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CHARACTERIZATION OF THE SPATIO-TEMPORAL EVOLUTION OF DEFORESTATION : CASE OF THE INNER NIGER DELTA, MALI

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ABSTRACT

In the frame to improve the analysis methods of the landscape existing on the environments. It is essential to lead a surveilling at large view on the area through the geospatial data. So far This research for this field has focused on the statistical outcomes of the environment variation through the time. However, sufficient data and tools and has been used to highlight behaviours of a complex environment of the Inner Delta of Niger (IDN). In this paper, we propose an approach based on the decision-tree to recognize the advancement of different states of the spatial transformation whom undergone the environment. As well to analyse and to predict statistically the change state. The results indicate a decrease of 4.20 % of "abundant vegetation" and 1.74 % of "open water" between 2000 and 2017 in favour of "flooded sparse vegetation", "dry soil covered by vegetation" and "bare soil". Structural dynamics show the environmental landscape submission to 60 % degradation of set of the dissection, attrition, and fragmentation through spatial transformation process (STP). However, the predicting status denotes a strong deforestation in "abundant vegetation", a slight decrease in "open water", and a strong increase in remaining elements of the landscape. As a whole, the study area has sustained a remarkable transformation, linked mainly to climate change associated with anthropogenic effects caused by demographic pressure.

Keywords : *decision tree, spatial transformation process, anthropogenic effects, climate change, Inner Delta of Niger.*

RÉSUMÉ

Caractérisation de l'évolution spatio-temporelle de la déforestation : cas du Delta Intérieur du Niger, Mali

Dans le cadre d'améliorer les méthodes d'analyse du paysage existant sur les milieux, il est essentiel de mener une surveillance d'ensemble sur la zone à travers les données géospatiales. Jusqu'à présent, cette recherche dans ce domaine s'est concentrée sur les résultats statistiques de la variation de l'environnement à travers le temps. Cependant, suffisamment de données et d'outils ont été utilisés pour mettre en évidence les comportements d'un environnement complexe du Delta Intérieur du Niger (IDN). Dans cet article, nous proposons une approche basée sur l'arbre de décision pour reconnaître l'avancement des différents états de la transformation spatiale que subit l'environnement et également pour analyser et prédire statistiquement le changement d'état. Les résultats indiquent une diminution de 4,20 % de la « végétation abondante » et de 1,74 % des « eaux libres » entre 2000 et 2017 au profit de la « végétation clairsemée inondée », du « sol sec recouvert de végétation » et du « sol nu ». La dynamique structurelle montre la soumission du paysage environnemental à 60% de dégradation de l'ensemble de la dissection, de l'attrition et de la fragmentation par le processus de transformation spatiale (STP). Cependant, l'état prédictif dénote une forte déforestation en « végétation abondante », une légère diminution de « l'eau libre », et une forte augmentation des éléments restants du paysage. Dans l'ensemble, la zone d'étude a subi une transformation remarquable, liée principalement au changement climatique associé aux effets anthropiques dus à la pression démographique.

Mots-clés : *arbre de décision, processus de transformation spatiale, effets anthropiques, changement climatique, Delta Intérieur du Niger.*

I - INTRODUCTION

The transformation of many landscapes around the world is due to the human activities performed to meet the socioeconomic needs of the populations [1, 2] and currently because of the effects of climate change [3, 4]. These causes lead on the one hand, to weaken the biodiversity and on the other hand to accentuate desertification. These distressing phenomena about the biodiversity and functioning of ecosystems disrupt the management of the environment [2]. In the Sudano-Sahelian zones of Africa, the structure and physiognomy of the vegetal cover are of various types under the effect of the forms of disturbance which are: the rarity of the rains, and the anthropogenic pressure [4, 5]. To confront this perilous situation, the observation of changes in the environmental landscape throughout the time is essential to estimate the nature of the nature degradation. Hence an obligation of the analysis of the dynamics of the landscape unities is imposed. Nowadays, The geospatial data are used only to monitor and to analyze the landscape spatially in last decades, particularly in the field of vegetal cover management [6, 7]. Besides, it is a way to characterize the state of the degradation over time (temporal-spatial). Nevertheless, numerous studies [8 - 11] have been carried out on the groundwater resources of the Inner Delta of Niger using geospatial data, but knowledge of the landscape unities dynamics is lacking. Thus the variability of the landscape units progress in the IDN plays a key role in the fluctuating productivity levels of biological resources [12, 13]. The main objective of this study is to determine the Eighteen (18)-years evolutionary trend of the landscape in a way to characterize and to predict the landscape unities status including their transition rate.

II - MATERIAL AND METHODS

II-1. Data and Study Area

The study area is located in Mali, between 13° and 18° north latitudes and between 7° and 1° west longitudes, and covers an area of 131886.607 km^2 ***(Figure 1)***. This area is characterized by annual rainfall averages between 150 and 750 mm and a temperature between 12 and 29 °C, between a tropical climate and a semi-arid climate (54 and 84 °F) [8, 13]. The greater part of its soil includes the granite Precambrian, old sandy sedimentary rocks, and quartz formations. Agriculture is an extensive type characterized by drought in some places [15, 16]. Forestry and climate instability have had an impact in recent years [3, 15]. Four groups of mosaics of 14 scenes (from path 198 / row 48 to path 196 / row 51) has been used. They are: ETM+ (Enhanced Thematic Mapper Plus) in October 2000, ETM+ in March 2005, TM (Thematic Mapper) in September 2010, Landsat 8 OLI (Operational Land Imager) in October 2017. Indeed, all of images are taken during the winter period. The images have a spatial resolution of 30 m (UTM_Zone_30_Northern_Hemisphere and reference ellipsoid WGS84) and are freely available on USGS (United States Geological Survey) websites. The data of reference in the ***Table 1***. are collected from our topographic surveying operations based on/and supplemented by a satellite imagery photographer [19]. The processing and analysis of these images were ensured by software ENVI 5.1, Arc Map 10.5, XLSTAT.

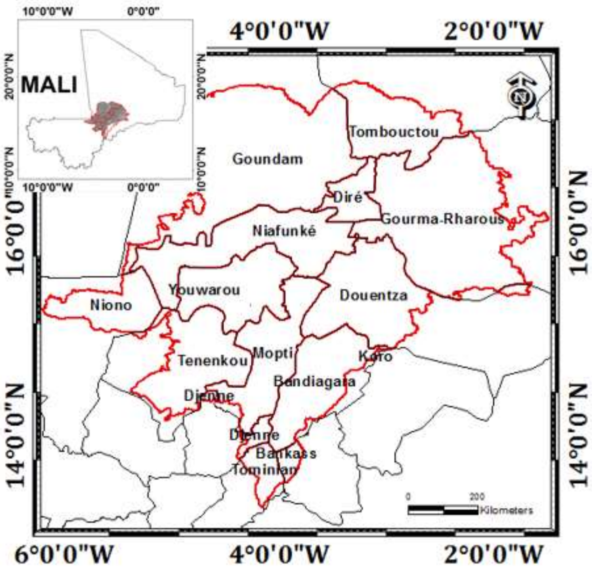


Figure 1 : *Study area location*

Table 1 : *The coordinates of the verification surfaces collected by topographic survey*

Pt	class	area	X(m)	Y(m)
1	abundant vegetation	227ha96a28ca	322939.46	1648688.14
2			321129.721	1649755.34
3			323340.254	1650507.41
4			323709.808	1650091.2
5		207ha50a30ca	343189.838	1636423.13
6			343734.466	1637373.98
7			341725.737	1637679.73
8			341575.562	1636392.38
9			340954.93	1638720.87
10	dry soil covered by vegetation	221ha09a11ca	277877.158	1643245.51
11			279153.287	1642243.59
12			278683.843	1641640.72
13			277813.538	1641485.93
14			276888.411	1642001.05
15		222ha66a08ca	388090.674	1614838.82
16			386802.634	1615840.36
17			386912.414	1616282.32
18			388423.714	1616994.4
19			389336.179	1616298.85
20			388059.596	1615962.65
21	flooded sparse vegetation	156ha58a72ca	330199.253	1666865.92
22			330098.253	1667862.34
23			330962.863	1668631.23
24			331929.893	1668625.01
25			331223.469	1667525.2
26		275ha21a71ca	349277.31	1678165.05
27			349374.83	1676615.47
28			347546.67	1676405.96
29			347445.67	1677402.38
30			348310.28	1678171.27

II-2. Methods

The diagram ***(Figure 2)*** shows the different steps of our methodological processes by starting from data to outcomes while passing by the different processing's.

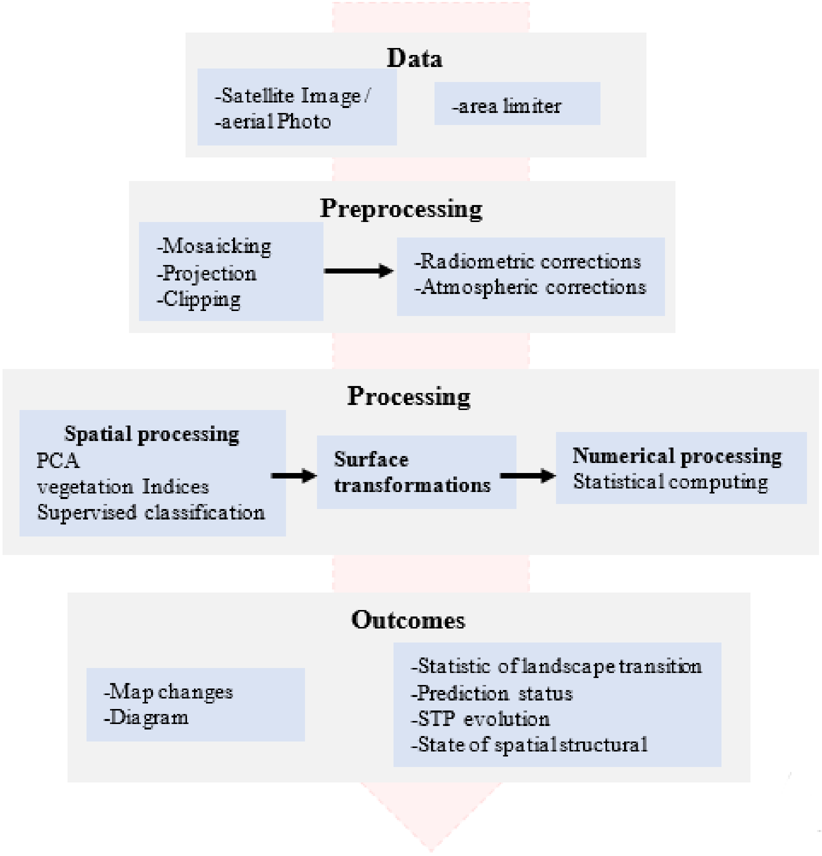


Figure 2 : *Study diagram (PCA: principal component analysis, STP : spatial transformation process)*

II-2-1. Refining images

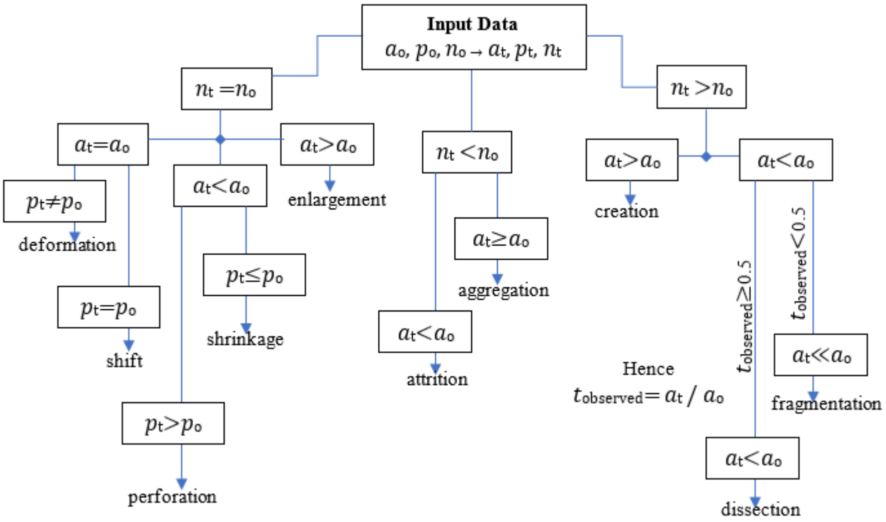
We applied the radiometric and atmospheric corrections to remove speckles that alter the spectral characteristics of landscape occupancy [17,18]. At this point, we applied the principal component analysis (PCA) to the images to attenuate noises. Different vegetation indices were calculated from Red (R), Middle-infrared (MID) and Near-infrared (NIR) bands: NDVI (Normalized Difference Vegetation Index), NDWI (Normalized Difference Water Index), IB (Index of brightness), and SAVI (Soil-Adjusted Vegetation Index). From the fusing of vegetation indices, different existing units were identified by referring to the collected data from the field and supplemented by the contribution of the satellite imagery photographer of Jean Claude Olivry [19, 20].

II-2-2. Processing and verification

The fake-coloured composition (CC) has been realized through different vegetation indices calculated on each of four images from different dates (2000, 2005, 2010 and 2017). Therefore, images underwent an improvement in contrast by using the histogram linear stretching to better discriminate the classes. Based on the ground truth data of landscape, the sampling plan was realized by defining the verification sites (region of interest) so as to be in homogeneous zones [21, 22]. A visual verification was carried out on the classes other than the open water and the bare soil. The set of classes describing the five units of landscape is shown the ***Figure 4*** (flooded sparse vegetation, dry soil covered by vegetation, abundant vegetation, bare soil, open water) was then mapped for each composite image by using the supervised classification approach [26]. Then the perimeters of these individuals were measured and then determine their surfaces. However, a filtering series was used to improve the pixel homogeneities in thematic images. Hence, the image homogeneity is high when the classification accuracy obtained by post-classification is high. Then an assessment of the quality of the classification was then performed by comparing both data (reference and classified) through a confusion matrix. Statistical and dynamic studies have been carried out to analyze the state of land occupancy with the aim of predicting the long-term outcome.

II-2-3. Surface transformation analysis

The landscaping maps from the supervised classification were superimposed two by two in a growing statistical order. Then, the transition matrices have been created to evaluate the transition frequencies between classes over well-defined periods. The spatial structure of the landscape was characterized for each of landscape classes based on the entities such as the number of patches, the area and the cumulative perimeter of the patches. The spatial transformation process (STP) was defined using a decision tree method [24, 25]. The different patterns in the landscape have been observed by using the entities (number of patches n, area a, and perimeter p) in the decision tree as key elements of measures [29]. Two periods of entities are used to identify the spatial process namely the beginning (n_0, a_0, p_0) and at a time (n_t, a_t, p_t) as shown the diagram below. The identification process was performed on the number of patches to partition the spatial process in three groups which are: $(n_0 > n_t)$, $(n_0 < n_t)$ and $(n_0 = n_t)$.



Firstly, the increase of the number of patches ($a_0 > a_t$) between the two periods (beginning and end) implies three patterns of transformations according to the evolution of the areas and which are: the creation (formation of new patches), dissection (subdivision of patches by small lines) and fragmentation. And in particular to distinguish the fragmentation and dissection, the ratio of $t_{obsrved} = a_t / a_0$ was compared to a predefined value of t = 0.5. If $t_{obsrved} \geq 0.5$, the STP will be the dissection, while the STP will be the fragmentation if $t_{obsrved} < 0.5$ [27]. Similarly, the decrease in the number of patches ($a_0 < a_t$) implies attrition (disappearance of patches) and aggregation (collecting units) as spatial transformation patterns but across areas. Hence are located the patterns of spatial transformation of the landscape of the Inner Delta of Niger. With regard to the equal numbers of patches ($a_0 = a_t$) and under the influence of areas and perimeters, it implies the deformation (change of shape of patches), the enlargement (expansion of size of staining), perforation (formation of holes in stains), shift (translocation of stains), shrinkage (reduction of stain size).

II-2-4. Statistical Analysis

A vectorization operation led to the segmentation of the image. The units are individualized i.e. each one has been extracted and exploited without overlaping the others [30], [31]. This step was followed by the export of the files in the Arc Map workspace to increase the flexibility in their handling while transforming them into shapefiles. Products from the processing have also been used to generate keys data spatial statistics. Overall, the spatial statistics focused on the exogenous variables (observation parameters), such as "patches, area and perimeter" of the classes. Linear regressions including multiple regressions have been mandatory for the statistical characterization of the classes namely "abundant vegetation, flooded vegetation, dry soil covered by vegetation, open water and bare soil". To investigate the state of each of the classes during this period, first a Pearson correlation test was performed on the three entities "patches, area and perimeter" among each of the five classes. This was used to determine the links strengths between the entities and the dependency in the model, as well as to determine the direction of the regression of the correlated classes during that period. The links strengths and the perpetrated errors between the relations years / entities were observed through the “goodness of fit”. Then the test for the presence of an atypical or several observation was made using the Bonferroni inequality [32]. More concretely, in practice, it is a question of comparing the residuals with the limits ± 2. Thus the obtained models have been used to predict the rate of different classes in the future and their rate of variability per year

III - RESULTS

III-1. Quality of the classification

At the point of selection of the sampling sites, a control series between classes (n = 5) showed considerable results with the number of class combinations equal to $\binom{n}{2}$ = 10 for each of the images, so 40 combinations in total for four images. The evaluation of separability denoted the coefficient Maximum 2 for 6 pairs, the coefficient 1.99 for 26 pairs, 1.95 for 2 pairs, then 1.9 and 1.97 each a pair. Hence, the choice of each training area was well sampled in order to better orientate the classification. The occupancy units were carefully classified, so the ETM + 2000 image reveals the best of classifications with 95.84 % overall accuracy and 93.01 % kappa coefficient ***(Table 2)***. The weak errors of omission and commission suggest that the bare soil and abundant vegetation classes are the best classified, i.e. those least affected by the other classes. The ETM + 2005 image gives 88.67 % of overall accuracy and 77.14 % of Kappa Coefficient, according to errors of omission and commission, the best classified units have been : open water, abundant vegetation and bare soil. The 2010 TM image indicates 93.98 % of overall accuracy and 84.58 % of Kappa Coefficient, where the omission and commission errors show that the bare soil, the abundant vegetation and the dry soil covered by vegetation are the best classified. Finally, the image L8 OLI 2017 presents as overall accuracy 90.47 % and kappa coefficient 85.76 %. thus the best classified has been the bare soil and open water. Therefore, some weak confusion was observed between the abundant vegetation classes and the flooded sparse vegetation.

Table 2 : *Confusion matrix of the Landsat images classification for 2000, 2005, 2010 and 2017*

		Ground truth data					
Y	Class	Abun_	Flo_Sp_veg	Dr_Slcov_ve	Open	Bare Soil	E.O
ETM+ 2000 in % Classified	Unclassif	0.01	0.00	0.00	0.00	0.00	0.00
	Abun_ve	98.81	0.27	0.54	0.12	0.03	1.19
	Flo_Sp_v	0.99	99.29	0.00	15.27	0.00	0.71
	Dr_Slcov	0.13	0.00	99.41	0.02	0.08	0.59
	Open	0.04	0.44	0.00	84.56	0.01	15.44
	Bare Soil	0.02	0.00	0.06	0.03	99.88	0.12
	E.C	0.13	89.28	10.33	0.09	0.04	
	Overall Accuracy = 95.84 %; Kappa Coefficient = 93.01 %						
ETM+ 2005 in % Classified	Unclassif	0.00	0.00	0.00	0.00	0.00	0.00
	Abun_ve	98.47	1.30	0.64	0.00	0.07	1.53
	Flo_Sp_v	1.43	98.70	0.00	0.17	0.00	1.30
	Dr_Slcov	0.07	0.00	99.09	0.00	0.08	0.91
	Open	0.01	0.00	0.00	99.70	0.00	0.30
	Bare Soil	0.01	0.00	0.00	0.13	0.00	0.16
	E.C	0.98	21.69	24.50	0.01	0.03	
	Overall Accuracy = 88.67 %; Kappa Coefficient = 77.14 %						
TM 2010 in % Classified	Unclassif	0.00	0.00	0.00	0.00	0.00	0.00
	Abun_ve	98.21	1.37	0.00	0.07	0.03	1.79
	Flo_Sp_v	0.06	98.63	0.00	0.79	0.00	1.37
	Dr_Slcov	0.00	0.00	99.46	0.00	0.02	0.54
	Open	1.72	0.00	0.00	98.94	0.00	1.06
	Bare Soil	0.00	0.00	0.54	0.20	99.95	0.5
	E.C	0.31	17.40	0.91	1.47	0.06	
	Overall Accuracy = 93.98 %; Kappa Coefficient = 84.58 %						
L8 OLI 2017 in % Classified	Unclassifie	0.02	0.00	0.00	0.00	0.00	0.00
	Abun_vege	98.42	7.49	9.45	1.72	0.00	1.58
	Flo_Sp_ve	1.58	71.23	0.06	11.88	0.00	28.77
	Dr_Slcov_	0.00	18.33	89.97	1.64	4.57	10.03
	Open	0.00	0.00	0.00	82.85	0.00	17.42
	Bare Soil	0.00	2.95	0.52	2.77	95.43	4.57
	E.C	30.42	34.20	21.19	0.00	1.69	
	Overall Accuracy = 90.47 %; Kappa Coefficient = 85.76 %						

TM = Thematic Mapper ; ETM + = Enhanced Thematic Mapper plus; L8 OLI = Landsat 8 Operational Land Imager ; Flo_Sp_veget = Flooded Sparse vegetation; Dr_Slcov_veget = Dry Soil covered by vegetation ; Abun_veget = Abundant vegetation; E.O = Error of Omission, E.C = Error of Commission,

III-2. Dynamics of landscape

III-2-1. Composition of landscape at the environmental scale

The evolution in landscape between 2000 and 2017 shows in general a decrease in the extent of "abundant vegetation" and "open water" formations ***(Figure 3 and Figure 4)***. Except the "bare soil" class, the class "dry soil covered by vegetation" constituting the dominant matrix landscape as well the "flooded sparse vegetation" class which in 2000 with (11.63 % and 3.23 %) have known each a spatial progress respectively up to (19.94 % and 4.69 %) in 2017. In revenge, the "abundant vegetation" and "open water" classes, each has undergone a strong regress from (6.50 % and 3.23 %) to (2.30 % and 1.49 %) between 2000 and 2017, either an annual decrease of 0.25 % for "abundant vegetation" and 0.17 % for "open water". What made the class "open water" the most dominated matrix of the landscape.

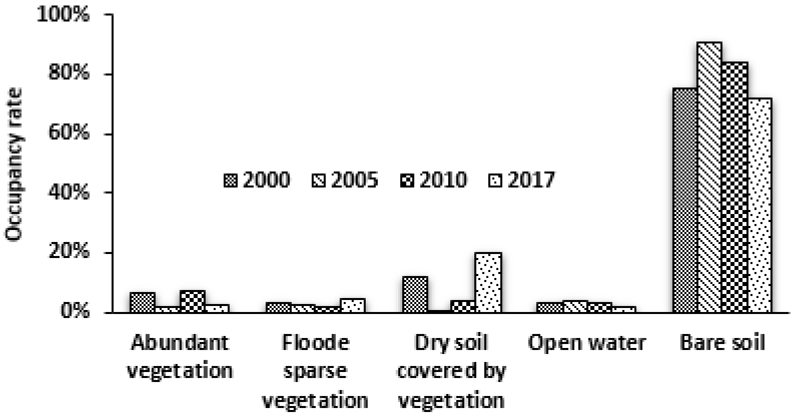


Figure 3 : *Temporal change of land occupancy*

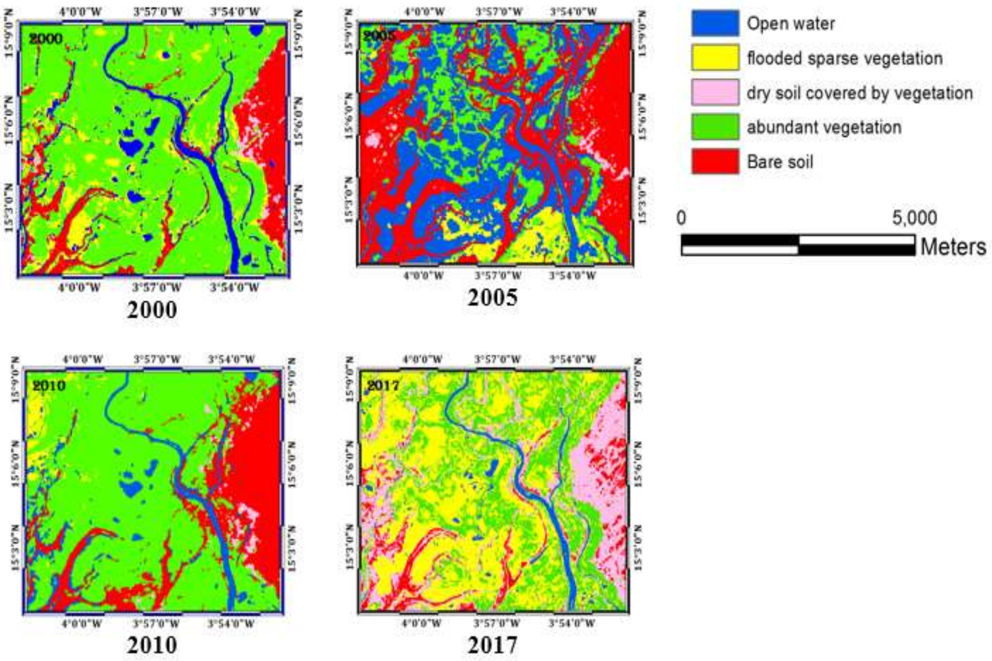


Figure 4 : *Landscape change of 2000, 2005, 2010 and 2017 in the IDN*

III-2-2. Landscape unities transition

In 2005, only 0.13 % of the 6.50 % of the landscape area occupied by abundant vegetation in 2000 remained intact, while 0.16 %, 0.02 %, and 0.25 % became respectively flooded sparse vegetation; dry soil covered by vegetation and open water ***(Table 3)***. The abundant vegetation thus fell by around 5.93 % mainly in favour of bare soil (69.97 %). The proportion of the classes "open water” went from 3.23 % to 3.36 % during the same period. Finally, the "flooded sparse vegetation" and "dry soil covered by vegetation" classes, with a 0.08 % and 0.06 % of permanence rate, constitute the most unstable classes of the landscape. Globally, the period 2000-2005 is characterized by three main types of landscape dynamics: a stability of the landscape classes (70.37 % of the landscape), a dynamic of densification of the vegetation cover (5.80 % of the landscape), and an opening of the environment (23.84 % of the landscape) expressed to varying degrees: abundant vegetation to bare soil at 5.95 % then abundant vegetation to flooded sparse vegetation, dry soil covered by vegetation and open water at 0.16 %, 0.02 % and 0.25 % respectively, flooded sparse vegetation to open water and bare soil 0.13 % and 3.16% respective, dry soil covered by vegetation to open water and bare soil 0.38% and 10.82 % respectively, and finally open water to bare soil with 2.98%. These dynamics are also observed during the periods 2005-2010, 2010-2017, but in different proportions. In fact, in 2005-2010, the stability of the classes concerns 76.53 % of the landscape compared to 15.06 % and 8.41 % respectively for the dynamics of densification of the vegetation cover and the opening of the environment. Thus, 0.15 % of the landscape areas occupied by the abundant vegetation in 2005 remained unchanged in 2010, while the 1.82 % became bare soil, but the most stable (2.10 %) of the landscape except the bare soil class of the table. Over the 2010-2017 period, the stability of the landscape classes increased to 81.28 % in the presence of 3.30 % of vegetation densification dynamics and 15.42 % of opening of the environment. Only 0.001 % of the abundant vegetation remained unchanged in 2017, to except bare soil class, it remains the dominant matrix (7.15 %) and the least stable with of the landscape contrary to 2010 year. At the global scale of the study (between 2000 and 2017), abundant vegetation decreased around 6.4993 %. In fact, from 6.4998 % of the areas occupied by abundant vegetation in 2000, only 0.0005 % remained intact, 1.682 % became dry soil covered by vegetation, 0.003 % became open water, 0.032 % become flooded sparse vegetation and 4.783 % were totally converted to bare soil. The proportion of dry soil covered by vegetation passed from 11.63 % to 25.475 % i.e. 13.845 % of increase. Except the bare soil class, this class of dry soil covered by vegetation has again become the dominant matrix of a landscape previously dominated by the abundant vegetation class and also the most stable with 1.356 %. The same progressive trend is observed in the flooded sparse vegetation class with a rate of 2.936 % in favour of abundant vegetation. Indeed, from 25.475 % of the landscape occupied by the dry soil covered by vegetation in 2017, 1.682 % and 0.570 % were abundant vegetation and flooded sparse vegetation, while 0.219% and 21.648% were open water and bare soil respectively. During this period, 55.04 % of the areas have not changed class (stability), while 22.08 % of the areas have evolved in terms of vegetation reconstitution through a succession process. Similarly, 22.08 % of areas sustained losses at the prejudice of vegetal cover. The desertification thus becomes the most important phenomenon, while taken its big part among flooded sparse vegetation, dry soil covered by vegetation and open water.

Table 3 : *Land Use Transition Matrix (%) between the periods 2000-2005, 2005-2010, 2010-2017, 2000-2017*

Year		**2005**					
	Classes	Abun_veget	Flo_Sp_veget	Dr_Slcov_veget	Open Water	Bare soil	Total
2000	Abun_veget	0.13	0.16	0.02	0.25	5.93	6.50
	Flo_Sp_veget	0.06	0.08	0.00	0.13	3.16	3.43
	Dr_Slcov_veget	0.16	0.22	0.06	0.38	10.82	11.63
	Open Water	0.05	0.07	0.01	0.12	2.98	3.23
	Bare Soil	0.96	1.37	0.42	2.48	69.97	75.20
	total	1.36	1.91	0.51	3.36	92.86	100

Year	2010						
	Classes	Abun_veget	Flo_Sp_veget	Dr_Slcov_veget	Open Water	Bare soil	Total
2005	Abun_veget	0.15	0.03	0.06	0.05	1.82	2.10
	Flo_Sp_veget	0.17	0.04	0.00	0.02	2.30	2.53
	Dr_Slcov_veget	0.04	0.00	0.02	0.01	0.55	0.62
	Open Water	0.28	0.07	0.02	0.13	3.58	4.08
	Bare Soil	6.44	1.54	3.61	2.88	76.20	90.67
	Total	7.07	1.68	3.71	3.09	84.44	100

Year	2017						
	Classes	Abun_veget	Flo_Sp_veget	Dr_Slcov_veget	Open Water	Bare soil	Total
2010	Abun_veget	0.001	0.135	2.588	0.008	4.415	7.15
	Flo_Sp_veget	0.002	0.168	0.327	0.005	1.428	1.93
	Dr_Slcov_veget	0.00	0.00	0.360	0.00	3.619	3.98
	Open Water	0.001	0.063	0.314	0.002	2.825	3.28
	Bare Soil	0.007	0.065	2.825	0.022	80.754	83.67
	Total	0.010	0.430	6.414	0.036	93.111	100

Year	2017						
	Classes	Abun_veget	Flo_Sp_veget	Dr_Slcov_veget	Open Water	Bare soil	Total
2000	Abun_veget	0.0005	0.032	1.682	0.003	4.783	6.50
	Flo_Sp_veget	0.0114	0.280	0.570	0.029	2.542	3.43
	Dr_Slcov_veget	0.0002	0.013	1.356	0.0008	10.260	11.63

Open Water	0.0007	0.039	0.219	0.0005	2.975	3.23
Bare Soil	0.0024	0.130	21.648	0.017	53.406	75.20
Total	0.0153	0.494	25.475	0.049	73.966	100

Each value of the table corresponds to a fraction of the converted landscape, between 2000, 2005, 2010 and 2017 of the class indicated on the line to the class at the head of the column. For example, 0.07% expresses the fraction of the landscape belonging to the open water class in 2000 and which was converted to the flooded sparse vegetation class in 2005. Bold values indicate class permanence. Below the diagonal are the dynamics of densification of vegetation and those above present dynamics of desertification. Flo_Sp_veget = Flooded Sparse vegetation; Dr_Slcov_veget= Dry Soil covered by vegetation; Abun_veget= Abundant vegetation.

III-3. Dynamics of spatial structure and status evolution of landscape

Between 2000 and 2005, the "abundant vegetation", "flooded sparse vegetation" and "dry soil covered by vegetation" classes have undergone a decrease in the number of patches in parallel with a decrease in the total area ***(Figure 5 and Table 4)***, which gave rise to an attrition (disappearance of patches). Therefore, the creation of new patches is the dominant transformation process in the "bare soil" classes, with an increase in the number of patches but also in the total area. The aggregation process (collecting units) is observed on the class "open water" with a decrease in the number of patches aligned with a sharp increase in the total area. Between the years 2005 and 2010, the process of creating new tasks is observed in the classes "abundant vegetation" and "dry Soil covered by vegetation", while the process of attrition (disappearance of patches) concerned class "bare soil", because the decrease in the number of patches in 2010 was accompanied by a decrease in the total area of these classes. The classes "flooded sparse vegetation" and "open water" have undergone a dissection on the basis of respective values of $t_{obsrved} = 0.76$, $t_{obsrved} = 0.80$ higher than the threshold $t = 0.5$. Concerning 2010-2017, the classes "abundant vegetation" and "bare soil" have undergone the attrition process with a decrease of patches number and areas. While by increase of patches number and areas, the classes "flooded sparse vegetation" and dry soil covered by vegetation" have gained new places (creation). Thus, the fragmentation process (breaking of continuity at several disjoint patches; $t_{obsrved} = 0.46$ inferior at the threshold $t = 0.5$) was observed over the "open water" by an increase of patches number and a decrease of areas. On the scale 2000-2017, was observed at the same time a dissection process (subdivision of patches by small lines, $t_{obsrved} = 0.95$ higher than the threshold $t = 0.5$) on the class "bare soil", with an increase in the number of patches in parallel with a decrease in the total area. While at the same period the decrease in the number of patches was accompanied by a slight decrease in the total area, for an imposition of the aggregation process on the classes "open water" and "abundant vegetation". As for the "flooded sparse vegetation" and "dry soil covered by vegetation" classes, the increase in the number of patches and the area, suggests a process of creating patches. The Spatial Transformation Process shows that the environmental landscape is submissive to degradation on the conditions bases involving 60 % by the set of dissection, attrition, and fragmentation compared to appearance of new land-cover units by the creation and aggregation process (40 %) ***(Figure 6)***. Hence the vegetal cover is becoming one of the most degraded ecosystems in the Sudan–Saharan areas.

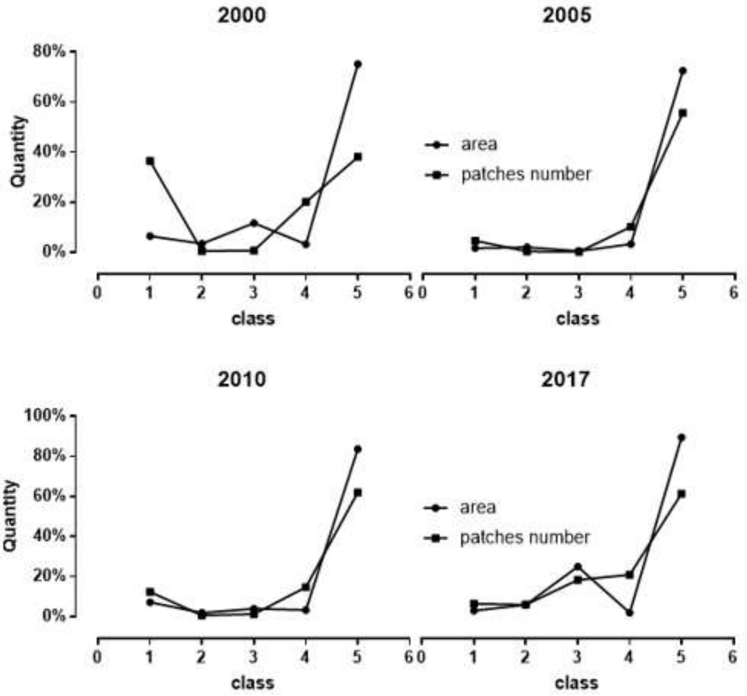


Figure 5 : *Areas and patches number of the different occupancy classes according to the years 2000, 2005, 2010 and 2017. 1 : abundant vegetation, 2 : flooded sparse vegetation, 3: dry soil covered by vegetation, 4 : open water, 5 : bare soil*

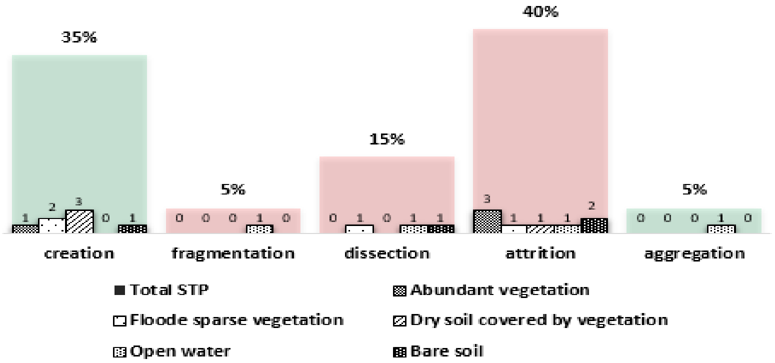


Figure 6 : *Spatial transformation processes (STP) evolution*

Table 4 : *Identification of Spatial Transformation Process (STP) of the classes of occupation between 2000-2005 2005-2010, 2017–2010 and 2017–2000*

Years	**Classes**	$n_{2005} - n_{2000}$	$a_{2005} - a_{2000}$	$P_{2005} - P_{2000}$	a_{2005} / a_{2000}	**STP state**
2005–2000	Abun_veget	-30.67%	-4.40%	-20122.19	0.32%	attrition
	Flo_Sp_veget	-0.09%	-0.90%	142977.28	0.74%	attrition
	Dr_Slcov_veget	-0.52%	-11.01%	-452609.18	0.05%	attrition
	Open Water	-7.32%	0.84%	342792.35	1.26%	aggregation
	Bare Soil	31.43%	15.47%	-13038.26	1.21%	creation
2010–2005	**Classes**	$n_{2010} - n_{2005}$	$a_{2010} - a_{2005}$	$P_{2010} - P_{2005}$	a_{2010} / a_{2005}	
	Abun_veget	6.59%	5.05%	125226.24	3.41%	creation
	Flo_Sp_veget	0.21%	-0.60%	-120642.92	0.76%	dissection
	Dr_Slcov_veget	1.06%	3.35%	195306.05	6.37%	creation
	Open Water	1.86%	-0.80%	-278691.59	0.80%	dissection
	Bare Soil	-7.58%	-7.00%	78802.23	0.92%	attrition
2017–2010	**Classes**	$n_{2010} - n_{2000}$	$a_{2010} - a_{2000}$	$P_{2010} - P_{2000}$	a_{2010} / a_{2000}	
	Abun_veget	-7.19%	-4.85%	-299656.40	0.32%	attrition
	Flo_Sp_veget	4.21%	2.76%	-50285.44	2.43%	creation
	Dr_Slcov_veget	13.35%	15.97%	540467.09	5.01%	creation
	Open Water	2.08%	-1.78%	-240593.55	0.46%	fragmentation
	Bare Soil	-12.79%	-12.10%	50068.31	0.86%	attrition
2017–2000	**Classes**	$n_{2010} - n_{2000}$	$a_{2010} - a_{2000}$	$P_{2010} - P_{2000}$	a_{2010} / a_{2000}	
	Abun_veget	-31.28%	-4.20%	-194552.35	0.35%	attrition
	Flo_Sp_veget	4.32%	1.26%	-27951.09	1.37%	creation
	Dr_Slcov_veget	13.89%	8.31%	283163.95	1.71%	creation
	Open Water	-3.38%	-1.74%	-176492.79	0.46%	attrition
	Bare Soil	11.06%	-3.63%	115832.28	0.95%	dissection

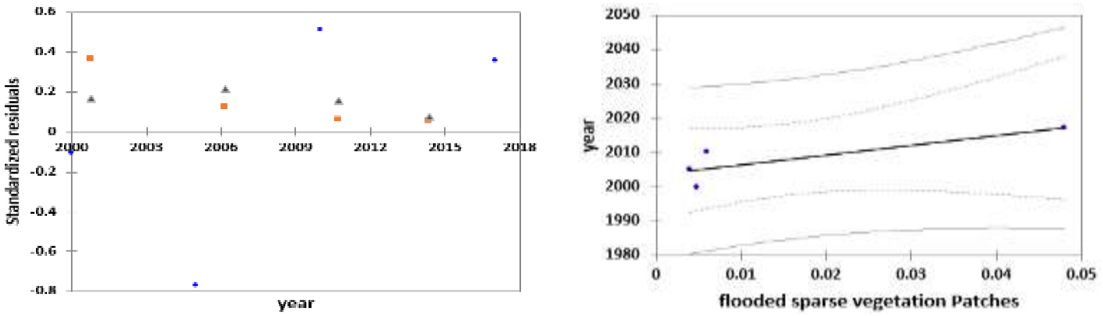
The Spatial Transformation Process has been calculated and its evolution status is determined by the decision tree proposed by (Bogaert, and al.2004). Therefore, knowing *n* (number of spots) *a* (area) and *p* (perimeter), the ratios $t_{obsrved} = a_{2005} / a_{2000};\ a_{2010} / a_{2005};\ a_{2017} / a_{2010};\ a_{2017} / a_{2000}$ were compared to a predefined value of $t = 0.5$ in order to separate fragmentation and dissection. Abun_veget= Abundant vegetation; Flo_Sp_veget = Flooded Sparse vegetation; Dr_Slcov_veget= Dry Soil covered by vegetation

III-4. Multiple and simple linear regressions

Statistically analyzed occupancy classes reveal considerable changes for the future. In fact, the observation was performed on the entities (exogenous variables) namely the patches number, area, perimeter, for each occupation class. Therefore, the multiple regression concretized of each of the classes "abundant vegetation" and "open water" is ensured and explained by two variables among the three, while each of the classes "flooded sparse vegetation", dry soil covered by vegetation "and" bare soil "is inspected by a simple regression each. However, for each of the classes "abundant vegetation" and "open water" the endogenous variable (year) has a links strength (r) and negative progress with two entities per class respectively, the "patches number (-0.74); perimeter (-0.55)" and "area (-0.76); perimeter (-0.53) ". In the same way, the models suitable for the "flooded sparse vegetation", "dry soil covered by vegetation" and "bare soil" classes were carried out on the basis of good positive correlation of the dependent variable (year) with the respective entities "patches number (0.84)”, "area (0.84)" and the "perimeter (0.93)". Hence the basis of their modeling to predict although the variables of each class have no significant effect in the models. The quality of the adjustment (R^2) indicates respectively that 65.32 % and 77.74 % of the variances contained in the "abundant vegetation" and "open water" are explained by their explicative variables. Thus, expected errors on each of the classes "abundant vegetation" and "open water" for using their models to predict will be respectively 7.40 and 5.93. Similarly, the remaining classes with simple linear regression each, have provided R^2 respectively as well as expected errors, namely "flooded sparse vegetation" (70.27 %, RMSE = 4.85), "dry soil covered by vegetation" (71.09 %, RMSE = 4.77) and "bare soil" (86.17 %, RMSE = 3.31).

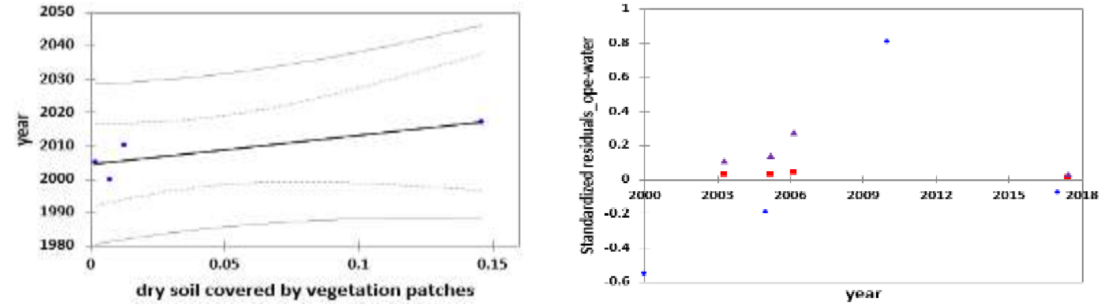
III-5. Predicting status of landscape in the IDN

The assessment of the regression of each of the models provided by the ***Figure 7*** shows for the "abundant vegetation" and "open water” classes by looking their residuals plots, that more the bigger year, the smaller space. While those of "flooded sparse vegetation", "dry soil covered by vegetation" and "bare soil" indicate that more the bigger years, the bigger spaces with the opening of the confidence Interval (mean 95 %). Therefore, the absolute value of all the standardized residuals at each occupancy class level is less than two, hence all the observations have their residuals in the norm. Based on realized models, the forecasted landscape in the future (until 2050) has been performed ***(Figure 8)***. Thus the perimeter and the patches number of the "abundant vegetation" will undergo regressions over time with annual regression rates of -0.49 % and -1.05 % respectively. Concerning "open water", its area will have a rise followed by 'a small decrease and continual over time, hence an annual rate of variability 0.003 %. As for the "flooded sparse vegetation", "dry soil covered by vegetation" and "bare soil", they will each have a progression in the environment with respective variability rates per year : 0.37 %, 1.17 % and 1.50 %.



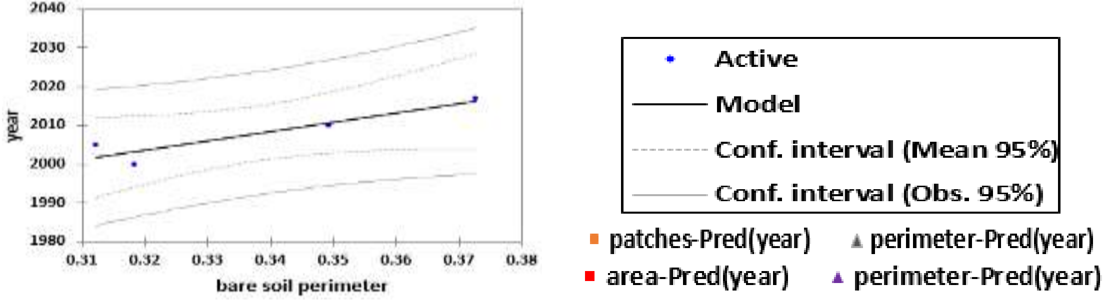
(a) year = 2019-42.28**perimeter*-31.10**patches number;* R^2: 0.653

(b) year = 2004+281.80**patches;* R^2: 0.702



(c) year = 2004+87.97**patches;* R^2: 0.711

(d) year = 2033-1199**area*+80.85**perimeter;* R^2: 0.777



(e) year = 1927+239.82**perimeter;* R^2: 0.861

Figure 7 : *Relationships between year and entities (patches, area and perimeter). (a) abundant vegetation; (b) flooded sparse vegetation; (c) dry soil covered by vegetation; (d)open water; (e)bare soil*

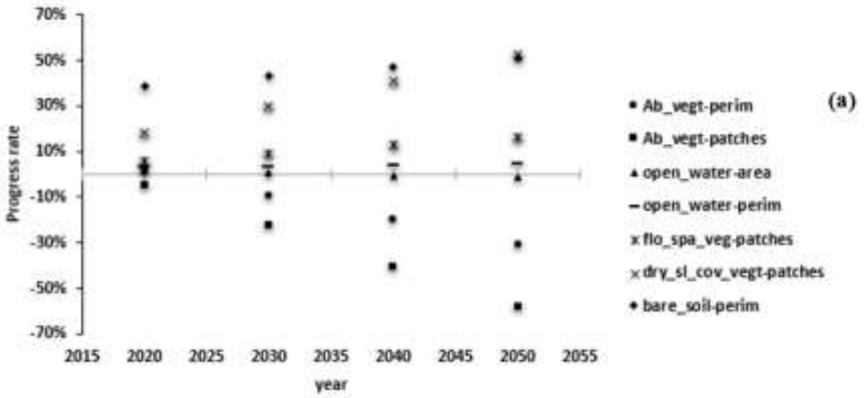


Figure 8 : *Évolution rate forecasting of landscape in the IDN according area, perimeter and patches number*

IV - DISCUSSION

According to the Landis and Koch (1977) scale, the Kappa coefficient values ? obtained 93.01 %, 77.14 %, 85.58 %, and 85.76 %, respectively for the years 2000, 2005, 2010 and 2017 prove that the classifications carried out are reliable [30 - 32]. The evaluation of the results class-by-class confusion matrix confirms that at the level of the four images, overall, there was only slight confusion between the classes. This is due, on the one hand, to the quality of the images and, on the other hand, to the choice of training areas. Indeed, the analysis of certain parts of the images has been made difficult by the presence of parallel streaks generated by the sensors. Hence a compromise between the spatial quality of the images, the complexity of the landscape of the area and the statistical results. The recognition of the study area followed by the collection of field data during the "ground truth" facilitated the analysis and visual interpretation of the images. The analysis of the dynamics of change revealed between 2000 and 2017, 60 % for the whole process of dissection, attrition, and fragmentation of patches by which the environment is subjected to a strong degradation ***(Figure 6)***. And more particularly the disappearance of patches at the level of the "abundant vegetation" by the process of attrition leading to a reduction of its perimeter. This decrease in perimeter comes from the intensive deforestation of the abundant vegetation, and spotted bush etc. It could be explained otherwise by the lack of protection even in the absence of human activities. In some parts of the IDN, moreover, forests are usually burned during the dry season [5]. The transition between occupation classes favors the new patches creation within the "flooded sparse vegetation", "dry soil covered by vegetation" and especially the opening of middle by the "bare soil" class to the detriment of "abundant vegetation". This transition is also related to the geographical locations of certain "abundant vegetation" formations along the Sahara that accentuate the effects of desertification [33, 34]. In fact, precision analyzes show that the transformation of small areas generates more errors than that of large areas. In addition, some limits can be established by spatial resolution of the data through influence on the accuracy of classification. In the "open water" class, similar to the "abundant vegetation", it has also undergone a decrease caused by a process of attrition after a slight increase ***(Table 2)***. This noted decrease, on the one hand embraces the rarity of the rain in these last years and on the other hand, it is due the silting of the banks along the rivers by the anthropogenic activities (agricultural and pastorals) [38, 39]. One of the causes of this continual decrease may be related to the demographic expansion causing the intensive exploitation of rivers [6]. Thus, the transition matrix showed the decrease of its area more in favor of "bare soil" than the other classes. Concerning the dynamics of the classes "flooded sparse vegetation" and "dry soil covered by vegetation", they knew each one of the increase during all the period (from 2000 to 2017). This increase, led by a STP for the creation of new patches, varies between 1.93 % and 4.69 % for the "flooded sparse vegetation" formations and varies between 0.62 % and 19.94 % for the "dry soil covered by vegetation" class. Except the "bare soil" transition, the class "flooded sparse vegetation" takes more space in the "open water", than the class "dry soil covered by vegetation" has occupied in the "flooded sparse vegetation". However, the process of change is variable according the considered formations. Therefore, with regard to the question of the predictability of the landscape ***(Figure 7)***, an intensive decrease in "abundant vegetation" is expected in the coming years while an increase is expected in classes "flooded sparse vegetation" and "dry soil covered by vegetation". Then the class "open water" will suffer a modern decrease.

V - CONCLUSION

The current study highlights the relevance to analyze a complex landscape in the IDN from geospatial data and thus contributes to the interpretation of it with prediction in the future. The study proves that the human pressures associated with current climate change on biomass are in dissension with the regeneration capacities of natural plant formations that are thus terribly threatened. Beside, a strong decrease of areas with abundant vegetation and "open water" is observed in favor of formations "flooded sparse vegetation", "dry soil covered by vegetation" and "bare soil". Therefore, the forecast indicates a significant decrease in "abundant vegetation" and a moderate decrease in "open water". This global variation is due to starting from the anthropic pressures, the irregularities of the rains, associated with a strong advance of the desert, undermines the durability of the ecological, and economic & social processes in a zone strongly dependent on the climatic conditions. To sustainably conserve natural resources, it is necessary to develop an integrated and participative management planning at the local and regional scales. The foundations of this management will be based first of all on development programs clearly exposing the units of biomass, the ecological processes, their evolutions and their protections which are the subject of the study, secondly underhand a sensibilization campaign of the local population through local officials. Thus, this document will serve as a basis for future decisions-making in the fight against desertification in the Inner Delta of Niger.

RÉFÉRENCES

[1] - F. G. FABIEN A, MM. WAZIRI, DB. DIMITRI, “Degradation des ressources vegetales au contact des activites humaines et perspectives de conservation dans le massif de l’Aı¨r (Sahara, Niger).,” *Rev. en Sci. l’Environnement*, Vol. 7, (2006) 1 - 12

[2] - W. EDDY, K. BAKARY, K. J. VANDER and Z. LEO, *Ecologie et Gestion durable des ressources naturelles: Delta intérieur du fleuve Niger*, (2002)

[3] - C. RES, M. HULME, R. DOHERTY, T. NGARA, M. NEW and D. LISTER, “African climate change : 1900 – 2100,” *Clim. Res.*, Vol. 17, (2001) 145 - 168

[4] - Z. LIN, L. ZHANG, S. TANG, Y. SONG and X. YE, “Evaluating cultural landscape remediation design based on VR technology,” *ISPRS Int. J. Geo-Information*, Vol. 10, N°6 (2021), doi: 10.3390/ijgi10060423

[5] - D. F. YOSSI H, M. KAREMBE, “Influence des perturbations anthropiques et de la duree de la jachere sur la dynamique de la vegetation ligneuse en zone soudanienne du Mali.,” *Commun. a l’Atelier Natl. Valid. des acquis Sci. Tech. du Proj. Rech. sur l’amelioration la jachere en Afrique l’Ouest Phase I FED–IER Sikasso*, (2003)

[6] - F. DEMBELE, “Influence du feu et du pâturage sur la végétation et la biodiversité dans les jachères en zone soudanienne-nord du Mali.Cas des jeunes jachères du terroir de Missira (cercle de Kolokani).,” *Thèse Dr. Univ. Droit, d’Economie des Sci. AixMarseille II*, (1996)

[7] - SA. KHRESAT, Z. RAWAJFIH, M. MAOHAMMAD, “Land degradation in nordh-wester Jordan : causes and processes. :,” *J. Arid Environ.*, Vol. 39, (1998) 9 - 623

[8] - V. I. DIALLO H, I. BAMBA, YS. SABAS BARIMA, M. VISSER, A. BALLO, A. MAMA and M. MAIGA, J. BOGAERT, “Effets combines

du climat et des pressions anthropiques sur la dynamique evolutive de la vegetation d'une zone protegee du Mali (Reserve de Fina, Boucle du Baoule)," *Sécheresse,* Vol. 22, (2011) 97 - 107

[9] - C. PIQUET, "Géodynamique d'un hydrosysteme tropical peu anthropisé le bassin supérieur du Niger et son delta intérieur (Geodynamics of a tropical hydrosystem with little anthropisation of the upper Niger basin and its inner delta)," *HAL Id tel-00006189 https//tel.archives-ouvertes.fr/tel-00006189, Univ. Montpellier II "Sciences Tech. du Languedoc,"*, (2004) 1 - 470

[10] - J. OLIVRY, "Fonctionnement hydrologique de la Cuvette Lacustre du Niger et essai de modélisation de l ' inondation du Delta Interieur (Hydrological functioning of the Nigerian Lake Basin and attempt to model the flooding of the Inner Delta)," *Source:OAI,* (1993) 27 - 41 p., [Online]. Available : https://www.researchgate.net/publication/32972540

[11] - G. MAHE, D. ORANGE, A. . MARIKO and J. P. BRICQUET, "Estimation of the flooded area of the Inner Delta of the River Niger in Mali by hydrological balance and satellite data (Estimation of the flooded area of the Inner Delta of the River Niger in Mali by hydrological balance and satellite data)," *IAHS-AISH Publ.*, Vol. 344, (2011) 138 - 143, [Online]. Available: http://www.scopus.com/inward/record.url?eid=2-s2.0-81755168950&partnerID=40&md5=ca83c4a2a186fb16f469f32b926151bc

[12] - J. LETEN *et al., Etat des lieux du Delta Intérieur - vers une vision commune de développement,* (2010)

[13] - G. MAHE, G. LIENOU, F. BAMBA, J. E. PATUREL and O. ADEAGA, "Le fleuve Niger et le changement climatique au cours des 100 dernières années (The Niger River and climate change over the past 100 years)," *Hydro-climatology Var. Chang. Symp. J-H02 held Dur. IUGG2011 Melbourne, Aust.*, N° 344 (2011) 131 - 137

[14] - K. T. DERIBEW, "Spatiotemporal analysis of urban growth on forest and agricultural land using geospatial techniques and Shannon entropy method in the satellite town of Ethiopia, the western fringe of Addis Ababa city," *Ecol. Process.*, Vol. 9, N° 1 (2020), doi: 10.1186/s13717-020-00248-3

[15] - C. CENSIER, J. C. OLIVRY and J. P. BRIQUET, "Les apports detritiques terrigenes dans la cuvette lacustre du niger entre mopti et kona (republique du mali)," *Gd. Bassins Fluviaux, Paris,* (1993) 305 - 315

[16] - M. THIBAULT, "Modelisation Hydrodynamique couplee 1D-2D du delta Interieur du fleuve Niger," *HAL Id dumas-00944942 https//dumas.ccsd.cnrs.fr/dumas-00944942*, (2013) 1 - 41 p.

[17] - D. TINE *et al.*, "Contribution of Sentinel-2/Landsat-8 OLI Images to Extracting Vegetation Cover and Wetlands Area in Urban Zones: Case of the Dakar Region (Senegal)," *J. Geogr. Inf. Syst.*, Vol. 13, N° 04 (2021) 523 - 537 p., doi: 10.4236/jgis.2021.134029

[18] - A. INGER, O. DIONE, M. JAROSEWICH-HOLDER, and J.-C. OLIVRY, “Le Bassin du fleuve Niger Vers une vision de developpement durable (The Niger River Basin Towards a vision of sustainable development),” *Banq. Mond.*, (2006) 1 - 172

[19] - JEAN CLAUDE OLIVRY, “Synthese des connaissances hydrologiques et potentiel en ressources en eau du fleuve Niger (Synthesis of hydrological knowledge and potential in water resources of the Niger river),” *Banq. Mond. Autorité du Bassin du Niger*, (2002) 1 - 167

[20] - N. TAMKUAN and M. NAGAI, “Fusion of Multi-Temporal Interferometric Coherence and Optical Image Data for the 2016 Kumamoto Earthquake Damage Assessment,” *ISPRS Int. J. Geo-Information*, Vol. 6, N°7 (2017) 188 p., doi: 10.3390/ijgi6070188

[21] - J. YANG, G. FANG, Y. CHEN and P. DE-MAEYER, “Climate change in the Tianshan and northern Kunlun Mountains based on GCM simulation ensemble with Bayesian model averaging,” *J. Arid Land*, Vol. 9, N°4 (2017) 622 - 634 p., doi: 10.1007/s40333-017-0100-9

[22] - C. REN, L. CHEN, Z. WANG, B. ZHANG, Y. XI and C. LU, “Spatio-temporal changes of forests in Northeast China: Insights from landsat images and geospatial analysis,” *Forests*, Vol. 10, N°11 (2019) doi: 10.3390/f10110937

[23] - BARIMA Y. S. S, N. BARBIER, BAMBA. I, D. TRAORE, J. LEJOLY and B. J., “Dynamique paysagère en milieu de transition forêt-savane ivoirienne,” *Bois Forêts des Trop.*, Vol. 299, N°1 (2009) 15 - 25

[24] - T. C. SU, “A filter-based post-processing technique for improving homogeneity of pixel-wise classification data,” *Eur. J. Remote Sens.*, Vol. 49, (2016) 531 - 552 p., doi: 10.5721/EuJRS20164928

[25] - S. SAKELLARIOU, P. DA COSTA, B. CABRAL, P. MÁRIO, S. ROCHINHA DE ANDRADE CAETANO and F. PLA, “Spatiotemporal Analysis of Forest Fire Risk Models: a Case Study for a Greek Island,” (2018)

[26] - M. S. BEGUM, S. K. BALA, A. S. ISLAM, G. T. ISLAM and D. ROY, “An Analysis of Spatio-Temporal Trends of Land Surface Temperature in the Dhaka Metropolitan Area by Applying Landsat Images,” *J. Geogr. Inf. Syst.*, Vol. 13, N°04, (2021) 538 - 560 p., doi: 10.4236/jgis.2021.134030

[27] - J. BOGAERT, R. CEULEMANS, and D. SALVADOR-VAN EYSENRODE, “Decision Tree Algorithm for Detection of Spatial Processes in Landscape Transformation,” *Environ. Manage.*, Vol. 33, N°1 (2004) 62 - 73 p., doi: 10.1007/s00267-003-0027-0

[28] - S. K.COLLINGE and R. T. T. FORMAN, “A conceptual model of land conversion processes: predictions and evidence from a microlandscape experiment with grassland insects,” *Oikos*, Vol. 82, (1998) 66 - 84 p.

[29] - R. H. JR. GILES and M. K. TRANI, "Key elements of landscape pattern measures," *Environ. Manage.*, Vol. 23, (1999) 477 - 481

[30] - T. BLASCHKE, "Object based image analysis for remote sensing," *ISPRS Journal of Photogrammetry and Remote Sensing*, Vol. 65, N°1 (2010) 2 - 16 p., doi: 10.1016/j.isprsjprs.2009.06.004

[31] - J. BÖHNER, T. SELIGE and A. RINGELER, "Image segmentation using representativeness analysis and region growing," in *SAGA - Analyses and modelling applications*, Vol. 115, (2006) 13 - 28

[32] - F. TAMÁS and MÓRI, "BONFERRONI INEQUALITIES AND DEVIATIONS OF DISCRETE DISTRIBUTIONS," Vol. 33, N°1 (1996) 115 - 121 p.

[33] - JR. LANDIS, GG. KOCH, "The measurement of observer agreement for categorical data," *Biometr*, Vol. 33, (1977) 159 - 74

[34] - S. KHORRAM *et al.*, *Accuracy assessment of remote sensing-derived change detection*, (1999)

[35] - I. TREPANIER, J.-M. M. DUBOIS and F. BONN, "Suivi de l'evolution du trait de cote a partir d'images HRV (XS) de SPOT : Application au delta du fleuve Rouge, Viet-nam," *Int. J. Remote Sens.*, Vol. 23, N°5 (2002) 917 - 937, doi: 10.1080/01431160110070348

[36] - M. DIATTA, F. FAYE, M. GROUZIS, P. PEREZ, "Importance de la haie vive isohypse sur la gestion de l'eau du sol et le rendement des cultures dans un bassin versant de Thyssé-Kaymor, Sénégal," *Sécheresse*, Vol. 12, N° 15 (2001) 24 p.

[37] - Food and Agriculture Organization FAO, "Aménagement des forêts naturelles des zones tropicales sèches,". *Rome, FAO*, N°32 (1997)

[38] - M. DIARRA, "Opération de Développement Intégré du Kaarta (ODIK) vue à travers les terroirs de Diaman Konkan et de Kourgue. Une étude de conservation des ressources naturelles dans le cadre des Opérations de Développement Rural (O.D.R) du Mali," *Thèse Dr. Univ. Caen*, (1985)

[39] - SB. TRAORE, FN. REYNIERS, M. VAKSMANN, B. KONE et A. SIDIBE, A. YOROTE, "Adaptation à la sécheresse des écotypes locaux de sorghos du Mali," *Sécheresse*, Vol. 11, (2000) 227 - 237