibia and South Africa. Besides that the agricultural areas surrounding Pretoria and Johannesburg also show negative variations in a broad region. An even higher loss of productivity can be found in the surroundings of Port Elizabeth for forest areas, where the variation partially exceeds 100 %. This describes the change of the vegetation being a carbon sink towards a carbon source. Hence the calculated NPP reaches negative values, resulting from a greater amount of carbon being released to the atmosphere by maintenance respiration than the amount being assimilated during photosynthesis. The structures discussed before in Lesotho, in the South African province Neustaat, in Swaziland, or north of Johannesburg show the highest reduction in vegetative productivity at rates greater than 100 %. In contrast to the previous regions the equally high negative variation for the Okavango Delta can not only be attributed to the soil type. This region is particularly classified as regularly flooded marshland. This vegetation type has a very low electron transport rate ($J_m = 37 \mu\text{mol}(\text{CO}_2) \text{ m}^{-2} \text{ s}^{-1}$, (Knorr 1997)) hence the photosynthetic activity is highly susceptible to variations in the climatic conditions.

The primary vegetation type in the entire area is scrubland followed by grasslands. On the other hand, the distribution of the negative productivity variations indicates a higher susceptibility to degradation of the grassland vegetation. This is attributed to the intensive grazing land use in southern Africa. Due to grazing of large areas these ecosystems take considerable damage, which is reflected in the reduced productivity of the plants (Perkins and Thomas 1993). However, not the

entire decline in the productivity can be claimed to the demands caused by human. Additional effects are especially caused by variations in rainfall.

12.3.3 *Anomalies in Climatic Time-Series*

It has to be determined whether a negative variation in productivity is attributable solely to the management of the natural area and no additional adverse climatic conditions have affected plant growth. Therefore variations for the time-series of precipitation and temperature are computed for the years 99/00–09/10 analogous to the NPP variations shown before.

For the pixel shown in Fig. 12.3 a negative variation of -16.8 mm a^{-1} ($R^2 = 0.35$) for annual precipitation and negative variation of $-0.019 \text{ }^\circ\text{C a}^{-1}$ ($R^2 = 0.03$) for mean temperature was observed. These variations can help to identify if the vegetation is regressive despite or because having good climatic conditions.

The variation of the annual precipitation rate is negative for almost the whole study area (Fig. 12.5a). Exceptions are the western coast, with its desert areas of the Namib and the cape region of South Africa, and areas in the northeastern part of South Africa and the northeastern part of Zimbabwe. The variations are distinct with positive and negative direction, representing an increase or decrease of up to 50 % of the initial value in the period 99/00. The regions in southern Namibia and western South Africa having a dry climate but especially broad regions of central South Africa and Lesotho are affected by a significant decline in precipitation amount. This seems to have direct impact on the local ecosystem, as can be seen from the vegetative variation in Fig. 12.4.

The variation of the mean annual temperature shows a more heterogeneous distribution (Fig. 12.5b). Botswana as an example shows negative variations in temperature for almost the whole country and is surrounded, except for the north, by regions with positive variations up to +30 % (Lesotho and its northeastern surrounding) compared to the initial value in 99/00. These local peaks represent a raise of mean annual temperature of about $0.5 \text{ }^\circ\text{C}$ for the considered period of 11 years. The Namibian and South African coast in the west and the south again show negative variations. In the eastern part of the study area (Mozambique) the raise of temperature reaches up into the north also covering large parts of Zimbabwe. The coefficient of correlation of the linear fit especially for high temperature variations ($>\pm 15 \%$) has good values of 0.5 and higher.

An analysis of the anomalies of the single years of precipitation compared to the long time mean of 1989–2010 of ECMWF data revealed that the periods 99/00, 03/04 and 05/06 had a very high rate of precipitation. Extensive dry periods appeared for 04/05, 06/07, 08/09 and 09/10, pointing out the negative precipitation variations of Fig. 12.5a. The analysis of the mean annual temperature permanently shows positive anomalies for the periods 99/00–09/10 except for small regions in Botswana and Zimbabwe. Hence, the region of southern Africa is undergoing a

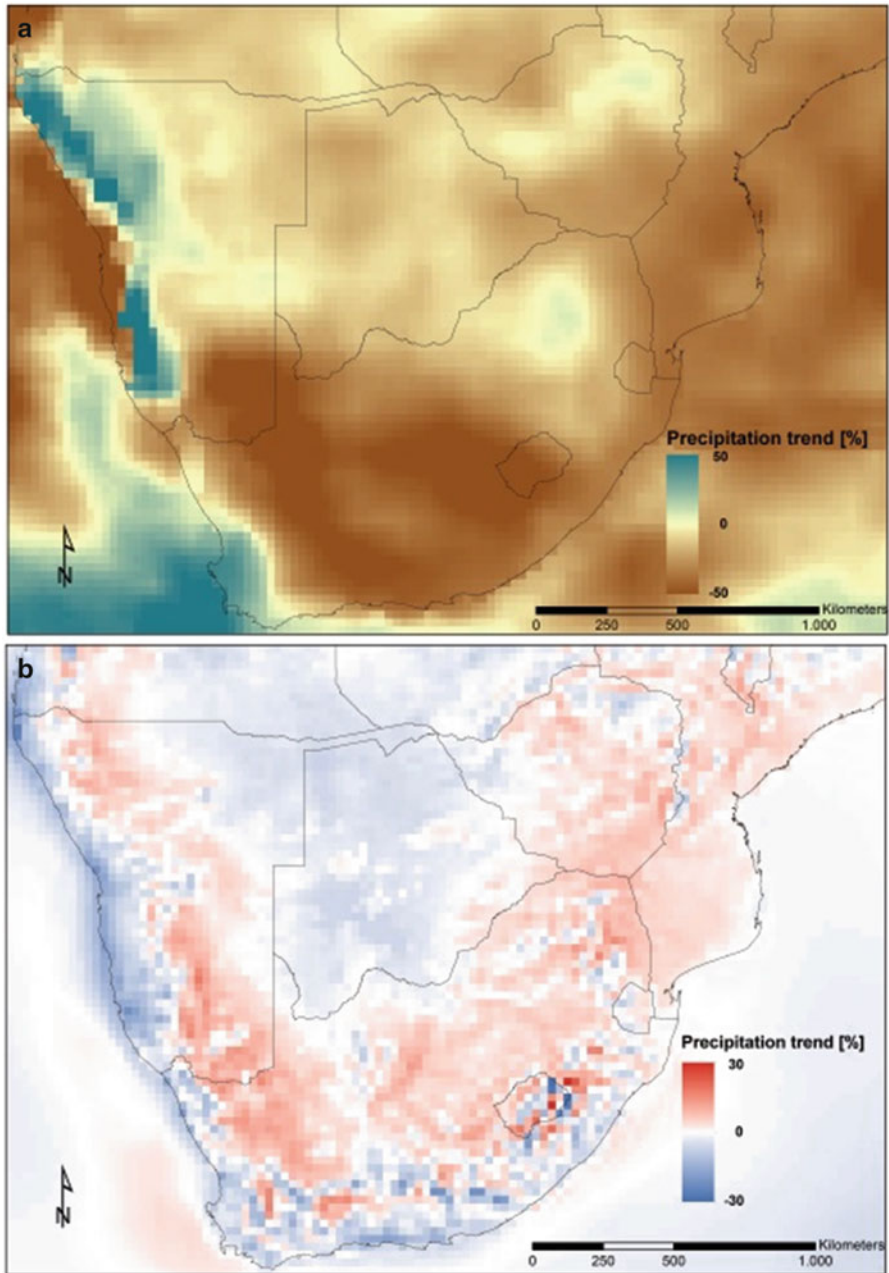


Fig. 12.5 Relative variation of the mean annual precipitation (a) and mean annual temperature (b) relating to the initial values of the period under observation 99/01–09/10

phase of rising temperature for the last two decades. This effect may on one hand lead to an increase in length of the growth periods, but on the other hand reduce the productivity due to limitations in photosynthetic activity when temperatures exceed a certain threshold, or due to decreasing water availability resulting from higher evaporation rates.

In the following definition of the degradation index only an increase of temperature and a decrease of precipitation rates will be considered. These are believed to be the most important drivers of vegetative productivity undergoing the highest changes due to climate variations. Only variations with a coefficient of correlation higher than 0.5 will be considered relevant for the index. Thus a climatological impact is assumed, if the temperature rises more than 10 % in the time period or the amount of rain is reduced by 30 %. Depending on the region this represents a rise in temperature of about 1–2 °C and a decrease in rainfall of 60–420 mm.

12.3.4 The Degradation Index

Assessing the land degradation using the model results of BETHY/DLR is supposed to consider climatic conditions. This can be helpful to determine if the cultivation of land surface by man has led to a decline in vegetative productivity. Especially the shrub- and grassland of southern Africa is extensively used as rangeland (Ross 1999; Fox and Rowntree 2001). To separate climatic and non-climatic variations the presented NPP-variations of Fig. 12.4 are grouped in four categories (Table 12.3, Fig. 12.6). If the variation in precipitation is below –30 % the area is grouped in category B (brown). Areas with a temperature variation of +10 % and higher are grouped in category C (red). Category D (blue) includes areas where both criteria are met. Here it is assumed, that the vegetation is experiencing a significant change in climatic conditions that has a direct impact on the development. If there is neither a negative variation in precipitation (<–30 %) nor a positive variation in mean temperature (>+10 %) areas with decrease in productivity are grouped in category A (green). This loss of productivity might be explained by anthropogenic influences. To further evaluate the grade of this loss the categories are separated in classes. Class 1 describes a decline of productivity of up to 25 %. Areas having a loss between 25 and 50 % are assigned to class 2, with loss between 50 and 75 % to class 3 and higher than 75 % to class 4.

12.4 Results

A direct influence of climate change can be seen for wide areas of the Namib Desert in southern Namibia and northwestern South Africa, which is classified as grassland. Here an extensive decline of about 50 % (LDI D2) is observed with local peaks of more than 75 % (LDI D4). Such areas can also be seen in Lesotho,

Table 12.3 Classification of the LDI using the color code of Fig. 12.6

Δ NPP	Non-climatic	Δ P<-30 %	Δ T>+10 %	Δ P<-30 % & Δ T>+10 %
<-75 %	A4	B4	C4	D4
-50 % to -75 %	A3	B3	C3	D3
-25 % to -50 %	A2	B2	C2	D2
0 % to -25 %	A1	B1	C1	D1

Δ NPP is the NPP-Variation, Δ P the precipitation variation and Δ T the temperature variation for the study period 99/00–09/10

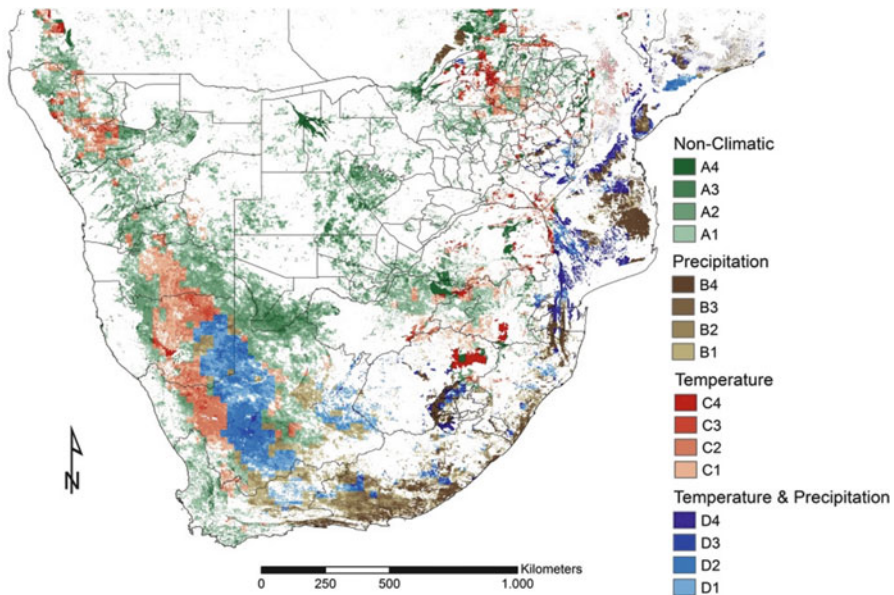


Fig. 12.6 Degradation index of the study area with the separation in categories A: non-climatic (green), B: significant decline of precipitation (brown), C: significant rise in temperature (red) and D: combined raise in temperature and decline of precipitation (blue). The numbers represent the grade of the NPP decline: 1: 0–25 %; 2: 25–50 %; 3: 50–75 %; 4: 75 % and higher

Swaziland and northern Zimbabwe, where generally an index of D4 is reached. They mostly coincide with the discussed soil types which typically have poor water storage capacities. This also can be seen for category B of which the highest values (LDI B4) also occur for these soil types. In these cases the problem of poor soil conditions facing decreasing water input from rainfall becomes apparent. Large regions grouped in category B include the forest areas at the southern coast of South Africa. These plants encounter loss of productivity of 75 % and more.

High increase of mean annual temperature may be the cause of the NPP decrease in wide areas of the Namib mainly in Namibia, but also in northwestern South Africa. An LDI of C2 and C3 is common for this region, but there also exist decreases of more than 75 % (LDI C4). The same classifications can be found in the west of the Etosha-pan in northern Namibia (shrub- and grassland) and in northern Zimbabwe (cultivated area). The LDI C4 in the South African province FreeState in turn can be explained by the properties of the soil type.

For the remaining regions no significant variations in climatic conditions can be observed (category A). These regions have a high potential of being intensively threatened by human cultivation. This can also be true for regions classified in categories B, C and D, but here it is assumed, that human impact solely is responsible for the changes in NPP. This is true for all negative NPP variations in Botswana with the highest index of A4 at the Okavango Delta. In South Africa the cultivated areas are affected adjacent to the metropolitan area of Johannesburg and Pretoria, but also in the Cape-region. Furthermore high loss rates of up to 75 % (LDI A3) are found for the grassland areas of the Kalahari at the border between Botswana and South Africa, partially exceeding 75 % (LDI A4). For the adjacent areas of category B, C and D in South Africa and Namibia a combination of overstraining from human land use and changes of climatic conditions can be assumed that causes the decline of productivity of the vegetation.

12.5 Discussion

To evaluate the results of the presented classification there are no existing studies for the whole region of southern Africa. Thus the consistent comparison of our results is not possible. However, we have the opportunity to analyze our product by comparing it to local or regional studies. These studies are presented in the following subsections and compared to our LDI.

12.5.1 *Namibia*

Strohbach (2001) describes degradation processes in the northern Oshikoto region of Namibia and the central region surrounding the capital Windhoek. This study uses the gradient of degradation developed by Bosch et al. (1987) and Bosch and van Rensburg (1987). This gradient observes the transition of a grass covered landscape to woody savannah vegetation due to intensive rangeland usage. In addition the loss of vegetated areas is relevant for many regions like the northern Oshikoto region west of the Etosha pan or the Oshana plain in the north (Strohbach 2000a, b). For both regions a LDI of A2 to A3 is classified as cultivated areas in the north and grassland in the west. For regions where the natural vegetation is replaced by other plants the change in productivity may not be represented with a

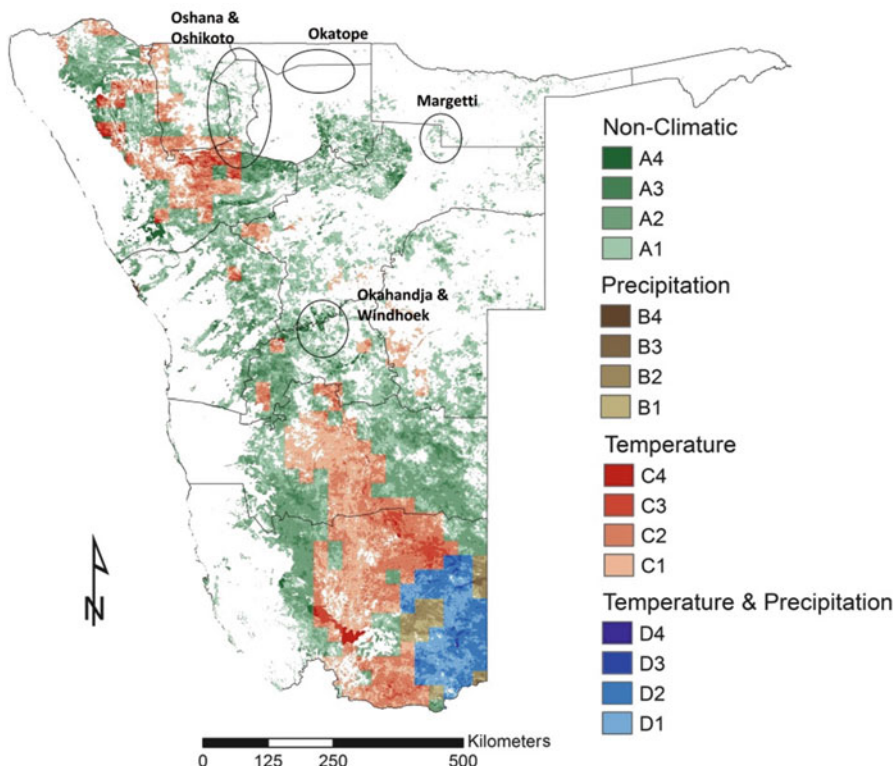


Fig. 12.7 Degradation index for Namibia with study regions of Strohbach (2000a, b, 2001) (black markings)

classification of the degradation index, as can be seen for the Okatope region in the northeast of the Etosha pan (Strohbach 2001).

In the Mangetti region a loss of shrubland vegetation is reported (Strohbach 2001) that can be affirmed by a LDI A2 in this region. Here also the land use as rangeland seems to be responsible for the loss of productivity. For central Namibia in the districts Okahandja and Windhoek a strong decline of grassland vegetation is observed for the period 1985–2001, where partially the whole vegetative soil cover is lost (Strohbach 2001). This also applies for good climatic conditions resulting in a LDI of up to A4 for the development in the period 99/00–09/10 for both regions. This is an obvious sign for the influence of the natural vegetation by intensive livestock farming (Fig. 12.7).

12.5.2 Botswana

Less than 5 % of the area of Botswana is suited for rain fed agriculture. Most of the land is used for livestock farming, whereas 71 % are operated by municipals and tribes, 23 % is state territory and the other 6 % are operated by commercial farms. 18 % of the area is rangeland and simultaneously identified as national parks and game reserves whereof conflicts arise progressively (Darkoh 1999).

The arid and semi-arid ecosystems, as they are in the Kalahari, obviously are extremely resilient due to the adaptation to the local climatic conditions. Though, the growing demand of rangeland, wood resources or agricultural land puts an immense stress on the vegetation the ecosystems can hardly cope with. These are the direct consequences of the faster growing population in these regions resulting in growing droves and intensifying cultivation of land. This problem seems to be persisting over the last decade, since all observed regions of the country are grouped in the category A (Fig. 12.8) and hence no climatic variations occurred in this period. Van Vegten (1981) already reported a reduction of grass cover in the southern Kgatleng district from 6–15 to 0–2 % caused by the local livestock farming. From our model results we get a LDI of A2 to A3 for cultivated areas and grassland (Fig. 12.8). Similar high values (partially A4), but spatially broader, are found for the Boteti region west of the Makgadikgadi salt pan. For this region Darkoh (1999) found obvious indications of land degradation and desertification over a period of 30 years from the end of the 1960s to the end of the 1990s. Following our model results this development can be seen to date.

The relevance of the industrial stock farming for the strain of the grass- and scrubland also was discussed by De Queiroz (1993). These studies in the Khutse wildlife reserve in the Kalahari showed that the decline of the local vegetation is in direct relation to the intensive grazing. The same was found by Dougill et al. (1999) for the vegetative development at the 'Uwe-Aboo-Farm' in the northeast. In this area the loss of mainly grassland vegetation was reported for the 1990s which is partly replaced by scrubland. At the persisting farms a high degradation index of A2 to A3 can be found for the period 1999–2010.

One specific feature in Botswana of course is the regularly flooded swamp region of the Okavango Delta. This area is classified with the highest LDI of A4. Hamandawana et al. (2007) used historical records, surveys regarding the environmental changes and satellite data (Landsat and Corona) to assess the land degradation in the delta covering the period 1860–2001. The analysis of the surveys reveals a decreasing amount of surface water, declining of the ground water level and the loss of pasture land. Negative precipitation variations, vegetation loss caused by floods and increasing demands by migrations to the region are accounted as reasons for the degradation. The assessment of the satellite images has also shown decline of the environmental status. A decrease of surface water by more than 12 % was observed before 1989. The tree cover reduced by 5 % between 1989 and 2001, whereas the scrubland increased by 6.6 % from 1967. A considerable decrease of about 44 % was found for grassland between 1967 and 2001. The main reason for

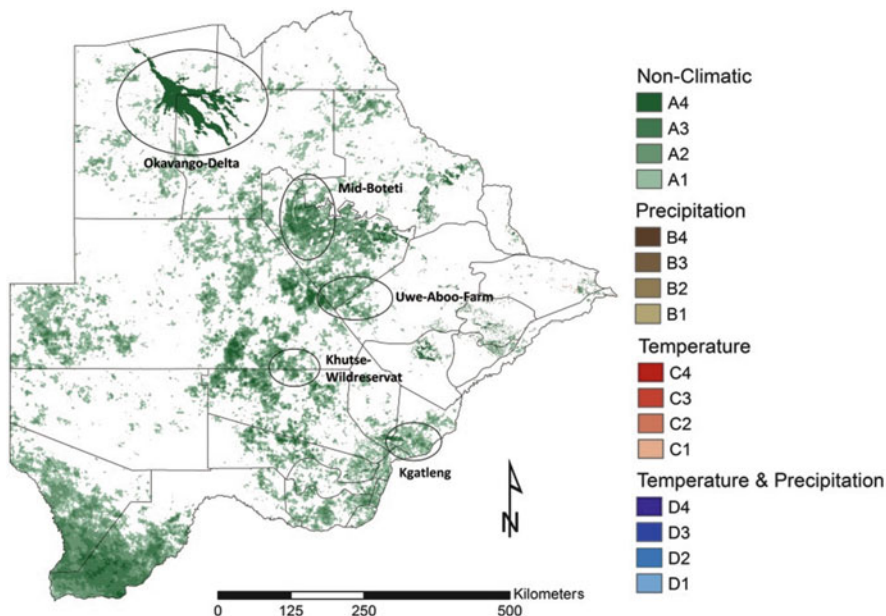


Fig. 12.8 Degradation index for Botswana with study regions of Van Vegten (1981), Darkoh (1999), and De Queiroz (1993) (black markings)

this development is the growth of population in the area of more than 50 % in the years between 1981 and 2001, causing an increase in livestock farming (Hamandawana et al. 2005). The results of the model presented in the degradation index show these variations to persist in the subsequent decade.

12.5.3 Zimbabwe

In Zimbabwe the Buhera District (marked in Fig. 12.9a) was analyzed by Mambo and Archer (2007) by comparing two sets of Landsat TM (Thermal Mapper) and ETM (Enhanced Thematic Mapper) scenes of 1992 and 2002 to derive negative changes in the vegetative cover (Fig. 12.9c).

Both approaches locate degradation processes in similar regions. The locations of the degrading areas are generally in agreement, but both maps show a more detailed distribution for different areas. The classification also differs between the two products in some cases. This could be caused by the different types of approaches for derivation of degrading areas. The main reason for differences, however, can be assumed to arise from the different periods of observation. In summary the main regions in this district, the North and the South, are found to be degrading by both approaches. Other comparisons to regional studies in Namibia, Botswana, Lesotho and South Africa show similar coinciding results.

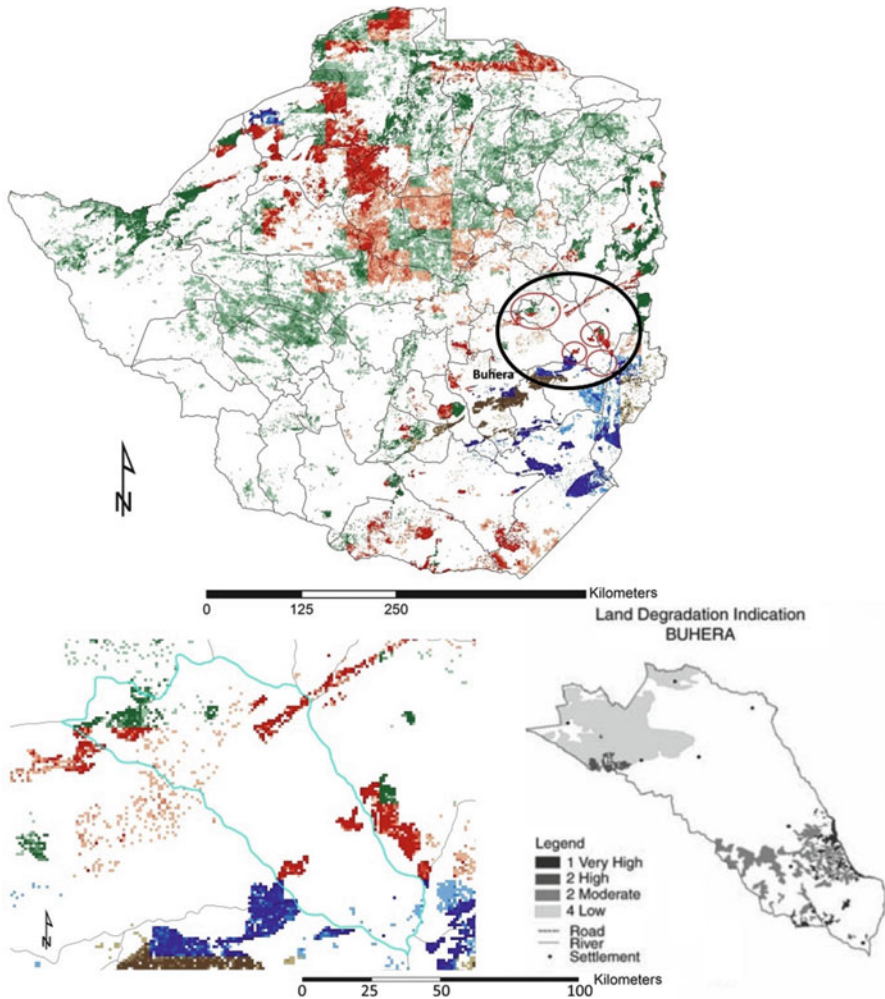


Fig. 12.9 Degradation index for Zimbabwe (a) and a zoom to the Buhera District (b) in comparison to the Landsat-NDVI derived land degradation indication (c) from Mambo and Archer (2007) (Color legend and categorization is according to Fig. 12.6 and Table 12.3)

12.6 Conclusion

The purpose of this study was to develop an approach to derive a Land Degradation index (LDI) for arid and semi-arid regions. For this we used calculated Net Primary Productivity (NPP) from our remote sensing data driven model BETHY/DLR. As area of interest the southern African countries of Namibia, Botswana, Zimbabwe, South Africa, Lesotho and Swaziland were chosen. From meteorological (ECMWF), soil (FAO/IIASA), land cover and phenological (SPOT) data, we

calculated annual NPP sums at 1 km spatial resolution. With this data we could derive variations in vegetative productivity for the years 1999–2010 to cover a time period of 11 years. With these variations the grade of land degradation could be assessed.

Additionally, variations in climatological time-series for mean annual air temperature and annual precipitation have been computed from the ECMWF model input data. From these time-series we were able to estimate the influence of meteorological changes over the observed period of 11 years. These three variations have been combined to an index of land degradation for the sub-continental region of southern Africa. The degradation map of southern Africa not only shows area of degradation but additional parameters controlling degradation as meteorological factor (air temperature and/or precipitation) and non-climatic factors which we relate to human induced changes.

Wide ranges of non-climatic caused degradation for example can be found in Botswana and Namibia. For these countries intense land use by grazing and farming is reported by several studies. Comparisons with regional studies show spatial consistency on regional scale, but detailed agreement can hardly be achieved due to spatial and/or temporal discrepancies in the scope of these works. However, with this method a degradation assessment of sub-continental regions can be performed for a whole decade with a spatial resolution of 1 km. As the temporal and spatial coverage of remote sensing data is driven to higher resolutions, the presented calculation of the variation in NPP will gain more and more in significance. This time-series will be extended and optimized as remote sensing products will continuously be enhanced.

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