Ann. For. Res. 58(1): 109-123, 2015
DOI: 10.15287/afr.2015.350

ANNALS OF FOREST RESEARCH
www.afrjournal.org

Land cover change and plants diversity in the Sahel: A case study from northern Burkina Faso

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Kadeba A., Nacoulma B.M.I., Ouedraogo A., Bachmann Y., Thiombiano A., Schmidt M., Boussim J.I., 2015. Land cover change and plants diversity in the Sahel: A case study from northern Burkina Faso. Ann. For. Res. 58(1): 109-123.

Abstract. Understanding land cover degradation patterns and the effects of geomorphological units on phytodiversity is important for guiding management decisions and restoration strategies in the Sahelian vulnerables zones. This paper describes land cover degradation by combining Landsat TM image analysis and field data measurements in the Gourouol catchment of the Sahelian zone of Burkina Faso. Erdas Imagine 9.2 and ArcGIS.10 were applied. The change patterns were obtained by superposing land cover maps for 1992 and 2010. The field data were collected by the mean of inventories according to the Braun-Blanquet phytosociological relevés methods. Plot sizes were 50 m x 20 m for woody species and 10 m x 10 m for herbaceous species. Six land cover types were identified and mapped: cultivated lands, bared lands, lowlands, which all spatially increased; and shrub-steppes, grasslands and water bodies, which all spatially decreased. The dynamic patterns based on the geomorphological units were non-degraded lowlands, stable sand dunes and degraded glacis. High plant diversity was found in lowlands, whereas low diversity occurred in glacis. A significant dissimilarity was observed between communities. The Shannon diversity indices in plant communities were approximately close to ln(species richness). The Pielou indices were close to 1, indicating a species fairly good distribution. Our results showed a variation of land cover over time and the effects of geomorphological units on phytodiversity. Furthermore, this variation helps oppose land degradation in the Sahel.
Keywords land degradation, land cover changes, phytodiversity, geomorphology, Burkina Faso.

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Manuscript received October 27, 2014; revised February 11, 2015; accepted February 21, 2015; online first March 18, 2015.

Introduction

Developing countries inhabitants use strongly the natural resources for their daily needs (Mwavu et al. 2008, Traoré et al. 2011, Nacoulma et al. 2011). This use has negative impacts on natural resources causing particularly the decline of the vegetation cover (Sounoun et al. 2007). The vegetation cover protects soil against erosion and contributes significantly to improve soil fertilities. Plants foliage provides habitat for fauna and flora. The degradation of the vegetation cover increases the ecosystems vulnerability contributing significantly to global change because vegetation is one of the principal components of the environmental system (Arouna et al. 2011). Understanding how extend of global change affects land cover variation is important to predict and to combat ecosystems degradation. The combined effects of natural events and anthropogenic pressure on lands is often reported as the main causes of land cover degradation (Nicholson et al. 1998, Rasmussen et al. 2001, Ouédraogo et al. 2006). Human activities affect profoundly ecosystems by habitat degradation and biodiversity reduction. Natural resource use is a factor that widely contributes to land degradation (Biro et al. 2011, Ceyhun 2009, Kessler et al. 2006, Gong et al. 2006). It is source of modification of the structure of land cover and reduces the biodiversity richness (Barima et al. 2010, Nacoulma et al. 2011). Broadly, the term "land use" is related to human use of the land (Meshesha et al. 2010). "Land cover" is defined as the biological and the physical characteristics of the land surface (Duadze 2004). Many studies revealed that natural factors including rainfall variability, geomorphological units and soil physical and chemical properties are causes of land degradation (Azarnivan 2002, Boakye et al. 2008). Geomorphological units affect vegetation in all stages of development and specially filtering the species of plants at the establishment (Frederick et al. 1980). Geomorphology controls the degradation process such as soil compaction, water infiltration, finally wind and water erosion. It represents an important environmental factor that determines the distribution of certain biological assemblages, as well as the variety of human activities.

In Burkina Faso, the human activities in the Sahel predominantly consists of livestock farming and agricultural farms (Lalit et al. 2002). The main natural factors that determine the land cover types in this zone are the climate conditions and the geomorphology. According to Grouzis (1983), the desertification in the Sahel is due to the deforestation and the overgrazing.

In different studies in Burkina Faso Sahel, rangelands productivity (Grouzis 1984, Kiema et al. 2008), restoration potentials (Ganaba 2008; Kiema et al. 2008, Kagambèga et al. 2011), vegetation dynamics and structures (Rasmussen et al. 2001, Anyamba et al. 2005, Olsson et al. 2005, Ouédraogo 2006, Sop et al. 2010) and distribution patterns of plant diversity (Schmidt et al. 2008) were analyzed. Few studies have assessed the dynamics of vegetation cover and the effects of geomorphological units on phytodiversity.

Anthropogenic stress on natural resources adds to the deteriorating effects of climate change on vulnerable environments such as in the Sahel (Ouédraogo 2006) intensifies ecosystems degradation. Thus, it is urgent to examine the land cover changes and the influence of geomorphological units on phytodiversity. For this purpose, remote sensing and vegetation measurements are effective tools for detecting land cover changes (Meaille et al. 1990, Weng 2002, Lalit et al. 2002). The study goals were (i) to assess the Sahel vegetation cover evolution over eighteen years (from 1992 to 2010) using remote sensing tools and (ii) to determine how extent geomorphology affects phytodiversity and to understand the geomorphology-based gradient of vegetation trends. Consequently, these research questions were asked: (i) to what extent does land cover vary over time in the Sahel of Burkina Faso? and (ii) how does geomorphology affects plant diversity in Burkina Faso Sahel?

Material and methods

Study area

The study was conducted in the strict-Sahel of Burkina Faso (Guinko 1984). The site of interest was the Gourouol catchment in the Seno province (Figure 1) which covers approximately 390 000 ha and is located between 14°3'-14°10'N and 0°5'-0°11'W (Kiéma et al. 2008). The water system is based on the Gourouol river which tributaries are Féléol and Goudébo (Barral 1967). The Gourouol area is characterized by two contrasting seasons: one dry season with nine months (October-June) and one rainy season with three months (July-September) (Ganaba et al. 2008, Kiéma et al. 2008). The mean annual rainfall ranged between 200 and 400 mm. According to Grouzis (1984), three main types of geomorphological units exist in the strict-Sahel: glacis, dune systems and lowlands. The vegetation is comprised of thorny steppes dominated by Fabaceae-Mimosoideae species, banded thickets and somewhat eroded tiger bush (Thiombiano et al. 2012). The main ethnic groups living in the

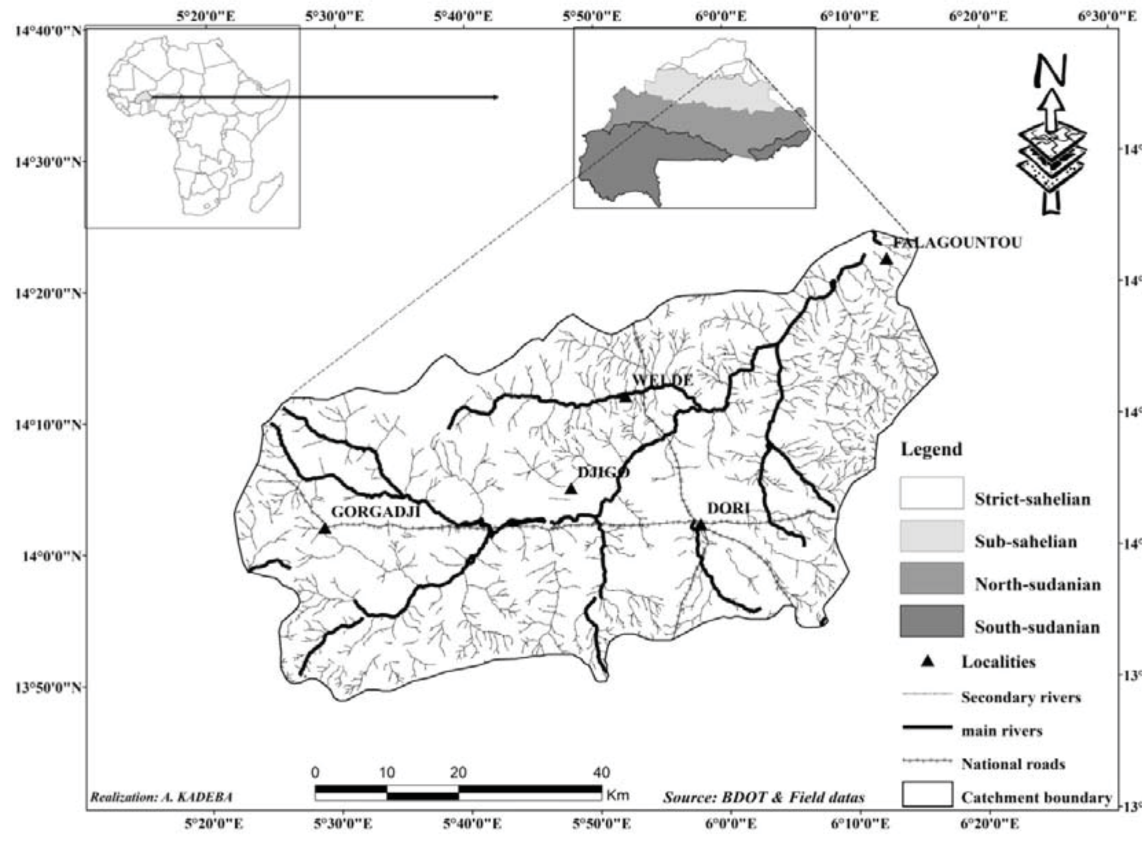

Figure 1 Localization of Gourouol catchment

area are Fulani, Sonraï and Touareg who practice agriculture and livestock breeding.

Effects of land use on vegetation cover changes patterns

Satellite images data collection and processing

Landsat TM (Thematic Mapper) data were selected for this study due to the high monitoring frequency and cover areas which are suitable for large geographical environment. The analyzed image periods were chosen because the variations in vegetation cover in the study area were supposed to be high during this period. Landsat TM images for the years 1992, 2002 and 2010 were analyzed via an unsupervised classification method. This method allowed classification of the images into different vegetation cover classes (Boakye et al. 2008) and to examine their statistical patterns (Erdas, 1999). The land cover statistics were then compared to assess the changes among the years and to understand the quantitative changes of vegetation cover classes. A post-classification approach was applied to examine the statistics for each vegetation cover class from the analyze images (1992, 2002 and 2010) separately. The change patterns in the Gourouol catchment areas were obtained by the superposition of the analyzed images from 1992 to 2010. The land cover classes of each year (1992 and 2010) were firstly encoded and numbered as follows: lowlands (1); shrub-steppes (2); grass lands (3); cultivated lands (4) and bared lands (5). The change pattern map was then created by superposing the two maps respectively to the encoded number trends gradient. If the trend is expressed by the direction gradient 1; 2; 3; 4; 5 (e.g., a change from lowlands to bared lands) between the two years, the change pattern is a regression trend. Conversely, if the trend is expressed by the direction gradient 5; 4; 3; 2; 1 (e.g., a change from bared lands to lowlands) between the two years, the change pattern is a progression trend. If there isn't any change in vegetation cover between the two years the change pattern is called stability trend (Hountondji 2008).

Statistical analysis of images

Softwares program including Erdas Imagine 9.2 and ArcGIS 10 were applied to process the images and analyze the data. We first, generated the statistics of the land cover classes using Erdas Imagine and then the maps using ArcGIS.10. We finally validated the classification results with field observations to obtain a classification accuracy (Congalton 1991). Thirty points were chosen randomly for the assessment in each land cover class. The classified land cover was compared to the know land cover obtained by field work and presented in a confusion matrix or error matrix. In this matrix, the referenced vegetation cover classes are observed in the columns and the classified in the rows. The cell values show the classification accurateness and the diagonal display the correct classifications (P-correct) (Duadze 2004). Using the confusion matrix, the overall accuracy (OA) and the Kappa index (K) were calculated for each image by application of equations (1), (2) and (3). After the evaluation of the classification accuracy, the areas sizes covered by each vegetation cover class type for the period (1992; 2002; 2010) were compared. This comparison allows us for the determination of the magnitude of the difference between the dates. The directions trends of the change between (1992-2002; 2002-2010; 1992-2010) were determined.

The overall accuracy was calculated as follows:

$$OA = \sum(\text{diagonal numbers})/\sum(\text{all row numbers or column numbers}) \quad (1)$$

The Kappa index was computed as follows:

$$K = P_{correct} - P_{chance1} / P_{chance} \quad (2)$$

$P_{chance} = {}_{i=1n} P_{row\ i} \cdot P_{column\ i}$ (3)

The classification quality was appreciated using the scale proposed by Blum et al. (1995) in which the kappa index arranged to 1-81%; 80-61%; 60-41%; 40-21%; 20-0% and < 0% corresponds to excellent, good, average, low, negligible and bad respectively.

Effects of geomorphological units on plants diversity

Vegetation data collection. A stratified random sampling design was used for the vegetation inventory. Phytosociological relevés were made in 2011 and 2012 from August to September in each geomorphological unit (glacis, sand dunes and lowlands) according to Braun-Blanquet (1932). Plant species were recorded respecting their cover/abundance scale. Plot sizes were 50 m x 20 m for woody species and 10 m x 10 m for herbaceous species. The herbaceous plots were installed inside each of the woody plots. Species were directly identified in the field or in the laboratory using specific books (floras).

Vegetation data analysis. Multivariate analyses were performed with Pc.ord.6. Matrixes of 112 species in 90 plots of phytosociological data were ordinated using detrended correspondence analysis (DCA). Categorized vegetation communities were subjected to cluster analysis based on the Sørensen distance, which defines plant communities based on their species composition and abundance. Each plant community was characterized by its indicator species value and identified with one woody and one herbaceous indicator species name. To compare plant communities, Shannon index (4), Pielou's index (5) and Sørensen's index (6) were assessed:

- Shannon index (H'): $H' = -i = 1S_{pilnpi}$ (4)
- Pielou index (E): $E = H'/lnS$ (5)
- Sørensen index (C_s): $Cs=2j/2j + a + b$ (6)

In these equations, S and p_i represents the recorded species and the species individual number respectively. In the Sørensen index, j is the common species number for plant communities, a represents the species belonging at community A and b is the species recorded at community B. A non-parametric test was performed to examine the differences between plant communities using a Kruskal-Wallis comparison test at a 5% threshold in R-2.15.3 software (The R Core Team 2013). Raunkiaer (1932) species life form classification was used to establish a degradation gradient based on geomorphological units. Knowledge of species life forms is important because species life forms are good indicators of communities structure, physiognomy and adaptation strategies. Two life forms spectra represented by the raw spectrum and the weighted spectrum were edited. The raw spectrum is elaborated using the species number in each community whereas the weighted spectrum is calculated using the relative frequency and the mean cover of the species in each community.

Results

Change of land cover in the sahelian zone

Six vegetation cover classes represented by cultivated lands, bared lands, lowlands, grasslands, shrub-steppes vegetation and water bodies) were distinguished and classified during the classification procedure. Others land cover classes (roads and building) were also identified in the study area (Figure 2).

Table 1 presents the vegetation cover change and the changes direction (positive or negative) in the Gourouol catchment. The crop area increased over the 18 year period from 29.75% in 1992 to 53.79% in 2010. During the same period, the bared lands increased from 1.26% to 6.09% in 2010. The lowlands vegetation also increased from 2.51% in 1992 to 24.42% in 2010. Conversely, there was a remarkable

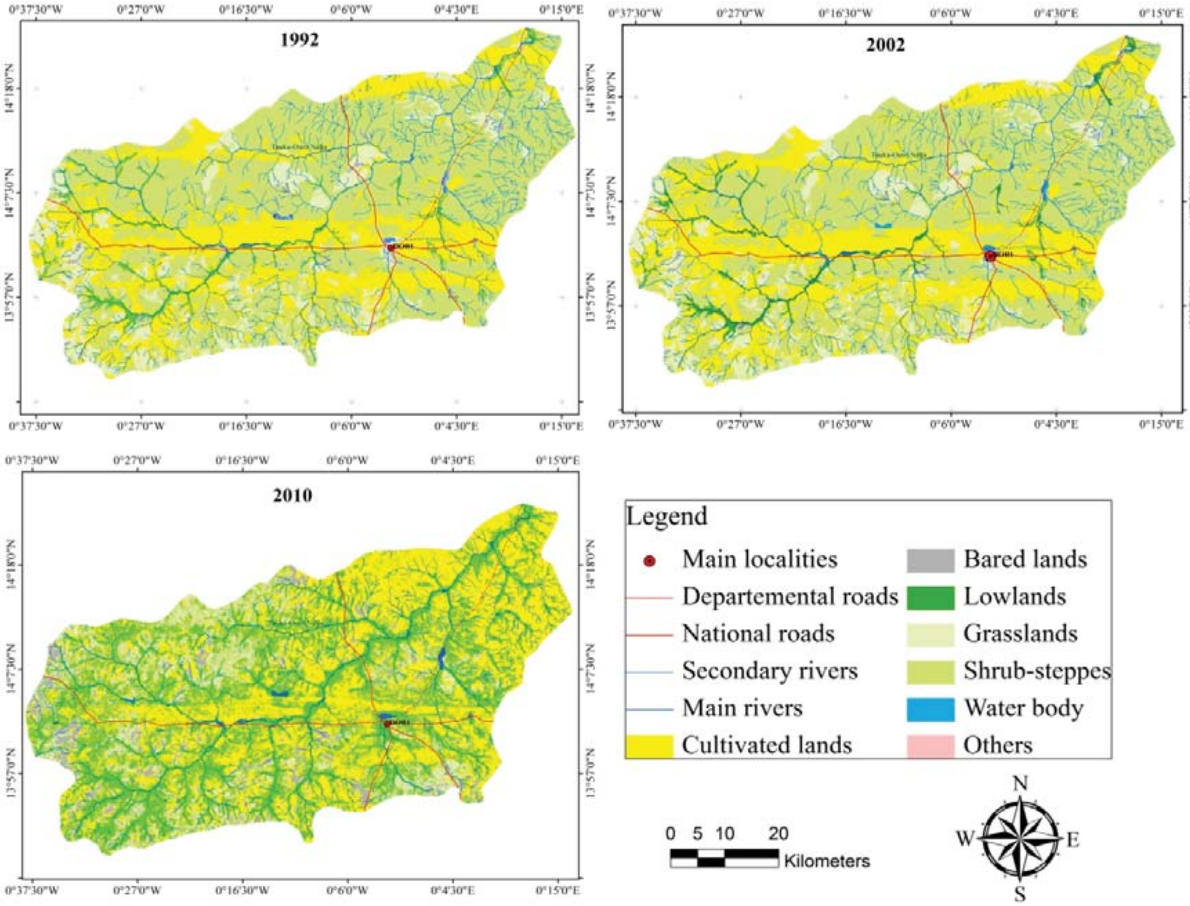

Figure 2 Land cover change between 1992, 2002 and 2010 in the Gourouol

decrease in the shrub-steppe and grasslands. Specifically, the shrub-steppe decreased from 54.69% in 1992 to 4.87% in 2010. The grasslands exhibited a slight decrease from 11.57% in 1992 to 10.71% in 2010. A positive change was observed in the Gourouol catchment. This type of direction trend concerns mainly the cultivated lands (+1.66%) for the period 1992-2002, (+22.38%) for 2002-2010 and (+24.04%) for 2002-2010, the bared lands (+0.06%) for the period 1992-2002, (+4.77%) for 2002-2010 and (+4.83%) for 1992-2010, the lowlands (+0.37%) for the period 1992-2002, (+21.54%) for 2002-2010 and (+21.91%) for 1992-2010, the water bodies and the others land covers with (+0.14%) and (+0.04%) respectively for the period 1992-2002. A negative change was also observed in the Gourouol catchment. It concerns the shrub-steppes (1.63%) for the period 1992-2002, (-48.19%) for 2002-2010 and (-49.82%) for 1992-2010, the grass lands (-0.23%) for the period 1992-2002, (-0.63%) for 2002-2010 and (-0.86%) for 2002-2010, the water bodies (-0.17%) for the period 2002-2010 and (-0.03%) for 1992-2010, others land covers (-0.1%) for the period 2002-2010 and (-0.06%) for 1992-2010.

Table 2 displays the classified image accuracy for 1992, 2002 and 2010. This table shows confusions between the classified lands cover classes during the classification procedure. In 1992, cultivated lands were more confused with bared lands; with shrub-steppes in 2002 and with lowlands and grass lands in 2010; lowlands were more confused with shrub-steppe in 1992 and with cultivated lands in 2002; Water bodies were more confused with grass lands in 2002 and with bared lands and

Table 1 Land covers change in the Gourouol catchment

Land covers	1992		2002		2010		Change (%)	Change (%)	Change (%)
	Area (ha)	Per cent	Area (ha)	Per cent	Area (ha)	Per cent	1992-2002	2002-2010	1992-2010
Cultivated lands	115299.71	29.75	121726.27	31.41	208288.81	53.79	+1.66	+22.38	+24.04
Shrub-steppes	211956.27	54.69	205636.47	53.06	18856.89	4.87	-1.63	-48.19	-49.82
Bared lands	4895.71	1.26	5109.10	1.32	23593.27	6.09	+0.06	+4.77	+4.83
Grass lands	44855.21	11.57	43948.68	11.34	41515.76	10.71	-0.23	-0.63	-0.86
Lowlands	9739.18	2.51	11183.65	2.88	94643.61	24.42	+0.37	+21.54	+21.91
Water bodies	383.68	0.10	930.72	0.24	289.17	0.07	+0.14	-0.17	-0.03
Others	409.55	0.11	596.54	0.15	191.95	0.05	+0.04	-0.10	-0.06

Table 2 Accuracy assessment (percent) for the 1992, 2002 and 2010 land cover maps

Land covers	1992							2002							2010						
	CL	BL	L	GL	SS	WB	OT	CL	BL	L	GL	SS	WB	OT	CL	BL	L	GL	SS	WB	OT
Cultivated land (CL)	**93**	2	0	7	1	0	0	**89**	0	2	0	9	2	0	**98**	2	7	13	0	3	0
Bared lands (BL)	2	**89**	4	1	2	0	0	0	**98**	2	0	0	0	0	0	**79**	0	0	0	0	0
Lowlands (L)	1	5	**88**	1	7	0	0	0	1	**93**	0	0	0	0	1	0	**80**	0	0	0	0
Grass land (GL)	4	1	1	**91**	1	0	0	0	0	1	**94**	0	0	0	0	1	0	**83**	10	0	0
Shrub-steppe (SS)	0	3	7	0	**85**	4	0	6	0	1	0	**90**	0	0	0	1	0	0	**90**	0	0
Water body (WB)	0	0	0	0	4	**96**	0	0	0	0	6	1	**98**	0	0	17	6	4	0	**97**	0
Others (OT)	0	0	0	0	0	0	**100**	5	0	0	0	0	0	**100**	0	0	7	0	0	0	**100**
Overall accuracy (OA)	**91.71**							**95**							90						
Kappa index	**0.83**							**0.85**							0.79						

lowlands in 2010.

The results of the superposed maps analysis revealed different evolution trends of the geomorphological units (Figure 3). Three evolution patterns were observed. The First was expressed by the direction gradient 1; 2; 3; 4; 5 indicating a significant loss in land cover (regression trend). The second by the direction gradient 5; 4; 3; 2; 1 indicating a significant saving in land cover (progression trend). The thirst with no vegetation change indicating a stability trend. This result compared with geomorphological units showed that sand dune vegetation (20.57% in area) was stable, glacis vegetation (43.83% in area) declined and lowlands vegetation (35.54% in area) progressed.

The regression trend is expressed by the decline of vegetation cover (e.g., from lowlands to bare soils) due to several activities, whereas the progression is expressed by the increasing plant cover due to restoration processes (e.g., from bare soils to lowlands). Stability is observed when there is no change in vegetation cover or in the activities of the area between the two time periods (e.g., from cultivated land to cultivated land or from lowlands to lowlands).

Effects of geomorphological units on plants diversity

The ordination of ninety plots from all of the geomorphological units revealed three plant communities (Figure 4).

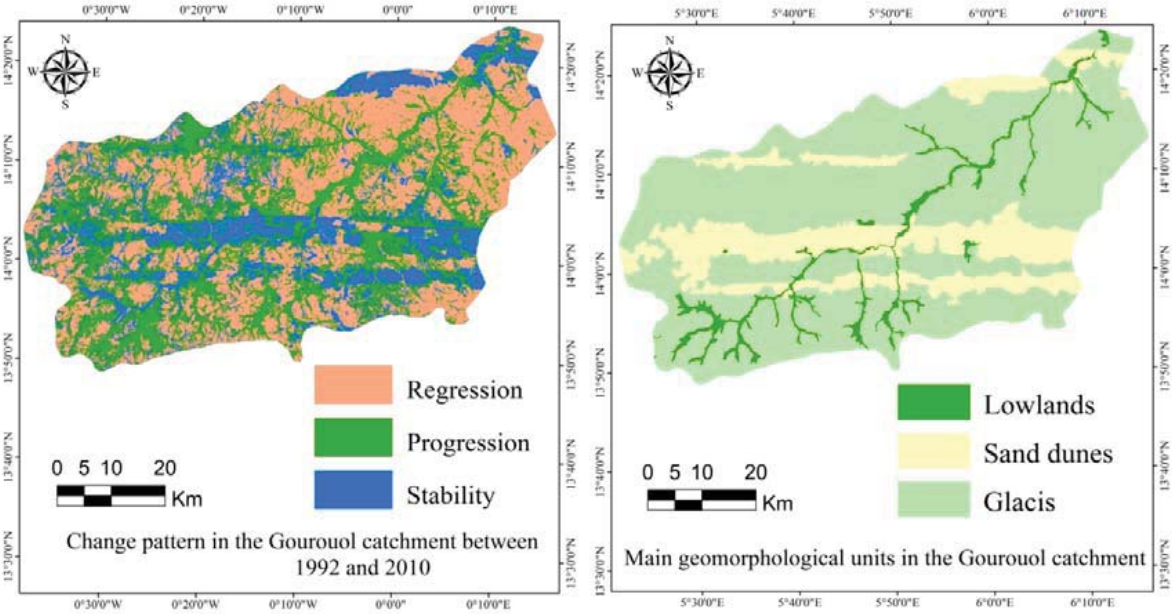

Figure 3 Relationship between the change pattern and geomorphological units in the Gourouol catchment

These plant communities are the plant community of glacis plots (C2), the plant community of sand dunes plots (C3) and the plant community of lowlands plots (C1). The results of a dissimilarity analysis (Table 4) revealed significant differences in species composition between all geomorphological units (Cs = 83%-90.1%). Specifically, plant species compositions were dissimilar between lowlands and glacis (Cs=88.01), lowlands and sand dunes (Cs=83.89%) and glacis and sand dunes (Cs=90.10%). The length of the first axis is 4.305 showing an eigenvalue and an explained variance of 0.76 and 20.10% respectively. The second axis measures 4.395. His eigenvalue is 0.47 with an explained variance of 23.4%. The total explained variance (inertia) was 55.61%. The cumulative percentage of the species total variance as represented by both first axes was 43.50%. This value is justified by the fact that several factors interact simultaneously in relation to the diversity of species (e.g., geomorphology, soil type, and land cover). The glacis community was characterized by *Acacia tortilis* (Forssk.) Hayne and *Schoenefeldia gracilis* (Kunth.). The lowlands community was characterized by *Anogeissus leiocarpa* (DC.) Guill. & Perr. and *Cassia obtusifolia* L.. The sand dunes community was characterized by *Faidherbia albida* (Delile) A.Chev. and *Digitaria horizontalis* (Willd.) (Table 3).

Regarding the change pattern, a close relationship existed between the plant communities and geomorphological units in the Gourouol catchment areas. The glacis plant community was involved in a regression trend, the sand dunes plant community was stable and the lowlands plant community was progressing. A total of 112 species were recorded in the Gourouol catchment areas. Specifically 63.55%, 37.68% and 44.91% of the species were found in lowlands, glacis and sand dunes, respectively. Table 4 presents the floristic parameters for each plant community.

Lowlands were significantly more diversified (75 species) than sand dunes (53 species) and glacis (44 species). Shannon's and Piélou's indexes values were average in all communities. This indicates that all of the species had fairly comparable abundances of individuals within the communities.

An analysis of life forms represented by the raw spectrum (RS) and the weighted spectrum (WS) revealed the dominance of therophytes

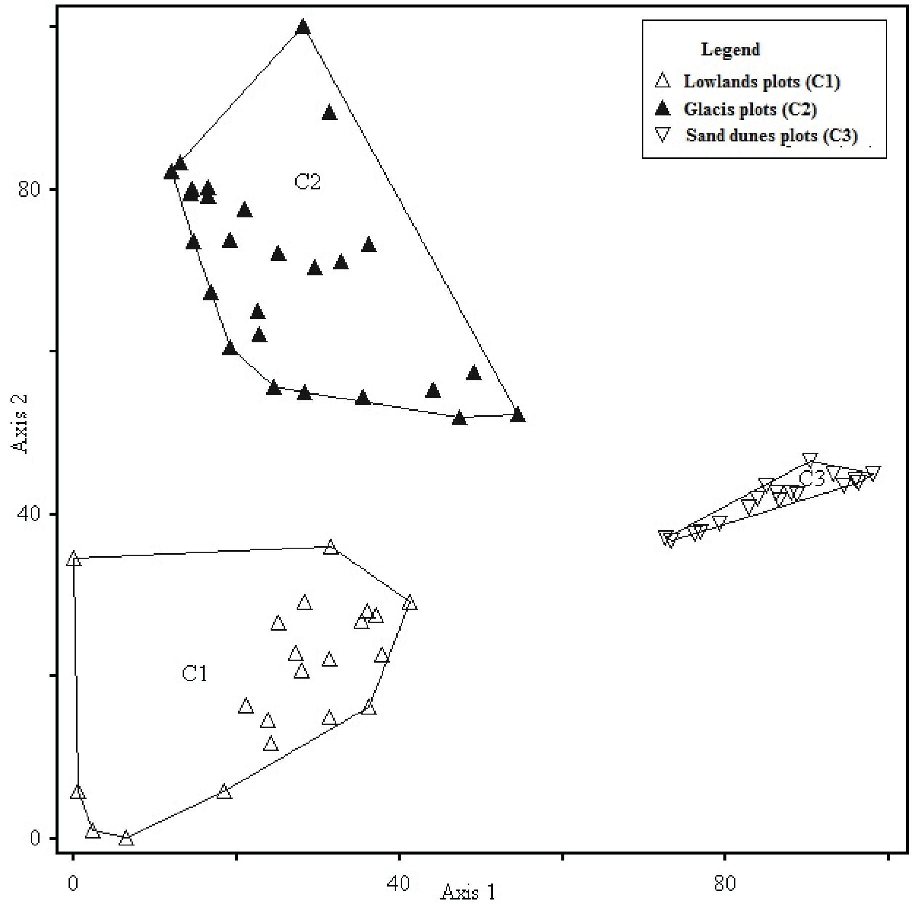

Figure 4 Ordination diagram of the vegetation (lowlands, sand dunes and glacis) based on species cover in the herb and woody layers. The ordination was based on 112 species (75 in lowlands, 53 in sand dunes and 44 in glacis) in 90 plots (30 in lowlands, 30 in sand dunes and 30 in glacis). The length of the first axis is 4.305 with an eigenvalue of 0.76, and the explained variance is 20.10%. The length of the second axis is 4.395 with an eigenvalue of 0.47, and the explained variance is 23.4%. The total variance (inertia) is 55.61%. Three plant communities were observed: the plant community of lowlands (C1); the plant community of glacis (C2) and the plant community of sand dunes (C3).

(annual species) in all of the geomorphological units. This dominance of therophytes was more noticeable in sand dunes (64.15% RS; 90.43% WS) and glacis (70.45% RS; 83.46% RW). In these geomorphological units, therophytes were followed by phanerophytes (20.75% RS; 07.91% WS) in sand dunes and (18.18% RS; 15.89% WS) in glacis and chamaephytes (11.32% RS; 01.38% WS) in sand dunes and (04.54% RS; 0.31% WS) in glacis. Lowlands units are dominated by phanerophytes (54.66%RS; 41.66% WS), followed by therophytes (34.66% RS; 56.56% WS). The lowlands are mainly dominated by perennial broadleaf species (phanerophytes), such as *Anogeissus leiocarpus* (DC.) Guill.&Perr., *Combretum micranthum* G.Don, *Ziziphus mauritiana* Lam., *Mitragyna inermis*(Willd.) Kuntze, *Guiera senegalensis* J.F.Gmel, *Pterocarpus lucens* Lepr. Ex Guill. & Perr., *Piliostigma reticulatum* (DC.) Hochst. and *Combretum aculeatum* (Vent.). Sand dunes are dominated by annual species (therophytes) and a few perennial species (phanerophytes) with large leaves, such as *Combretum glutinosum* (Perr. ex DC.). Glacis are dominated by annual

Table 3 Indicator species of plant communities in Gourouol catchment

Indicators species of lowlands	Indicators species of sand dunes	Indicators species of Glacis
Anogeissus leiocarpa (DC.) Guill. & Perr.	*Digitaria horizontalis* Willd.	*Acacia tortilis* (Forssk.) Hayne
Cassia obtusifolia L.	*Zornia glochidiata* Rchb. ex DC.	*Schoenefeldia gracilis* Kunth
Acacia seyal Delile	*Faidherbia albida* (Delile) A.Chev.	
Brachiaria lata (Schumach.) C.E.Hubb.	*Alysicarpus ovalifolius* (Schumach.) J.Léonard	
Panicum laetum Kunth	*Sesamum alatum* Thonn.	
Balanites aegyptiaca (L.) Delile	*Alysicarpus rugosus* (Willd.) DC.	
Eragrostis pilosa (L.) P.Beauv.	*Abutilon ramosum* (Cav.) Guill. & Perr.	
Pennisetum polystachion (L.) Schult.	*Elionurus elegans* Kunth	
Ziziphus mauritiana Lam.	*Polygala arenaria* Willd.	
Combretum micranthum G.Don	*Tephrosia bracteolata* Guill. & Perr.	
Pennisetum pedicellatum Trin.	*Tragus racemosus* (L.) All.	
Combretum aculeatum Vent.	*Corchorus tridens* L.	
Hygrophila auriculata (Schumach.) Heine	*Commelina benghalensis* L.	
Mitragyna inermis (Willd.) Kuntze	*Cucumis melo* L.	
Pterocarpus lucens Lepr. ex Guill. & Perr.	*Combretum glutinosum* Perr. ex DC.	
Acacia nilotica (L.) Willd. ex Delile	*Leptadenia hastata* (Pers.) Decne.	
Cyperus amabilis Vahl	*Cassia mimosoides* L.	
Guiera senegalensis J.F.Gmel.	*Tephrosia uniflora* Pers.	
Ipomoea aquatica Forssk.	*Ipomoea coptica* (L.) Roth ex Roem. & Schult.	
Piliostigma reticulatum (DC.) Hochst.	*Ipomoea eriocarpa* R.Br.	
Sida alba L.	*Tribulus terrestris* L.	
	Leucas martinicensis (Jacq.) R.Br.	

Table 4 Species parameters of plant communities in Gourouol catchment

Plant communities	S	Ln(S)	*E* ± SE	*H'* ± SE	MC ± SE	Dissimilarity Sørensen indices (Cs) Lowlands (%)	Glacis (%)	Sand dunes (%)
Lowlands	75	4.3174	0.598 ± 0.0033	2.581 ± 0.014	21.77 ± 8.17	0		
Glacis	44	3.7841	0.522 ± 0.0034	2.606 ± 0.012	2.74 ± 0.86	88.01	0	
Sand dunes	53	3.9702	0.442 ± 0.0038	1.754 ± 0.015	12.84 ± 7.1	83.89	90.10	0
P-value			0.03282*	0.01959*	0.00254*			

Note. Abbreviations: * - significant at 5% threshold, *S* - species richness, *J* - Pielou's index, *H'* - Shannon's index, *MC* - mean cover, *SE* - standard error.

species (therophytes) such as *Schoenefeldia gracilis* Kunth and perennial species (phanerophytes) with small leaves (e.g., *Acacia tortilis* (Forssk.) Hayne (Table 3). Figure 5 presents a raw spectrum and weighted spectrum of species in these different geomorphological units.

Discussion

Land use effects on vegetation cover change patterns

The confusion matrices (error matrices) analysis revealed a significant overall accuracy (Ov=90-95) and a significant kappa index (k=0.79-0.85) for the classified images in 1992, 2002 and 2010. According to Blum et al. (1995), the classification results were satisfactory. The observed confusions between lands cover classes can be explained by the Landsat images qualities due to their taking periods and also by the spectral similarities between certain classes in the study area.

Degradation of vegetation cover in the Gourouol catchment is mainly due to the expansion of crop and bared lands. The increase of crop and bared areas can be explained by the exponential growth of the human population and pressures from livestock grazing. This result is supported by many studies based on remote sensing analysis to measure changes of land cover (Meshesha et al. 2010; Hammad et al. 2010). These authors have also underlined urbanization, poverty, and climate change as the main factors that are causing land degradation. The rapid growth of the human population (Arouna et al. 2011) is most likely linked to the political crisis in Côte d'Ivoire between 2002 and 2011. High numbers of Burkina Faso migrants lived in that country and were forced to return to Burkina Faso. This problem contributed significantly to the increase in agricultural lands and consequently, the degradation of the vegetation cover. Furthermore, the negative impact of the political crisis on the environment was also reported in the eastern Mediterranean by Hammad et al. (2010). As the population grows, marginal areas that were previously regarded as poor and unusable lands are exploited. The expansion of bare soils causing degradation of land covers is also due to the regression of some species in the area (Kiéma et al. 2008). These authors underlined that the degradation of land cover in the sahelian zone is explained by the regression of the plant species such as *Balanites aegyptiaca* (L.) Delile, *Pterocarpus lucens* Lepr. ex Guill. & Perr. , *Maerua crassifolia* Forssk., *Andropogon gayanus* Kunth, *Echinochloa stagnina* (Retz.) P.Beauv., *Vossia cuspidate* (Roxb.) Griff. The land cover maps for 1992 and 2010 in the Gourouol catchment showed that crop fields only existed on sand dune units, which are more suitable cultivated areas of the strict Sahel zone in Burkina Faso.

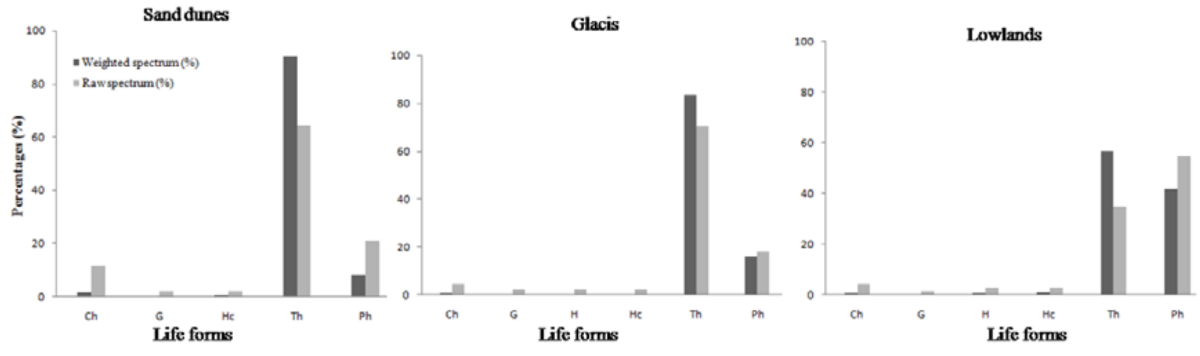

Figure 5 Biological spectrum of species in geomorphological units (Ch: Chamaephytes, G: Geophytes, Hc: Hemicryptophytes, Th: Therophytes, Ph: Phanerophytes, H: Helophytes)

According to Rasmussen et al. (2001), dunes systems are preferred for cultivation because their soils are easy to till and more soil water is available due to higher infiltration compared to the pediplains. The conquest of new cultivated lands between 2002 and 2011 due to population pressure took place on glacis, which caused a reduction of the steppe vegetation. Al-Awadhi et al. (2005) found that the causes of land degradation are related to population growth, economical activities for the development and terrible droughts. The intensive cultivation and overgrazing of these fragile lands combined with the unpredictable climate conditions lead to their rapid degradation (Zombré 2006).

The rainfall fluctuations in Burkina Faso, and particularly in the Sahel (Boly 2009), have often led to flooding and to the destruction of crop fields near the lowlands (Adams 1992). Adams states that the seasonal high water regimes of the rivers in semi-arid Africa are a serious problem as they lead to extensive inundation. To address seasonal flooding, farmers leave a margin between the lowlands and the fields, which increase the lowlands vegetation. The same observation is reported in the northern part of Burkina Faso by Couteron (1997). The strict Sahelian was classified as a partial reserve on December 9th, 1970 and a rule was established to leave a 100 m margin between lowlands and the fields. Meanwhile, many development and research institutions implemented restoration programs and projects in the study area, which likely had a positive impact on the strict Sahelian vegetation. Greening of Sahelian vegetation was also noted (Rasmussen et al. 2001, Olsson et al. 2005, Lars et al. 2006). The previous studies suggest that increasing rainfall causes substantial inter-annual changes in species diversity as well as their cover and productivity. The increase of the lowlands vegetation observed can be attributed to some plant species in lowlands areas such as *Cassia obtusifolia* L. whose expansion in the lowlands areas of the Sahel in the last decades is noticeable (Kiéma et al. 2008). Kiéma et al. (2008) observed that some plant species like *Acacia tortilis* (Forssk.) Hayne, *Cassia obtusifolia* L., *Schoenefeldia gracilis* Kunth and *Zornia glochidiata* Rchb. ex DC. are expanding in Burkina Faso Sahel. The excellent agricultural properties of the soils on sand dunes (Rasmussen et al. 2001) encourage people to cultivate them every year. Thus, stability is observed in these geomorphological units. Because of the lack of fertile lands and the increasing demand of crop areas, people have been cultivating also the interdunal depressions. More people have abandoned fields around lowlands because of the inundation problem (Adam 1992). Adam (1992) also reported that floodplains have had serious adverse environmental impacts on riverine wetlands in West Africa. These different stresses explain the current and accelerated decline of glacis vegetation and the increase of lowlands vegetation.

Effects of geomorphological units on phytodiversity and plants life form: Existence of a degradation gradient based on both field and satellite datas

Vegetation measurements in the Gourouol catchment revealed a distinct difference between the vegetations composition of the three geomorphological units. This study indicates that geomorphological units explain the variation in vegetation cover and species diversity. Burnett et al. (1998), Azarnivan (2002) and Assani et al. (2006) demonstrated a close relationship between geomorphological units and species richness. Plot ordinations revealed different plant communities according to geomorphological units. Frederick (1980) stressed that geomorphological units influence the ecosystems physiognomy by disturbing the vegetation cover. Similarly, Assani et al. (2006) noted that different geomorphological units provide a diversification of the species habitat types.

Based on satellite image analysis combined with vegetation measurement, a degradation gradient was defined as follows: glacis'vegetation are degraded, sand dunes 'vegetation are stable (moderately degraded) and lowlands'vegetation are slightly degraded. This degradation gradient was expressed by the biological spectrum which showed clearly the dominance of therophytes (annual species) in glacis. Glacis are followed by sand dunes and lowlands. This is in accordance with Jauffret (2001) who showed in his study that the augmentation of annual species (therophytes) indicates the degradation. The degradation gradient was also proved by the dominance of perennial broadleaf species (phanerophytes) in lowlands. On sand dunes their number was medium and just a few of perennial broadleaf species were found in glacis. Ganaba (2008) stated that the quantity of perennial broadleaf species indicates the land degradation stage.

Conclusions

The land cover degradation in the Gourouol catchment areas of the Burkina Faso is mainly caused by land use effects. The extent of the degradation depends on the geomorphological units. Landsat image analysis, fieldwork on vegetation measurements and geomorphology revealed various vegetation trends and compositions. Lowlands are mostly dominated by perennial species than are sand dunes, whereas sand dunes are more dominated by perennial species than are glacis. Conversely, glacis are significantly more dominated by annual species than are sand dunes, whereas sand dunes are more dominated by annual species than are lowlands. These two results confirm a degradation gradient. This study improves the understanding of the degradation processes in the sahelian ecosystems and facilitates a sustainable decision-making. It helps to start a debates amongst the involves parties about restoration actions of highly degraded glacis areas in the Sahel by identifying the appropriate geomorphological units.

Acknowledgments

The authors thank the UNDESERT project (EU FP7 243906) which provided us the financial support for this study. They also thank Mr. Sidibé Norbert of SP/CONEDD for providing the Landsat images and Mr. François Ouédraogo for his help with the image analysis. Thanks also to anonymous reviewers, whose comments and suggestions improved the manuscript.

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