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MODIS NDVI trends and fractional land cover change for improved assessments of vegetation degradation in Burkina Faso, West Africa

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ABSTRACT

Reduction of natural vegetation cover in the savannah of West Africa constitutes a pressing environmental concern that may lead to soil degradation. With the aim to assess the degradation of natural vegetation in the savannah of Burkina Faso, this study combined NDVI trends and fractional Land Use/Cover Change (LULCC). Fractional LULCC maps, derived from the aggregation of a 30 m Landsat LULCC map (1999–2011) to 250 m resolution of MODIS, were used to assess natural vegetation conversions in the small-scale spatial patterns of savannah landscapes. Mann-Kendall's monotonic trend test was applied to 250 m MODIS NDVI time series (2000–2011) to assess modifications of natural vegetation cover. Finally, the Spearman's correlation was employed to determine the relationship of natural vegetation degradation with environmental factors. The study revealed a vast conversion of natural vegetation into agriculture (15.9%) and non-vegetated area (1.8%) between 1999 and 2011. Significant decreasing NDVI trends ($p < .05$) indicated negative modifications of natural vegetation (2000–2011 period) occurring along the protected areas borders and in fragmented landscapes characterized by disruption of continuity in natural vegetation. Spearman's correlation showed that accessibility, climatic and topographic conditions favored natural vegetation degradation. The results can enable the development of efficient land degradation policies.

1. Introduction

Natural vegetation cover is a key component of the terrestrial ecosystem (Peng et al., 2015). The degradation of natural vegetation cover, seen as reduction in biomass or declining in the natural vegetative ground cover, constitutes a pressing environmental concern that threats biodiversity and may lead to soil degradation (Yengoh et al., 2015). Assessing the degradation of natural vegetation is therefore essential for regions like West Africa where natural vegetation is confronted with high anthropogenic pressure and extreme climate variations (IPCC, 2007). Besides, in this part of the world, reliable results on vegetation dynamics are crucial for the development of efficient forests safeguarding policies.

Studies have been assessing natural vegetation degradation based on land use/cover change (LULCC) analysis (Houessou et al., 2013; Ouedraogo et al., 2010). The technique of post-classification comparison of land use/cover (LULC) was often used to determine areas of natural vegetation conversions (Xu et al., 2010; Duadze, 2004). Conversions, seen as abrupt changes (Xu et al., 2016), refer to the complete replacement of natural vegetation cover by another type of land cover (Lambin et al., 2003), for example a change from natural vegetation cover to agriculture or to a non-vegetated cover type (e.g. bare surface), and they are often caused by anthropogenic deforestation (e.g. cropland expansion, wood extraction, change in urban extent). Several other authors have focused on vegetation productivity trends to determine hotspots of degradation (Xu et al., 2016; Kaptué et al., 2015; Harris et al., 2014; Forkel et al., 2013; Peng et al., 2012a,b; Lanfredi et al., 2004). This kind of analysis, which usually deals with time series of vegetation indices like NDVI (Normalized Difference Vegetation Index), is suitable to capture modifications occurring gradually and continually (Xu et al., 2016) in vegetation cover. According to Lambin et al. (2003), modifications of vegetation indicate more subtle changes (reduction or densification of vegetation cover) that affect the character of vegetation cover without changing its overall classification, and they are often related to changes of plant coverage or species composition (Forkel et al., 2013; De Jong et al., 2011). However, very few studies,

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such as Wright et al. (2012), combined LULCC and vegetation productivity trends to monitor natural vegetation degradation. Yet, this integration could enable a more complete analysis of vegetation degradation (Wright et al., 2012) and also improve the assessment of potential driving factors.

Several environmental factors have been identified as driving vegetation dynamics. Climate through its parameters, such as rainfall and temperature, plays an important role in vegetation dynamics (Peng et al., 2015; Zeng and Yang, 2009; Nezlin et al., 2005). Over West Arica, rainfall is perceived as determining largely vegetation development (Zoungrana, 2016; Knauer et al., 2014; Traore et al., 2014). Topography is also a natural factor restricting land use change (Peng et al., 2012a) and driving vegetation dynamics (Peng et al., 2012b). Furthermore, anthropogenic impacts on vegetation cover are assumed to be motivated by accessibility factors (Braimoh and Vlek, 2005) such as roads, settlements and rivers. The link between vegetation dynamics and environmental factors has been subject of investigation in literature (Peng et al., 2012b, 2015; Braimoh and Vlek, 2005). However, little was done in the savannah of Burkina Faso especially on the relationship between natural vegetation degradation and environmental factors.

Remote sensing has become indispensable for vegetation change monitoring, since it provides updated satellite data on vegetation cover. Among the numerous remote sensing sensors, MODIS (Moderate Resolution Imaging Spectroradiometer) presents relevant assets for assessing natural vegetation degradation (e.g. conversions and modifications of natural vegetation), as it provides global data (MODIS Global Land Cover products) for LULCC mapping (e.g. Usman et al., 2015; Zhan et al., 2002) as well as NDVI data (MODIS NDVI) for vegetation productivity trends analysis (e.g. Jacquina et al., 2010). Moreover, MODIS vegetation indices have improved spatial resolution (250 m × 250 m) and were found to be better correlated to in situ measured vegetation indices in West Africa as compared to NOAA/AVHRR NDVI (Fensholt and Sandholt, 2005) or SPOT VGT (Fensholt et al., 2006). Nonetheless, dealing only with MODIS-derived LULCC and NDVI data in the fragmented savannah landscapes could be misleading due to the small-scale spatial patterns. Fragmented landscapes describe areas where continuous mosaics of native vegetation are transformed into disjunct pieces of native vegetation surrounded by a matrix of cement, grass, crops, and degraded lands (Marzluff and Ewing, 2001; Meyer and Turner, 1992). In those areas, the coarse pixels of MODIS in reality often cover a mixture of small patches of different LULCC types (Latifovic and Olthof, 2004). In this context, fractional LULCC approach in combination with MODIS NDVI-based vegetation productivity trends will be more suitable and will better represent the heterogeneity of the savannah landscapes (Gessner et al., 2013).

This idea was adopted in the present study which aimed at combining MODIS NDVI trends and fractional LULCC data to assess the degradation of natural vegetation cover in the savannah of Burkina Faso. Specifically, the study aimed to i) assess natural vegetation cover conversions in the study area between 1999 and 2011, ii) assess modifications occurred in natural vegetation cover based on vegetation productivity trends in the period 2000–2011, and iii) determine the relationship of natural vegetation degradation with environmental factors. For that, Landsat LULCC map (30 m × 30 m resolution) was aggregated to the 250 m MODIS resolution with fractional covers of the LULCC classes derived. MODIS NDVI monotonic trends were used as proxy for vegetation productivity dynamics and to assess modifications occurred in natural vegetation cover. Finally, the Spearman's correlation was employed to determine the relationship of natural vegetation degradation with environmental factors. In Burkina Faso, as in the entire savannah of West Africa where LULC is changing rapidly (Orekan, 2007), localizing vegetation degradation hotspots is relevant and crucial for policy makers who aim at food security, biodiversity conservation, and reduction of carbon emission, e.g., from deforestation.

2. Materials and methods

2.1. Study area

A study area covering 5120 km^2 was located in the Black Volta basin in the southwest of Burkina Faso (Fig. 1). This region belongs to the Sudan climate zone. As in the entire West Africa, its climate is governed by the oscillations of the Inter-Tropical Convergence Zone (ITCZ) from south to north and vice versa. According to Nicholson (2013), the ITCZ over West Africa is marked by the convergence of the north-easterly Harmattan winds that originate in the Sahara and the southwest monsoon flow that emanates from the Atlantic. The climate of the study area is thus characterized by a rainy season that extends from May to October and a dry season that occurs from November to April. Rainfall in this region shows high inter-annual variability. The mean annual rainfall amounts to 862.87 mm (1981–2012), and the average monthly temperature ranges from 26 °C to 32 °C (Zoungrana et al., 2015a).

The soils of the study area are dominated by Lixisols (Zoungrana, 2016) that have low organic matter content (Callo-Concha et al., 2012) and are very susceptible to erosion and compaction (Callo-Concha et al., 2013). Savannah vegetation of the Sudan phytogeographic zone covers the study area and is mainly composed of woody savannah. Agriculture, which is the principal livelihood activity in this area, is rudimentary with low inputs (e.g. fertilizers). Cotton and cereals (e.g. millet, sorghum, maize and rice) are the main growing crops in the southwest of Burkina Faso.

2.2. Data collection

2.2.1. Bi-temporal LULC maps

Landsat based-LULC maps of 30 m × 30 m spatial resolution covering the study area were collected from Zoungrana et al. (2015b) for the years 1999 and 2011 with woodland, mixed vegetation, water, agricultural area and bare surface as mapped LULC types. The map of 1999 (2011), with an overall accuracy of 94% (95%), was developed based on random forest algorithm classification of a combination of Landsat imagery and ancillary data (e.g. soil type and topographic data). The five LULC classes have been regrouped into three main LULC classes (Fig. 2): natural vegetation (woodland and mixed vegetation), agriculture (agricultural area) and non-vegetated area (bare surface and water).

2.2.2. Reference data for change map validation

High resolution imageries (RapidEye and Google Earth images of 2011, and Quickbird image of 2012) and aerial photos of 1999 were collected in addition to the corresponding Landsat images of the LULC maps of 1999 and 2011. All those satellite images were already geometrically adjusted and projected to UTM WGS 84 zone 30 like the LULC maps, and they enabled accuracy assessment of the generated LULCC map between 1999 and 2011.

2.2.3. MODIS NDVI data

NDVI data were collected from 250 m MODIS Terra MOD13Q1 16-day vegetation index product (2000–2011) and used as proxy for vegetation productivity. The NDVI data have been downloaded from the USGS′ MRTWeb interface (https://mrtweb.cr.usgs.gov/) and re-projected to UTM WGS 84 zone 30 by using MRT (Modis Reprojection Tool) and further resized to the outline of the study area. The Time-Series Generator (TiSeG) (Colditz et al., 2008) was used to assess NDVI data quality, correct invalid data and fill data gaps by linear interpolation. The setting UI5-CS (Perfect-Intermediate, no Cloud and no Shadow) was applied because of the closeness of its results with the undisturbed situation (normal monthly NDVI curve of the vegetative covers). The NDVI data of the year 2000 were available from mid-February to December. Therefore, to be consistent and include the year 2000 in the trend assessment, time series of annual NDVI average (from

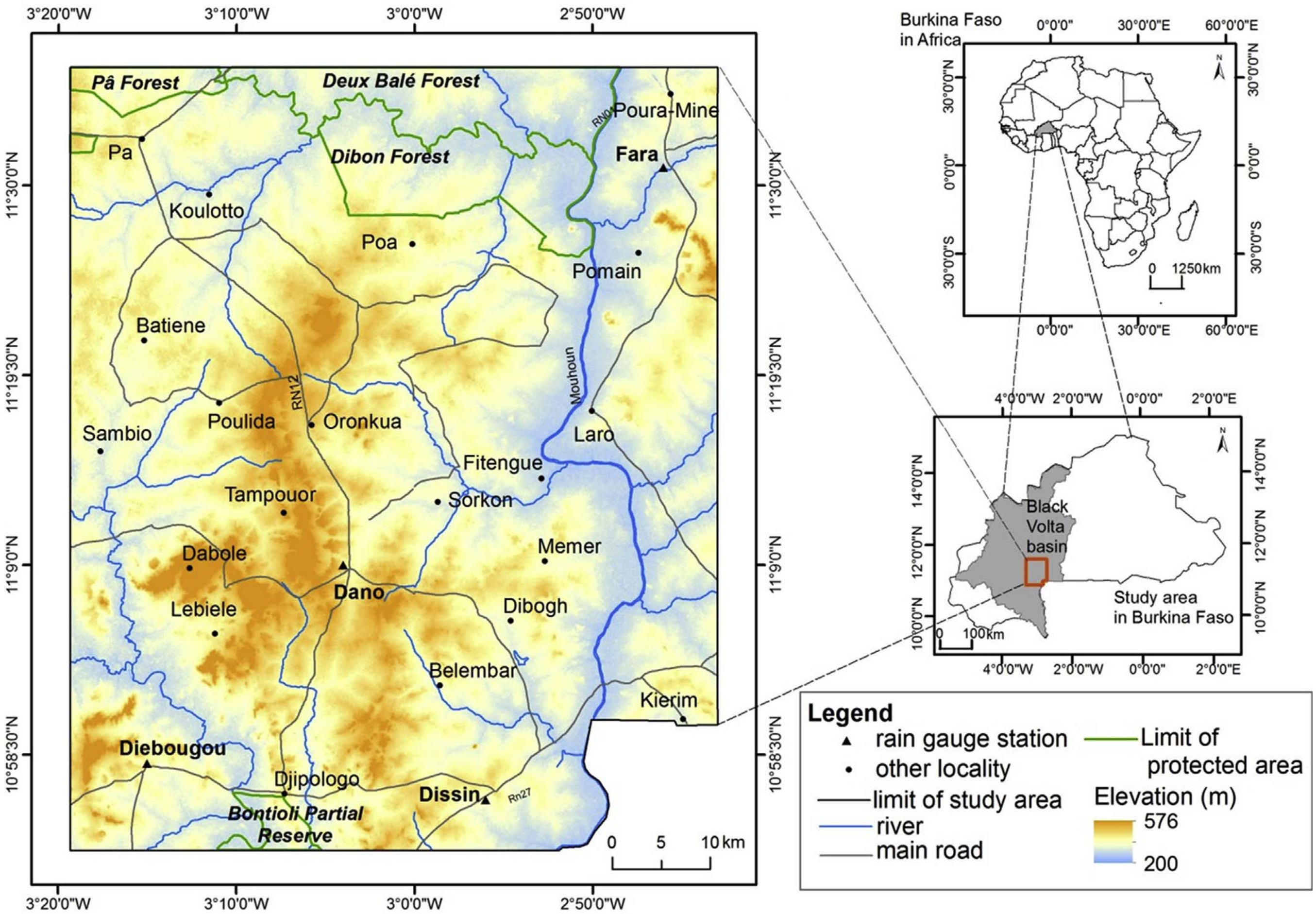

Fig. 1. Location of the study area.

mid-February to December) was produced from 2000 to 2011 to assess per-pixel NDVI trends.

2.2.4. Ancillary data

Topographic, climatic and accessibility data were collected to analyze natural vegetation degradation in the study area (Table 1). Terrain parameters, namely elevation a.s.l. and slope, were extracted from the ASTER Digital Elevation Model (DEM) version 2 (NASA JPL, 2009). Mean annual rainfall for the period (1981–2011) were obtained from TAMSAT data (Maidment et al., 2014; Tarnavsky et al., 2014). For each pixel within the MODIS grid, Euclidean distance to the nearest road, settlement and river were derived from vector layers obtained from the Geographical Institute of Burkina Faso (IGB). All ancillary data were projected to UTM WGS 84 zone 30, rasterized and resampled to 250 m to match the MODIS pixel size.

2.3. Data analysis

2.3.1. LULCC map

Change detection was performed on the reclassified LULC maps of 1999 and 2011 with natural vegetation, agriculture and non-vegetated area as classes. A 30 m × 30 m spatial resolution change map was produced with six change classes identified: natural vegetation to agriculture (NV-A), natural vegetation to non-vegetated (NV-NoV), agricultural to non-vegetated (A-NoV), unconverted natural vegetation (UNV), unconverted agriculture (UA) and other change (OC). Unconverted natural vegetation refers to pixels that were covered by "natural vegetation" in 1999 and 2011. It is also the same for unconverted agriculture.

A set of reference points were collected using stratified random sampling to validate the LULCC map. For that, LULCC classes were considered as strata, and the selection of reference data focused on areas where LULCC map of 1999–2011 and references images overlap following the procedure described in Zoungrana et al. (2015b). In all, 383 LULCC reference pixels were selected (Table 2), and each of them was labelled based on the LULCC map and visual interpretation of the reference images that allowed the construction of an error matrix (Congalton and Green, 2009). The accuracies and area of LULCC classes were computed using the method suggested by Olofsson et al. (2014) for stratified random sampling that consists in adjusting the pixel count error matrix by the area of each LULCC category on the map. The computation of overall, user's and producer's accuracies as well as area estimate is detailed by Olofsson et al. (2014) and Zoungrana et al. (2015b).

2.3.2. NDVI trends analysis: Mann-Kendall's monotonic trend test

Mann-Kendall monotonic trend test was performed to detect trends in the annual NDVI average time series (2000–2011). It is a non-parametric method which does not require the data to meet specific criteria (e.g. normal distribution), and deals better with data skew (Smith, 2000). Two parameters were considered: correlation coefficient and significance. The correlation coefficient, ranging from −1 to +1,

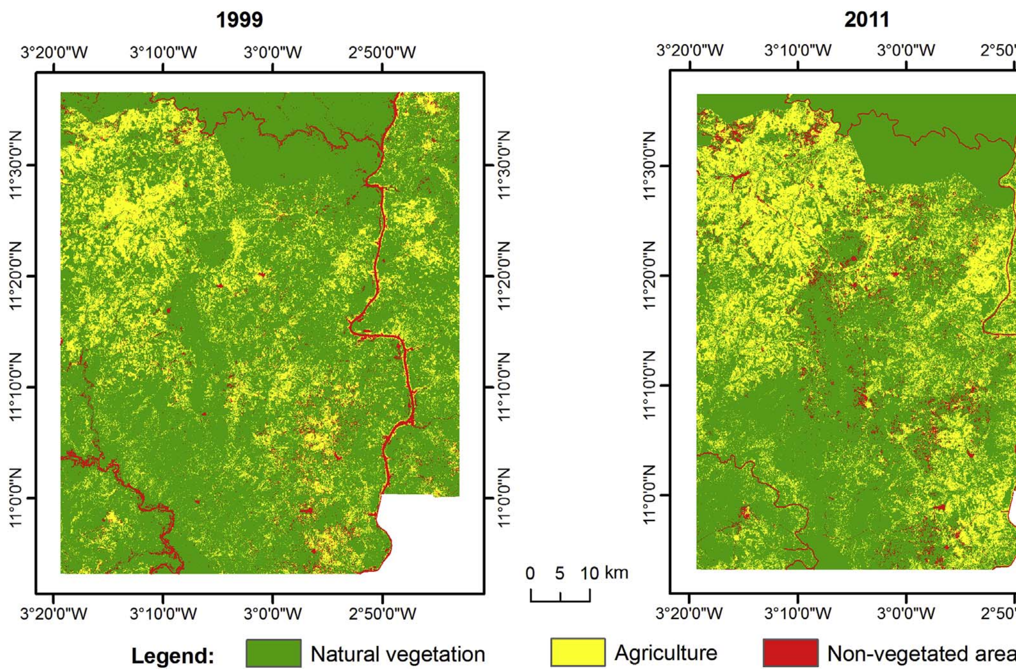

Fig. 2. LULC distribution in 1999 and 2011, modified from Zoungrana et al. (2015b).

Table 1
Ancillary data collected in the present study.

Environmental factors	Variables	Source	Unit	Spatial resolution
Climatic	Mean annual rainfall	TAMSAT	Millimeter	250 m
Topographic	Elevation	ASTER DEM version 2	Meter	250 m
	Slope	ASTER DEM version 2	Degree	250 m
Accessibility	Distance to road	IGB	Meter	250 m
	Distance to river	IGB	Meter	250 m
	Distance to locality	IGB	Meter	250 m

Table 2
Sample allocated to each LULCC classes.

LULCC class	Sample allocation
Unconverted natural vegetation (UNV)	122
Unconverted agriculture (UA)	64
Natural vegetation to agriculture (NV-A)	69
Natural vegetation to non-vegetated (NV-NoV)	43
Agriculture to non-vegetated (A-NoV)	33
Other change (OC)	52
Total	383

measures the degree to which a trend is consistently increasing or decreasing (Wessels et al., 2012), while the significance value highlights the significance of the trend slope. In this study, a trend with p value less than 0.05 was qualified as significant. The Mann-Kendall statistic (S) is given by Equation (1).

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_j - x_i) \tag{1}$$

where (Equation (2))

$$Sign(x_j - x_i) = \begin{cases} 1 & if\ (x_j - x_i)\ >0 \\ 0 & if\ (x_j - x_i)\ =0 \\ -1 & if\ (x_j - x_i)\ <0 \end{cases} \tag{2}$$

and n is the length of time series data, x_i and x_j are the observations at time i and j respectively. The computation of Mann-Kendall significance produces a standardized statistic Z (Equation (3)) and corresponding probability p (Equation (5)). Z here follows a standard normal distribution, and a positive (negative) value of Z signifies an upward (downward) trend.

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if\ \ S > 0 \\ 0 & if\ \ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & if\ \ S < 0 \end{cases} \tag{3}$$

with (Equation (4))

$$Var(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5)\right] \tag{4}$$

where n is the number of data points, g is the number of tied groups (a tied group is a set of sample data having the same value), and t_p is the number of observations in the p^{th} group.

$$p = 2[1 - \phi(|Z|)] \tag{5}$$

where

$$\phi(|Z|) = \frac{2}{\sqrt{\pi}} \int_0^{|Z|} e^{-t^2} dt \tag{6}$$

2.3.3. Determination of areas of natural vegetation degradation

Fig. 3 summarizes the different steps to map natural vegetation degradation. A fractional approach was adopted in this analysis, and for that purpose, the pixels of the Landsat-based LULCC map (30 m × 30 m spatial resolution) between 1999 and 2011 were aggregated to the resolution of 250 m MODIS with the fractional cover of each LULCC classes extracted. Conversions of natural vegetation were directly obtained from

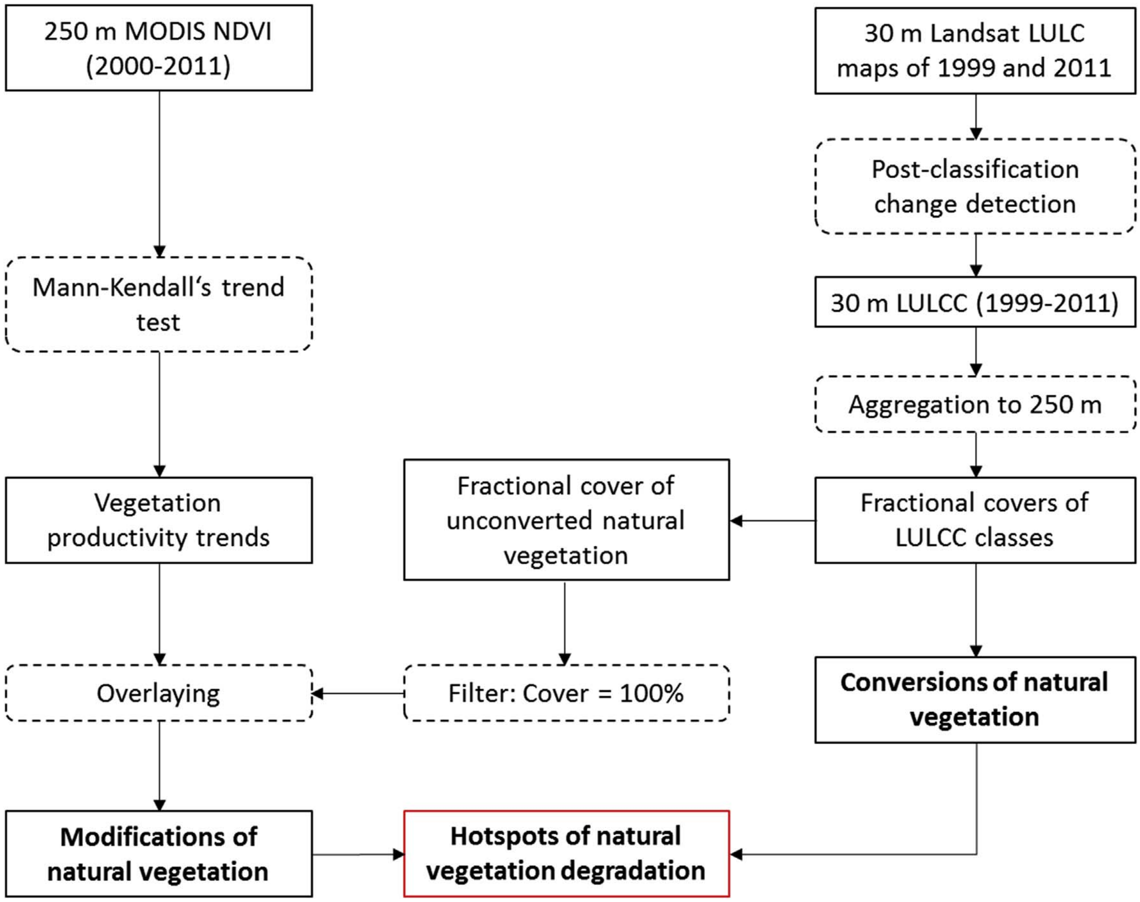

Fig. 3. Diagram of the methodology used to map natural vegetation degradation.

Table 3
Pixels count error matrix of LULCC mapping between 1999 and 2011.

	NV-A	NV-NoV	A-NoV	UA	UNV	OC	Total
NV-A	65	0	0	2	2	0	69
NV-NoV	0	40	3	0	0	0	43
A-NoV	0	2	31	0	0	0	33
UA	3	0	0	60	0	1	64
UNV	1	0	0	1	120	0	122
OC	1	0	0	0	1	50	52
Total	70	42	34		123	51	383

UNV: unconverted natural vegetation; UA: unconverted agriculture, NV-NoV: natural vegetation to non-vegetated; A-NoV: agriculture to non-vegetated; NV-A: natural vegetation to agriculture; OC: other change.

Table 4
Accuracies and area of LULCC classes based on adjusted error matrix (Olofsson et al., 2014).

LULCC	Mapped area	Estimated area		User's accuracy	Producer's accuracy	Overall accuracy
	%	%	Conf. interval (95%)			
NV-A	15.5	15.9	± 1.2	0.94	0.92	0.97
NV-NoV	1.8	1.8	± 0.2	0.93	0.97	
A-NoV	0.8	0.9	± 0.2	0.94	0.86	
UA	13.8	13.5	± 1.1	0.94	0.93	
UNV	57.9	57.7	± 0.8	0.98	0.99	
OC	10.2	10.2	± 0.7	0.96	0.98	

the 1999–2011 LULCC map. Vegetation modifications occur gradually and continually (Xu et al., 2016), but they may also include short periods of rapid changes (Lambin et al., 2003). The present study targeted particularly modifications occurring continually and highlighting reduction of natural vegetation. This entailed the combination of MODIS NDVI trends derived for the 2000–2011 period and the 1999–2011 LULCC map. The analysis of natural vegetation modifications focused on pixels covered at 100% by unconverted natural vegetation; this in order to avoid mixing the effect of vegetation conversion into the NDVI trends while assessing modifications of natural vegetation. NDVI trends stood as proxy for natural vegetation modifications, that is, significant NDVI trends (non-significant trends) observed in unconverted natural vegetation pixels indicate significant modifications (non-significant modifications) with 0.05 as significance level. The simultaneous analysis of natural vegetation conversions and modifications enabled the identification of hotspots of natural vegetation degradation.

2.3.4. Relationship of natural vegetation degradation with environmental factors

Correlation analysis of natural vegetation degradation (conversions and modifications) with accessibility, climatic and topographic factors was performed using the Spearman's correlation to determine possible associations. It is a non-parametric method, and as such, it does not require any assumptions about the data distribution. Spearman's correlation determines the strength and direction of the monotonic relationship or association between two variables. It ranges from −1 to +1 and is calculated as:

$$r_s = 1 - \frac{6\sum d_i^2}{n(n^2-1)} \tag{7}$$

where, $d_i = rg(X_i) - rg(Y_i)$, which is the difference between the two ranks of each observation, and n is the number of observations.

The analysis targeted areas with fractional covers of natural vegetation conversion classes and those affected by modifications of natural vegetation. Correlation analysis was performed between fractional covers of natural vegetation conversions and the environmental variables, as well as between significant modifications (expressed as significant correlation coefficients of NDVI trends) and the environmental variables. Pixels were selected randomly, whereas the sizes of the samples were defined with confident level of 95% and margin of error of less than 5%.

3. Results

3.1. Distribution of LULCC classes and patterns of natural vegetation conversions between 1999 and 2011

The pixels count error matrix indicates little confusion between LULCC classes (Table 3). The LULCC map had an overall accuracy of 97%, and the producer's and user's accuracies ranged from 86% to 99% and 93%–98% respectively (Table 4).

Table 4 shows that between 1999 and 2011 the landscape of the study area was in majority covered by unconverted natural vegetation (57.7%) and to a lesser extent by the conversion of natural vegetation to agriculture (15.9%) and unconverted agriculture (13.5%). In the same period only few spots were converted from agriculture to non-vegetated area (0.9%) and from natural vegetation to non-vegetated area (1.8%). Fig. 4 shows the distribution of the fractional covers of each LULCC class. It indicates a high concentration of unconverted natural vegetation in the north (within the protected areas), center and southwest of the study area. Natural vegetation conversions (Fig. 4b and c), dominated by the conversion to agriculture, were observed throughout the study area and along the borders of the protected zones.

3.2. NDVI trends in the study area

The development of vegetation productivity in the period 2000–2011 is shown by the results of the NDVI trends analysis (Fig. 5a–c). About 57.5% of the study area were characterized by negative trends of NDVI whilst positive trends occurred on 42.5%. Fig. 5b revealed a large dominance of non-significant trends of NDVI (77.3%) in the study area. From the significant trends, negative trends were prominent (19.6%) and largely accumulated in the northwestern part of the study region. Only 3.1% of the pixels showed significant positive trends. The latter mainly occurred in the north of the protected areas, and to a minor extent in the southern half of the study area. The significant positive trends were frequently found in homogeneous MODIS pixels (as shown in Fig. 5c) dominated by unconverted natural vegetation. As for the patterns of significant negative trends, they often occurred outside of the protected zone in the fragmented landscapes which was mainly characterized by the patches of unconverted natural vegetation, unconverted agriculture and the conversion of natural vegetation to agriculture.

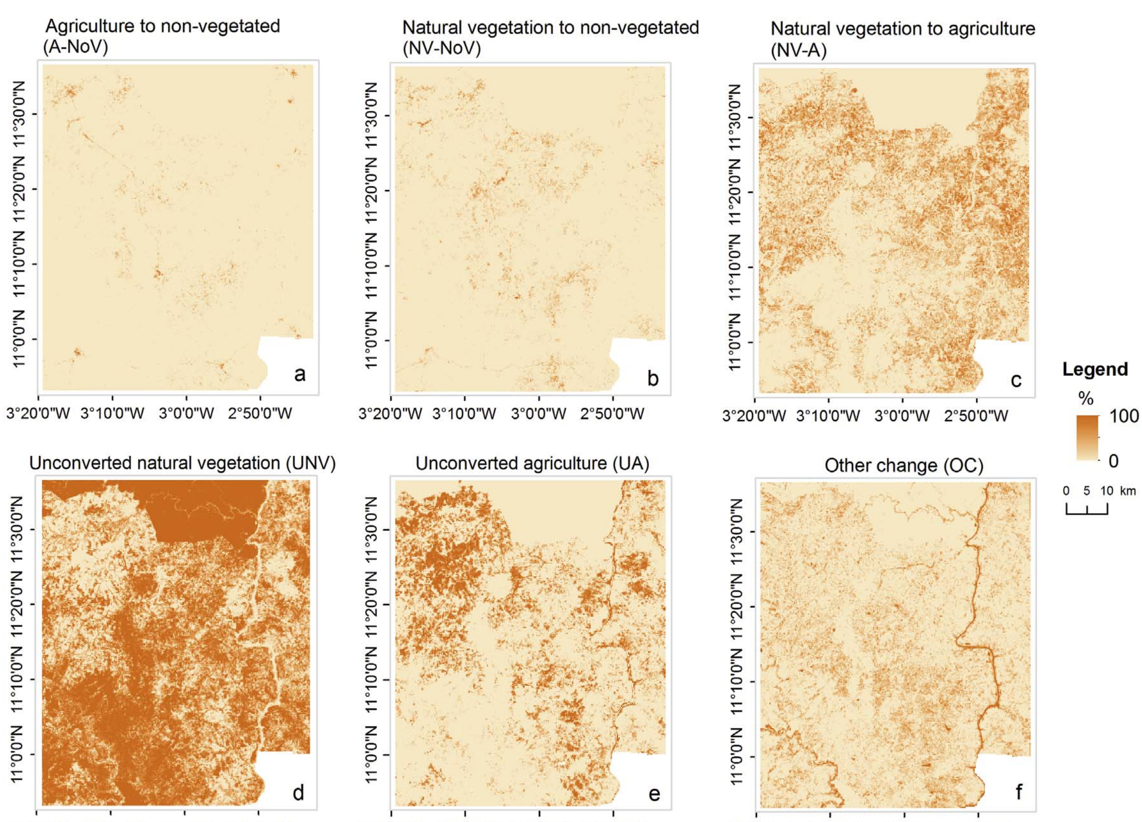

Fig. 4. Fractional cover of LULCC classes between 1999 and 2011 (250 m resolution).

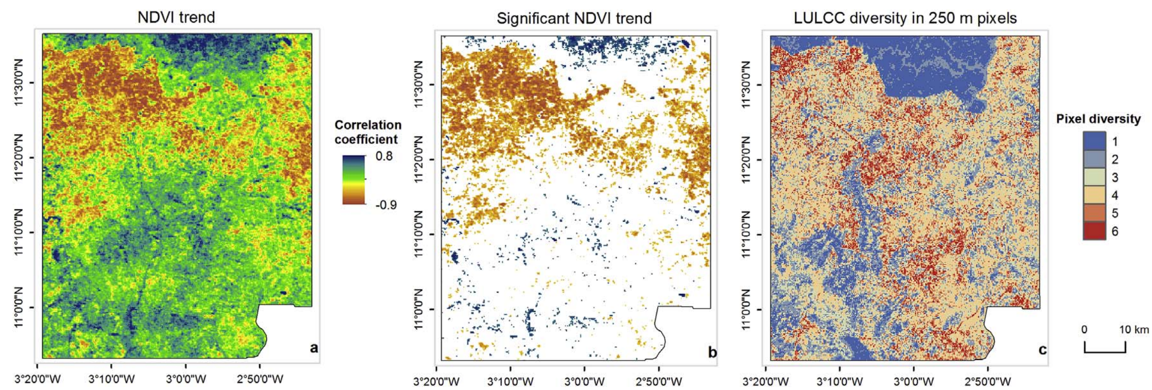

Fig. 5. a: NDVI trends in the study area in the period 2000–2011; b: trends showing a significance level of at least 0.05; c: LULCC class (1999–2011) diversity within the 250 m pixels of MODIS, class diversity is the number of LULCC classes occurring within one pixel.

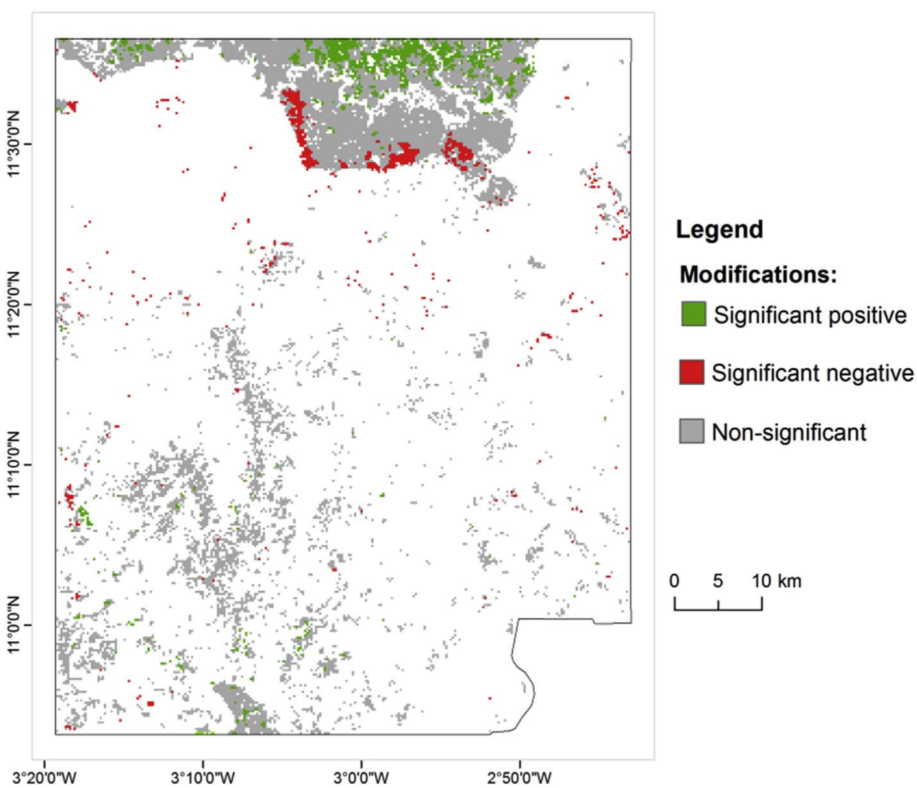

Fig. 6. Modifications patterns in natural vegetation in the period 2000–2011.

3.3. Modifications of natural vegetation in the period 2000–2011

The fractional cover map of unconverted natural vegetation enabled the extraction of pixels covered at 100% by natural vegetation during the observation period. Those pixels have been targeted in the analysis of natural vegetation modifications. Fig. 6 shows the patterns of modifications that occurred in natural vegetation pixels during the period 2000–2011. Fig. 7 indicates that natural vegetation pixels have largely exhibited non-significant modifications (84.4%), and only 15.6% of natural vegetation pixels showed significant modifications. Significant positive modifications (9.8%) were found mainly in the protected areas. As for significant negative modifications (5.8%), they were observed along the borders of the protected areas with some patches distributed throughout the fragmented landscapes.

3.4. Relationship of natural vegetation degradation with environmental factors

The identified relationships between vegetation degradation and the environmental variables are presented in Table 5. In general, all correlations exhibited either moderate or low coefficients. Nevertheless, some significant relationships were detected. Unconverted natural vegetation showed a significant positive correlation with distance to river, distance to road and elevation. On areas where natural vegetation disappeared (non-vegetated area) a significant negative association with the distance to settlement and a significant positive association with the distance to river and elevation were found. A significant positive relationship was found between conversion of natural vegetation to agriculture and mean annual rainfall. However, all accessibility factors as well as elevation had a significant negative relationship with areas converted from natural vegetation to agriculture. Table 5 also

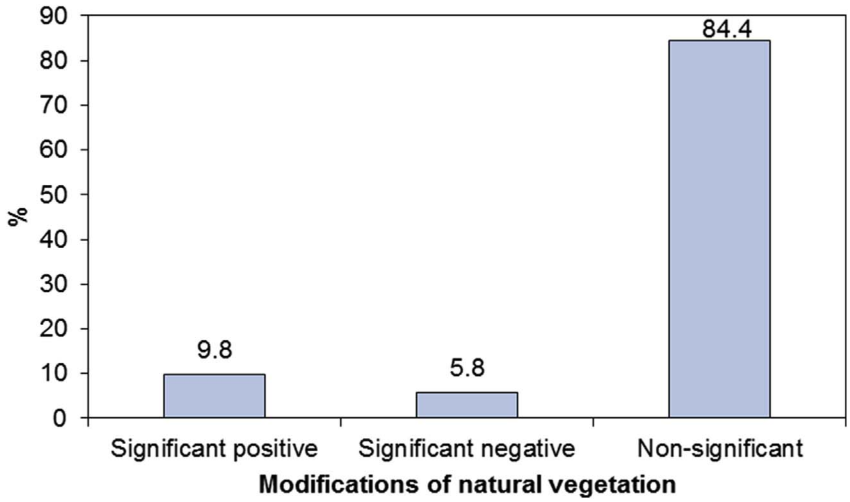

Fig. 7. Proportion of natural vegetation modifications (2000–2011).

Table 5
Spearman's correlation between vegetation degradation and environmental factors.

		Distance to settlement	Distance to river	Distance to road	Elevation	Slope	Mean annual rainfall
UNV	Coef.	0.3	0.3[a]	0.2[a]	0.3[a]	0.2	−0.148
	Sig.	0.06	0	0	0	0.98	0.325
NV-NoV	Coef.	−0.2[b]	0.4[a]	−0.2	0.2[a]	−0.2	0.109
	Sig.	0.02	0	0.068	0	0.37	0.098
NV-A	Coef.	−0.3[a]	−0.2[a]	−0.2[a]	−0.5[a]	0.4	0.229[a]
	Sig.	0	0	0	0	0.75	0.000
Modification	Coef.	−0.2[a]	0.4[a]	−0.3	0.1	−0.2[b]	0.064
	Sig.	0	0.006	0.375	0.884	0.047	0.334

Conversion: N = 3000; Modification: N = 1200.
[a] Correlation is significant at the 0.01 level (2-tailed).
[b] Correlation is significant at the 0.05 level (2-tailed).

indicates significant negative correlations of vegetation modifications with distance to settlement and slope, and a significant positive correlation with distance to river.

4. Discussion

The conversions of natural vegetation to agriculture and non-vegetated area as observed in the study area is a common feature over the West Africa's Sudan savannah zone and go in line with previous results on LULCC (e.g. Houessou et al., 2013; Ouedraogo et al., 2010; Braimoh, 2004). However, at least between 1999 and 2011 and despite the observed conversions, the study area remained largely covered by natural vegetation.

The analysis of NDVI trends in the period 2000–2011 revealed a predominance of non-significant trends of vegetation productivity in the study area. This dynamics has also characterized the entire West Africa as found by Leroux et al. (2014) who noted that about 70% of 250 m MODIS NDVI pixels exhibited non-significant trends over West Africa during the period 2000–2012. Compared to the positive trends, the prominence of negative NDVI trends testifies to a progressive reduction of vegetation productivity in the southwest of Burkina Faso. This result indicates the continuation of the negative vegetation trends postulated by Hountondji et al. (2006) in Burkina Faso over the period 1982–1999, at least for the study region.

The high occurrence of significant decreasing NDVI trends in fragmented pixels shows that sub-250 m pixel LULC conversions have likely contributed to the declining trends of NDVI in the period 2000–2011. In other words, natural vegetation cover conversions, such as conversions from natural vegetation to agriculture and to non-vegetated area, were probably the major drivers of significant negative trends of NDVI, and vegetation modifications played a minor role. This emphasizes the role played by human activities in natural vegetation degradation and seems to support that natural vegetation decline in the southwest of Burkina Faso over the years under investigation can mainly be assigned to unsustainable anthropogenic land use (Dimobe et al., 2015; Zoungrana et al., 2015b). The statistical assessments give a strong indication that it is exactly the case for the study area. The correlation analysis showed that the proximity of accessibility factors, such as roads, settlements and rivers, constitutes a threat for natural vegetation. For instance, in a study conducted in northern Ghana, Braimoh and Vlek (2005) concluded that roads serve as incentive to the loss of natural vegetation. The results of our study agree with such a conclusion and even include other accessibility factors like settlements and rivers as influencing natural vegetation status in southwestern Burkina Faso. However, some discrepancies can be found. For example, the proximity to river seems to favor the conversions of natural vegetation to agriculture, whereas it reduces vegetation negative modifications. Rainfall seems acting as a catalyst for natural vegetation conversion to agriculture in the study area. Indeed, the positive correlation between natural vegetation conversion to agricultural and rainfall indicates that the more an area is rain-fed the more its natural vegetation cover is likely to be transformed into agriculture area by farmers.

Although in the southwest Burkina Faso one used to observe important developments of vegetation cover in the depressions along the rivers (Cord et al., 2010), currently some of them are replaced for irrigated crops production. This also explains the positive association of elevation with unconverted natural vegetation fraction and the opposite with the conversion of natural vegetation to agriculture. The accessibility, climatic and topographic factors have influenced the distribution of natural vegetation degradation, but their contribution, compared to one another, can be measured deeply by a modelling approach, which could be a window for further researches.

On the approach employed, the study showed that the combination of MODIS NDVI trends with fractional LULCC provides more information to analyze vegetation change in the heterogeneous savannah of West Africa. The analysis of LULCC reveals pixels trajectories over the years which is relevant for a good interpretation of NDVI trends and for driving factors analysis. The fractional approach emphasized the heterogeneity within the majority of 250 m MODIS pixels over the savannah of southwest Burkina Faso. It also revealed the distribution of several patches of loss of natural vegetation in the study area between 1999 and 2011. However, the efficiency of the combination of NDVI trends with fractional LULCC is closely linked to the degree of accuracy of the aggregated higher resolution LULCC map. In the present study, the Landsat-based LULC and LULCC maps had overall accuracies higher than 90% which gives confidence to the results achieved.

5. Conclusion

Detecting, monitoring and assessing vegetation degradation is crucial for countries like Burkina Faso where reliable results on vegetation dynamics are needed for the development of efficient forests safeguarding policies. The present investigation assessed the degradation of natural vegetation cover in the savannah of southwest Burkina Faso. The results revealed that between 1999 and 2011 the study area was still largely covered by natural vegetation despite the observed conversions and negative modifications. The dominance of declining changes in vegetation productivity in the period 2000–2011 was more favored by the fragmentation of the landscape by conversions of natural vegetation. The proximity to accessibility factors (roads, settlements and rivers) as well as rainfall and topographic positions in low elevation areas favored the degradation of natural vegetation cover in the study area. However, the forests management seems to perform well as evidenced by the positive development of natural vegetation cover in the protected zones.

In this study, the combined analysis of MODIS NDVI trends and fractional LULCC has given more details on natural vegetation changes in the heterogeneous savannah of the southwest Burkina Faso which could not be obtained from either analysis only. The fractional LULCC approach highlighted the heterogeneity within the 250 m MODIS pixels in savannah areas. It also provided more analytical options, such as the computation of class diversity at the sub-pixel level, to better understand MODIS NDVI trends. Furthermore, the fractional approach could improve the assessment of potential driving factors of vegetation degradation. This combined method, efficiently applied, can contribute to a more effective monitoring of natural vegetation changes and sustainable environmental management of savannahs at the landscape scale.

Author contributions

Benewinde J-B, Zoungrana, Christopher Conrad and Michael Thiel designed this study. They processed the data with help and suggestions from Leonard K. Amekudzi and Evariste Dapola Da. The manuscript was drafted by Benewinde J-B. Zoungrana with input from all coauthors.

Conflicts of interest

Authors declare no conflict of interest.

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