**IOSR Journal of Engineering (IOSRJEN)** **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 05, Issue 06 (June. 2015), ||V2|| PP 10-18

# Assessing the inter-relationship between vegetation productivity, rainfall, population and land cover over the Bani River Basin in Mali (West Africa)

Souleymane S. TRAORE[1†], Eric K. FORKUO[2], Pierre C.S. TRAORE[3], Tobias LANDMANN[4]

[1]*Dept. of Civil Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana*
[2]*Dept. of Geomatic Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana*
[3]*International Crop Research Institute for Semi Arid Tropics, ICRISAT, Bamako, Mali*
[4]*International Centre for Insect Physiology and Ecology, ICIPE, Nairobi, Kenya*

***†:** Contact Person: Souleymane S. TRAORE, sstraore@yahoo.fr*

**Abstract: -** This research investigated the inter-relationship between vegetation productivity, measured using the Normalized Difference Vegetation Index (NDVI), change in rainfall and population density in the context of perceived greening and degradation trends over the Bani River Basin (BRB). A 30-year (1982-2011), 8-km gridded rainfall data sets was produced by inverse distance weighted (IDW) interpolation of monthly data from 40 meteorological stations contained within the basin. Population data were retrieved from the National Population Statistic data base for 1987, 1997, and 2009. Rainfall and NDVI time-series trends were computed for the 30-year period and analysed. The relationship between rainfall and NDVI at pixel level, and NDVI and population densities was analysed using a Pearson correlation. Land Use and Land Cover (LULC) conversion rates were computed for the same period using multi-temporal 30-meter Landsat imagery; ground surveys for selected areas within the basin were used for further cross-verification. The computed NDVI trends revealed that, vegetation 'greening' trends are mostly associated with areas where natural vegetation is still well represented. Concurrent with increases in rainfall over the period analysed, this finding supports the hypothesis that re-greening observed in that area is the result of multi-decadal fluctuations in climate, rather than improved land management.

**Keywords:**- Vegetation productivity, Rainfall, Population, Inter-relationship, Mali.

## I. INTRODUCTION

Global monitoring of vegetation with remote sensing helps to understand the linkages between vegetation, climate, and anthropogenic activities. Changes in land use resulting from population growth have triggered a research interest to investigate the inter-relationships between trends in NDVI as a proxy for vegetation dynamics, population density and rainfall patterns. The West African (WA) region is a rainfall driven system in the semi-arid tropical region, where land cover change responds to most significant impact on the environment due to climatic change and variability as well as anthropogenic land use patterns [1]. Over the last 30-year major human and climate-induced disturbances have affected this area such as severe drought which started in early 1970s and cause a decrease of rainfall for about 15-30% [2], (ii) a high demographic growth with an annual growth rate of 3% and mining activities [3], especially. There were (i) Land cover change within the agro-ecological system in the region is largely a result of the interplay of the mentioned factors occurred. However, data and information on the relationship between these factors, their magnitudes and spatial and temporal dynamics are limited and largely not available.

Earth Observation provides a vital tool to capture the temporal dynamics of vegetation change in response to climate shifts, at spatial and temporal resolutions fine enough to capture the spatial heterogeneity [4]. Frequent satellite data products have been used to study time-series of ecological parameters related to vegetation dynamics [5]–[7]. Among many available remote sensing products, the Normalized Difference Vegetation Index (NDVI) has been frequently used in vegetation dynamics studies. NDVI is a well established indicator for vegetation growth and vigour [8]. It is calculated from the reflected solar radiation in the near-infrared (NIR) and red wavelengths. NDVI values range from -1 and 1; values are generally higher (0.5 or greater) for dense vegetation. NDVI data sets are frequently used to assess spatio-temporal changes in vegetation dynamics in response to changes in climate and anthropogenic activities [9][10].

The aim of this study is to examine recent trends in the vegetation productivity and the relationship of these trends with climatic factors, population density and rate of land conversion (i.e. land cover change) in the

Bani River Basin (BRB) from 1980s to 2013. Specifically this study focussed on the following aspects: (i) to assess long-term trend in NDVI and rainfall, (ii) to analyze the relationship between NDVI and rainfall we well as NDVI and population density, and (iii) to compute the rate of land use/land cover conversion in the study area.

## II. MATERIALS AND METHODS

### a. Study area

The Bani River is the most important tributary of the Niger River. It spans the North Guinean, Sudanian and Sahelian agro-ecological zones and is principally located in the Southern part of Mali from Latitudes 9˚17' N to 14˚18' N and Longitudes 4˚10' W to 8˚12' W (Figure 1). With a catchment area of around 130,000 km$^2$ at its confluence with the Niger at Sofara, it is one of the largest river systems in West Africa. It flows into the inner Niger Delta at Mopti and is a large contributor to flooding in the annual delta. The rainfall regime has undergone an abrupt change since the 1970s, along with a 16% decline in the quantity of rain that falls in the rainy season [11].

The distribution of vegetation in the basin depends largely on climate, and in particular on the amount of annual rainfall and the length of the rainy season, which varies along the climatic gradient. The availability and formation of vegetation is subject to climatic variations and human activities such as bush clearing and deforestation for agricultural or energy purposes, Smallholding farming is still the most common agricultural practice and livelihood activity in the region, except in the few cities such as Sikasso or Koutiala. Millet, sorghum and cotton are primarily cultivated, whilst bovines, goats and sheep are bred. Woody savannas and forests are largely being exploited for firewood and charcoal production. These activities have been intensifying over the last 40-year in line with the increasing population density [11]. Within the study area, four reference areas were identified and used for cross-verification of LULC processes.

### b. Data used

#### i. NDVI time-series data

Earth Observation based NDVI data are the most commonly used, and often represent the only available data source for the analysis of phenomena such as the vegetation dynamic in the study area [12]. This study used a 30-year (1982-2011) monthly NDVI time-series data created from original 15-day Global Monitoring and Mapping System (GIMMS) data sets from 1982 to 2000 and extended with the 10-day Satellite Pour l'Observation de la Terre Vegetation Sensor (SPOT-VGT) data from 2000 to 2011. Firstly, a monthly time-series for the two data sets was generated using a maximum value compositing (MCV) technique [13]. Secondly, the SPOT VGT time-series was resampled to match the coarser 8-km of GIMMS by spatial averaging [14]. Thirdly, a linear correlation was applied between the two data sets using their overlapping period and then a new 8-km time-series data for the 30-year period using GIMMS 1982-2000 and VGT 2001-2011 data following Zhang et *al* [15] was generated.

### ii. Rainfall time-series data

As previously mentioned, rainfall time-series data for the period 1982-2011 was used. These data sets were retrieved from gauge measurement using 40 gauges stations throughout the study area for the period 1982-2000. The data sets for the study period 2000-2011 were generated from the 3B43 product of the passive radar of Tropical Rainfall Measurement Mission (TRMM) using the equation developed by Almazroui [16]. For the purpose of this study, an 8-km grid resolution rainfall time-series data sets for the 30-year was produced using the inverse distance weighting (IDW) method to match NDVI pixels.

### iii. Population data

The demographic data sets consisted of cumulative population per district. These data were retrieved from the population census report of years 1987, 1997 and 2009 carried out by the National Institute of Statistics of Mali (INSAT). Population density is calculated using this formula:

$$Density = \frac{Total_{hts}}{Area_{km^2}} \qquad (1)$$

Where$Total_{hts}$ is the total population per administrative area (district in this study) and $Area_{km2}$ is the area of each administrative limit in square kilometer.

### c. Data Analysis

i. Mann-Kendall test

Vegetation and rainfall trend statistics were computed for every pixel using the Mann-Kendall (MK) non parametric test. MK was deemed suitable for this analysis since its validity does not require the data to be normally distributed. This test has been applied in many studies of time-series of remotely sensed data [17]. The

Mann-Kendall statistic (MK $\tau$) is calculated by evaluating all pair-wise combinations of values over time for each pixel and counting the number decreasing or increasing with time. The Mann-Kendall statistic is the relative frequency of decreases minus the relative frequency of increases and ranges from -1 to 1. The Mann-Kendall significance (MK $Z$) expresses the significance of a Mann-Kendall trend. The resulting significance image shows $Z$-scores that express certain levels of significance ($\alpha$): $Z = \pm 2.576$ refers to $\alpha = 0.01$, $Z = \pm 1.960$ refers to $\alpha = 0.05$ and $Z = \pm 1.645$ refers to $\alpha = 0.1$ [18]

ii. NDVI versus explanatory variables (rainfall, population density)

The spatio-temporal relationship between NDVI and rainfall was investigated. The Pearson correlation coefficient was calculated and mapped to illustrate the per-pixel temporal relationship between NDVI and rainfall during the months April to October which is the vegetation growing period. Likewise, mean NDVI for each district was extracted and then correlated with population density. The formula of Pearson correlation (r) is given in Equation (2) as:

$$r = \frac{\sum_{i=1}^{n}(X_i - \overline{X})(Y_i - \overline{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \overline{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i - \overline{Y})^2}} \quad (2)$$

Where $X_i$ and $Y_i$ are individual observations of variables X and Y, respectively. $\bar{X}$ and $\bar{Y}$ are the means of X and Y respectively.

iii. Mapping Land Cover Change

In order to find some explanations of perceive negative or positive trend, four (4) areas were selected along the Sudanian agro-ecological system to map LULC dynamics using multi-temporal 30-meter Landsat imagery. As can be seen in Table 1, three sets of Landsat images were acquired for each selected site for the following years: 1986; 1999/2000 and 2013. The Landsat imagery was geometrically corrected using first order polynomial. Image selection was always at the end of rainy season (October-December) to ensure minimal cloud contamination and better discrimination of different LULC types [19]. The corresponding images for each selected site (box) were extracted and classified using the Maximum Likelihood supervised classification method. The following classes were derived; croplands (CRP), Open woodlands (OW), closed woodlands (CW), shrublands (Shr), grassland (GRs) and bare lands (BL) .Water bodies and settlement were not mapped because they represent less than 1% of the total area. The most recent images were classified first and validated using ground truth data collected in January 2014. Ancillary data such as land use and land cover maps were also used to support the image classification. The maps were produces by Mali's Land Resource Inventory Project (PIRT, 1984) and Ligneous Resource Inventory Project (PIRL, 1990). The accuracy of the classification was assessed using the error matrix approach, which is one of the most common used for accuracy assessment [20]. A 5×5 majority filter was applied to each classification to recode isolated pixels classified into the majority class of the filter window.

Table 1: Acquisition dates and path and row identifiers of the Landsat images used

| Site # | Site size (km$^2$) | Path/Row | TM | ETM+ | L8 |
|---|---|---|---|---|---|
| Dieba | 102.3 | 199/52 | 14/11/1986 | 25/10/1999 | 8/11/2013 |
| Sibirila | 133.1 | | | | |
| Sukumba | 206.9 | 197/52 | 16/11/1986 | 17/11/2000 | 10/11/2013 |
| Nompossela | 201.0 | | | | |

Landsat TM/ETM+/L8: Thematic Mapper/Enhanced Thematic Mapper Plus/ Landsat 8 Operational Land Imager

## III. Results and Discussion

a. Vegetation and rainfall trend detection by Mann-Kendall test

The long-term trends in NDVI time-series were analysed to reveal the greening/browning of vegetation growth over the BRB study area for the past 30-year. The result showed increases in vegetation 'greenness' mostly occurring in the central part of the study area (Figure 2). As can be seen in Figure 2, decreases in NDVI 'greenness' were mostly localised in the North-Central and Southern sections of the catchment. The z-value estimator reveals that from a total of 2032 pixels for the whole catchment, 79 pixels showed significant negative trend and 651 pixels showed significant positive trend at α=0.01; 138 pixels showed significant negative trend and 866 pixels showed significant positive at α=0.05 while 180 pixels showed significant negative trend and 1016 pixels showed significant negative trend at α=0.1. The negative trend was located in area where the LULC is dominated by cropland (>70% of the area) and 'mosaic shrublands grassland', contrariwise the positive trend was mainly located in areas dominated by natural vegetation such as open savannah, woodland or mixed trees savannah cropland (Traore et *al* [10]).

The rainfall seasonal trend using the TRMM time-series data was obtained from the z-value estimator of the MK test (Figure 3). The rainfall showed a general increase however only a few areas showed a significant positive trend. Areas showing a significant positive trend were mostly found in the Eastern, Northern and the Southern section of the catchment. This result supports the observation of Begue *et al* [21] who, in the same area, observed a similar pattern in rainfall during the period 1982-2005.

b. NDVI response to rainfall variability

Figure 4 illustrates the relationship between NDVI and Rainfall over the whole basin. A Pearson correlation analysis was used to test the strength of the relation between rainfall, as an independent variable, and NDVI as being the dependant variable. Results showed a positive correlation between NDVI and rainfall, indicating the major contribution of rainfall in vegetation productivity. In most of the basin, the positive correlation indicated that productivity is mostly limited by rainfall even though only a few areas showed significant positive correlations. However, the low coefficient of correlation (r) can be explained by many factors, such as the time lag in the response of the vegetation to changes in rainfall, localized and seasonal rainfall distribution [22] or low signal-to-noise ratio [23] or a lack of sensitivity of the NDVI to variations in rainfall. The non significance of the Pearson correlation can be explained by the lack of sensitivity of NDVI to rainfall variations at certain stages. In the Southern part of the catchment, the negative correlation between rainfall and the NDVI could be due to signal saturation above certain biomass values due to a deficit of solar radiation used for photosynthesis because of cloud cover [23] or due to residual atmospheric contamination of the images used [24].

c. Population density as an explanatory of NDVI change

When assessing the impact of population on the surrounding environment, as in the case of urban growth, it is important to think in terms of spatial distribution of human population, not only absolute numbers. Naturally the total number of people living in a city, or region, has an impact on its surroundings, but it is the concentration of people in spatially localized areas that has the more significant environmental impacts both at the local and at the global scale This is why population density as the principal demographic characteristic of urban and suburban areas was used. The Pearson's product moment correlation coefficient between population density and mean NDVI at district level are shown in Table 2. The result showed a negative correlation (r= -0.25 to -0.45) between population densities and NDVI. This observation indicates that population density is not a major factor contributing towards vegetation change at a district level.

**Table 2: Correlation between NDVI and Population density at district level**

| | 1987 | | | | 1997 | | | | 2009 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | r | p | n | | r | p | n | | r | p | n |
| **NDVI vs. POP** | -0.45 | 0.07 | 16 | | -0.38 | 0.14 | 16 | | -0.25 | 0.33 | 16 |
| **Equation** | NDVI = 0.312 - 0.003*POP | | | | NDVI= 0.297 - 0.002*POP | | | NDVI = 0.294- 0.001*POP | | | |

POP: Population density, r: Pearson correlation coefficient, p: P-value of the correlation, n: sample size (here number of districts)

This result was similar to that found in Djoufack *et al* [25]. However, the relationship between NDVI and Population density in this study have been computed at the district spatial size and this coarse scale may hide much variability for the NDVI as well as for the population density. Conventionally population density is computed for an administrative area. In the study area the district is the second to last administrative area unit with densities known to be higher around urban areas than in rural districts. This result reflects the fact that NDVI variations are less sensitive to the number of inhabitants per district.

d. Land Use and Land Cover (LULC) Change as an explanatory of NDVI change

LULC is increasingly recognised as being an important driver of vegetation change [26]. In this study, multi-temporal 30-meter Landsat imagery was used to verify the mapped NDVI trends using independent approach within some selected sites in the BRB. These areas have been selected because of the availability of historical data on land cover and socio-economic data, which is used as 'training' data for the Landsat classification. Classification results for the selected years and sites are represented in Figures (4 and 5) for the selected sites. The areas showed two different patterns in land use and land cover dynamics. The *Dieba* and *Sibirila* sites presented a high LULC dynamic with a rate of land conversion while *Sukumba* and *Nompossela* sites presented a low rate of LULC dynamics.

i. *Dieba and Sibirila* sites

Figures 5a and 5b present the results of land use and land cover dynamics obtained for *Dieba* and *Sibirila* respectively for the period of study. Much of the land is still covered by natural vegetation (closed and open woodlands, grassland) providing more wood to surrounding cities. The most marked changes since 1986 have been the extension of cropland and the reduction some vegetation classes (e.g. closed woodland, open woodland). As seen in Figure 5-a, cropland increased from 13% (1358.30 ha) in 1986 to 17% (1713.03 ha) in 1999 and reach 21% (20.94 ha) of the area in 2013. It could be seen that open woodland also increased from 29% (2999.91 ha) to 47% (4770.85 ha) over the same period. Contrariwise, closed woodland decreased from 34% (3437.06 ha) in 1986 to 20% (20.31.24 ha) in 2013. Similarly, cropland increased from 7% (935.51 ha) to 18% (2446.92 ha) between 1986 and 2013 (Figure 5-b). During the same period, closed woodland decreased from 46% (6074.04 ha) to 36% (4740.57ha) and open woodland decreased from 39% (5169.74 ha) to 35% (4607.22 ha) of the total area.

ii. *Sukumba* and *Nompossela* sites

Figures 6a and 6b present the results of land use and land cover dynamics obtained for *Nompossela* and *Sukumba* respectively. The overall land cover changes from 1986 to 2013 showed a moderate change over the 27-year observation period, depending upon the land cover class. Again in *Nompossela*, cropland showed an increasing trend from 42% (8499.67 ha) in 1986 to 79% (14247.65 ha), whereas natural vegetation cover showed a general decreasing trend. Between 1986 and 2013, closed woodland decreased from 10% (1942.91ha) to 7% (1363.04 ha), open woodland decreased from 22% (4376.56 ha) to 9% (1777.55 ha), while shrublands decreased from 25% (4963.23 ha) to 12% (2418.46 ha). In *Sukumba*, cropland increased from 40% (8209.86 ha) in 1986, to 45% (9380.02 ha) in 2000 and reach 52% (10673.00 ha) in 2013, shrublands also increases from 7% (1398.22 ha) to 24% (4983.01ha) during the same period. Closed and open woodland showed a general decreasing trend during the same period. From 1986 to 2013, closed woodland decreased from 11% (2244.43 ha) to 3% (649.97 ha), open woodland decreased from 40% (6410.41 ha) to 10% (2150.35 ha) during the same period.

The results indicate a general decrease in area under vegetation cover and an increase in area agricultural land. These results are in conformity with Ruelland *et al* [27], who observed that the area under agriculture land increased in the same study region. The increase in area under cultivation is in response to the increased demand for land to produce more food for the increasing human population.

## IV. CONCLUSION

This research sought to provide some explanation of perceived greening/browning trend over the Bani River Basin using a long-term time-series of NDVI data. The trend analysis reveals an accumulation of areas showing a significant negative trend in the Northern and Southern part of the catchment and a significant positive trend in the central part. In contrast the rainfall pattern showed an increase for almost the whole area but only few portions showed a significant positive trend. The result also showed a good correlation between NDVI and rainfall indicating that rainfall is the major factor of vegetation growth in the area. Contrariwise as expected the results indicated negative correlation between mean NDVI and population densities. The study suggest to do more investigation using pixel level analysis between population densities and NDVI since the population is rather link to settlement than administrative boundary. The LULC assessed from selected subset showed a different pattern of change and at a glance confirm previous finding that most of the vegetation cover in WA depend on climate variability and most specially driven by rainfall variability. The findings of study provide a preliminary understanding of the determinant of vegetation cover change in the BRB. Therefore, further investigations, including more ground survey, are needed to better explain the perceive vegetation trend over the study area.

## ACKNOWLEDGMENT

The authors are grateful to WASCAL programme for fully funding this research and LABOSEP Sotuba for helping in field data collection.

Note: This paper was presented in the International Conference on Enhancing Resilience to Climate and Ecosystem Changes in Semi-arid Africa, CECAR-Africa that was held in Tamale in August 6-8, 2014 under the title: *Trends in NDVI and relationship with rainfall, population density and land use land cover change over the Bani River Basin*, and now submitted for publication in this journal after modifications.

## REFERENCES

[1]. S. M. Herrmann, A. Anyamba, and C. J. Tucker, “Exploring Relationships between Rainfall and Vegetation Dynamics in the Sahel Using Coarse Resolution Satellite Data,” 2005.

[2]. L. Barbe, “Rainfall Variability in West Africa during the Years 1950 – 90,” *J. Clim.*, pp. 187–202, 2002.

[3]. V. Schueler, T. Kuemmerle, and H. Schröder, “Impacts of surface gold mining on land use systems in Western Ghana,” *Ambio*, vol. 40, no. 5, pp. 528–539, 2011.

[4]. C. Li, J. Qi, L. Yang, S. Wang, W. Yang, G. Zhu, S. Zou, and F. Zhang, “Regional vegetation dynamics and its response to climate change—a case study in the Tao River Basin in Northwestern China,” *Environ. Res. Lett.*, vol. 9, no. 12, p. 125003, 2014.

[5]. A. Anyamba, J. Small, C. Tucker, and E. Pak, "Thirty-two Years of Sahelian Zone Growing Season Non-Stationary NDVI3g Patterns and Trends," *Remote Sens.*, vol. 6, no. 4, pp. 3101–3122, Apr. 2014.

[6]. S. M. Herrmann, A. Anyamba, and C. J. Tucker, "Recent trends in vegetation dynamics in the African Sahel and their relationship to climate," *Glob. Environ. Chang.*, vol. 15, pp. 394–404, 2005.

[7]. A. Anyamba and C. J. Tucker, "Analysis of Sahelian vegetation dynamics using NOAA-AVHRR NDVI data from 1981 – 2003," *J. Arid Environ.*, vol. 63, pp. 596–614, 2005.

[8]. M. Boschetti, F. Nutini, P. A. Brivio, E. Bartholomé, D. Stroppiana, and A. Hoscilo, "Identification of environmental anomaly hot spots in West Africa from time series of NDVI and rainfall," *ISPRS J. Photogramm. Remote Sens.*, vol. 78, pp. 26–40, Apr. 2013.

[9]. T. Landmann, M. Schramm, C. Huettich, and S. Dech, "MODIS-based change vector analysis for assessing wetland dynamics in Southern Africa," *Remote Sens. Lett.*, vol. 4, no. 2, pp. 104–113, Feb. 2013.

[10]. S. S. Traore, T. Landmann, E. K. Forkuo, and P. C. S. Traore, "Assessing Long-Term Trends In Vegetation Productivity Change Over the Bani River Basin in Mali (West Africa)," *J. Geogr. Earth Sci.*, vol. 2, no. 2, pp. 21–34, 2014.

[11]. D. Ruelland, A. Dezetter, and C. Puech, "Long-term monitoring of land cover changes based on Landsat imagery to improve hydrological modelling in West Africa," *Int. J. Remote Sens.*, vol. 29, no. 12, pp. 3533–3551, 2008.

[12]. Y. Z. Ibrahim, H. Balzter, J. Kaduk, and C. J. Tucker, "Land Degradation Assessment Using Residual Trend Analysis of GIMMS NDVI3g, Soil Moisture and Rainfall in Sub-Saharan West Africa from 1982 to 2012," *Remote Sens.*, vol. 7, pp. 5471–5494, 2015.

[13]. B. N. Holben, "International Journal of Remote Sensing Characteristics of maximum-value composite images from temporal AVHRR data," vol. 7, no. 11, pp. 1417–1434, 1986.

[14]. R. Fensholt, K. Rasmussen, T. Theis, and C. Mbow, "Evaluation of earth observation based long term vegetation trends — Intercomparing NDVI time series trend analysis consistency of Sahel from AVHRR GIMMS , Terra MODIS and SPOT VGT data," *Remote Sens. Environ.*, vol. 113, no. 9, pp. 1886–1898, 2009.

[15]. G. Zhang, Y. Zhang, J. Dong, and X. Xiao, "Green-up dates in the Tibetan Plateau have continuously advanced from 1982 to 2011.," *Proc. Natl. Acad. Sci. U. S. A.*, vol. 110, no. 11, pp. 4309–4314, Feb. 2013.

[16]. M. Almazroui, "Calibration of TRMM rainfall climatology over Saudi Arabia during 1998–2009," *Atmos. Res.*, vol. 99, no. 3–4, pp. 400–414, Mar. 2011.

[17]. K. M. de Beurs and G. M. Henebry, "Land surface phenology, climatic variation, and institutional change: Analyzing agricultural land cover change in Kazakhstan," *Remote Sens. Environ.*, vol. 89, no. 4, pp. 497–509, Feb. 2004.

[18]. A. Schucknecht, S. Erasmi, I. Niemeyer, and J. Matschullat, "Assessing vegetation variability and trends in north-eastern Brazil using AVHRR and MODIS NDVI time series," *Eur. J. Remote Sens.*, vol. 46, pp. 40–59, 2013.

[19]. D. Ruelland, A. Tribotte, and C. Puech, "Comparison of methods for LUCC monitoring over 50 years from aerial photographs and satellite images in a Sahelian catchment," *Int. J. Remote Sens.*, vol. 32, no. ISSN 0143–1161, pp. 37–41, 2011.

[20]. D. Lu and Q. Weng, "A survey of image classification methods and techniques for improving classification performance," *Int. J. Remote Sens.*, vol. 28, no. 5, pp. 823–870, Mar. 2007.

[21]. A. Begue, E. Vintrou, D. Ruelland, M. Claden, and N. Dessay, "Can a 25-year trend in Soudano-Sahelian vegetation dynamics be interpreted in terms of land use change ? A remote sensing approach," *Glob. Environ. Chang.*, vol. 21, pp. 413–420, 2011.

[22]. N. Martiny, P. Camberlin, Y. Richard, and N. Philippon, "Compared regimes of NDVI and rainfall in semi- arid regions of Africa," *Int. J. Remote Sens.*, vol. 27, no. 768605948, pp. 5201–5223, 2006.

[23]. P. Camberlin, N. Martiny, N. Philippon, and Y. Richard, "Determinants of the interannual relationships between remote sensed photosynthetic activity and rainfall in tropical Africa," *Remote Sens. Environ.*, vol. 106, pp. 199–216, 2007.

[24]. J. Li, J. Lewis, J. Rowland, G. Tappan, and L. L. Tieszen, "Evaluation of land performance in Senegal using multi-temporal NDVI and rainfall series," *J. Arid Environ.*, vol. 59, pp. 463–480, 2004.

[25]. V. Djoufack, B. Fontaine, N. Martiny, and M. Tsalefac, "Climatic and demographic determinants of vegetation cover in northern Cameroon," *Int. J. Remote Sens.*, vol. 33, no. 21, pp. 6904–6926, 2012.

[26]. Z. Zhang, J. Peterson, X. Zhu, and W. Wright, "Modelling Land Use and Land Cover Change in the Strzelecki Ranges," in *MODSIM07 International Congress on Modelling and Simulation , Christchurch, New Zealand*, 2007, pp. 1328–1334.

[27]. D. Ruelland, F. Levavasseur, and A. Tribotte, "Patterns and dynamics of land-cover changes since the 1960s over three experimental areas in Mali," *Ruelland, D., Levavasseur, F., Tribotte, A. (2009). Int. J. Appl. Earth Obs. Geoinf. Patterns Dyn. land-cover Chang. since 1960s over three Exp. areas Mali. doi10.1016/j.jag.2009.10.006,* 2009.

**Appendices:**

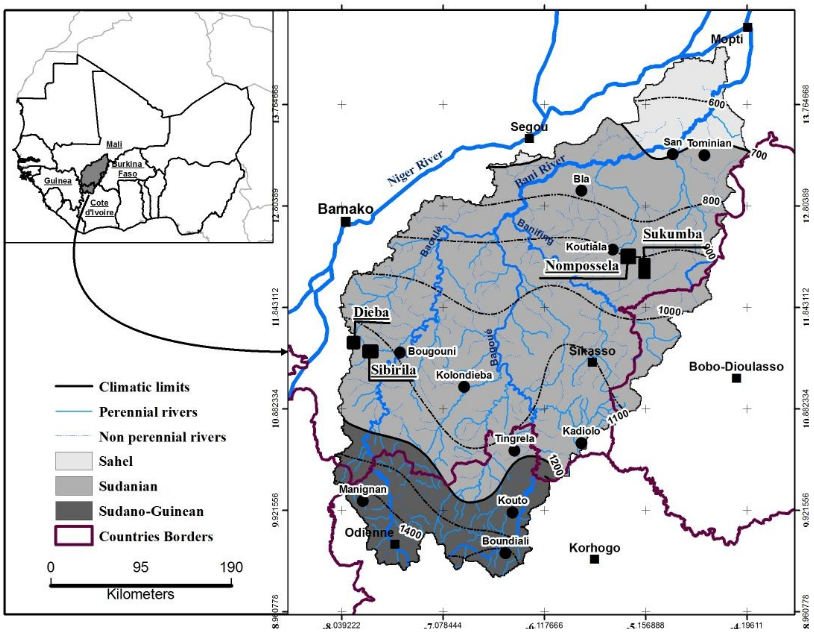


**Figure 1: Location of the study area and the selected sites for LULCC**

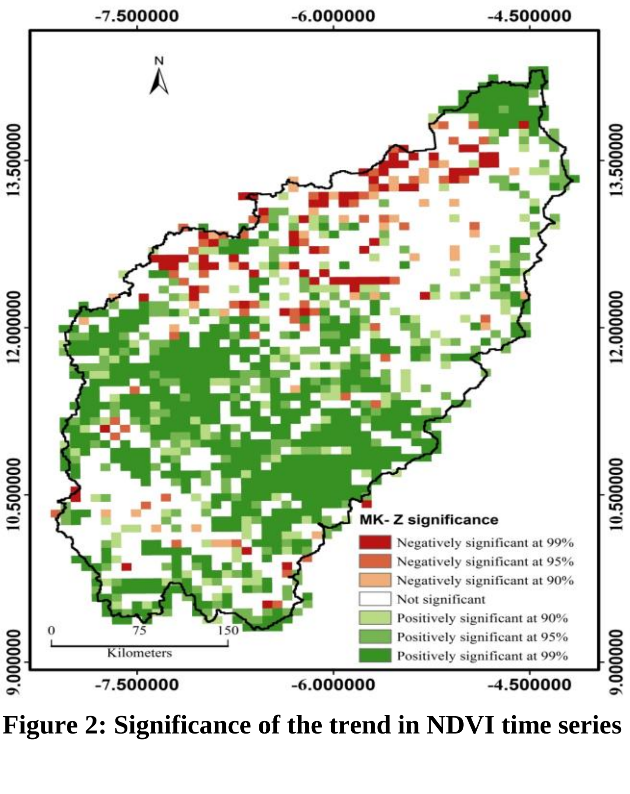


**Figure 2: Significance of the trend in NDVI time series**

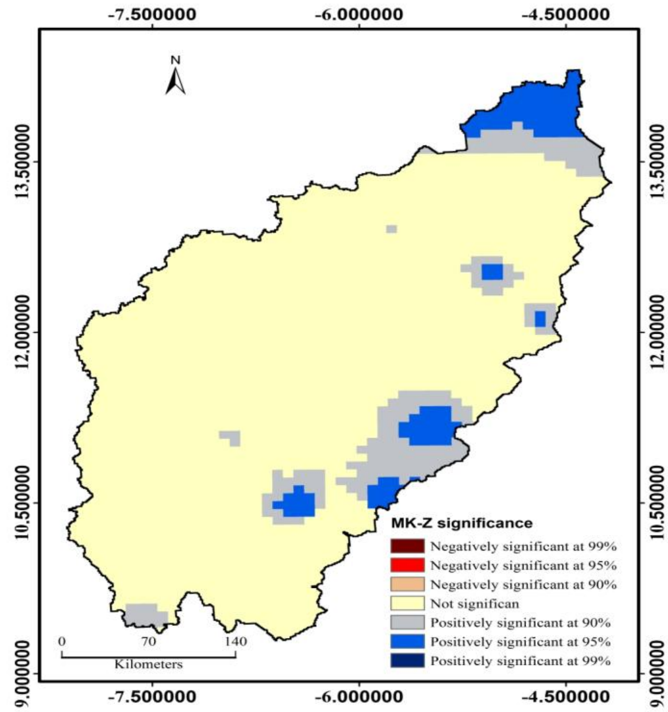


**Figure 3: Significance of the trend in rainfall time series**

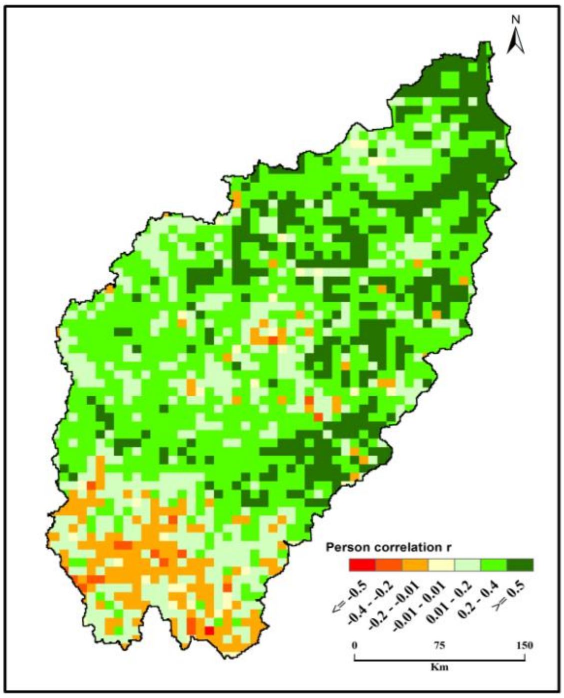


**Figure 4: Map showing the Pearson correlation coefficient between long-term NDVI and Rainfall for the growing season (April to October)**

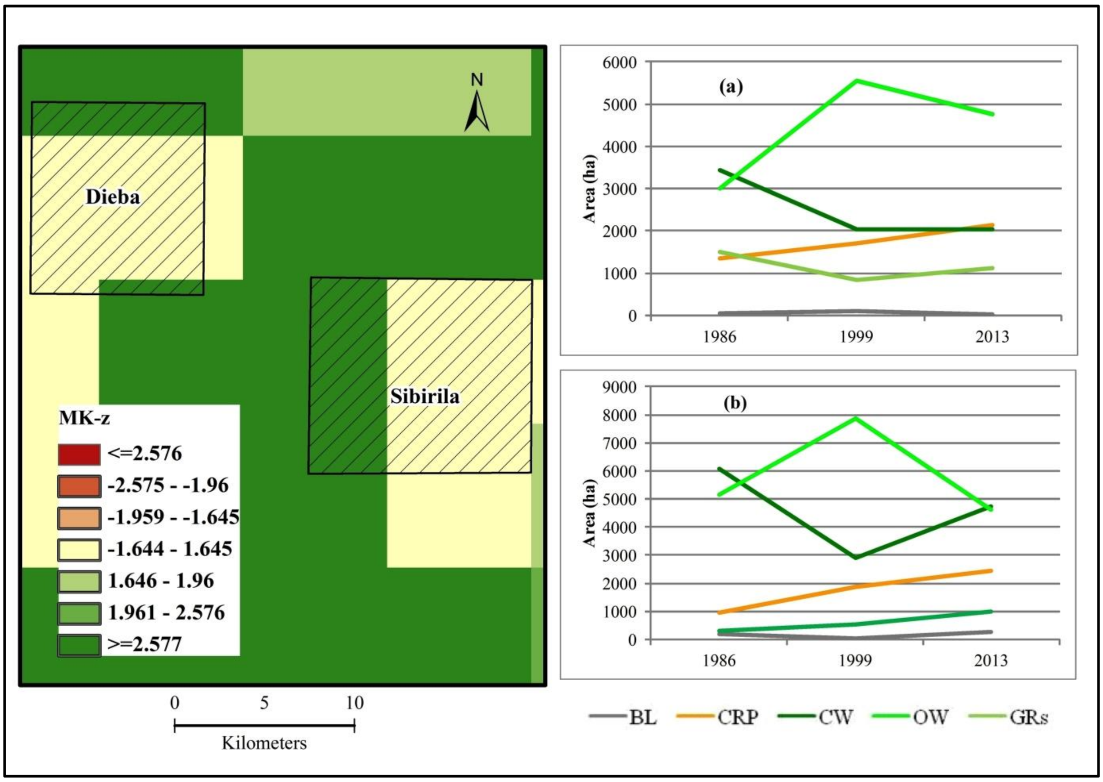


**Figure 5: Hot spot map and corresponding histograms of Land Use Land Cover Change for (a) Dieba and (b) Sibirila.**

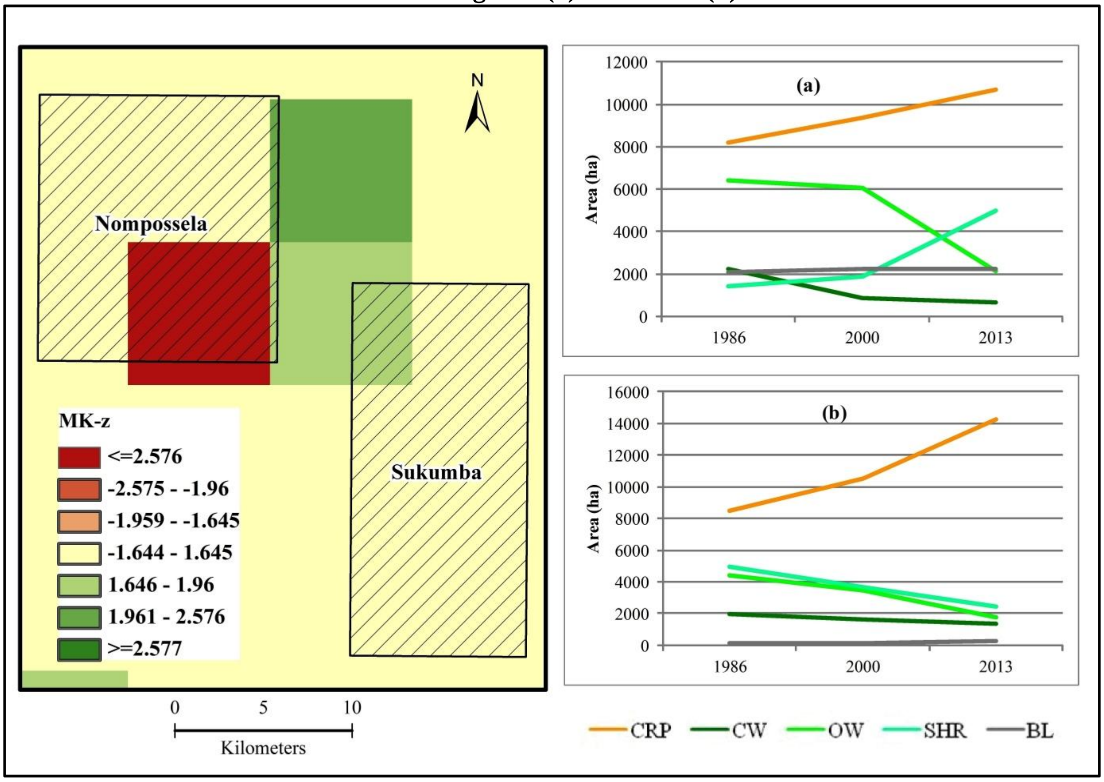


**Figure 6: Hot spot map and corresponding histograms of Land Use Land Cover Change for (a) Nompossela and (b) Sukumba**