ISSN: 0975-833X

Availableonlineathttp://www.journalcra.com

International Journal of Current Research
Vol. 11, Issue, 09, pp.6836-6843, September, 2019

DOI: https://doi.org/10.24941/ijcr.36410.09.2019

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

RESEARCHARTICLE

MAPPING NATURAL VEGETATION VULNERABILITY TO CASH CROP EXPANSION: THE CASE OF CASHEW PLANTATION IN NORTH-EAST COTE D'IVOIRE

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ARTICLE INFO

Article History:
Received 11th June, 2019
Received in revised form
20th July, 2019
Accepted 18th August, 2019
Published online 30st September, 2019

Key Words:

Land use/cover change,
Cashew plantation,
Forest savanna transition,
Vulnerability,
GIS multicriteria analysis.

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ABSTRACT

The increasing world demand for cashew (*Anacardium occidentale L.*) nuts and by-products generates rapid expansion of cashew cultivation across West-African countries especially in Cote d'Ivoire. This has created wealth for many smallholders. This is not to mention the pressure on forest-savanna transition zone. The aim of this study is to contribute to a better management of rural land by investigating the spatial trends of cashew production and assessing the natural vegetation vulnerability to future cashew expansion in the forest-savanna transition zone. A spatial dynamics of land use were analysed from 2001 to 2015 at a watershed level based on remote sensing-based classification and post-classification change detection. GIS and multicriteria analysis were used to analyse the natural vegetations' vulnerability to future cashew expansion. The results identified cashew expansion (a rate of 7.24% per annum for the periods 2001-2015) as a major land use changes. From 2001 to 2015, more than 13305 ha (i.e. 19%) and 22539 ha (i.e. 33%) of forest/woodland and savanna areas respectively were converted to cashew plantations. Natural vegetation vulnerability to future cashew expansion was in the descending order of forest/woodland (21.43%), tree savanna (11.87%) and tree/shrub savanna (8.27%). This implies that cashew expansion is of higher threat to more woody vegetation which has serious implication in terms of conservation and carbon emissions. There is therefore a need for a more sustainable management approach to cashew agriculture practices to ensure optimum production for farmers, while conserving the forest-savanna ecosystem.

Citation: Akpa You Lucette, Dibi n'da Hyppolite, Danumah Jean Homian, Bruno Kouassi Kpangui and Valere Carin Jofack-Sokeng, **2019.** "Mapping natural vegetation vulnerability to cash crop expansion: the case of cashew plantation in north-east Cote d'Ivoire", *International Journal of Current Research*, 11, (09), 6836-6843.

INTRODUCTION

Land use has considerably changed all around the world as a consequence of interactions between climatic conditions, economic development and local livelihoods. In developing countries, agriculture as the major economic activity, source of income and development is a threat to the natural environment through cropland expansion. This has led to a decline and loss of intact natural forests accompanied by changes in their ecological functioning, to the depletion of carbon stocks in vegetation and soil, issue in land competition (Sohl *et al.,* 2012; Smith *et al.,* 2010; Dale and Polasky, 2007; Goetze *et al.,* 2006). Recently, there is an important expansion of cashew in West Africa countries mainly driven by a high demand of cashew nuts and kernel at world level (Venkattakumar, 2009; Lawal *et al.,* 2011). Cashew production has then contributed to improve livelihoods of farmers and even to the national economy in some countries. Moreover, projections suggest that this demand will continue increasing by 2020. The world cashew kernel demand is expected to grow by 5.9% per annum and the cashew demand would increase with a percentage growth of 4.6% (Malhotra, 2008).

There is therefore a need to assess the extent of cashew farming and its implication for future natural vegetation ecosystems through the vulnerability assessment. The concept of vulnerability has emerged, within the last decade, as a response to the global change that has occurred in the environment (O'Brien *et al.,* 2004). Vulnerability is a tool to assess the harmful impact of a given phenomenon on the environment or society. Thus vulnerability can be seen as a function of the character, magnitude and rate of natural resources change and variation to which a system is exposed, its sensitivity, and its adaptive capacity (Adger *et al.,* 2007; Boori and Amaro, 2010). It is based on exposure (linked to the character, the magnitude or the rate of the stressor), sensitivity characterises the first order effect of the stress. It determines the degree to which a system is adversely or beneficially affected by exposure to a stressor (Marshall *et al.,* 2010). Sensitivity is typically shaped by natural and/or physical attributes of the system including topography, the capacity of different soil types to resist erosion and land cover type. But it also refers to human activities which affect the physical constitution of a system, such as tillage systems, water management, resource depletion and population pressure (Fritzsche *et al.,* 2013).

Adaptive capacity: refers to the responses to the effect of the stress (Boori and Vozenilek, 2014), or the ability of the system to adjust after the stress or to cope. In the forest or natural vegetation context, adaptive strategies are those ecological functions that support adaptation processes to altered exposure conditions (Blatt *et al.,* 2011). The vulnerability assessment is then a useful tool to (i) identify existing and/or future general and specific problem in the area of investigation, (ii) raise awareness of existing and/or future problems, (iii) explore uncertainties related to possible future changes using scenarios (iv) and find management solutions that are robust under changing conditions (Zsuffa *et al.,* 2013). Vulnerability assessment has been widely implemented to understand the impact of climate change and natural hazards such as floods, wildfires, droughts, tsunami (IPCC *et al.,* 2007; Dubois *et al.,* 2011; Boateng, 2012; Becker *et al.,* 2014) on soil erosion or degradation (Imbrenda *et al.,* 2013; Kempena *et al.,* 2014), of land use change (Metzger *et al.,* 2006) on biodiversity and ecosystem services (Metzger *et al.,* 2006; Idinoba *et al.,* 2010; Reece *et al.,* 2013) and human (Locatelli *et al.,* 2008). The vulnerability assessment involves expert knowledge and stakeholders in the analytical framework to capture the actual or potential impact of the harm and locate the hotspot of exposure and identify the factors of vulnerability that should be considered in the assessment in a multi criteria decision tool and GIS-based tools (Aretano *et al.,* 2015). The vulnerability assessment, thus offers a potential visual output or results that can be useful for the scientific community and policy-makers, and local communities through spatial explicit representation of the vulnerability distribution. This allows local stakeholders after observation of the vulnerability map to well understand the problem and inform a guide to adaption strategies (Preston, 2009; Aretano *et al.,* 2015).Thus the aim of this study is to assess the natural vegetation vulnerability to cashew plantation expansion in the forest-savanna transition zone. Specifically, this paper in one hand assess land use/cover change between 2001 and 2015 by emphasising on cashew expansion, and in the other hand will analyse natural vegetation vulnerability to future cashew expansion. This work at terms will give accurate information to decision makers, for a better management of natural resources in the context of intensive agriculture practices.

MATERIALS AND METHODS

Study area: The study area is located within the forest-savanna transition ecological zone (latitudes 8˚26 N and 7˚20 N and longitudes 3˚32 W and 3˚28 W) (Figure 1). The average rainfall is between 800 mm and 1400 mm per annum, and average temperature ranging from 26˚C to 27˚C (Youan Ta, 2008). The mean monthly temperature is between 24˚C and 28.6˚C, with the highest value (more than 27 ˚C) occurring during the long dry season (Youan Ta, 2008). The relative humidity has a unimodal curve going from 82% during the rainy periods to the minima of 50% in January. The vegetation, reflecting its geographical and climatic position, is mainly made up of savanna woodlands, tree savanna and shrub savanna. The site which is under lateritic deposit is close to the Comoe National Park (Fournier, 1983). Many riparian forests are observed along the rivers whilst dense forest islands are scattered mainly on hilltops. Soils are mainly acrisols (82%) followed by luvisols and cambisols according to the FAO classification. that the soils are mainly disturbed or typical with hard ground (at middle or low depth) and with some eutrophic brown soils.

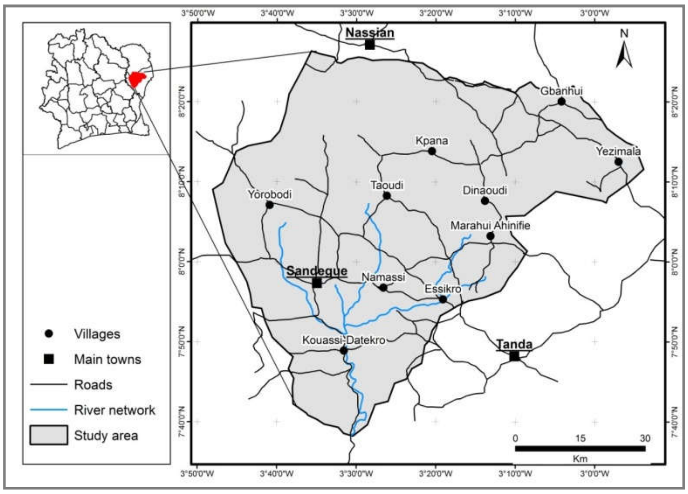

Figure 1.

Land use/cover change assessment: Two sets of 30 m spatial resolution Landsat imagery (ETM+, OLI) were used to analyse the trends in land use change at a watershed level. These images captured during the dry season (December to March) to assure free cloud images for the years 2001 and 2015, were acquired from http://www.usgs.gov/ web site. These images were pre-processed (radiometric and geometric corrections were performed on each Landsat scene, using Landsat 8 OLI as reference). False color composite and image enhancement methods (NDVI, Tasselled cap orthogonal transformation, PCA) were applied. Images were classified and the 2015cashew information was first interpreted and then used as basis to retrospect land use for the other years. About 520 control points that were collected on the field for accuracy assessment. Land use change dynamics algorithm was also used to evaluate the rate of change, its spatial distribution and change trajectories.

Assessing vegetation vulnerability to cashew expansion: Vulnerable area refers to areas susceptible to change from natural vegetation (forest, woodland, savanna) to cashew plantation. Thus criteria of vulnerability were identified in the context of the current study and their choice depends on their availability, their spatial distribution and also their contribution in the studied process. The stressor in this study is the cashew production and the system is the natural environment. Cashew has been identified as a non typical agroforestry system in which most trees are removed; the adaptive capacity of the environment cannot be conceived. Thus the vulnerability of the natural environment to cashew expansion will be only limited to the exposure and the sensitivity. The work was achieved through processes of data collection and model generation.

The exposure indicator: Exposure defined as the direct danger or the nature and extent of changes of the main stressor (ICRISAT, 2009), is represented by the ongoing cashew expansion process. The map of the stressor was based on the change in cashew areas between the year 2001 and 2015. Thus Land use map for 2001 and 2015 were generated based on satellite Lands at archive images classification procedure. Later map of rate of change in cashew areas where generated within each 1km x 1km pixel and the Jenkins break was used to classify and evaluate the level of exposure.

The sensitivity indicators: Sensitivity indicators represent all variables that contribute or worsen or trigger the stressor (Gbetibouo and Ringler, 2009). In the current situation, sensitivity factors are those that influence the cashew expansion process. Sensitivity map were generated through GIS multicriteria analysis through the following steps:

Identification of factors influencing cashew expansion: These factors reflect both natural potential and anthropogenic pressure. They are selected based on their contribution to the phenomenon, their availability, spatial patterns. There are: proximity to roads (DIST_RDS), proximity to villages (DIST_VIL) and proximity to existing cashew plantations (DIST_PL), population density (POP_DENS) as anthropogenic factors, and also elevation (ELEV), soil type (SOIL TYP), land cover (LND_COV) as biophysical components.

Normalisation and Classification: Criteria were normalised and classified to facilitate interpretation. These variables were transformed into a standardised unit and value range by the process of Normalisation. The following formula was applied:

$$X_{ij} = \frac{X_{ij} - \underset{i}{Min}(Xij)}{\underset{i}{Max}(Xij) - \underset{i}{Min}(Xij)}$$

Weighting Indicators: It defines the load of the indicators according to their contribution to the phenomenon being explained. The indicators were assigned weight using the AHP (Analytic Hierarchy Process) tools developed by Saaty (2008), which is based on experience and theoretical expert knowledge (Ercanoglu *et al.,* 2006). Thus a questionnaire was drawn and submitted to 50 experts and stakeholders from various environmental and agriculture related fields, i.e. soil science, forestry and agriculture experts, rural development technicians, member of cashew cooperative. The approach adopted by the study can be summarised in four main parts: development of the hierarchy, binary combination, development and prioritisation matrices, and test the consistency of the experts' judgments.

- Development of the hierarchy: For the development of the hierarchy, the parameters identified above were grouped in a homogeneous and all disposed in different levels. Each element of the same given level was then compared with all the other elements of the upper level. The different levels of AHP were:

  Level 0: general objective which evaluates the sensitivity of the natural vegetation to cashew expansion
  Level 1: decision criteria or analysis. Two decision criteria were selected. Saaty recommends limiting the number of decision criterion to seven (7) (Saaty, 1980)
  Level 2: refers to the characteristics of criteria. The characteristics of the criteria in this study were the various parameters contributing to the sensitivity of the natural vegetation to cashew expansion
  Level 3: constitutes the different alternatives under each criterion.

- Binary combination: In the case of the structure, three matrices are distinguished. The first two matrices, allow comparisons to be carried out in each element, and each criterion and the last matrix will allow comparison of each criterion by comparing with the overall goal. Thus, in a matrix, the element of the column is left successively compared to each element of the row of the matrix. If the comparison does not support the element on the left column in relation to an element of the line, assessment is expressed using the fraction or otherwise using a whole (Saaty, 2008).

- Development and prioritisation matrices**:** The principle of development in the following matrix is based first on determination of the eigenvectors (Vp) of each criterion for each item, and computation of the weighting coefficients (Cp) which sum must be equal to 1

$$Vp = \sqrt[K]{W1 \times .... \times Wk}$$

$$Cp = \frac{Vp}{Vp1 + ... + Vpk}$$

With k: number of parameters compared, Wk ratings of main parameters

- Test the consistency of the experts' judgments:Due to the subjectivity of the expert's judgments, the study adopted the following steps proposed by Saaty (1980) to assess the consistency level of experts, and thus to qualify the profile of each respondents in terms of consistency.

$$CI = \frac{\lambda_{\max} - n}{n - 1}$$

$$CR = \frac{CI}{RI}$$

$$\lambda_{\max} = \sum_{i=1}^{n} X_{ij} \times W_{ij}$$

Where CI is the consistency index, n the number of parameters, λ is the average of the eigenvalue of the normalized comparison matrix (λ_{max}), RI is the random index (Table 2).

Criteria aggregation: The weighted linear combination as suggested by Geneletti (2012) was selected as the aggregate. In this method the appropriate weight was applied to each factor and later all new weighted factors were combined by summation to yield the final sensitivity indicator map (Equation 29).

$$CI =_1 \times w_1 + I_2 \times w_2 + ... + I_n \times w_n$$

Where *CI* is the composite indicator, I_i is the indicator and W_i is the weight for each indicator *i*.

Mapping vegetation vulnerability: Later, the exposure and sensitivity maps were combined in the ARCGIS platform. The Jenks natural breaks classification was applied in order to minimize each class average deviation from the mean of the other groups (Jenks, 1967) and to determine the best arrangement of sensitivity and pressure values into five different classes (Aretano *et al.,* 2015). The final vulnerability map was derived using a simple combination of the exposure and sensitivity maps using the Raster calculator tool of ARGIS interface.

$$Vu\ln erability = Exposure \times Sensitivity$$

Table 1. The fundamental scale for pairwise comparisons (Saaty, 2008)

Scale	Judgment of preference	Description
1	Equally important	Two activities contribute equally to the objective
3	Moderately important	Experience and judgment slightly favour one activity over another
5	Important	Experience and judgment strongly important favour one over another
7	Very strongly important	An activity is favoured very strongly over another; its dominance demonstrated in practice
9	Extremely important	The evidence for favouring one activity over another is of the highest possible validity order of affirmation
2, 4, 6, 8	Intermediate preference between adjacent scales	When compromise is needed

Table 2. Random Index matrix of the same dimension (Saaty, 1991)

Number of criteria	2	3	4	5	6	7	8	9	10	11
RI	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

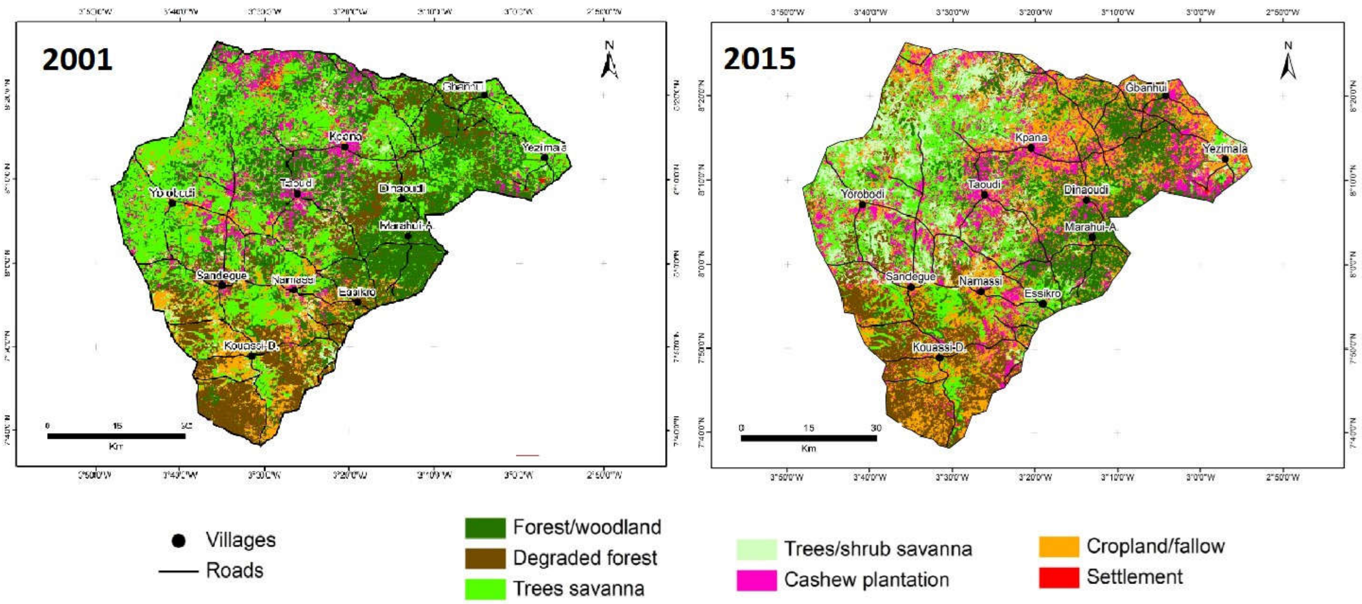

Figure 2.

RESULTS

State of Land use/cover change between the years 2001 and 2015

Analysis of land use maps (Figure 2) from 2001 to 2015 is presented in Table 3. Most of the land use changed either negatively for natural vegetation or positively for man-made environments. Forest/woodland, degraded forest and tree savanna cover decreased from 30%, 30% and 48% respectively, while trees/shrub, cashew plantation and cropland increased significantly during this period. Cashew recorded the highest rate of change estimated at 11.42% per year compared to the other land use classes. Nearly 48% of tree savanna was converted to other land use/ land cover classes with an annual rate of 5.47% per year. Tree/shrub savanna also increased to about 42121 ha at the highest annual rate of 11.42 ha/year. Forest area coverage declined from 25% to 17.69% of the total area; and degraded forest area (with 78059.3 ha in 2001) decreased by 29.36% in 2015 with annual rate of variation estimated at 2.9% per year. Cropland and fallow representing only a little more than 10% of the total landscape in 2001, increased to 24.19% in 2015 which represents an increase of about 138% compared to 2001. Its change rate was estimated at 7.24 ha/year. Cashew plantation showed an increase of 29160 ha from 2001 to 2015 corresponding to an annual rate of 4.53%/year of variation.

Land use/cover transition to cashew plantation

A general summary of the land use transition is presented in Table 4.Land transition with a "To" identifier based on statistical analysis on changed areas shows that during the 14-years time, conversion of land use/ land cover to cashew was about 15% of the total change. From 2001 to 2015 most of the new converted cashew areas were from tree savannas (31.06%) and forest/woodland (19.3%) and only 9.55% are cropland area. The analysis showed a great contribution of forest/woodland and tree savanna areas to cashew cropping areas.

Exposuremap

The exposure indicator was represented by the spatial distribution of change in cashew area from 2001 to 2015 (Figure 3). The very high exposure varied between 48 and 79.47% of change which covered only 3760.04 ha of 0.8% of the total area. The implication for natural vegetation is presented in Table 5. All natural vegetation, forest/woodland, tree savanna and tree/shrub savanna were under low to very low exposure to cashew expansion with 126790.1 ha (91.5%), 80410.5 ha (91.1%) and 51892.2 (91.9%), respectively.And less than 1% of each vegetation type was under high and very high exposure to cashew expansion with 1103.54 ha, 691.67 ha and 331.5 ha for forest/woodland, tree savanna and tree/shrub savanna, respectively.

Sensitivity map

Contribution of each factor to the natural vegetation sensitivity: The sensitivity indicators were weighted using Multicriteria analysis tools. The results of the AHP method based on expert's judgements are presented in Table 6.

Table 3. Change in areas of each land use/ land cover class between 2001 and 2015

Land use/ land cover classes	Area coverage in 2001		Area coverage in 2015		Change between 2001 and 2015		
	ha	%	ha	%	ha	%	Rate
FOR_WD	118364	25.00	83345.7	17.69	-35018	29.58	-2.92
DEG_FOR	78059.3	16.49	55140.91	11.70	-22918	29.36	-2.89
TR_SAV	170192.4	35.94	88282.08	18.74	-81910	48.13	-5.47
TR_SHR	14336.43	3.03	56457.8	11.98	42121	293	11.42
CASH_PL	40367.9	8.53	69527.91	14.76	29160	72	4.53
CROPLD	47797.36	10.09	113980.6	24.19	66183	138.5	7.24
SETTL	4394.62	0.93	4439.419	0.94	45	1.02	0.08

Table 4. Statistics of land use/ land cover transition to cashew with "To" identifiers

	To Cashew 2001-2015	
	ha	**%**
FOR_WD	13305.65	19.29
DEG_FOR	4443.43	6.44
TR_SAV	21425.13	31.06
TR_SHB	1114.75	1.62
CASH_PL	21476.46	31.13
CROP_LD	6584.66	9.55
SETTL	628.73	0.91

Table 5. Degree of exposure of all natural vegetation classes in ha and percentage

Class	Change	FOR_WD		TR_SAV		TR_SHR	
	%	ha	%	ha	%	ha	%
Very high	48-79.47	92.66799	0.1	32.25106	0.04	19.31036	0.03
High	28.91-48	1010.87	0.7	659.4221	0.7	312.1856	0.6
Medium	10.30-28.91	10594.82	7.7	7176.41	8.1	4233.107	7.5
Low	3.45-10.30	19002.4	13.7	15676.43	17.8	10902.54	19.3
Very Low	0-3.45	107787.7	77.8	64744.07	73.3	40989.61	72.6

Table 6. Factors contributing to the sensitivity of the natural vegetation to cashew plantation with their equivalent weight

Natural factors	Weight	Anthropogenic factors	Weight
ELEV	0.1	DIST_VIL	0.45
SOIL_TYP	0.26	DIST_RDS	0.16
LND_COV	0.64	DIST_PL	0.29
		POP_DENS	0.10
CR = 2%		CR = 1%	

Note that CR is the Consistency Ratio

Table 7. Distribution of sensitivity level of natural vegetation in ha and percentage

Class	FOR_WD		TR_SAV		TR_SHR	
	ha	%	ha	%	ha	%
Very high	6553476.0	41.8	18733.8	1.6	2625.4	0.7
High	7570711.2	48.3	258874.9	21.8	30886.2	7.7
Medium	1537693.3	9.8	638023.0	53.8	79237.2	19.8
Low	9875.6	0.1	252694.9	21.3	173766.4	43.4
Very Low	4549.3	0.03	17384.2	1.5	114043.3	28.5

Table 8. Distribution of natural vegetation vulnerability to cashew expansion

Class	FOR_WD		TR_SAV		TR_SHR		TOTAL	
	ha	%	ha	%	ha	%	ha	%
Very high	22523.81	16.26	4963.8	5.62	1036.11	1.84	28523.71	10.07
High	7153.443	5.17	5517.1	6.25	3885.1	6.88	16555.73	5.85
Medium	67256.14	48.56	14393	16.30	9327.9	16.52	90977.08	32.12
Low	8657.09	6.25	33077.67	37.47	20696.2	36.66	62431.03	22.04
Very Low	32898.03	23.76	30336.9	34.36	21511.3	38.10	84746.3	29.92

In allocating land for cashew production, land cover was the most influential factor among the natural environment factors with a weight of 0.64. Whereas elevation and soil type weights were estimated at 0.1 and 0.26, respectively. The experts' judgement for anthropogenic indicators were consistent (with a Consistency Ration CR = 2%). The contribution of human factors in land conversion to cashew plantation (Table 6) showed that population density does not contribute much to the process.

Proximity appeared as the major anthropogenic factors in the land use conversion process. Thus distance to villages and distance to old cashew plantation continued at 0.45 and 0.29, respectively. The load for distance to roads was only 0.16. The experts' judgments were consistent with a consistency ratio equal to 1% which was less than the 10% threshold proposed by Saaty (2008). Finally the experts were asked to score the contribution of the main indicators: natural and anthropogenic factors to the cashew expansion process.

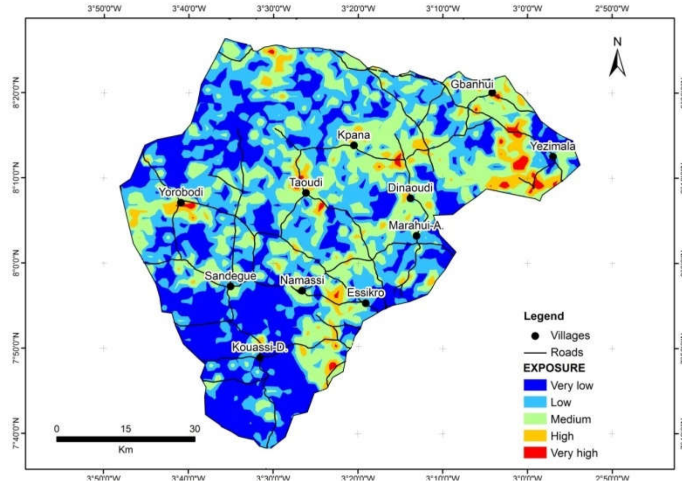

Figure 3.

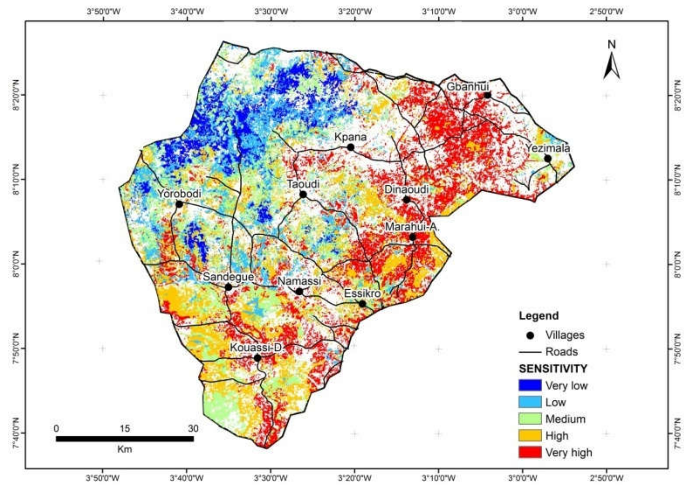

Figure 4.

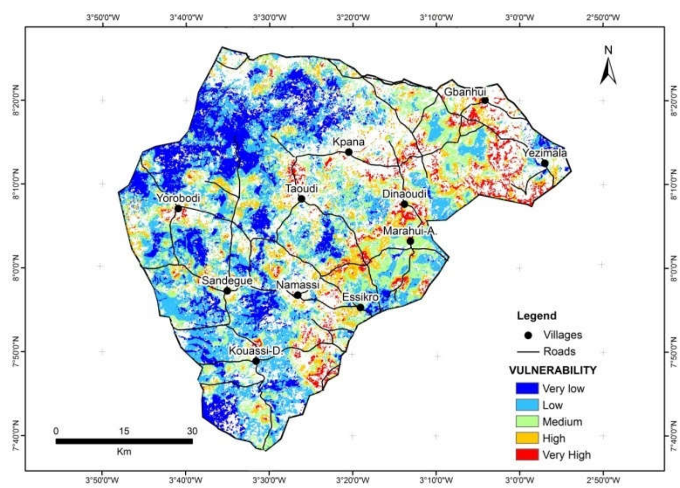

Figure 5.

The result showed that the two factors had the same contribution of 0.5 to the process. The consistency index ratio was equal to 0.001 which makes this result acceptable.

Natural vegetation sensitivity to cashew expansion:The sensitivity of each natural vegetation class is presented in Figure 4 and Table 7.It is observed that 41.8 % of the forest was under very high sensitivity, 48.3 % under high sensitivity and less than 9.8 under medium sensitivity (Table 7). For Tree savanna, 1.6 % was under very high sensitivity, 21.8 %, high sensitivity 53.8 % medium sensitivity and 21.3, low sensitivity. The Table showed that tree/shrub savanna was less sensitive than forest and tree savannas. Only 0.7 and 7.7 % of tree/shrub savanna was under very high and high sensitivity, respectively.

Overall vulnerability of natural vegetation to cashew crop

The following map showed the spatial distribution of the vulnerability of natural vegetation to cashew crop expansion (Figure 5). The detailed distribution of vulnerability of the area to cashew expansion is presented in Table 8 where it can be observed that forests present the largest area with the highest vulnerability compared to the other vegetation classes.For tree savanna areas vulnerability to cashew is relatively low with only 5.62% and 6.25 % of the area under high and very high vulnerability, respectively. Tree/shrub savannas had the least overall vulnerability. Only 16.52 % of this vegetation class was vulnerable to cashew expansion whilst 75 % was considered to have low or very low vulnerability.

DISCUSSION

In this study, anthropogenic and biophysical factors were used as key components to understand the eco-environmental system interaction. But these two factors are very difficult to combine in terms of contribution of each to the later process. The expert-based knowledge was used to compute the weight of each vulnerability indicator. At the end of the weighting process, both anthropogenic and biophysical indicators were assigned the same weight. This implied that both human and nature contribute equally to land allocation process through farmer's decision making. Critically, the significance the importance weights of particular indicators can vary significantly from place to place, depending on cultural characteristics, domestic policy, or other issues difficult to perceive in aggregated data (Eakin and Luers, 2006). In the current situation, this implies that both anthropogenic and biophysical context have to be taken into account in the understanding of the process and therefore in any related decision-making. The overall sensitivity indicator as a result of both biophysical and anthropogenic factors showed a decreasing order from forest/woodland to tree savannas and tree/shrub savannas. This was mainly related to the current trends of change observed during the last decade where forests areas were more converted to cashew plantations how it is in Guinea Bissau (Tumedo and Abrantes, 2014). In villages surrounded by forest areas where savanna is not widely spread, farmers have relied more on forest land to establish cashew since they realized that cashew does also well under forest/woodlands as in savanna area. Furthermore, forest/woodland is located in areas where there is high concentration of villages. Thus the high weight attributed to proximity to villages and roads have increased the forest sensitivity to cashew plantations. This situation was also noticed in the Denguele District where farmers affirmed that they are clearing forest to expand their cashew farms (Lebailly *et al.,* 2012). From the vulnerability map, only 15.95% of the total natural ecosystems is vulnerable to cashew expansion. Indeed, the vulnerability was a combination of natural vegetation exposure and sensitivity. Although more than 83.6% of the total areas is under high sensitivity to cashew expansion, generally these environments (91.5%) were mainly under low and very low exposure; principally because they were not located in areas where major cashew change occurred. Thus the combination resulted in only 16% of high vulnerable areas. The low exposure did strongly contribute to the reduction of the threat. Indeed, forest/woodland biodiversity and carbon stocks are much higher than tree savanna and tree/shrub savanna. Thus more forest/woodland under high vulnerability to cashew expansion, will then contribute to a significant decrease in carbon stocks and biodiversity. For savannas, which have less area under high vulnerability, the carbon likely to be lost might be later recovered by cashew plantations. Though few areas are under high vulnerability, an early conservation strategy has to be implemented in order to protect and above all anticipate the future possible variation of the threat. This calls for the concept of reactive and proactive response in the process of prioritisation of the biodiversity conservation strategy as explained by Brook *et al*. (2006). Their study prescribed reactive strategies for areas under high vulnerability with high biodiversity and crisis regions and proactive strategies for those with low vulnerability but including high biodiversity areas. As suggested by Phalan *et al*. (2010), the areas under low vulnerability have not yet been used not because they are not uncultivable but rather because the socio-economic and political contexts have not promoted conversion so far. However the upcoming land demand for agricultural expansion driven by a continuing global market change would increase pressure on the low vulnerable areas and shift them under high vulnerability. Indeed in the current government policy about cashew production, farmers are encouraged to increase their production and other initiatives including cashew values addition. This will surely increase the land demand for cashew production with its implicit clearance for more fertile and forest lands by farmers (Lebailly *et al.,* 2012). Thus conservation measures should be a priority for both high and low vulnerable areas.

CONCLUSION

The assessment of land use/cover dynamics from 2001 to 2015 showed a decrease in natural vegetation (Forest/woodland, degraded forest and tree savanna cover) at the expense of agriculture areas (mainly cashew plantations). During this period, nearly 20% and 31% of cashew areas were previously forested lands and trees savannas areas, respectively. Whereas only 9.55 % and 6.44 % of the land converted to cashew was tree/shrub savannas and degraded forest respectively. The risks posed to the forest savanna transitional zone, by cashew production as evaluated using the vulnerability assessment tool which includes exposure and sensitivity concepts, does not appear to be high. The analysis showed that most (> 90%) of the natural vegetation; forest/woodland, tree savanna and tree/shrub savanna were under low exposure to cashew expansion. Even though, the sensitivity presented a different trend with more than 90% of forest/woodland areas for instance being under high and very high sensitivity, the combination of exposure and sensitivity maps resulted in a vulnerability of natural vegetation to cashew expansion that was considered low to moderate. Generally, about 16% of the natural vegetation is under high to very high vulnerability. Specific vegetation vulnerability was in the descending order of forest/woodland, tree savanna, and tree/shrub savanna. Therefore cashew expansion is of higher threat to more woody vegetation which has serious implication in terms of conservation and carbon emissions.

Funding: The authors are grateful to German Ministry of Science and Education (BMBF) through WASCAL for fully funding this research.

Conflict of interest: The authors declare that they have no conflict of interest.

Glossary of abbreviations

AHP: Analytic Hierarchic Process
CASH_PL: Cashew plantation
CROPLD: Cropland/Fallow
DEG_FOR: Degraded Forest
DIST_PL: proximity to existing cashew plantations
DIST_RDS: Proximity to Roads
DIST_VIL: proximity to villages
ETM+ : Enhanced Thematic Mapper Plus
FAO: Food and Agriculture Organisation of the United Nations
GIS: Geographic Information Systems
IPCC: Intergovernmental Panel on Climate Change
OLI : Operational Land Imager
NDVI : Normal Difference Vegetation Index
PCA : Principal Components Analysis
ICRISAT: International Crops Research Institute for the Semi-Arid-Tropics
POP_DENS: Population density
ELEV: Elevation
SOIL TYP: Soil type
LND_COV:Land cover
FOR_WD: Forest/Woodland
SETTL: Settlement
TR_SAV: Trees savanna
TR_SHR: Trees/shrub savanna

REFERENCES

Adger, W. N., Agrawala, S., Mirza, M. M. Q., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit, B. and Takahashi, K. 2007. Assessment of adaptation practices, options, constraints and capacity. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

Aretano, R., Semeraro, T., Petrosillo, I., De Marco, A., Pasimeni, M. R. and Zurlini, G. 2015. Mapping ecological vulnerability to fire for effective conservation management of natural protected areas. Ecological Modelling, 295, 163-175.

Becker, D., Renner, K. and Schneiderbauer 2014. Assessing and Mapping Climate Change Vulnerability with the Help of GIS: Example of Burundi. In: Vogler, R., Car, A., Strobl, J. and Griesebner, G. (eds.) GI_Forum 2014. Geospatial Innovation for Society.

Blatt, J., Ellner, B., Kreft, S., Strixner, L., Luthardt, V. and Ibisch, P. 2011. A methodological approach for an index-based analysis for Brandenburg (northeastern Germany). In: Eberswalde University for Sustainable Development (University of Applied Sciences), G. (ed.).

Boateng, I. 2012. GIS assessment of coastal vulnerability to climate change and coastal adaption planning in Vietnam. Journal of Coastal Conservation 16 (1), 25-36.

Boori, M. S. and Amaro, V. E. 2010. Detecting and understanding drivers of natural and ecoenvironmental vulnerability due to hydro geophysical parameters, ecosystem and land use change through multispectral satellite data sets in Apodi estuarine, Northeast Brazil. International Journal of Environmental Sciences, 1 (4), 15.

Boori, M. S. and Vozenilek, V. 2014. Land Use/Cover, Vulnerability Index and Exposer Intensity. Journal of Environments, 1 (1), 7.

Brooks, T. M., Mittermeier, R. A., da Fonseca, G. A. B., Gerlach, J., Hoffmann, M., Lamoreux, J. F., Mittermeier, C. G., Pilgrim, J. D. and Rodrigues, A. S. 2006. Global biodiversity conservation priorities. Science, 313 (5783), 58-61.

Dale, V. H. and Polasky, S. 2007. Measures of the effects of agricultural practices on ecosystem services. Ecological economics, 64, 11.

Dubois, N., Caldas, A., Boshoven, J. and Delach, A. 2011. Integrating Cliamte Change Vulnerability Assessments into Adaptation Planning: A case study Using the NatureServe Climate Change Vulnerability Index to inform Conservation Planning for species in Florida , Washington D.C.

Eakin, H. and Luers, A. L. 2006. Assessing the Vulnerability of Social-Environmental Systems. Annual Review Environment Resources, 31, 365-394.

Ercanoglu, M., Weber, K. T., Langille, J. and Neves, R. 2006. Modeling Wild Land Fire Susceptibility Using Fuzzy Systems. GIScience and Remote Sensing, 43 (16), 268.

Fritzsche, K., Schneiderbauer, S., Bubeck, P., Kienberger, S., Buth, M., Zebisch, B. and Kahlenborn, W. 2013. The Vulnerabilit Sourcebook. Concept and Guidelines for standardised vulnerabilty assessments. 180.

Gbetibouo, G. and Ringler, C. 2009. Mapping South african Farming sector Vulnerability to Climate Change and Variability. International Food Policy Research Institute.

Geneletti, D. 2012. Multicriteria analysis to compare the impact of alternative road corridors: a case study in the northen Italy. Impact Assessment and Project Appraisal, 23 (2). 135-146.

Goetze, D., Horsch, B. and Porembski, S. 2006. Dynamics of forest-savanna mosaics in north-eastern Ivory Coast 1954 to 2002. Journal of Biogeography (J.Biogeogr.), 33, 653-664.

ICRISAT 2009. Quantitative assessment of Vulnerability to Climate Change (Computation of Vulnerability Indices). ICRISAT, pp 31.

Idinoba, M., Nkem, J., Kalame, F. B., Tachie-Obeng, E. and Gyampoh, B. 2010. Dealing with reducing trends in forest ecosystem services through a vulnerability assessment and planned adaptation actions African Journal of Environmental Science and Technology, 4 (7), 419-429.

Imbrenda, V., D'Emilio, M., Lanfredi, M., Simoniello, T., Ragosta, M. and Macchiato, M. 2013. Integrated Indicators for the Estimation of Vulnerability to Land Degradation.

IPCC, Adger, W. N., Agrawala, S., Mirza, M. M. Q., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit, B. and K., T. 2007. Assessment of adaptation practices, options, constraints and capacity. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

Jenks, G. F. 1967. The Data Model Concept in Statistical Mapping. International Yearbook of Cartography, 7. 186-190.

Kempena, A., Boudzoumou, F., Nganga, D. and Ray, H. 2014. Cartography of environmental vulnerability to soil erosion of the urban area of Brazzaville using Geographic Infromation System (GIS). International Research Journal of Environment Sciences, 3 (5), 9.

Lawal, J. O., Oduwwole, O. O., Shittu, T. R. and Muyiwa, A. A. 2011. Profitability of value adistion to cashew farming households in Nigeria. African Crop Science Journal, 19 (1), 6.

Lebailly, P., Lynn, S. and Seri, H. 2012. Etude pour la préparation d'une stratégie pour le développement de la filière anacarde en Côte d'Ivoire. Programme FED de l'Union Europeenne pour la Cote d'Ivoire. AGRER Consortium.

Locatelli, B., Hety Herawati, H., Brockhaus, M., Idinoba, M. and Kanninen, M. 2008. Methods and Tools for Assessing the Vulnerability of Forests and People to Climate Change. An Introduction. CIFOR Working Paper No. 43, 24.

Malhotra, S. P. 2008. World Edible Nuts Economy.

Marshall, N. A., Marshall, P. A., Tamelander, J., Obura, D., Malleret-King, D. and Cinner, J. E. 2010. A framework for social adaptation to climate change: Sustaining tropical coastal communities and industries. IUCN, Gland.

Metzger, J., Rounsevell, M. D. A., Acosta-Michlik, L., Leemans, R. and Schroter, D. 2006. The vulnerability of ecosystem services to land use change. Agriculture, Ecosystems and Environment, 114, 69–85.

O'Brien, K., Leichenko, R., Kelkar, U., Venema, H., Aandahl, G., Tompkinsa, H., Javedc, A., Bhadwalc, S., Bargd, S., Nygaarda, L. and Westa, J. 2004. Mapping vulnerability to multiple stressors: climate change and globalisation in India. Global Environnmental Change, 14 (4), 303-313.

Preston, B. L., Brooke, C., Measham, T.G., Smith, T.F., Gorddard, R., 2009. Igniting change in local government: lessons learned from a bushfire vulnerability assessment. Mitig. Adapt. Strat. Global 14 (3), 251-283.

Reece, J. S., Noss, R. F., Oetting, J., Hoctor, T. and Volk, M. 2013. A Vulnerability Assessment of 300 Species in Florida: Threats from Sea Level Rise, Land Use, and Climate Change. PLoS ONE 8 (11): e80658. doi:10.1371/journal.pone.0080658.

Rubber Research Institute of India, Cochin (2005), pp. 246-255.

Saaty, T. L. 1980. The analytic hierarchy process. McGraw-Hill, New-York.,

Saaty, T. L. 1991. Some mathematical concepts of the Analytic Hierarchy Process. Behaviormetrika, 29, 1-9.

Saaty, T. L. 2008. Decision making with the analytic hierarchy process. Int. J. Services Sciences, 1 (1):83-98.

Smith, P., Gregory, P. J., van Vuuren, D., Obersteiner, M., Havlik, P., Rounsevell, M., Woods, J., Stehfest, E. and Baellarby, J. 2010. Competition for land. Philosophical Transactions of the Royal Society B-Biological Sciences, 365, 17.

Sohl, T. L.; Sleeter, B. M.; Sayler, K. L.; Bouchard, M. A.; Reker, R. R.; Bennett, S. L.; Sleeter, R. R.; Kanengieter, R. L.; and Zhu, Z. 2012. Spatially explicit land-use and land-cover scenarios for the Great Plains of the United States. Agriculture, Ecosystems, Environments 153, 1–15.

Tumedo, M. P. and Abrantes, M. 2014. The Cashew Frontier in Guinea-Bissau, West Africa: Changing Landscapes and Livelihooods. Human Ecology, 42, 14.

Venkattakumar, R. 2009. Socio-Economic Factors for Cashew Production and Implicative Strategies : An Overview. Indian Res. J. Ext. Edu., 9 (3), 8.

Youan Ta, M. 2008. Contribution de la télédétection et des systèmes d'informations géographiques à la prospection hydrogéologique du socle précambrien d'Afrique de l'Ouest : cas de la région de Bondoukou (Nord-Est de la Côte d'Ivoire).Thèse de Doctorat de l'Université de Cocody (Abidjan), Côte d'Ivoire., 259.

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