International Scholars Journals

African Journal of Geography and Regional Planning ISSN 3627-8945 Vol. 3 (3), pp. 230-239, March, 2016. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

Metrics approach to historical context to land dilapidation and desertification in the Tillabéry landscape

Helmut K. Luther[1]*, Adolf Bach Karl[2], Johann O. Frank[3] and Marlene G. Anne[4]

[1]University of Eduardo Mondlane, Maputo, Mozambique.
[2]Geography Department, University of Tubingen, Germany.
[3]Information Technology, Eberswalde University for Sustainable Development, Germany.
[4]University of Giessen, Germany.

Accepted 5 January, 2016

This paper sought to investigate and monitor desertification processes in the Tillabéry landscape (Sahel). To achieve this aim, it employed a landscape metrics approach. The usefulness of landscape structure was investigated in the context of desertification. A set of indices was selected to investigate multi-temporal change in the Tillabéry landscape affected by desertification. The percentage of land indices showed a decrease in plateau vegetation. Water bodies increased between 1973 and 1989 but later recorded a 50% decrease. The indices further revealed an increase in bare soils. Shrubs increased between 1973 and 1989. This increase can be attributed to reforestation activities. The results further revealed that the Tillabéry landscape has a high number of patches and patch sizes are very small, indicating that the original landscape is increasingly being converted into bare areas and agricultural fields, thereby accentuating the issue of land degradation in the region.

Key words: Landscape metrics, desertification, remote sensing, Tillabéry landscape.

INTRODUCTION

Developments in agriculture, urbanisation and mining coupled with a decrease in rainfall events have led to losses in biodiversity and land degradation, resulting in desertification in the Sahel. Human activities and natural processes in the Sahel have permanently changed the ecosystem, with a resulting impact on the land cover and land use potential (Turner et al., 1994) and invariably the attractiveness of the landscape. Changes in the landscape of the region are apparent and can also be perceived directly. Such changes have been associated with a variety of factors ranging from biodiversity losses (Herrman et al., 2005); negative socio-cultural impacts; loss of soil quality; dramatic and unprecedented land use and land cover dynamics and lately, to global climate

*Corresponding author. E-mail: helmet.luther@gmail.com

change (Pielke et al., 2002).

Several conservation and development studies point to the fact that land degradation and desertification are a result of land use in the Sahel area, which is closely linked to demographic conditions (Forman et al., 2003; Amogu et al., 2010). However, lack of reliable data and survey information in some countries, have made the estimation of areas of intact desert and / or areas of land cover change and their relationship with economic indicators difficult to establish. Consequently, the extent and rate of desertification in the Sahel are less well known than in other regions of the world. The effects of desertification and land degradation in the Republic of Niger are so overwhelming in terms of the dramatic changes that the landscape has undergone within the last 40 years (Amogu et al., 2010; Mahamane et al., 2015). They span every aspect of human life in the area. It aggravates poverty conditions; decreases land productivity; increases the aridity of the climate; food insecurity and further induces diseases and malnutrition. It has led to the disappearance of certain herbaceous and ligneous plants used in traditional pharmacy (Mahamane, 2013). To compound it, it has led to an acute reduction in groundwater and merits urgent attention and action.

Government officials are aware of a degraded environment in the Sahel. This explains why planting of trees is a major part of the activities on the 3rd of every August (Independence Day of Niger) in Niger. However, there is inadequate research that quantifies environmental degradation processes in the Sahel Region of Niger. This research makes use of remote sensing data in the form of a time series analysis (1973, 1989, 2001 and 2007), which in effect gives the work an historical touch and provides quantitative information on the nature of environmental change and provides additional knowledge in understanding the phenomenon of land degradation in the Sahel region at large.

Quantifying fragmentation is important to identify land degradation (Schlesinger et al., 1990). The fragmentation processes are the division of continuous land cover into smaller patches which can be linked to three parts: direct removal, reduction in patch sizes and increasing isolation of the remaining patches (Nagendra et al. 2003). Nagendra et al. (2013) argued that landscape frag-mentation that emanates from the interaction between anthropogenic and natural disturbances has a negative influence on species dispersion, species mortality, decreases landscape connectivity, and reproduction rates.

Wu et al. (2000) reported that the evidence of fragmentation or degradation of local vegetation cover has been documented in many regions of the Sahel over the past decades. Much of this degradation is attributed to drought and climate change.

Notwithstanding, increases in human and livestock population have aggravated the problem of land degradation in Niger. This is a precursor to the desertification process and results from the investigated landscape metrics for the years 1973, 1989, 2001 and 2007 is depicting this trend in the Tillabéry landscape in Niger. As such, the fragmentation of the landscape due to desertification has had rigorous ecological consequences. This has contributed greatly to the loss in species diversity (due to the segregation of habitats and to the division of populations). It has also affected the quantity and quality of water in the area. The phenomenon of desertification in the Sahel is a complex one, which necessitated the formulation of one key objective in this research – to apply a landscape metrics approach in an historical context to understand land degradation and desertification in the Tillabéry landscape.

METHODS

Overview of the study area

This research was carried out in the Tillabéry region, West Niger, located at 13º 30´N and 15º 45´N latitude, 0º 10´E and 4º 20´E longitude. The region is composed of six districts, namely: Fillingue, Ouallam, Tera, Kollo, Say and Tillabéry covering an estimated area of 91,199 km² (7.19% of the total area of Niger). The study area is located as shown in Figure 1, within the departments of Tillabéry, Tera, and Ouallam and includes part of the wide valley of the Niger River. It covers approximately 21,328 km² (23.39% of the total area of the Tillabéry region) and the annual precipitation is between 250 mm and 400 mm. The soil in this area is dominated by loam soils and is very infertile and poses enormous challenges for agricultural production (Mahamane, 2015). This area was selected due to the fact that desertification is the most serious environmental problem in the area. A situation that is made more important when one considers the fact that the depth and breadth of River Niger is continuously on a decrease, an issue associated with the moving of sand.

Data and analysis

Landscape metrics

Primary data used in this work are: Landsat Multi-spectral Scanner (Landsat MSS), with a resolution of 60 m, acquired in September 1973, Landsat Thematic Mapper (Landsat TM) with a resolution of 30 m acquired in September 1989 alongside a Landsat Enhanced Thematic Mapper Plus (Landsat ETM +) with a resolution of 30m acquired in September 2001. Added to this is a Landsat TM image with a resolution of 30 m acquired in September 2007. The Landsat MSS image was resampled (Majority algorithm was selected) to a resolution of 30 m in order to standardize the resolution of the different images. These were the primary sources of data (Table 1). The month of September was selected because it is the peak period in the rainy season, which makes it possible to have a more accurate extent of the vegetation cover in the Tillabéry area. Also, only September was selected to avoid the influence of inter and intra-seasonal fluctuations in the Tillabéry landscape.

With regards to classification, a supervised classification technique was used in classifying all the images and maximum likelihood algorithm using Erdas imagine was selected in order to generate the land use and land cover of the landscape. The Landsat MSS image of 1973 had an accuracy assessment of 83%

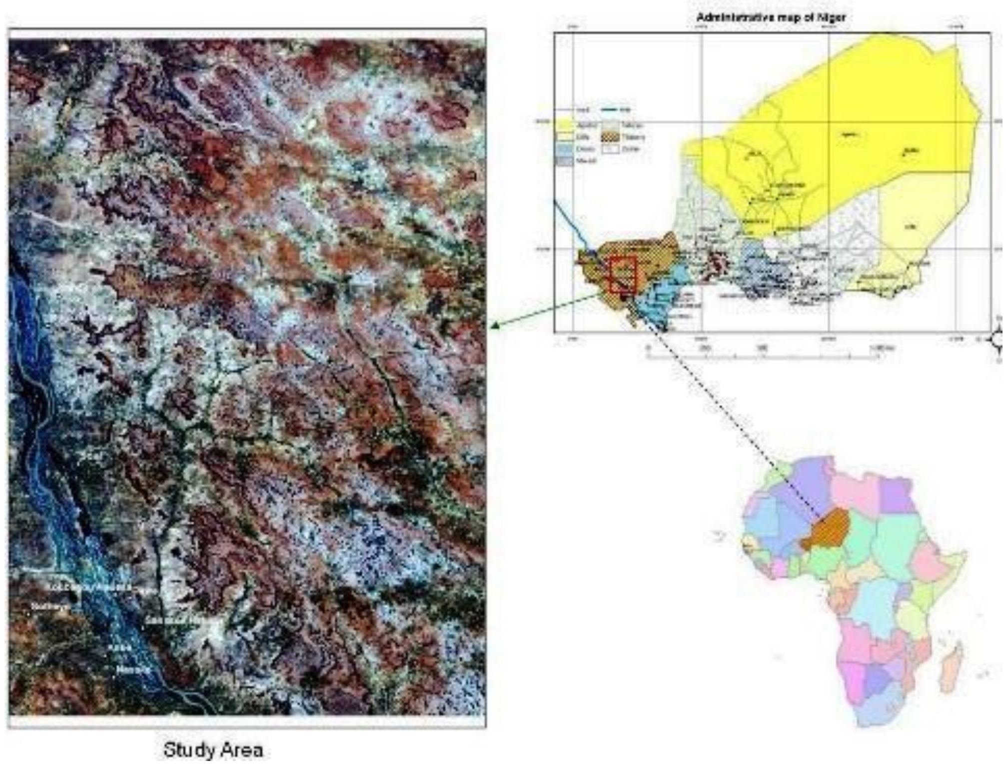

Figure 1. Map of Niger, its location in Africa and the study area.

Table 1. Data used.

Landsat	Date	Pixel (m)	Number of Bands	Scene identification
MSS	1973-09-30	60	4	EMP298r49_3m19730913
TM	1989-09-17	30	7	P193r50_4t890917
ETM+	2001-09-18	30	7	P193r050_7t20010918
TM	2007-09-27	30	7	LT51930502007270MPS00

and the Landsat TM image of 1989 had an accuracy assessment of 91%. The Landsat ETM+ image of 2001 and the Landsat TM image of 2007 both had accuracy assessments of 92% and 90% respectively. Landscape metrics were used to investigate landscape changes over time from 1973 to 2007. In order to calculate landscape metrics indices, land use and land cover maps were converted into Grid formats using ArcGIS 9.3.1 and integrated into the FRAGSTATS software (version 3.3).

Many indices have been used to describe landscape structure in order to investigate the effects of land degradation and desertification. McGarigal and Cushman (2002) and McGarigal and Cushman (2005) have provided a detailed definition of these indices. The selected metrics that appear in this work were chosen because of their ability to capture the changing pattern in spatio-temporal change with regards to the composition and configuration of landscape elements, which together offer a comprehensible overview of the changes in the landscape both at the class and at the landscape level. A square moving window analysis with a 60 m side length was chosen to create a continuous landscape metrics index for statistical analysis. The size of the moving window was chosen because the original images had a 30 m pixel size and a 60 m window will present a logical output (without exaggerating or minimizing) the composition and configuration of landscape elements.

Landscape composition

The indices selected for describing landscape composition at the class level, which are suitable to capture desertification were: Percentage of Land (%LAND) and landscape level Number of Patches (NP), Total Area (TA), Patch Density (PD) and Largest Patch Index (LPI).

Landscape configuration

Landscape configuration at class and landscape level was analysed by means of the following landscape metrics: Landscape Shape Index (LSI), Interspersion and Juxtaposition Index (IJI) and Mean Patch Fractal Dimension Index (MPFD).

The degree of fragmentation

This index quantifies landscape fragmentation; it is based on the probability that two points chosen randomly in a region would be connected (Jaeger et al. 2007). In a bid to express the physical connectivity of the patches, as well as to capture the spatial pattern of the degree of fragmentation due to desertification at the landscape level, the inverse mesh index was developed.

Fragmentation index = $1/\left(\frac{\sum_{j=1}^{n} a_{ij}^{2}}{A}\right)\left(\frac{1}{10,000}\right)$

Where:

n= number of patches; Ai a_{ij}= *area (m²) of the patch ij*; A A = total area of the study area investigated which has been fragmented into n patches.

The mesh index was selected because it gives information about the spatial connectivity of the landscape. Jaeger et al. (2007) reported that the mesh index is suitable for analyzing the degree of fragmentation of landscape and has already been used for case studies in Baden-Wurttemberg, Bavaria, Hessen, Thuringia, Saxony, Schleswig-Holstein and South Tyrol. However, an inverse of this index is capable of capturing the degree of spatial fragmentation in the landscape under investigation based on the land use and land cover maps.

RESULTS AND DISCUSSION

Landscape composition metrics

Area metrics

The percent of land shows a decrease in plateau vegetation (54.78% in 1973, 20.11% in 1989, 18.07% in 2001 and 11.87% in 2007). This situation can be attributed to over grazing and an increasing trend towards arid conditions. Water on its part increased from 2.79 % in 1973 to 5.98 % in 1989. This could be explained by the fact that the preceding years (1970-1972) witnessed very low rainfall events (JISAO, 2013). However, water volume plummeted again by 50% between 1989 and 2001 (5.98% in 1989 and 2.34% in 2001) and remained the same between 2001 and 2007. This behavioural pattern of water availability is greatly tied to rainfall events, which is also highly subjected to influences from the Inter-tropical Convergence Zone (ITCZ).

This index also shows an overall increase in bare soils throughout the study period. Shrubs increased from 22.78% in 1973 to 29.34% in 1989 and decreased slightly by 2001. This pattern could be accounted for by reforestation activities and political stability and also because the period 1986 – 1988 were wetter years, providing favourable conditions for the establishment and growth of shrubs, which was easily captured by the 1989 image. Nevertheless, the percentage of shrubs on the landscape greatly decreased from 25% in 2001 to 15% in 2007 (Figure 2).

This can be explained by two factors; firstly, there was an increase in human population and a corresponding increase in the need for fuel wood as a source of energy to meet up with the energy needs of an increasing population (Charney, 1975 cited in Stephen, 2014). Secondly, there was a reported increase in overgrazing by browsing animals. This saw the percentage of bare areas increased from 10% in 2001 to 33% in 2007, resulting to land degradation and desertification in the study area.

Patch density, patch size and variability metrics

Knowledge on landscape fragmentation has considerable potentials to improve environmental management in the study area. PD, NP and LPI were calculated at the landscape level. The NP in the landscape stood at 33,678 in 1973. This figure increased significantly to 148,298 in 1989. In 2001, there was a further increase in the NP to 189.013 before drastically falling to 54,721 in 2007. The steady increase in the NP between 1973 to 2001 points to an increase in landscape fragmentation and an increasing trend towards desertification. The drop in the NP in 2007 indicates the amalgamation of many small bare areas producing larger clumps of bare areas, thereby accentuating the process of desertification in the study area. Pertaining to the PD, it was 11 in 1973. It then experienced an exponential increase to 47 in 1989. It further increased again in 2001 to 61 before falling again to 18 in 2007. This behavioural pattern of the PD shows an increase in landscape elements over time (between 1973 to 2001). The later decrease in PD in 2007 can be attributed to an amalgamation of patches, especially the class bare areas. The LPI on its part was 36 in 1973 then plummeted to 8 in 1989. It later experienced a major increase in 2001 to 20 and reduced to 10 in 2007. This indicates a trend in disintegration of the major land cover classes overtime.

Landscape configuration metrics

Shape metrics and fractal dimension

LSI is an index to measure landscape complexity. The evolution of the LSI at the class level is proof that the majority of elements in the landscape increased from 1973 to 2001. This indicates that all patches became increasingly disaggregated and fragmented as a result of desertification. The LSI of all patches decreased continuously from 2001 to 2007, indicating that the fragmented patches were being aggregated together

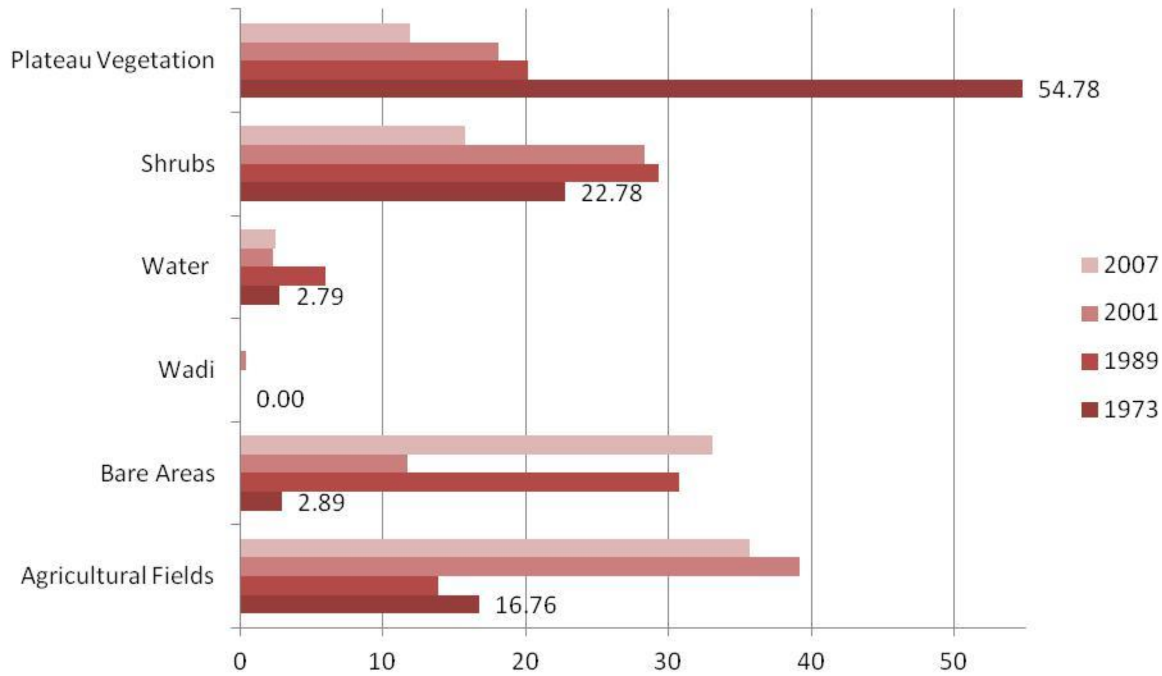

Figure 2. The percentage of land index at class level from 1973 to 2007.

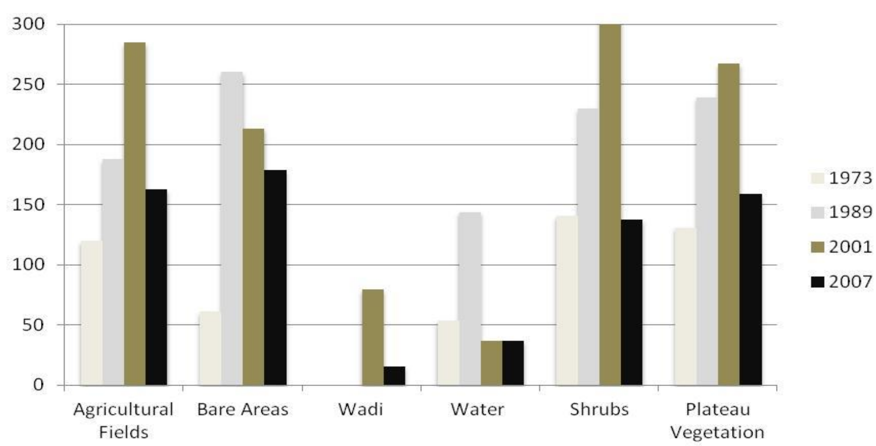

Figure 3a. Evolution of Landscape Shape Index (LSI) at the class level (1973-2007).

under a dominant land cover class (in this case, bare soil) on the landscape. The spatial distribution of LSI for the study area is presented in Figure 3a. The figure indicates that the higher the LSI, the more fragmented the landscape is.

Figure 3b shows the spatial distribution of the MPFD during the study period. The blue patches represent a departure from a Euclidian geometry (more complex in term of the shape). Patches with red represent a reduced shape complexity.

Interspersion and juxtaposition index (IJI)

The goal of this part is to investigate the degree of clumping of various land cover classes in the Tillabéry landscape. The degree of clumping deals with two spatial aspects (dispersion and interspersion). It is expressed in percentages and its value approaches zero when patch types are clumped (the distribution of unique patch adjacencies becomes uneven) and approaches 100 when all patch types are equally adjacent to all other patch

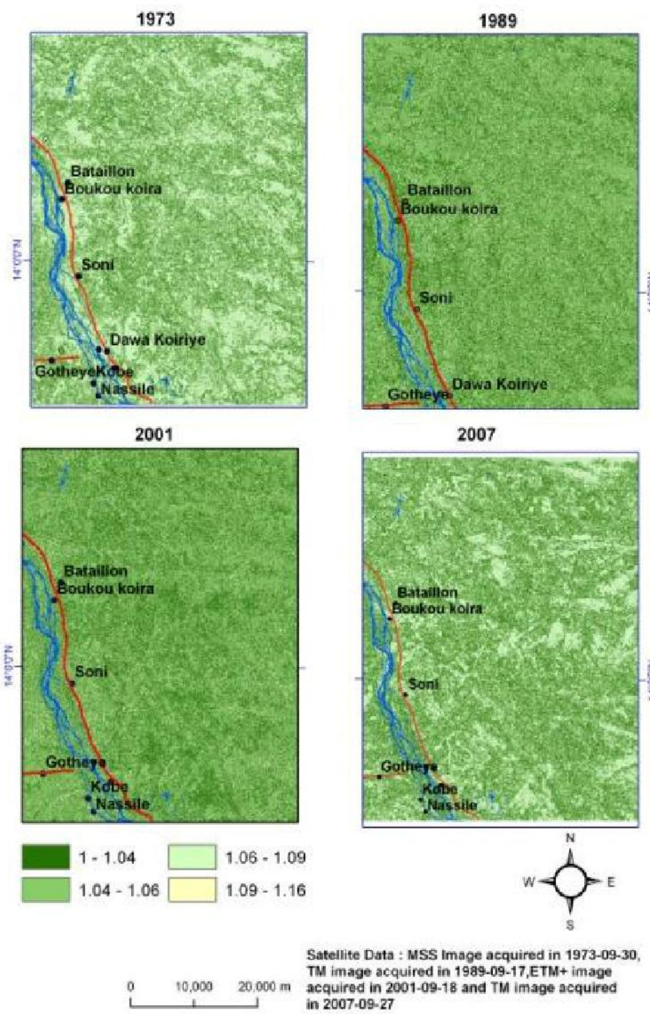

Figure 3b. Spatial distribution of Mean Patch Fractal Dimension Index.

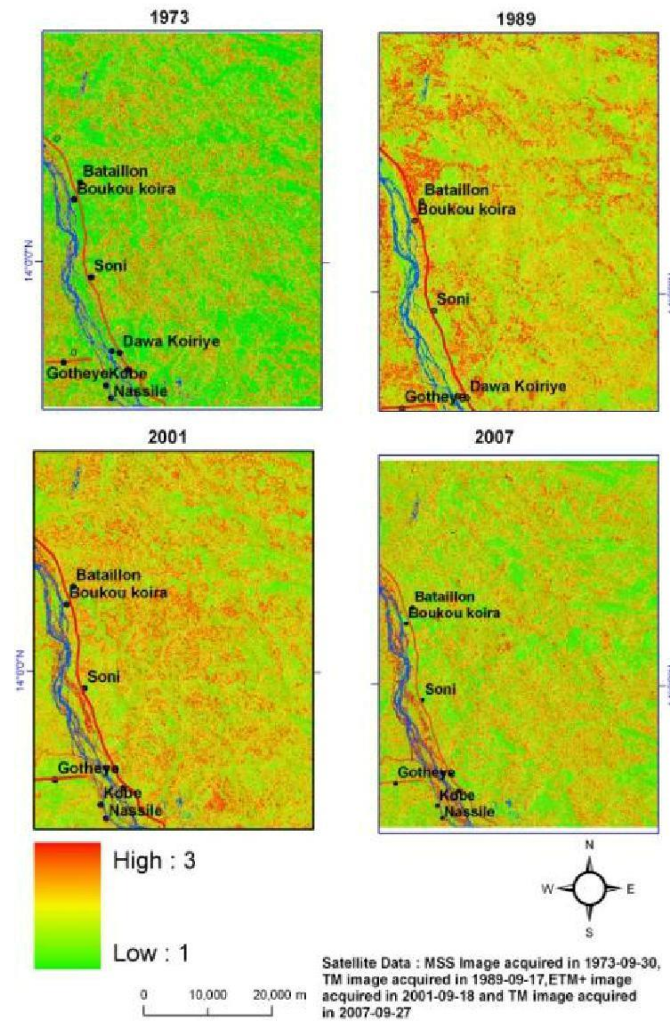

Figure 3c. Spatial distribution of Landscape Shape Index for study area.

types. The index is independent of the number, size or dispersion of landscape elements.

In the years 1973 – 2001, the IJI for all the landscape elements was high for all the classes compared to the period 2001 – 2007 when it decreased (Figure 4a). The spatial distributions of the changes in the IJI are further shown in Figure 4b. This is an indication that the different land cover types became poorly interspersed with time reflecting that they are dependent on water availability on the landscape. A focus on plateau vegetation show that the IJI is high in 2001 implying that the vegetation is adjacent to almost all other elements. This is a clear pointer to the fact that by 2001 the vegetation had been highly fragmented and large single patches were becoming a rare occurrence on the landscape, thereby depicting an increasing trend towards land degradation and desertification in the Tillabéry landscape. In 1989, a low value is observed with agricultural areas. This conforms to the findings of (Lal, 2001) that desertification has a negative impact on soil nutrient storage, which inadvertently leads to emission of carbon from the soil to the atmosphere.

Monitoring landscape fragmentation at landscape level (An environmental indicator)

Landscape fragmentation is considered as a key menace to biodiversity and fosters desertification in the study area. It decreases the area suitable for grasses (*Aristidastipoides, Schoenefeldiagracilis* and *Cenchrusbiflorus)*, and wood species such as *Acacia tortilis* (FAO 1986). Animal species such as *Gazelladama, Gazellaleptoceros* and *Lycaonpictus* have also become endangered (IUCN, 2004). It further manipulates interactions among species (Braschler, Lampel and Baur,

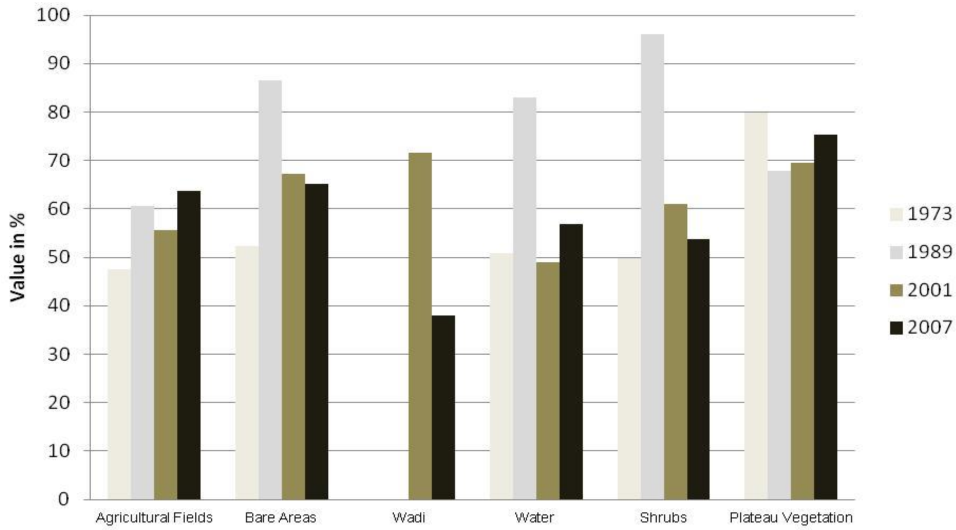

Figure 4a. Evolution of Interspersion and Juxtaposition (IJI) at the class level (1973-2007).

2003). The results of fragmentation analysis at landscape level are shown in Figure 5. It indicates that the patches are fairly stable but highly connected. From a visual interpretation of the degree of landscape fragmentation from the images for 1973, 1989, 2001 and 2007 it is clear that the landscape was comparatively stable in 1973 as it recorded a fragmentation rate of 0.9 as opposed to 2001 when the fragmentation rate increased to 2.15. As a more stable land cover class (bare soil) became more dominant on the landscape, the fragmentation rate further decreased to 1.20 in 2007.

From the images, it is also clear that the spatial distribution of the rate of fragmentation is randomly distributed and shows a dominance of bare areas over the other land cover classes. Areas that are severely fragmented also demonstrate low vegetation cover due to the absence of water breaks and a resulting high level of surface run-off and an associated high level of soil erosion (Wu et al. 2000). Areas that depicted low fragmentation values correspond to the land cover class called “resistance to deserts” such as river and vegetation.

The analysis evidently exposes the state of landscape fragmentation over time. In 1973 the study area shows a lower degree of fragmentation value, compared to 1989, 2001 and 2007. The spatial distribution of the degree of fragmentation indicates that the fragmented areas increased considerably between 1989 and 2001 especially around River Niger and at the centre of the study area (Figure 5a to d).

Conclusion

This study explored the applicability of a landscape metrics approach in analysing land degradation and desertification in the Tillabéry area (Niger). Prior to this study, most research topics in desertification have focused on the Medalus method, which focuses on climate, soils, vegetation, anthropogenic and geomorphological factors without any allusion to historical changes on the landscape as a parameter to capture and understand trends in land degradation and desertification. Applying a landscape metrics approach provided a useful technique for quantifying and qualifying the spatial location, the structural changes and at the same time illustrating the spatio-temporal dynamics of a landscape in an area prone to desertification. By combining previously applied methodology in investigating desertification and at the same time providing additional information for desertification studies in the form of a time series analysis, makes this approach novel.

The fundamental result of the study shows that desertification processes intensified between 2001-2007 and the landscape has been severely degraded. This makes it imperative for NGO's involved in landscape sustainability and the Niger government to step up efforts to combat desertification and land degradation processes in the Tillabéry landscape. As Sendzimir et al. (2011) and Larwanou and Saadou (2011) have demonstrated, prospects of achieving positive results are high especially when one takes into consideration the re-greening of the Tahoua and Maradi regions.

Conflict of Interests

The authors have not declared any conflict of interests.

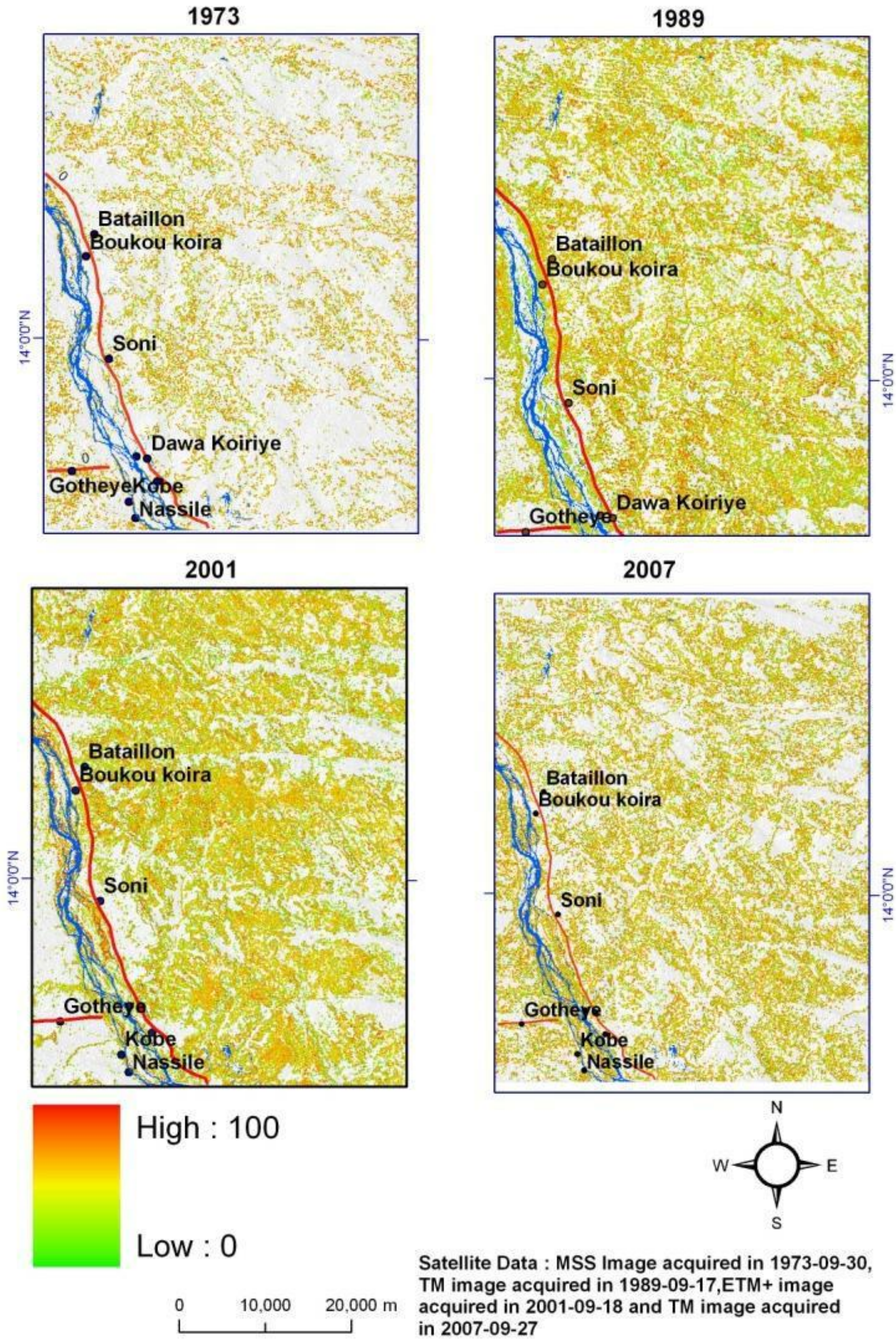

Figure 4b. Spatial distribution of Interspersion and Juxtaposition (IJI) at the landscape level (1973-2007).

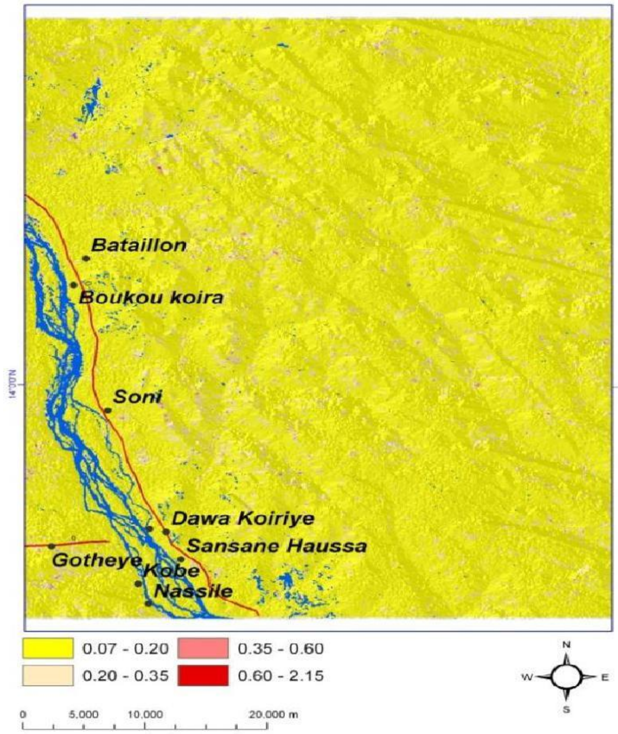

Figure 5a. Degree of landscape fragmentation rate from Landsat MSS image acquired in 1973-09-30.

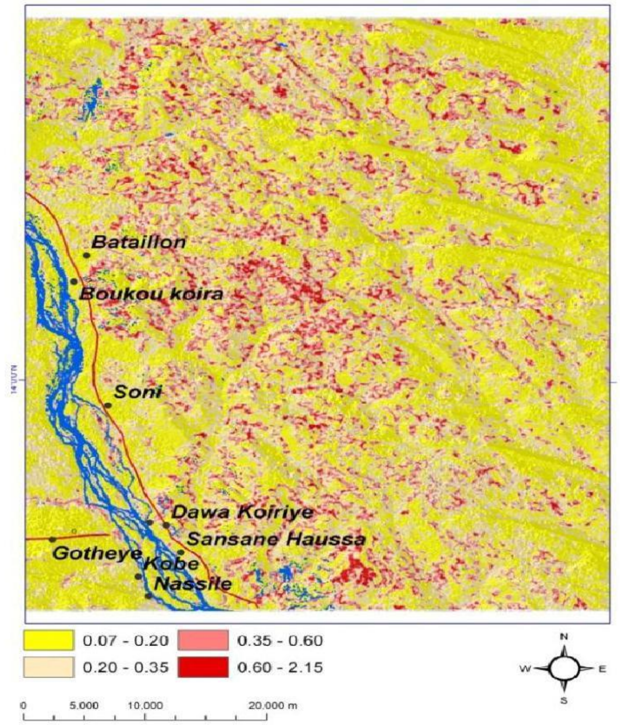

Figure 5c. Degree of landscape fragmentation rate from Landsat ETM +image acquired in 2001-09-18.

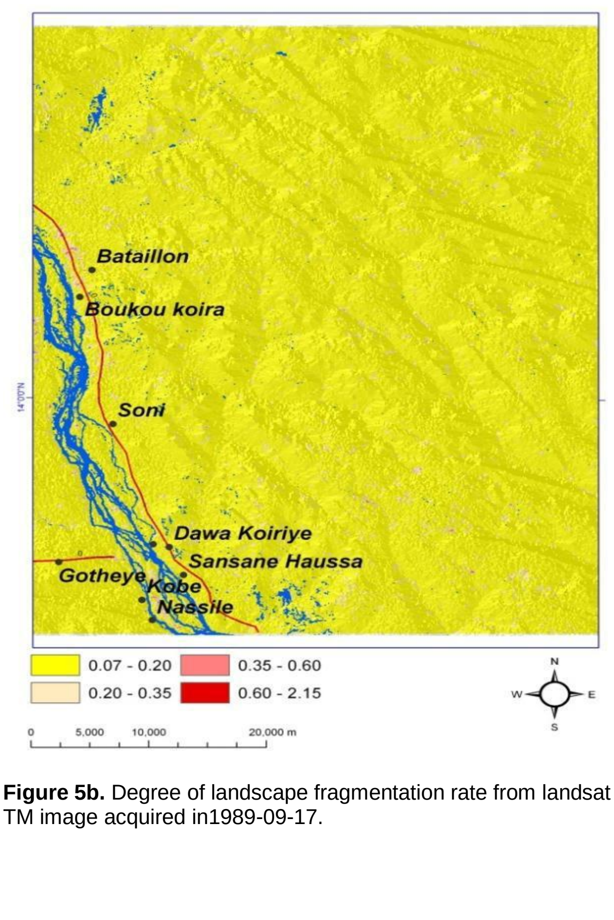

Figure 5b. Degree of landscape fragmentation rate from landsat TM image acquired in1989-09-17.

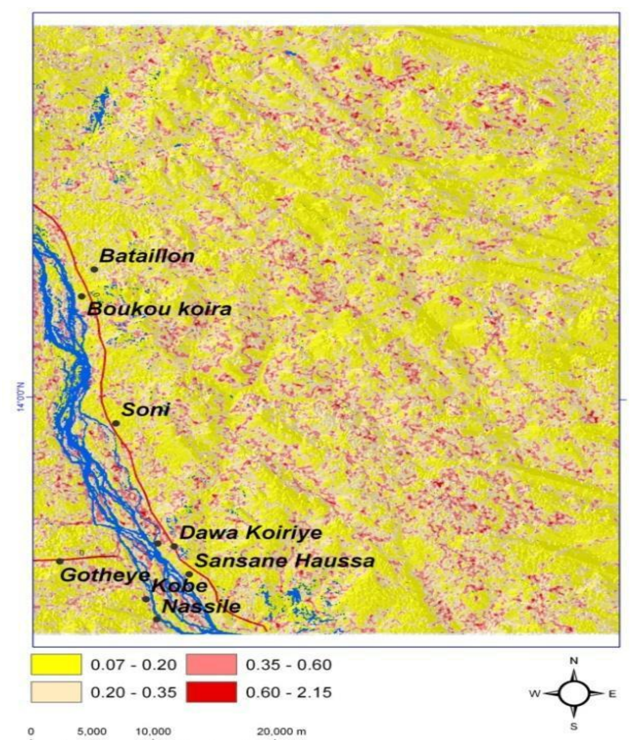

Figure 5d. Degree of landscape fragmentation rate from Landsat TM image acquired in 2007-09-27.

ACKNOWLEDGMENTS

This study was supported by the Friedrich Ebert Foundation.

REFERENCES

Amogu O, Descroix L, Yéro S, Breton L, Mamadou I, Ali A, Beleudy P (2010). Increasing River Flows in the Sahel? J. Water 2(2):170-199.

Braschler B, Lampel G,Baur B (2003). Experimental small-scale grassland fragmentation alters aphid population dynamics. Oikos 100:581-590.

Food and Agricultural Organization (FAO) (1986). Databook on Endangered Tree and Shrub Species and Provenances. FAO Forestry Paper 77 p.

Forman T, Sperling D, Bissonette A, Clevenger P, Cutshall D, Dale H, Winter C (2003). Road Ecology: Science and Solutions. Washington DC: Island Press.

Herrman M, Anyamba A, Tucker J (2005). Recent trends in vegetation dynamics in the African Sahel and their relationship to climate. Glob. Environ. Change 15(4):394-404.

International Union for the Conservation of Nature (IUCN) (2004). Red List of Threatened Species.

Jaeger A, Bertiller G, Schwick R, Muller C, Steinmeier K, Ewald C, Ghazoul J (2007). Implementing Landscape Fragmentation as an Indicator in the Swiss Monitoring System of Sustainable Development (MONET). J. Environ. Manage. 88(4):737-51.

Joint Institute for the Study of the Atmosphere and Ocean (JISAO) (2013). Sahel Precipitation Index, http://jisao.washington.edu/data/sahel/. Accessed 06/03/2014.

Lal R (2001). Potential of desertification control to sequester carbon and mitigate the greenhouse effect. Climat. Change 15:35-72.

Larwanou M, Saadou M (2011). The role of human interventions in the tree dynamics and environmental rehabilitations in the Sahel zone of Niger. J. Arid Environ.75:194-200.

Mahamane M (2013). Application of Remote Sensing and Geographic Information System techniques for desertification and land degradation monitoring and assessment in the Tillabéry landscape (Niger). Tuebingen University August-2013.

Mahamane M (2015). Assessing Soil Erosion Risk in the Tillabery landscape (Niger). Afr. J. Environ. Sci. Technol. 9(3):176-191.

Mahamane M, Hochschild V, Schultz A, Kuma J (2015). Monitoring Desertification in theTillabéryLandscape (Sahel Region) using Change Detection Methods and Land scape Metrics. Int. J. Appl. Res. 1(10):315-321.

McGarigal K, Cushman A (2005). The gradient concept of landscape structure. This is a chapter. In J. A. Wiens and M. R. Moss (Eds.), Issues and Perspectives in Landscape Ecology Cambridge: Cambridge University Press. pp. 112-119.

McGarigal K, Cushman A, Neel C, Ene E (2002). FRAGSTATS: Spatial Pattern Analysis Program for Categorical Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. Available at the following web site http://www.umass.edu/landeco/research/fragstats/fragstats.html.

Nagendra H, Southworth J, Turker C (2003). Accessibility as a determinant of landscape transformation in western Honduras: Linking pattern and process. Landsc. Ecol. 18(2):294-306.

Nagendra H, Lucas R, HonradoP, JongmanG, Tarantino C, Adamo M, Mairota P (2013). Remote sensing for conservation monitoring: Assessing protected areas, habitat extent, habitat condition, species diversity and threats. Ecol. Indic. 33:45-59.

Pielke A, Marland G, Betts A, Chase N, Eastman L, Niles O, Running W (2002). The influence of land-use change and landscape dynamics on the climate system: Relevance to climate-change policy beyond the radiative effect of greenhouse gases. Phil. Trans. R. Soc. Lond. A. 360: 1705-1719.

Schlesinger H, Reynolds J, Cunninigham L, Huenneke F, Jarrell M, Virginia A, Whitford G (1990). Biological feedbacks in global desertification. Sci. 247:1043-1048.

Sendzimir J, Reij P, Magnuszewski P (2011). Rebuilding resilience in the Sahel: regreening in the Maradi and Zinder regions of Niger. Ecol. Soc. 16(3):1.

Stephen J (2014). Land degradation and agriculture in the Sahel of Africa: causes, impacts and recommendations. J. Agric. Sci. Appl. 3(3):67-73.

Turner F, Trexler C, Miller L, Tayer E (1994). Temporal and spatial dynamics of larval and juvenile fish abundance in a temperate flood-plain river. Copeia 1:174-183.

Wu B, Thurow L, Whisenant G (2000). Fragmentation and changes in hydrologic function of tiger bush landscapes, south-west Niger. J. Ecol. 88:790-800.