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Viviane Djoufack, Bernard Fontaine, Nadège Martiny, Maurice Tsaléfac. Climatic and demographic determinants of vegetation cover in northern Cameroon. *International Journal of Remote Sensing*, 2012, 33 (21), pp.6904-6926. 10.1080/01431161.2012.693968 . hal-00690352

**HAL Id: hal-00690352**

**<https://hal.science/hal-00690352v1>**

Submitted on 11 Feb 2022

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# Climatic and demographic determinants of vegetation cover in northern Cameroon

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The objective of the study was to evaluate the spatio-temporal impacts of seasonal rainfall and urban population growth on the variations in normalized difference vegetation index (NDVI) in north Cameroon, which includes climates from south to north, the Sudanese and Sahelian climates. To this end, 48 points of measured rainfall were interpolated based on the kriging method at a spatial resolution of 8 km in accordance with the NOAA-AVHRR NDVI data set. Relationships between rainfall and NDVI, on the one hand, and urban population growth and NDVI, on the other, were analysed considering the 79 administrative units (AUs) in Cameroon. Seasonal (rainy season) variations of the vegetation cover were studied for the period 1987–2002 using the NDVI product at 8 km (NOAA-AVHRR) and 1 km (SPOT-VEGETATION) of spatial resolution. This article emphasizes the importance of the urban signal for the NDVI studies at finer scales, specifically in tropical areas.

## 1. Introduction

Vegetation indices are currently used to follow trends of vegetation cover at various temporal scales (Pouchin *et al.* 2002, Bigot *et al.* 2005, Hermann *et al.* 2005, Martiny *et al.* 2005, Tucker *et al.* 2005), as well as to estimate biomass yields (Lambin *et al.* 2003) or crop yields (Batholomé 1990, Hochheim *et al.* 1998, Odekunle *et al.* 2007). Relationships between vegetation indices such as the normalized difference vegetation index (NDVI) and climate parameters have shown that rainfall variability explains an important part of seasonal and intra-seasonal variations of vegetation activities in the Sudanese and Sahelian regions of Africa (Eklundh and Olsson 2003, Hermann *et al.* 2005, Martiny *et al.* 2006, Camberlin *et al.* 2007). However, changes in vegetation cover have also been linked to human activities, driven by socio-economic, cultural and demographic factors that also deserve to be explored. These anthropologic factors remain difficult to measure as they are much diversified and often connected to parameters that are not easy to quantify.

Northern Cameroon (or north Cameroon) is a particularly interesting region as it presents a juxtaposition of land-cover density and population density that are

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among the highest in the country as well as farming systems that are among the most intensive. The region is prone to climatic crises (intra-seasonal droughts, false starts and shortening of rainy seasons, etc.), which have direct consequences on the natural and cultivated vegetation cover. The leading climatic factor for vegetation-cover variability in the study area is rainfall. The leading anthropologic factors for vegetation-cover variability are primarily similar to those in many countries in sub-Saharan Africa: wood cutting (for heating and for sale), farming and agriculture, all directly related to demography (Dongmo 1998). Therefore, to face up the unceasing growth of population at the rate of about 2.8% per year (Central Office of Census and Demographic Studies of Cameroon (BUCREP 2010)), cultivators need to increase the area under cultivation.

Since the 1950s, agricultural clearings have significantly increased (Donfack 1998, Dongmo 1998, Yengué 2002) and, because of the economic crisis, since the end of the 1980s there has been a strong rural exodus. However, unemployment and low wages has led the majority of citizens to invest in agriculture, especially on the outskirts of the cities. In addition, urbanization is the most striking demographic fact revealed by the final results of the last population census of Cameroon. Thus, the practice of agriculture is no longer exclusive to the population living in rural areas: floodplains such as the Diamare and Benoue are most coveted because of their greater fertility (*Karal*), especially for dry season crops, e.g. *mousskouwari* (Mathieu 2000). In short, the vegetation cover (natural or cultivated) is considered a resource as it augurs good harvests and better pastures. So, it becomes necessary to identify the changes that affect vegetation in order to detect the most affected areas and to evaluate the sensitivity of vegetation cover to both climatic and demographic variations: this was the objective of this study conducted in northern Cameroon.

For this purpose, the NDVI (Tucker 1979) was used as an indicator of the vegetation cover, and *in situ* rainfall measurements were used as the climatic parameter. The demographic parameter was the urban population, defined as people living in areas of at least 5000 inhabitants (WALTPS, ONU), because the urbanization phenomenon involves the implementation of economic infrastructure (roads, industries, housing) and substantial migration (of jobs seekers) that are directly or indirectly connected with vegetation changes inside and around urban centres (Antoine 1997). Given the successive droughts that occurred at the beginning of the 1980s, the study focused on the period after 1987 in order to remove the inter-annual memory effects of vegetation. The originality of this study lies in the fact that it has been carried out on a scale that allows us to detect changes on a restricted space (pixel) and to evaluate interactions between rainfall, NDVI and urban population growth in each administrative unit (AU) in order to derive elements that could be used in decision-making in terms of climatic and anthropogenic impacts on changes in land cover. After presenting the key elements of the geographical context (§2), the data sets (NDVI, rainfall, urban population) and the main methodological approaches are presented (§3). The results are discussed in §4.

## 2. Geographical context

North Cameroon comprises a diversity of physical and natural conditions. Located between 6° N and 13° N, and 11° E and 16° E, it includes, from south to north, the Adamaoua, north and extreme north regions, spanning a total area of about 164 000 km<sup>2</sup> (figure 1).

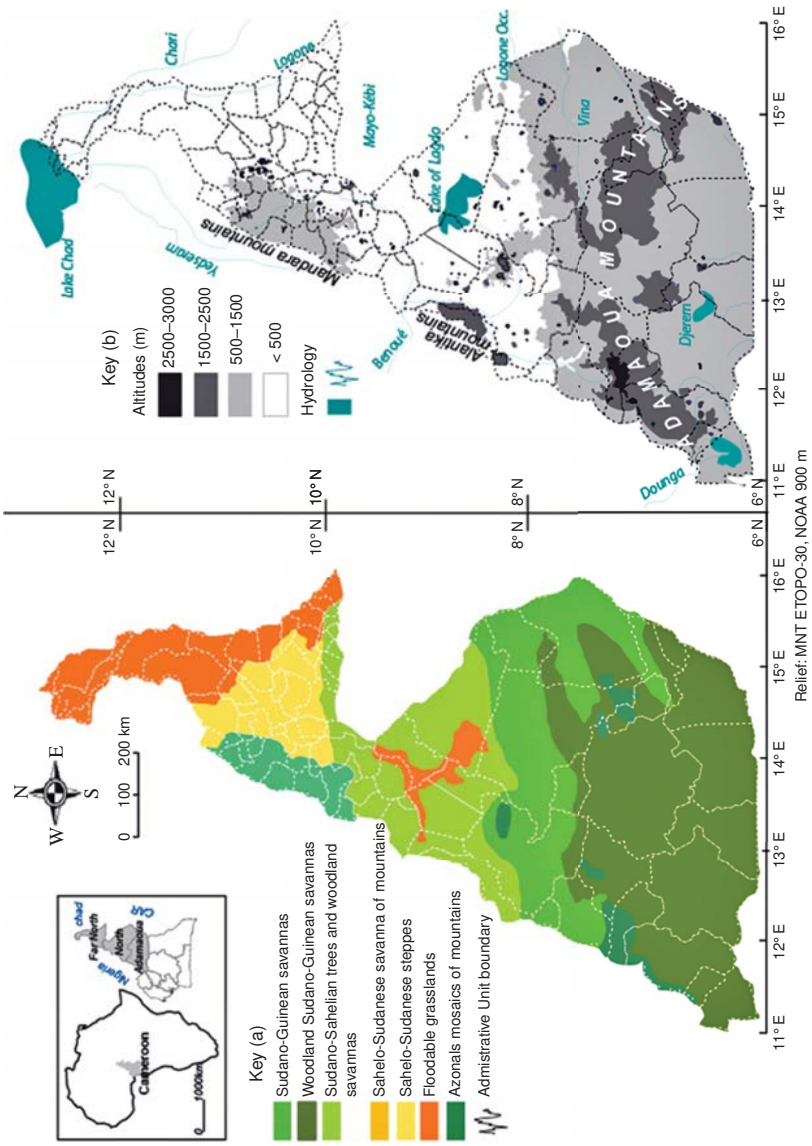


Figure 1. Some physical characteristics of northern Cameroon: (a) distribution of vegetation cover; (b) spatial distribution of altitude and hydrography (Adapted from Letouzey (1968) and White (1987)).

## **2.1 *Vegetation***

The vegetation cover (figure 1(a)), consisting of the Sudano-Guinean savannas and deciduous woodland south of 9° N, becomes irregular and discontinuous northwards; the central part of the extreme north region is occupied by sparse grasses and thorny Sahelian steppes, whereas ‘Sudanese savannas of Mountains’ (Letouzey 1968, White 1987) were found in the region of the Mandara Mountains. The eastern part of the far-north region is covered by floodable grassland.

## **2.2 *Topography***

Three main units can be distinguished (figure 2(b)): the Mandara and Alantika Mountains, from 900 to 1885 m, in the western part of the northern zone, between Cameroon and Nigeria; the Adamaoua plateaux (~1000 m) in the southern part of the region, which shelter mountains reaching up to 2500 m (figure 1(b)); and the plains (altitudes below 300 m), drained by the permanent rivers of Benoue and Logone and practically flooded from July to November.

## **2.3 *Climate***

North Cameroon is under the influence of the African monsoon and is dominated by the seasonal translation of the ITCZ (inter-tropical convergence zone) and by the Harmattan winds coming from the Sahara. It can be divided into two sub-climatic areas: the Sahelian zone stretching over the 8th parallel and the Sudanese (or Sudano-Sahelian) zone located southwards. The mean annual temperatures vary from 28°C in the Sahelian region to 24°C in Adamaoua, whereas the monthly maximums are 34°C and 28°C, respectively. The mean amount of annual rainfall ranges between 500 and 1500 mm, and shows a strong inter-annual variability (figure 6).

## **2.4 *Population***

According to the results of the last population census of Cameroon (2010), the size of the urban population had been increasing by 3.9% between 1976 and 2005, highlighting a particularly strong urban dynamism. In addition, the WALTPS (West African Long Term Perspective Study) showed that about 50% of the population of Cameroon lived in urban areas in 1995 and that this urban population was increasing by about 4.9% per year (Antoine 1997). In 2007, the north Cameroon population was estimated at nearly 5 700 000 (BUCREP 2008), i.e. an increase of more than 3 million since the population census of 1976. However, the spatial distribution of the population in that region is striking: the most populated regions are found in the capital town of each sub-region unit, specifically in Maroua, Garoua, Ngaoundere, Kousseri and Mora (refer to figure 2(c) to locate these places), whereas the countryside is often depopulated (Marguerat 1982). The populations of the extreme north, north and Adamaoua regions represent 18%, 10% and 5%, respectively, of the total population of the country.

## **3. *Data and methods***

### **3.1 *Normalized difference vegetation index***

Vegetation indices obtained by remote-sensing methods are widely used today as indicators of vegetation photosynthetic activity, which can be representative of the

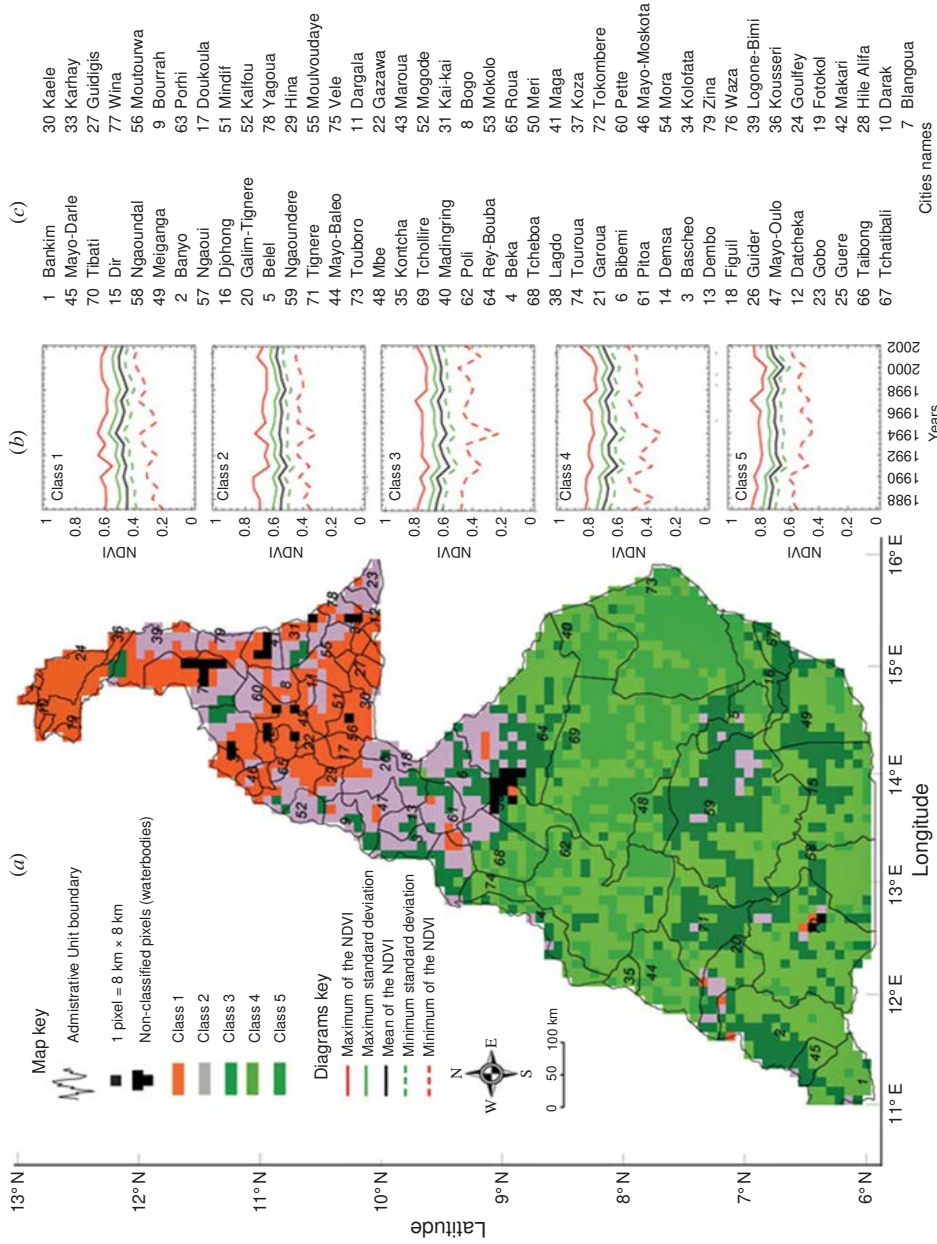


Figure 2. Discrimination of vegetation cover in northern Cameroon using NDVI at 8 km spatial resolution (mean of the period 1987–2002): (a) spatial classification of NDVI into five classes; (b) inter-annual variation of NDVI for each class; and (c) the names of administrative unit capitals of northern Cameroon (79).

vegetation cover of a region when the indices are time-integrated. These indices are computed based on the combination of spectral bands shown to be related to green biomass (Tucker 1979). The one used in this study is the NDVI, which is based on the ratio between the difference and the sum of the top-of-atmosphere reflectance in the ‘near-infrared’ (NIR) and the ‘visible’ (RED) spectral bands:  $NDVI = (NIR - RED)/(NIR + RED)$ . These reflectances are those of the AVHRR sensor (Advanced Very High Resolution Radiometer) of the NOAA (National Oceanic and Atmospheric Administration) satellites, compiled during various missions: NOAA-7 (1981–1985); NOAA-9 (1985–1988 and August 1994–January 1995); NOAA-11 (1989–1994); NOAA-14 (1995–2000); and NOAA-16 (since 2000). The data set is broadcast by Global Inventory Monitoring and Modelling Systems (GIMMS) and includes 15-day synthesis maps of NDVI at 8 km spatial resolution. Those bimonthly synthesis maps include corrections for calibration bias, orbital drifts and geometrical viewing/illumination conditions and stratospheric aerosol. The bimonthly integration of the NDVI enables us to remove the effects of clouds (Tucker 2005).

NDVI data were extracted on the ‘window’ of north Cameroon for a total of 2497 points (97° latitude and 53° longitude for each time period) from 1987 to 2002.

For each of the 16 years, the mean NDVI of the rainy seasons was computed, i.e. those where the average cumulative rainfall exceeds 50 mm (Suchel 1987): in the Sahelian region, the rainy season being defined in May–September and April–October for the region southwards to 9° N. The interest in working on seasonal average charts of NDVI during the subsequent rainy seasons was justified by the fact that it was the most active period for vegetation (Martiny *et al.* 2006). It was thus easier to separate various classes (or clusters) of vegetation at this period, although the distinction between woody savannas and crops remain fuzzy in the Sudanese areas (Achard and Blasco 1990). After having constituted seasonal NDVI meta-files of the 16 years, the next concern was to evaluate for each pixel the changes that occurred during the period 1987–2002.

The second NDVI data set we used comes from the VEGETATION (VGT) instrument of the Système Probatoire d’Observation de la Terre (SPOT) satellite, which ensures daily global coverage of the Earth’s surface with a 1 km spatial resolution. Data sets are broadcast by the Vlaamse Instelling voor Technologisch Onderzoek (VITO), which routinely carries out angular and atmospheric corrections on data that were available in 10-day composite NDVI and from 1 April 1998 to 31 October 2009. Values are encoded and the real NDVI values are derived using the following formula:

$$NDVI = -0.1 + 0.004X \text{ (} X \text{ represents encoded value)}. \quad (1)$$

Further information and VITO’s data are available at [www.vgt.vito.be](http://www.vgt.vito.be). This database was used to study efficiently the land-cover changes into urban areas, given their high spatial resolution. To do this, only years with complete data were taken into account, i.e. from 1999 to 2008.

**3.1.1 NDVI classifications.** The various methods of regionalization that use NDVI are based on the fact that each type of vegetation has its own spectral signature and may have a distinct photosynthetic activity with respect to rainfall. Thus, the regionalization methods allow us to discriminate between the main vegetation types. The isodata method was used in this study, and is a non-supervised approach: the

isodata algorithm compares radiometric values of each pixel based on initial cluster vectors, primarily assigned (maximum and minimum threshold), as well as the minimum aggregates by cluster and the minimal distance between classes (Tou and Gonzalez 1974, Lacombe 2007). At each iteration, averages are re-computed and pixels are re-classified according to new averages. The operation ends either when the preset number of iterations is reached or when the rate of changes in each cluster becomes lower than the fixed threshold. Post-classification operations enable us either to compact classes by eliminating isolated pixels or by merging classes presenting similar characteristics or remove those presenting non-realistic configurations. Note that the numbers of cluster vectors were assigned based on the main vegetation types of north Cameroon (Letouzey 1968, White 1987).

**3.1.2 Extraction of the NDVI in urban regions and out of urban areas.** Because our objective was to focus on small scales, a spatial resolution of 8 km seemed inaccurate to evaluate the impact of urbanization on vegetation. For that reason, the 1 km SPOT-VGT NDVI was used. Because the exact sizes of all of the cities were not available, the regions of interest (ROIs) over urban areas were selected from geographic information system (GIS) software, based on the population size of each AU (table 1).

Each ROI was constituted by the pixel containing the city itself, as well as the adjacent pixels that can be considered suburbs. In order to take into account the nonurban areas (rural), a mask was applied on urban areas previously located (cities and suburbs). Then, a radius of 4 km (equivalent to 4 pixels) was considered around those urban areas. The averages of those pixels were considered the NDVI of rural areas.

### 3.2 *Rainfall data and spatial interpolation at an 8 km spatial resolution*

Seasonal rainfall data of 48 stations (31 located in north Cameroon and 17 others in Chad, Nigeria and the Central African Republic) were selected to generate regular grids of rainfall at an 8 km spatial resolution in accordance with the NOAA-AVHRR NDVI grid. Most of the data of north Cameroon belong to the SODECOTON network (Bella-Medjo 2008), whereas other data were given by the direction of the national meteorology as well as by the departmental offices of meteorology of countries mentioned above. Several spatial interpolation methods were tested with the aim to find the one that will be closer to reality. The kriging method was finally selected. A kriging algorithm analyses statistical variations of values over different distances (closer points are weighted more heavily than distant points) and different directions (anisotropy) with the intention to determine those that will produce the minimum error in the rainfall estimate (Cressie 1991). It was initially checked (i) whether the

Table 1. Extraction of NDVI in urban areas, according to the size of the population.

Population size (inhabitants)	Region of interest (ROI) area (km <sup>2</sup> )
≤10 000	9
[10 000–20 000]	16
[20 000–30 000]	50
>70 000	81



average and variance of points were stationary, i.e. they only depend on the distance between points and (ii) whether there was a spatial coherence in rainfall distribution over the region. So, the spatial continuity of data was computed on points for which values were known and the degree of reliability of results can be expressed as an experimental variogram (or semi-variogram). Values of the variogram were computed by averaging the squared differences of all pairs of observations with the specified distance and direction (for further details, see Oliver and Webster (1990), Gratton (2002), Baillargeon (2005), Joly *et al.* (2008)). To obtain the results, the experimental variogram plot needs to be adjusted because its shape serves only as a basis for determining the appropriate model. Cross-validation is an approach to estimate how well the model chosen is going to perform for the yet unseen data. In this study, the linear model was the one that adjusted our variogram the best, i.e. where the error between the estimated and observed rainfall was the weakest. Then, using GIS, the data were re-adjusted on the north Cameroonian ‘window’ and gridded at an 8 km spatial resolution.

Standardized indices of each parameter (NDVI or rainfall) were computed using the formula below, where  $ny$  is the number of stations of year  $y$ ,  $p_s^y$  is the corresponding parameter for year  $y$  and station  $s$ ;  $\bar{p}_s$  is the seasonal mean of the considered parameter for station  $s$ ; and  $\sigma_s$  is the seasonal standard deviation of the considered parameter for station  $s$ . Results were expressed in standardized anomalies, computed as follows:

$$SI = \frac{1}{ny} \sum_{s=1}^{ny} \frac{p_s^y - \bar{p}_s}{\sigma_s}. \quad (2)$$

### 3.3 Demographic data

The demographic data set consisted of the urban population of 79 AUs that represent regions, sub-regions and districts of northern Cameroon. These data come from the Population Census report of years 1987 and 2005, as well as demographic surveys of 1998, 2002, 2007 and 2010, carried out by the National Institute of Statistics (NIS, for the year 2002), the National Office of Accounting and Statistics (DSCN, for the year 2002) and the BUCREP (for the years 1998, 2007, 2010). Demographic projections of intermediate years were computed based on the rate of growth of the urban population in each AU. The rate of population change was computed using the following formula:

$$\text{Population evolution} = \frac{\text{Population of year 2008} - \text{Population of year 1999}}{\text{Population of year 2008}} \times 100. \quad (3)$$

## 4. Results and analysis

### 4.1 Spatial patterns of NDVI in northern Cameroon (1987–2002)

Figure 2(a) displays the results of the classification (isodata) based on the mean NDVI annual regimes in northern Cameroon over the period 1987–2002. Referring to the prevailing land-use/land-cover type (GLC2000), as well as the cartography of the main types of ‘natural’ vegetations (figure 1(a)), the five NDVI clusters that result from the classification can somehow be matched with the main vegetation types of this region (figure 2(b)). Indeed, there was a gradation of vegetation from north to south: from 0.4 in the steppes (classes 1 and 2) to up to 0.7 in shrub lands and woodlands of the

southern region (classes 3–5). Although clusters can be constituted by different vegetation species (e.g. mosaics), the signal displayed refers to the dominant species. So, the averages of NDVI are a smoothing (often non-realistic) of data, which consist of reducing the variance. That is why it was interesting to consider other parameters such as maxima, minima or standard deviations that indicate the dispersion of NDVI in the different classes (figure 2(b)). All of these regions are over-exploited for agriculture and cattle livestock, with more damaging environmental consequences in the northern part.

At the inter-annual time scale (figure 3(a)), all classes emphasized an increase in NDVI at the end of the period 1987–2002. In early periods, classes 1 and 2 showed negative anomalies, whereas classes 3–5 were in surplus over the first four years of the period ( $>1$ ) and in deficit in the 1990s. The NDVI mean annual regimes presented an unimodal profile (figure 3(b)), with a flattened shape for classes 3–5. However, the duration and amplitude of the rainy season have changed considerably from north to south: maxima were observed in August with an increase in NDVI at the peak date, from 0.5 (north) to 0.7 (south); an early onset and an early shrinkage of vegetation were observed in northern classes (1 and 2), whereas there was an opposite situation in southern classes (3–5).

In summary, the vegetation of northern Cameroon is very diverse in terms of typology, annual cycle and inter-annual variations. Significant variations are also observed between urban areas. The average NDVI (1987–2002) in AU capitals show large variations from one city to another, even in those belonging to the same class of NDVI (figure 4), but a mean difference by  $8^\circ$  N ( $\sim 0.2$ ) clearly appears.

What are the parameters underlying those spatio-temporal changes in NDVI during the period 1987–2002? To answer this question, the spatial evolution of rainfall was initially explored, and the sensitivity of vegetation to rainfall variability was examined using the rainfall/NDVI correlations. Then, the anthropogenic impacts were studied through the urban population growth. The analyses were done under two assumptions:

- positive NDVI anomalies induce an above-normal vegetation activity that can be associated either with an increase in rainfall or with the conversion of fallow land or wasteland (with lower reflectance) into farmland (Beauvillain 1989, Gonné 2005);
- conversely, negative anomalies imply strengthening of activities that promote vegetation degradation; this can be due to decline in rainfall or due to some processes associated with urbanization, inducing the cutting and uprooting of trees to build new urban infrastructure or new residences (Dongmo 1998, Ndamé and Briltey 2004).

## 4.2 *First explanatory factor: the rainfall*

**4.2.1 Spatio-temporal variations of rainfall (1987–2002).** Figure 5(a) displays the rainfall spatial distribution in northern Cameroon as well as annual rainfall regimes averaged over three latitudes (figure 5(b)). It expresses a general north/south gradient with a more northeast/southwest orientation southwards to  $7^\circ$  N.

The annual rainfall amounts are lower than 1000 mm north of the 8th parallel; the local values vary from 1500 mm around the station of Tibati to approximately 600 mm in Kousséri, located in the extreme north of the region. Annual cycles that are unimodal with maxima observed in August show a prolongation of the duration

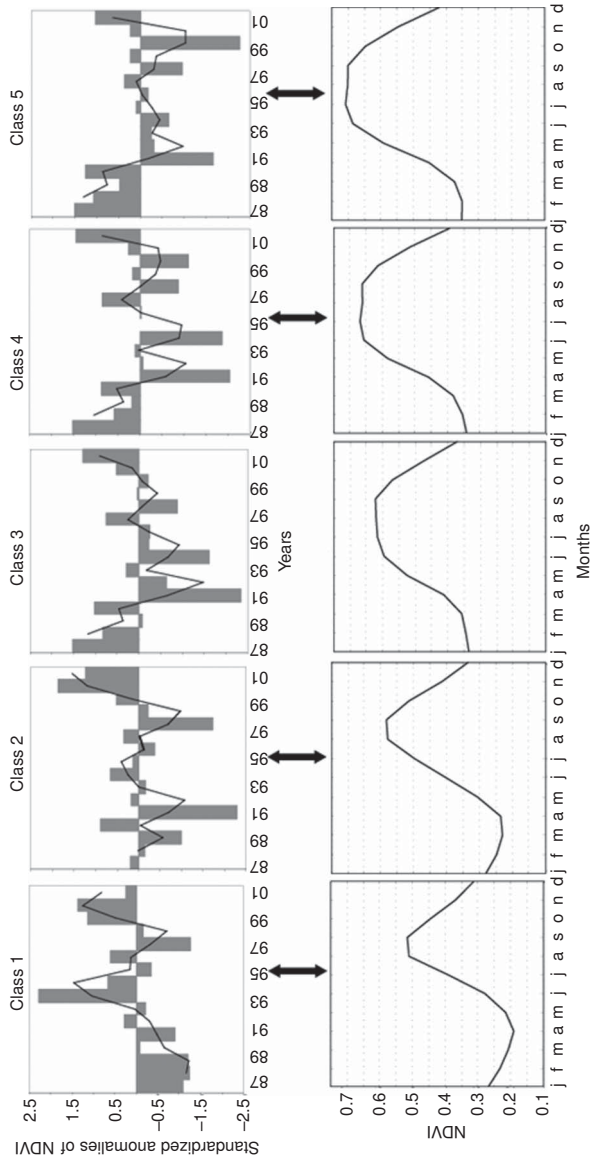


Figure 3. Annual and inter-annual variations of NDVI in northern Cameroon (mean of the period 1987–2002): (a) standardized anomalies of NDVI of five different classes (refer to figure 2); black curves represent moving averages (over 2 years) and (b) annual cycle of NDVI in each class.

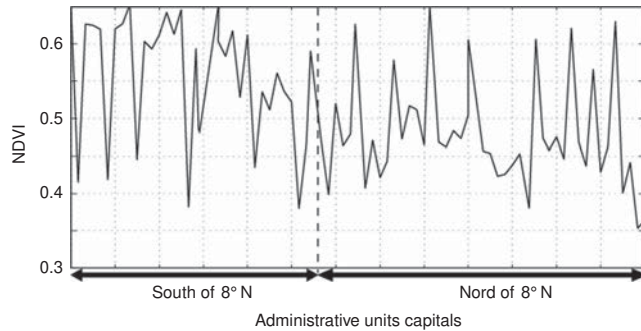


Figure 4. Means of NDVI into AU capitals (mean of the period 1987–2002); the AU capitals are sorted from the south to the north.

of the rainy season (monthly rainfall  $>50$  mm from March to October) in southern latitudes (figure 5(b)). Northwards to  $8^\circ$  N ( $>1000$  mm), inter-annual trends (figure 6) are positive, whereas south of this latitude, most years are deficient despite a few positive anomalies observed between 1994 and 1999. These results raise the question of a probable re-greening in the Sahel since the early 2000s (Ozer *et al.* 2003, Olson *et al.* 2005, Lebel and Ali 2009). Briefly, the rainy season extends from April to October in the Sudanese region and from May to September over the Sahelian area. These spatial particularities will be considered in the various analyses throughout the study. Does the localization of the maximum of rainfall in August as for the NDVI testify to the absence of lag between the rain and the NDVI? The answer to this question required a comparison of the two parameters provided that they are at the same spatial and temporal scale.

**4.2.2 Spatial interpolation of rainfall data at a spatial resolution of 8 km.** Figure 7 shows the scatter plots (44 points) observed versus estimated rainfall over the period 1987–2002 along with the regression line. It emerges that simple linear correlations were strong and significant as shown by the ‘line of best fit’ ( $r = 0.89$ ) reflecting both the quality of the adjustment model in the semi-variogram and the greater consistency in the spatial distribution of rainfall over the period.

**4.2.3 Composite analysis of rainfall and NDVI.** (a) In the whole region, figure 8 displays the mean rainfall/NDVI relationship considering 2497 pixels over the period 1987–2002. There is a gradual, simultaneous increase in both the parameters up to 1000 mm of rain while the NDVI is around 0.6. Above this threshold, the NDVI (between 0.6 and 0.7) remains constant independently of the increase in rainfall. This saturation phenomenon beyond 1100 mm is due to the physiological properties of plants that become non-responsive to rainfall variations when they have already reached a certain stage of phenological development. In this situation of hysteresis, rainfall is no longer a constraint for plant growth. The saturation threshold of NDVI varies according to bioclimatic characteristics as well as to the considered spatial scale. The threshold of saturation is often fixed at 1000 mm in east and west Africa (Malo and Nicholson 1990, Davenport and Nicholson 1993, Eklundh and Olsson 2003, Hermann *et al.* 2005, Camberlin *et al.* 2007, Seghieri *et al.* 2009).

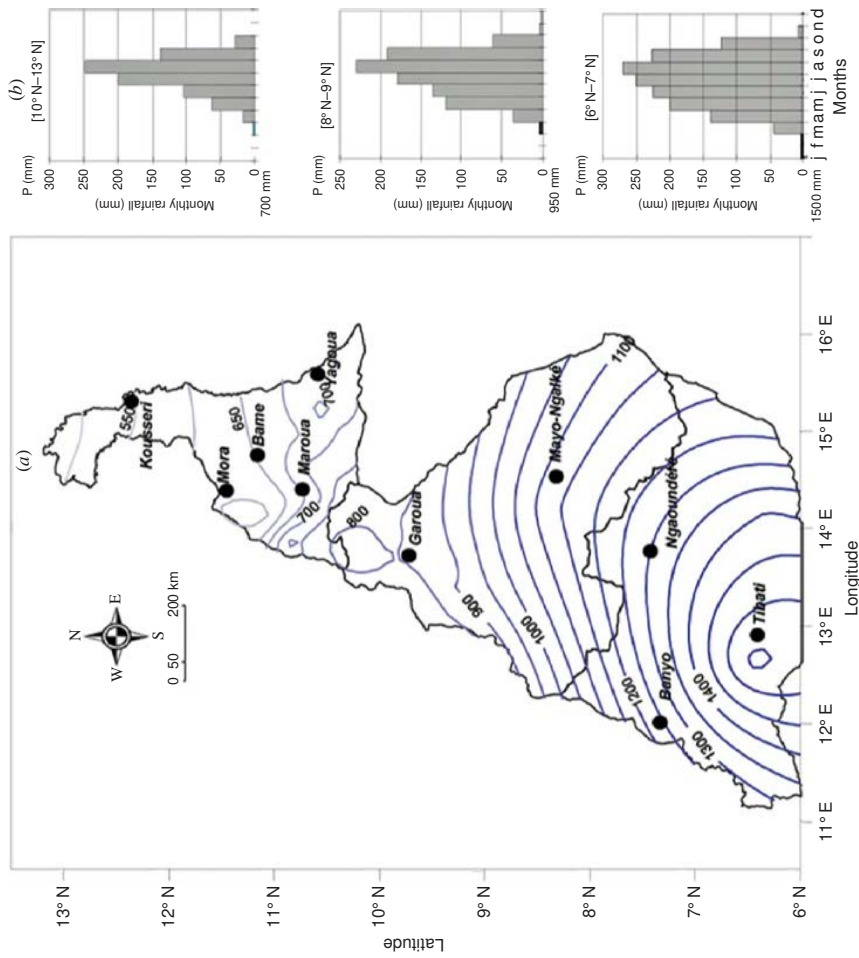


Figure 5. The main characteristics of rainfall in northern Cameroon. (a) Spatial distribution of rainfall (mean of period 1987–2002); (b) annual cycles of rainfall computed on a north/south transect.

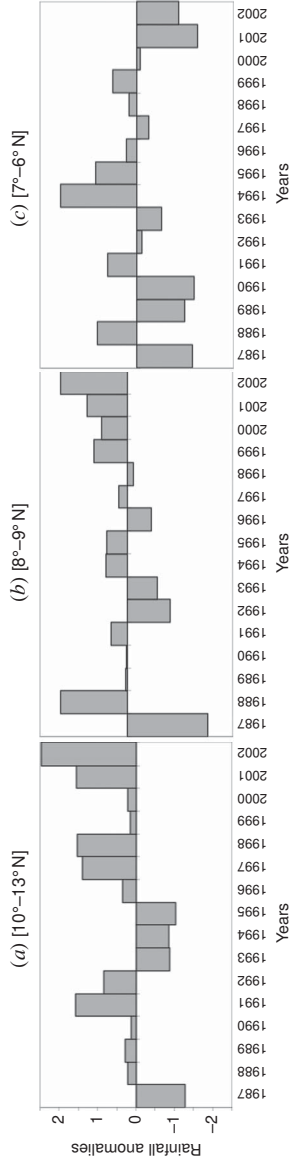


Figure 6. Inter-annual variability (standardized anomalies) of rainfall in northern Cameroon, computed on a north/south transect (refer to figure 4).

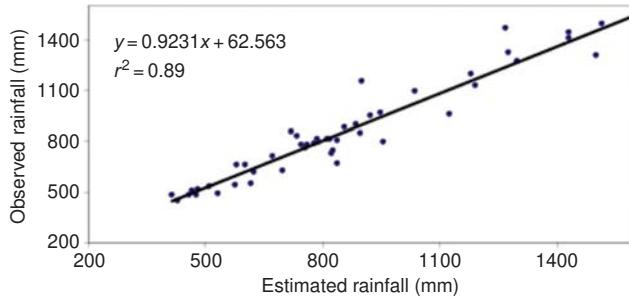


Figure 7. Cross-validation of the kriging model (mean of the period 1987–2002).

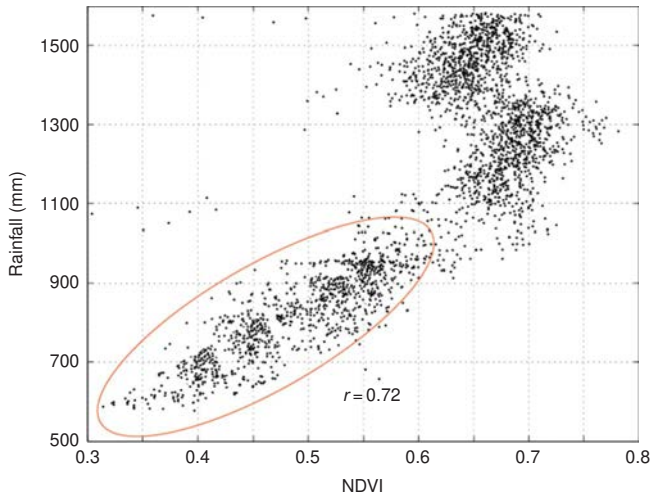


Figure 8. NDVI/Rainfall correlation ( $r$ ) at the rainy season (mean of 1987–2002).

Consequently, synchronous NDVI/rainfall correlations were around 0.7 when computed over the whole region, but this value can be improved over the Sahelian belt if the rainfall leads the NDVI by approximately 1 month (Shinoda 1995, Djoufack 2008).

(b) In urban and non-urban areas, figure 9 displays the rainfall/NDVI relationship in rural (figure 9(a)) and urban (figure 9(b)) areas. The urbanization explains the decrease in NDVI in urban areas and the presence of a large number of points around 0.25 despite increased rainfall. This requires two assumptions:

- in non-urban areas, the rainfall/NDVI relationship is quasi-natural and reflects the spatial distribution of the two parameters (figure 8);
- in urban areas, the correlation seems to be sensitive to the importance of cities.

Two groups of points have been clearly distinguished: NDVI below 0.35 corresponds to the largest cities in terms of urban infrastructure. Beyond 0.35, the weight of urbanization is less prominent. This result suggests that local NDVI values are likely to be biased by the urban signal. To verify this hypothesis, urban population data were examined as an indirect factor in cities' typologies, while knowing that more (less) populated city areas are more (less) important in terms of urban infrastructure.

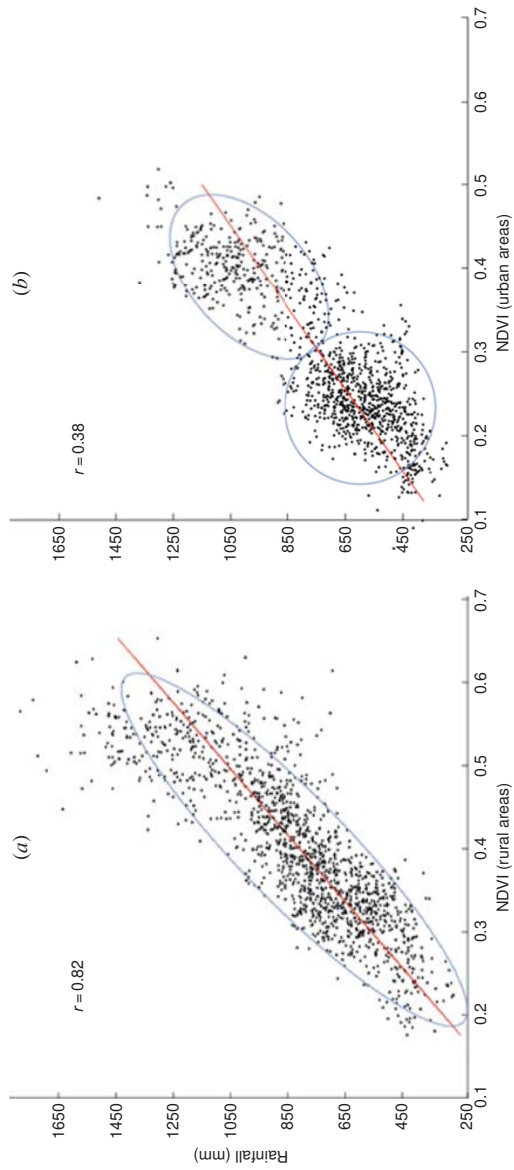


Figure 9. The highlighting of the impact of urbanization in urban and suburb areas. NDVI/rainfall correlations ( $r$ ) in rural (a) and urban (b) areas.



### 4.3 *Second explanatory factor: the urban population growth*

#### 4.3.1 **Spatial distribution and evolution of the urban population in north Cameroon.**

Given that phenomena such as urbanization are better apprehended by using high spatial resolution products, the NDVI data (SPOT 1 km) were used to study the relationship between NDVI and urban population. Because of the low temporal depth of these data, the study was undertaken over a 10-year period (1999–2008).

As in most countries of sub-Saharan Africa, the main characteristic of the spatial distribution of urban population in north Cameroon is ‘macrocephaly’, i.e. the overwhelming preponderance of a single city over the rest of the urban system (Marguerat 1982).

Indeed, in 2005, nearly 40% of the urban population of northern Cameroon was concentrated in the cities of Maroua, Garoua and Ngaoundere (>590 000 inhabitants), which also represent the capital cities of the three regions (figure 10(a)). These cities were followed by Kousseri and Guider, in which the urban population in 2005 was estimated to be around 89 000 and 52 500, respectively. Indeed 47 cities have urban populations under 10 000. Also, compared to the two other regions, the far north shows the highest urban densities due to the small areas of the AUs: this is one of the reasons for the high land crises in that region.

Figure 10(b) shows the evolution of the urban population in AU capitals between 1999 and 2008. In 10 years, 19 AUs experienced a population increase from 40% to 50%, whereas 22 AUs registered a population increase between 10% and 20%. The decline in urban population relates to only six AUs. It should also be noticed that the highest growths do not concern the most populous cities such as Maroua, Garoua and Ngaoundere (30%, 17% and 20%, respectively), but cities such as Djohong, Madingring, Zina, Blangoua and Datcheka, which increased their population by more than 45% in 10 years. Besides, Guider and Mokolo, which represent the 6th and 10th most populous cities of northern Cameroon, had only growths of 7% and 12%, respectively. This rapid rise in the population of cities considered as rural areas some years ago can be explained by natural growth (through birth) and more importantly by the urban exodus due to high urban unemployment. Population of a few towns located north of the eighth parallel increased by more than 30% in 10 years. South of this latitude, urban population growth over 30% only took place in the cities of Djohong, Madingring Kontcha and Ngaoui. Elsewhere, urban growth did not exceed the threshold of 30%.

**4.3.2 Composite analysis of NDVI/urban population growth relationships.** For each AU, the correlation coefficients between NDVI and urban population were calculated at the inter-annual time scale (79 AU  $\times$  10 years), for a set of 790 data for each parameter. Correlations were analysed and tested through Monte Carlo simulations at 95% confidence level. The results presented in figure 11 show that beyond the six cities experiencing population decrease, the urban demographic evolution in northern Cameroon is an exponential function. Based on this observation, it can be predicted that the relationship between NDVI and urban population growth will be the inverse, i.e. urban growth would imply a decrease in NDVI in urban areas. What about results?

The results have shown that, both parameters evolve in opposite ways, i.e. annual values of the NDVI decrease as the population increases. However, following the 10-year period, significant correlations ( $R = -0.32$  to  $-0.9$ ) were observed for cities such as Ngaoundal, Kaele and Gobo, where the urban expansion was between 8000 and

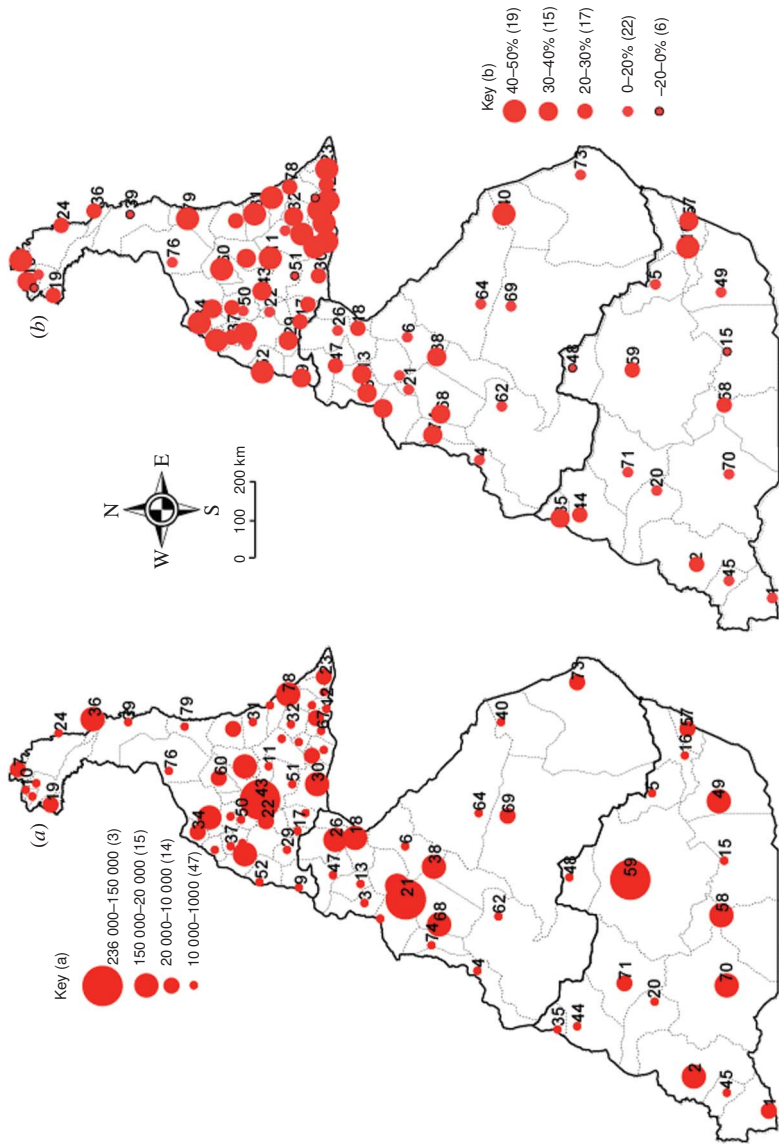


Figure 10. The urbanization in northern Cameroon: (a) the urban population distribution in 2005; (b) evolution (%) of the urban population from 1999 to 2008; refer to figure 2 for names of cities.

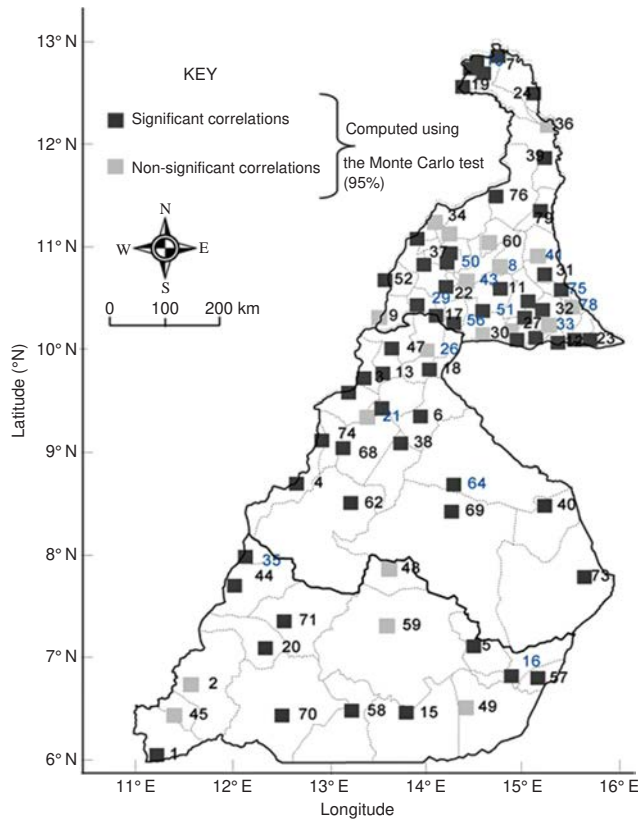


Figure 11. Correlations between NDVI (1 km) of urban areas and urban population growth (mean of the period 1999–2008). The correlations are computed using the Monte Carlo test at 95% confidence level.

30 000 inhabitants, and for those cities in which population increased by at least 30%, such as Mora, Ngaoui and Madingring. In both the cases, the vegetation cover decreased to the benefit of processes concomitant to population growth such as housing, political and economic infrastructure, etc. For cities such as Mbé, Taibong or Dembo, where the urban population remained low (<8000 inhabitants), and those where the population regressed (Zina, Doukoula, Porhi), the NDVI behaved the same way as it had in non-urban areas. In this case, NDVI variations seem to be more strongly related to rainfall, as shown in figure 9(a). Finally, the correlations between NDVI and urban population are weaker, i.e. NDVI values remain almost constant from year to year in more populated cities such as Maroua, Garoua, Ngaoundéré or Kousséri, where population has not increased significantly. Indeed, in those cities, the land-use process evolves in a gradual way compared to other regions where the rapid population growth entailed important changes in land use.

Significant correlations were found in both northern and southern cities, but the urban signal explains a larger part of vegetation-cover variations northwards to 9° N, where 19 AUs (out of 46 AUs) show no significant NDVI/urban population correlation. To the south of this region, the urban signal is equally important because only five AUs have not shown significant correlation.

These results might reflect the fact that NDVI variations are less sensitive to the number of inhabitants than to the urban extension caused by population growth. This is the reason why NDVI studies at the local scale require some caution. What also emerges from this study is that the demography of urban areas was growing sharply, particularly in cities still considered rural a few years ago. The populations of most of the cities located northwards of 8° N experienced a more than 30% increase between 1999 and 2008. In these localities, the NDVI–urban population enlargement relationship was significant because the increase is followed by a decrease in vegetation cover through the establishment or the expansion of urban infrastructures. Southwards to 8° N, the correlations were less significant in some cities such as Meiganga, Mayo-Darle and Banyo. This means that, in those specific cities, the vegetation dynamics are related to factors other than rainfall and urban population growth, because the vegetation cover is less dependent on rainfall.

It is noteworthy that these correlations have been computed at the cities' spatial scale because urbanization is known as one of the poles of vegetation degradation and more specifically of deforestation (Defries *et al.* 2010). Indeed, the dense population of urban areas and agricultural trade are the main drivers of deforestation in tropical regions, whereas the population of rural areas is not correlated with deforestation, indicating the importance of urban-based and international demands for agricultural products as drivers of deforestation.

## 5. Conclusion

The objective of this study was to evaluate the factors in vegetation-cover variations through NDVI at 8 and 1 km resolutions in northern Cameroon. With this intention, two parameters were tested: precipitation, because of its well-known relationship with NDVI, and urban population growth, considered an indirect factor for vegetation-cover decrease in urban areas and suburbs. Seasonal charts of NDVI at 8 km of spatial resolution were used as indicators of vegetation, whereas punctual rainfall data were interpolated, based on a kriging method at 8 km of spatial resolution according to the spatial resolution of NDVI data from 1987 to 2002. The study was focused on 79 AUs of northern Cameroon and dealt with the following three aspects.

1. **Inventory of vegetation-cover changes.** The main spatial patterns of NDVI as well as their annual and inter-annual evolution over the period 1987–2002 were described. The five spatial classes (cluster) of vegetation obtained from NDVI classification reproduced the vegetation type gradient from north to south. These clusters were different from each other by their inter-annual and annual characteristics: annual profile, start and duration of the greening season, inter-annual anomalies, etc. At the city scale, the NDVI also varies widely even in cities belonging to the same cluster.
2. **NDVI/rainfall relationship.** The changes in NDVI were explained using the spatio-temporal evolution of rainfall. The NDVI/rainfall relationship has shown better positive correlations northwards to the 1000 mm annual isohyets, confirming that rainfall variability clearly explains a smaller part of the vegetation-cover dynamics southwards to 8° N, where the amount of rainfall is greater.
3. **NDVI/urban population growth relationship.** NDVI changes were studied in urban areas that have shown a significant increase in population over the period 1999–2008, in order to assess the impact of urbanization on vegetation.

The NDVI/ urban population relationship is based on 10-year (1999–2008) data, due to the shallow temporal SPOT-NDVI data at 1 km resolution. The results show good correlations for both moderately populated cities (8000–30 000 inhabitants) and those cities that have experienced a rapid increase in population (>30%). In contrast, for the most populated cities such as capitals of regions, the urban signal is strong and NDVI values, although weak, remained constant despite changes in population. In the sparsely populated towns (<8000), the urban signal is weaker, so vegetation evolution depends more on rainfall or land-use related factors south of the eighth latitude. Thus, NDVI studies at local scales are often biased by anthropogenic factors in and around urban areas and therefore such studies call for some caution. Our results showed that NDVI variations are less sensitive to the number of inhabitants than to the urban expansion caused by the population growth.

These preliminary findings enable us to better understand the determinants of vegetation-cover change in northern Cameroon and, more generally, in the Sahelian and Guinean areas. Therefore, they suffer from methodological constraints because the NDVI spatial resolution of 8 or 1 km cannot detect changes below the size of that pixel. Consequently, the reflected signal is the proportion of photosynthetic radiation absorbed by the dominant land cover. A pixel is thus likely to gather several types of land use, which are often the results of complex anthropogenic or bioclimatic processes. This limit arouses one's interest to take into account products with a higher resolution, such as the Landsat data set at a 30 m spatial resolution available since 1972.

It would also be highly interesting to explore the impact of other demographic factors such as the rural population growth or migrations, particularly the seasonal movements of livestock (transhumance) that play a significant role in land use (Boutrais 1995). Additionally, the organization of human activities in northern Cameroon is generally closely related to ethnic origins: Islamic people (Peulh, Arabs) are basically cattle raisers or nomadic pastoralists whereas the non-Muslim populations are essentially farmers. The association between agriculture and livestock is made for socio-economic, cultural or health reasons and is very often mired by numerous land conflicts (Blanc-Pammard and Cambrézy 1995). So, it would be interesting to include those parameters to understand the mechanisms that are associated with land use. Discussions are ongoing to include such hypotheses using higher resolution satellite products and possibly field surveys.

### **Acknowledgements**

We are grateful to the Global Inventory Monitoring and Modelling Systems (GIMMS) group and the Vlaamse Instelling voor Technologisch Onderzoek (VITO), which provided NDVI data, and the National Meteorology offices of Chad, the Central African Republic, Nigeria and Cameroon for providing rainfall data. Special thanks also go to J. B. Djoumessi for his invaluable assistance in the acquisition and analysis of demographic data.

The study was supported by the Global Change and Ecosystems programme (EU Integrated project: African Monsoon Multidisciplinary Analysis (AMMA) and the French component of AMMA). Based on a French initiative, AMMA was built by an international scientific group and is currently funded by a large number of agencies, especially from France, UK, USA and Africa. Detailed information on scientific coordination and funding is available on the AMMA International web site <http://www.amma-international.org>.

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