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RESEARCH PAPER

Multi-criteria mapping of degraded lands in the communes of Bembèrèkè and Sinendé in North Benin

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Abstract

To monitor the progression of land degradation in dry tropical environments, spatial tools such as remote sensing and geographic information systems (GIS) seem to be preferred. This study aims to map the degraded lands of the commune's of Bembèrèkè and Sinendé in northeastern Benin. The main method used to achieve this combines the cartographic approach with multi-criteria analysis. Three indices were calculated from vector and raster data and represented in the form of maps. The first index is the RDPI (Relative Degradation Prediction Index), the second is the LUI (Watershed Occupancy Index) and the third is the CDI (Composite Degradation Index). The results show that areas of high degradation coincide with areas of friable and erodible lithology established on significantly steep slopes. It is a physical degradation due to water erosion of bare soil or very little natural vegetation. This type of degradation affects about 28% of the land in the study area, i.e. 1,541 km² of land. The sectors subject to moderate degradation are located in agricultural land. These are areas of crops and fallow land, the main cause of deforestation. Moderately degraded areas represent about 31% for the study sector, i.e. 1,699 km² of land concerned. These are mostly areas subject to biological degradation marked by a decrease in organic matter and biomass. Lands with low degradation correspond to sectors of low demographic weight with an important plant cover. They cover about 41% of the land, i.e. 2,253 km² of the middle land. In these sectors, the density of roads and population is low and the proportion of cultivated land is lower than the proportion of plant cover. The subsistence of the populations is thus increasingly threatened by soil losses.

Keywords: Land degradation, slope, GIS, Composite Degradation Index, North-Benin

Introduction

Soil is a living environment where biological processes vital to the continuity of life on earth take place. It constitutes, in fact, the basis of almost all our food and forest resources. Erosion has been shaping the earth since it emerged and for more than seven millennia, man has been struggling to fight against erosion to protect his land against the aggressiveness of rain and runoff, Boughalem (2013).

Humanity is now facing a global problem: desertification, both a natural phenomenon and a process linked to human activities. Never have the planet and natural ecosystems been so degraded by our presence. Long considered as a local problem, desertification is now part of the global issues for which we are all concerned, scientists or not, political decision-makers or not, inhabitants of the South as well as of the North (Brabant, 2010). Land degradation, which reduces or destroys the capacity of soils to be productive, is one of the major problems for the future of an increasingly anthropized planet. It is therefore normal that this problem is of great concern to the scientific authorities of our time. The international community has long been aware that desertification poses a serious economic, social and environmental problem for many countries in all regions of the world and particularly in sub-Saharan Africa (Boukheir et al., 2001).

The phenomenon of land degradation affects and threatens the agro-sylvio-pastoral areas of our country and water erosion presents the most important form of physical soil degradation affecting the relief, soil production and slope stability (B. Remini, 2000). Soil erosion by rainfall and runoff is a widespread phenomenon in the different countries (Boukheir et al., 2001). It results from agricultural intensification, land degradation and very high climatic variations. Such degradation is inherent, first of all, to the location of land on the very surface of the globe (the soil is indeed the Earth's epidermis); this puts it in direct contact, on the one hand, with the natural atmospheric elements and, on the other hand, with the various actions related to the most common human interventions (agriculture, livestock, pastoralism, road building, airports, residential buildings...); The latter have certainly ensured the life of mankind on our planet for a long time, but they can also cause either their disappearance (erosion), or an insidious degrading evolution by modifying the physical, chemical and biological properties of the soil, or simply put them out of action (constructions) (MCDD, 2017).

In Benin, land degradation is a problem that today compromises the development and even the survival of the population. The degradation of the vegetation cover is by far the most important phenomenon and is due to itinerant cultivation on burnt land, the action of transhumant herds, logging (production of wood for domestic energy, constructions and furniture) and vegetation fires. Soil and water conservation must be a national priority in countries south of the Sahara as it is the essential foundation for agricultural growth. It is also an important determinant of family and national food security (CPRS, 2007). The agricultural sector is of paramount importance for the strengthening of Benin's economy as it contributes an average of 32.5% of GDP, 75% of export earnings, 15% of government revenue and provides about 70% of employment (PSRSA Evaluation Report, 2016). It is therefore considered to be the sector whose many potentialities must be judiciously exploited to support national economic growth and thus contribute to effectively combating poverty (FAO and ECOWAS Commission, 2018). Taking stock of the consequences of desertification due to land degradation in Benin, the National Director for Environment and Climate Appolinaire Gnanvi, listed among others food insecurity, poverty, reduced water availability, increased vulnerability to climate change, and forced population immigration, loss of organic matter through erosion. He went on to argue that 24% of the world's agricultural land is degraded. In Benin, there are inadequate agricultural practices, which implies that 29 to 33% of the land is in a state of high and medium degradation respectively. Soils are highly degraded in the north of Benin, 84% of the land in the far north and 40% in the north. According to the director, these data call for a commitment to a campaign to reinvest the land (Lawin and Tamini, 2018).

Most of the cropping systems used lead to soil degradation (Baco et al., 2012). As a result, crop yields and the sustainability of the production system are compromised, exposing the population to risks of food insecurity, particularly in the northern part of the country. According to the ELD about one third of arable land is currently affected by degradation and desertification worldwide (ELD Initiative 2015). A recent analysis of several datasets and the approaches used for their development (e.g. expert opinion, net primary satellite data, biophysical models and abandoned cropland) was carried out by Gibbs and Salmon. They show that estimates of the area of degraded land worldwide range from 1 billion hectares to 6 billion hectares, depending on the database and methodology used (ELD Initiative 2017).

In the North of the country in general and in the commune’s of Bembèrèkè and Sinendé in particular the majority of tropical ferruginous soils are leached and characterized by low organic matter content, sandy texture, and a structure with a tendency to particulate matter. Land degradation is a problem that today compromises the development and even the survival of the population if we are not careful. The degradation of the vegetation cover is by far the most important phenomenon and is due to slash and burn agriculture, transhumant herding practices, logging (production of wood for domestic energy, construction and furniture) and wildfires (Egah et al., 2014). The uncontrolled exploitation of forest ecosystems for agricultural and urbanization purposes, imparts a strong dynamic of land use and land use that leads to deforestation and land degradation (Mama et al., 2020). This deforestation is one of the main causes of poor crop yields as soon as regular rainfall is no longer assured. The soil dries out rapidly and plants wilt. The main causes of negative land degradation trends are : rapid population growth, extensive farming and mining practices, political incentives for extensive agriculture, uncontrolled wood exploitation (charcoal, fuelwood and timber production), quarrying, uncontrolled urbanization, transhumance and overgrazing, solid and household waste, and wildfires, land tenure insecurity, shortcomings in forest monitoring and management mechanisms associated with the non-application of texts, shortcomings in the monitoring mechanisms of environmental and social management plans (ESMPs) associated with poor application of the relevant texts, soil erosion, congestion and silting of watercourses, and poverty (MCDD, 2017).

Anti-erosion development projects are not always adapted to local conditions, which leads to their failure since they introduce techniques in rural areas that are too costly, inefficient and not acceptable to producers, and increase the sensitivity of the land to degradation. Therefore, monitoring land degradation at the local scale through a multi-criteria mapping approach would be a good alternative. Remote sensing and Geographic

Information Systems (GIS) are a privileged tool for the localization and monitoring of the phenomenon. This study aims at mapping the degraded lands of the commune of Bembèrèkè and Sinendé in the north-east of Benin in a multi-criteria approach.

Materials and methods

Study area

Located in the extreme north of the department of Borgou, the study area covers an area of 5,492 km², or about 21.79% of the department's surface area and 2.90% of the national territory.

Between 9°57' and 10°31' north latitude and between 2°4' and 2°7' east longitude, it is limited to the north by the commune of Gogounou in the Alibori department, to the south by that of N'Dali, to the east by the communes of Kalalé and Nikki, and to the west by the commune of Péhunco in the Atacora department. Approximately 21.78% of the area in the middle is occupied by the Classified Forests of the Three Rivers, Ouénou Bénou and Upper Alibori, i.e. 1,196 km² of the total area (Figure 1).

The well-diversified vegetation is composed of wooded savannas, trees and shrubs with clear forests in places. Fields and fallows are made up of food and subsistence crops such as yam (Dioscorea spp), sorghum (Sorghum bicolor), etc. The fields and fallow land are made up of a variety of food and subsistence crops. Various economic activities are carried out in this area, but the most important one is agriculture, which employs about 78% of the active population. The area also hosts agricultural settlers from the departments of Atacora and Donga. In the past they were seasonal migrants but nowadays they have settled permanently. Tropical ferruginous soils occupy the greater part of the study area with more than 5,122 km². These are soils of very important agricultural aptitudes, suitable for the development of several crops. The study area is part of the humid Sudanian zone with two distinct seasons: a dry season and a wet season. The first extends from November to April and the second from May to October. The maximum rainfall is in August and can reach 1,350 mm. In general, the average temperature is around 29° and rises in the months of March to May to 40° (ASECNA, 2019). The average insolation is between 9 and 11 hours per day.

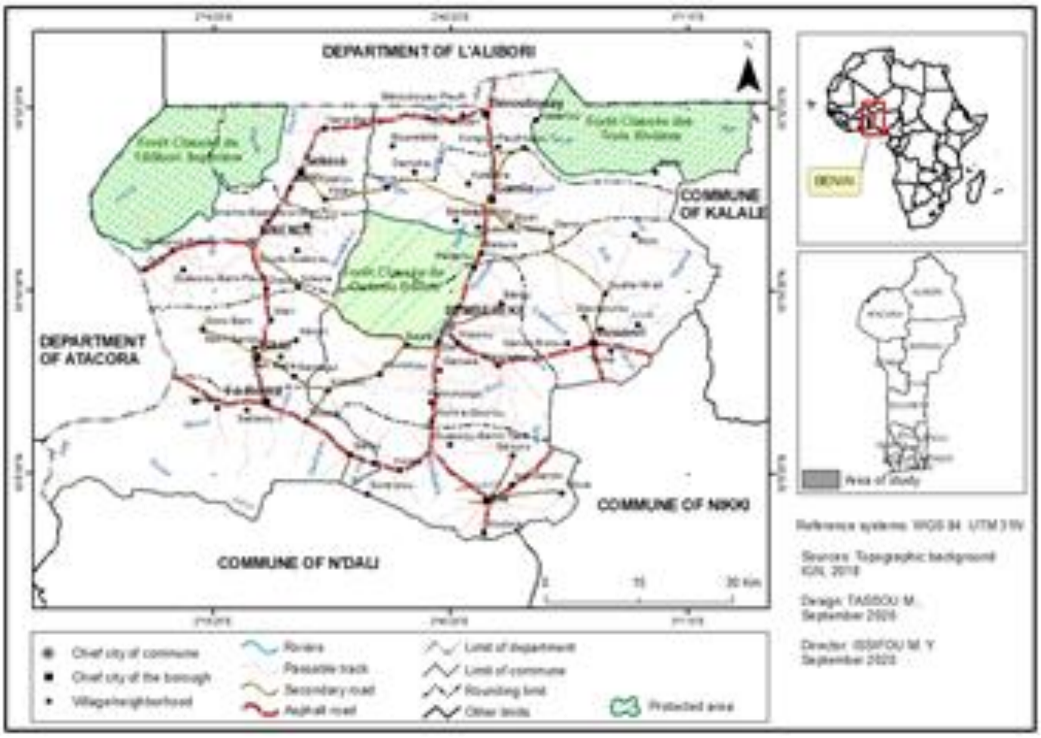

Figure 1: Geographic location of the study area

Data used

Two types of data are used: vector data and raster data relating to biophysical and anthropogenic factors. Five main biophysical factors are used including: slope, land use, rainfall intensity and seasonality, and soil types.

The slope was extracted from the 2015 SRTM images at 25m resolution, while the land cover data was extracted from the 2015 SPOT 7 images at 6m resolution, classified from the project "Observation of Central and West African Forests (OSAFCO)" from which the forest cover and deforestation rates were generated. The intensity of rainfall refers to the energy of the drops that reach the ground while the seasonality of rainfall refers rather to the interception of raindrops by vegetation (Paul-Hus, 2011). To determine rainfall intensity the following formula was used, based on Ahiepkor (2011): $R = 0.5 \times P \times 1.735$ with R (erosivity) of the USLE and (P) the mean value of annual rainfall. To evaluate the seasonality of rainfall, Fournier proposes a ratio: p2/P adopted by Atherton et al (2005). The variable p is the monthly average of the highest rainfall accumulation of the year. P is represented by the annual average rainfall. Precipitation data are obtained from ASECNA in 2019. Speaking of soil types, vector data are obtained from IGN Benin. These data come from the reconnaissance soil map of Benin at 1/200,000 by M. Viennot (1978), the only soil map of Benin that exists to date. In order to describe soil types, a soil classification index developed by Watling (1994) was applied. From this index, erodibility values were assigned by Atherton et al. (2005).

The density of roads, the density of watercourses, the rate of forest cover, the rate of deforestation and the demographic weight constitute the anthropic factors considered in this study. The density of roads and watercourses per square kilometer is deduced from the topographic vectorial data of IGN Benin of 2018. On the other hand, the demographic weight is calculated from the demographic data of the fourth general census of population and housing RGPH4 of the INSAE 2013.

Methods used

Using GIS, multiple methods have been developed around the world to describe the environment and to study the phenomenon of erosion. These methods, often based on spatial analysis, allow a better understanding and evaluation of this environmental problem in a multi-criteria approach. Depending on the risks involved, follow-up and monitoring methods can be set up to ensure the protection of people, the environment and property.

Multi-criteria analysis is another method frequently used for the analysis of problems including qualitative and/or quantitative aspects. This tool makes it possible to evaluate the relative importance of all the factors considered.

Several methods have been developed throughout the world to describe the environment and to study the phenomenon of erosion and land degradation. The best known are: the Universal Soil Loss Equation (USLE) method of Wischmeier (1959, p 247); the SIBERIA land evolution model (Willgoose and Riley, 1993); the KINematic Runoff and EROsion event model (Wahlstrom et al., 1999); the Water Erosion Prediction Project (WEPP) model (Bhuyan et al., 1999; 2002); the Water Erosion Model in a semi-arid environment of Forte Energie de Relief (Tidiane et al., 2003); the "soil erosion" hazard mapping models (Batti, 2005) and the three-index method for estimating soil degradation (Atherton et al., 2005). These methods, often based on spatial analysis, enable a better understanding and evaluation of this environmental issue.

In this study, land degradation was studied using the method of Atherton et al. (2005). This method was chosen because it integrates in addition to natural parameters, a set of anthropogenic parameters whose presence is quite decisive in the degradation process and especially because of the ease of its application. To characterize land degradation, Atherton et al (2005) calculated three indices from vector and raster data. Each index is represented in the form of maps. The first index, the RDPI (Relative Erosion Prediction Index, renamed Relative Degradation Prediction Index), aims to predict soil degradability based on biophysical parameters (i.e. slope, land use, rainfall intensity and seasonality, and soil erodibility). The second index, the LUI (Watershed Development Index, renamed Land Use Index) is obtained from anthropogenic parameters such as road density, yard density, population weight, forest cover and deforestation rate. The last index, the CDI (Composite Erosion Index, renamed Composite Degradation Index), is represented by the sum of the results of the first two indices. The values obtained make it possible to characterize the degraded sectors.

Table 1 below presents a summary of the biophysical and anthropogenic factors considered to calculate the indices.

Table 1: Summary of biophysical and anthropogenic factors considered

Paramters	Classes	Description	SIG Code
CDI (Composite Degradation Index) = RDPI + LUI			
RDPI (Relative Degradation Prediction Index)			
Slope	0-5 %	Low	1
	5-15 %	Moderate	2
	≥ 15 %	Strong	3
Rainfall intensity	0 – 850 mm	Low	1
	851 – 997 mm	Moderate	2
	≥ 998 mm	Strong	3
Seasonality of rainfall	0-60 mm	Low	1
	61-70 mm	Moderate	2
	≥ 70 mm	Strong	3
Soil erodibility	Raw, low evolved and hydromorphic	Low	1
	Ferrallitic soils	Moderate	2
	Tropical ferruginous soils	Strong	3
Land use and land cover (1995-2019)	Forests	Very Low	0
	Savanna's	Low	1
	Crops and fallow lands	Moderate	2
	Agglomerations and bare soils	Strong	3
LUI (Land Use Index)			
Road density per km²	0 – 5	Low	1
	6 – 10	Moderate	2
	≥ 10	Strong	3
Density of watercourses per km²	0 -5	Low	1
	6 - 10	Moderate	2
	≥ 10	Strong	3
Forest cover rate	67 – 100 %	Low	1
	34 - 66 %	Moderate	2
	0 - 33 %	Strong	3
Deforestation rate	0 - 33 %	Low	1
	34 - 66 %	Moderate	2
	67 – 100 %	Strong	3
Demographic weight	< 5	Low	1
	5 - 15	Moderate	2
	≥ 15	Strong	3

Source: Adapted from Atherton et al (2005)

For each of the parameters taken into account in the assessment of the degraded areas, values (GIS) were assigned.

Calculation of the RDPI Index

The general methodology adopted by Atherton et al. (2005, p 11) and Paul-Hus (2011) is to assign GIS values to each class of the selected parameters based on their degree of degradability. Degrees of degradability are first expressed as qualitative ordinal values (low, moderate, strong). A quantitative ordinal value is then assigned to each class. The value "1" is given to the "low" class, the value "2" to the "moderate" class, and the value "3" to the "strong" class. The more the parameter is related to the degradation phenomenon, the greater its GIS value.

The RDPI index is obtained from these five environmental factors (slope, soil erodibility, rainfall seasonality, rainfall intensity and land use) by averaging and then summing the values (GIS) of the five parameters taken into account. The results obtained were then divided into three main classes (low, moderate, strong) based on a discretization of the "equal intervals" type.

Calculation of the LUI index

In addition to the RDPI index, Atherton et al (2005) developed the LUI index. As previously mentioned, this index looks at the degree of impact of human activities on the degradability of the environment. The parameters that make up the LUI index are the density of roads and rivers, the rate of forest cover, the rate of deforestation and the demographic weight that we have added because of its influence on anthropic activities. As with the LUI, GIS values are assigned to all classes for each of the parameters assessed. The results obtained were also divided into three main classes (low, moderate, strong) based on a discretization of the "equal intervals" type.

Determination of the Composite Degradation Index (CDI)

The CDI index, representing degradation, is based on the RDPI and LUI index's. These two index are first added together. The results are then classified into three main classes (low, moderate and high) according to the discretization of equal intervals. To the "Strong" class are added the "Strong" classes of the RDPI and LUI index's (even if they do not sum to "Strong"). Overall, the higher the RDPI and LUI, the higher the CDI (Table 2).

Table 2: Rules for Combining the RDPI and LUI

CDI	RDPI		
LUI	Low	Moderate	Strong
Low	Low / Low	Low / Moderate	Low / Strong
Moderate	Moderate / Low	Moderate / Moderate	Moderate / Strong
Strong	Strong / Low	Strong / Moderate	Strong / Strong

Source: Adapted from Atherton et al (2005)

The methods employed by Atherton et al (2005) were adapted to the local context of the study area and the available data in the study area. In addition, the majority of the rankings proposed by Atherton et al. (2005) have been modified or completely re-evaluated to better correspond to the local context of the communes of Bembèrèkè and Sinendé.

Results

Land Degradability Mapping for Biophysical and Anthropogenic Factors

Relative land degradation was assessed based on the physical characteristics of the environment on the one hand and human and demographic aspects on the other. The combination of the five biophysical parameters resulted in the Relative Land Degradation Index (RDPI) in Map A. For Map B, the summation of the GIS codes of the five anthropogenic parameters resulted in the Land Use Index (LUI) (Figure 2). Figure 2 shows the land degradability map for biophysical and anthropogenic factors.

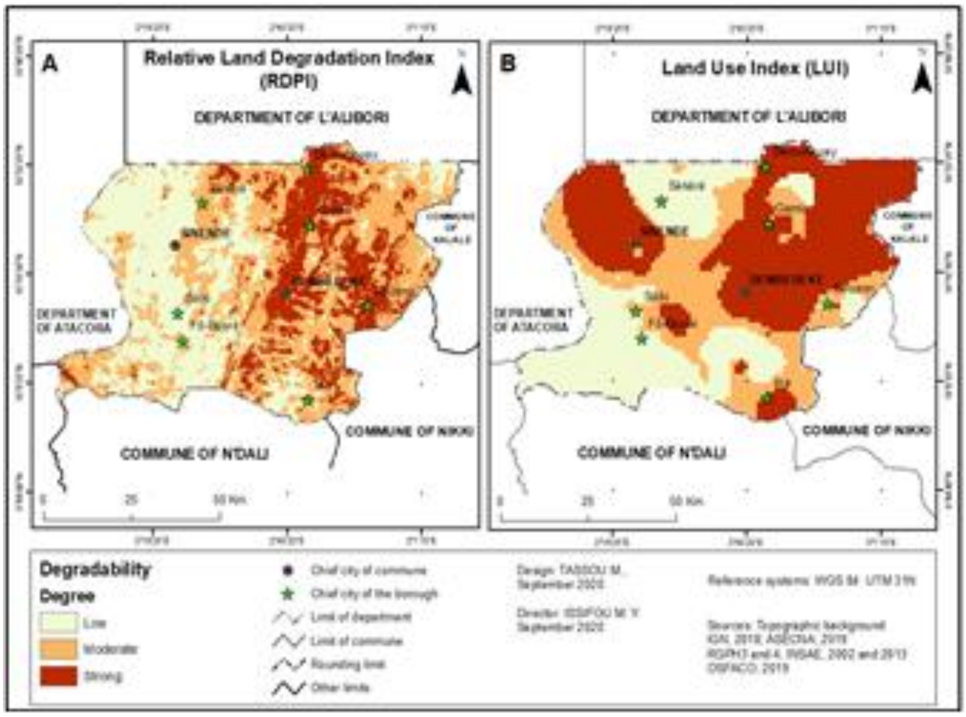

Figure 2: Degradability relative to biophysical and anthropogenic factors

The superimposition of land degradability zones with the physical characteristics of the environment (map A) shows a real concordance of areas of high degradability with a friable and erodible lithological nature (tropical ferruginous soils), slopes of average inclination (more than 15%) and especially bare land as well as agglomerations. On the other hand, areas of low degradability correspond to land that is mainly covered by vegetation. By the abundance of foliage, which reduces the kinetic energy of raindrops, the stems promote infiltration and the root network fixes the soil. The areas most exposed to high degradability are Bembèrèkè, Bouanri, Gamia, Béroubouay and to a lesser extent Sérèkè. Overall the cummune of Bembèrèkè is more exposed to degradability relative to biophysical factors than that of Sinendé.

It should be noted that the most influential physical factor is the slope in the study area, which is underpinned by the land use pattern. The analysis of degradability relative to anthropogenic factors (Map B) indicates high degradability in areas with low vegetation cover and high deforestation rates. Areas of high degradability are better suited to areas with high population density and high population density, which are highly anthropized areas. On the other hand, areas of low degradability coincide with less deforested areas with a high vegetation cover rate. These are the less populated sectors with a low demographic weight and low anthropization. The localities most sensitive to this type of degradability are those of Sinendé, Ina, Bembèrèkè, Gamia and Béroubouay.

It can be deduced that deforestation is the main factor in the relative degradability of land to anthropogenic factors, and is underpinned by demographic weight. The combination of these two types of degradability obtained from the calculation of the RDPI and LUI index made it possible to map the degraded land in the area using the Composite Degradation Index (CDI).

Degraded Land Mapping

Figure 3 shows the mapping of degraded areas in the communes of Bembèrèkè and Sinendé.

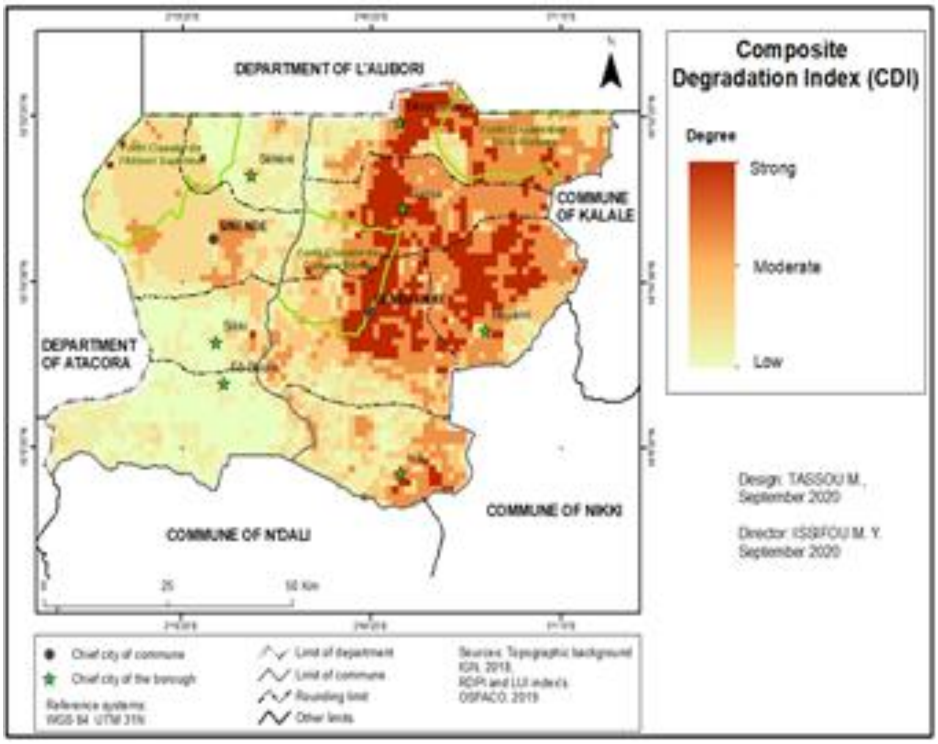

Figure 3: Location of degraded areas

From the analysis of Figure 3, it emerges that the heavily degraded sectors are located in the localities of Sinendé, Ina, Bembèrèkè, Gamia, Bouanri and Béroubouay. These sectors of strong degradation coincide with areas of friable and erodible lithology established on significantly steep slopes. It is a physical degradation due to water erosion of bare soil or very little natural vegetation. These are areas of very high density of roads, population and infrastructure. It contributes to the weakening of the soil structure inducing crusting, compaction, and erosion. This type of degradation affects about 28% of the land in the study area, i.e. 1,541 km² of land.

The sectors subject to moderate degradation are located in agricultural land. These are areas of crops and fallow land, the main cause of deforestation. In these areas the uncontrolled use of herbicides and pesticides makes the soil friable and porous. The direct consequence of this is an increase in surface runoff with probably an intensification of soil erosion. The consequent effects of deforestation and forest degradation is the reduction of the water retention capacity of natural plant formations and the exposure of land to erosion. Areas of moderate degradation represent about 31% of the study area, i.e. 1,699 km² of land concerned. These are mostly areas subject to biological degradation marked by a decrease in organic matter and biomass. These are cultivated lands regularly subjected to burning, chemical fertilization and the use of pesticides, and are thus witnessing a chemical pollution of the land. When the soil loses its nutrients, acidification is observed through the loss of bases such as calcium, magnesium and even iron. These elements are fundamental, however, because they possess several positive charges that allow them to create bridges between humus and clays, which are negative colloids.

Deprived of humus by the loss of organic matter and deprived of positive ions by the leaching of these elements, clays are no longer flocculated and will become suspended in runoff water. The biological degradation of agricultural soils leads to a loss of the nutritional value of food. Indeed, fertilizers are limited to 3 elements: N, P, K (nitrogen, phosphorus, and potassium). These promote the turgidity of plants but do not ensure a complete nutrition. If nothing is done to rehabilitate these degraded lands, we will witness a serious crisis of food insecurity. For only a living soil can properly feed people. Degraded soils only provide deficient nutrition and this is probably more serious than the pollution of our food by pesticides, dyes and antibiotics.

Low-degraded land corresponds to areas of low population weight with a high plant cover. They cover about 41% of the land, i.e. 2,253 km² of the middle land. In these sectors the density of roads and population is low and the proportion of cultivated land is lower than the proportion of plant cover. It is mostly land located in the protected areas whose conservation needs to be strengthened.

In spite of the uncertainties regarding the various data used, the parameters chosen seem to reflect fairly well the realities of the terrain. It would be judicious to validate the results obtained by laboratory tests on soil cores in order to confirm the chemical pollution of the soils.

Discussion

The Atherton and Allies method and the more global multi-criteria analysis have advantages and limitations. The RDPI and LUI indices are respectfully based on biophysical and anthropogenic factors. It is very relevant to clearly distinguish between degradation caused by natural phenomena and degradation triggered by human activities, as these are two real issues, which frequently meet. The use of qualitative data reduces, in some cases, the accuracy of the results obtained. When thresholds are established by specialists, qualitative data can sometimes facilitate analysis (C. Paul-Hus., 2011).

The most important advantage of multi-criteria analysis is its ability to simplify complex situations. Multi-criteria methods as employed by Atherton et al. (2005) consider that parameters vary continuously in space. In full aggregation methods, a synthesis index is used to represent the aggregation of all criteria. This implies that all criteria are measurable and that preferences are mathematically rational (EU, 2015). These methods establish a single criterion function, which is certainly the result of judgements made criterion by criterion, but which nonetheless amounts to a monocriterion aggregation. The lack of reliable data, over a sufficient period of time to set up and validate the methods may prove to be a handicap in certain situations. Moreover, by wanting to aggregate everything, these methods are likely to be nothing more than grinders crushing the nuances (S. Tahir, 2019). In this research, the method of Atherton et al. seemed to be adapted to the context of the study environment in relation to the data acquired and the various parameters taken into account. The multi-criteria analysis that was therefore favored allows a multitude of factors to be considered at the same time. However, it is criticized for being too subjective. Here, the results are nevertheless relevant.

The adaptation of the method of Atherton and allies made it possible to achieve the results presented and commented. The results obtained show that there is a real concordance of areas with high degradability with a friable and erodible lithological nature (tropical ferruginous soils), steep slopes (more than 15%) and especially bare land as well as agglomerations. On the other hand, the areas with low degradability correspond to land mainly covered by vegetation. Overall the commune of Bembèrèkè is more exposed to degradability relative to biophysical factors than Sinendé. It should be noted that the most influential physical factor is the slope in the study area, which is underpinned by the land use pattern. In the case of New Caledonia, C. Paul-Hus, (2011) observe that the role of slopes seems more realistic in the erosion process relative to natural factors.

The analysis of degradability relative to anthropogenic factors indicates strong degradability in areas with low vegetation cover and high deforestation rates. Degradability areas are more consistent with areas with high population density and high population density, which are areas with high anthropogenicity. It can be deduced that deforestation is the main factor in the relative degradability of land to anthropogenic factors, it is underpinned by demographic weight. In the commune's of Ouaké and Boukoumbé, J.Egal et al. (2014) observed that natural factors such as rainfall and relief, followed by anthropogenic factors such as farming and livestock practices, natural resource management methods and late wildfires were the two types of peasant perceptions of land degradation. The steep slope of the land was the most determining factor in soil degradation in the commune of Boukombé, while deforestation was the most important factor in the commune of Ouaké. The slope greatly influences the extent of erosion through its gravitational action and provides its erosive energy to water. Thus, the action of erosion increases strongly with the slope, because the detachment of particles is related to the square of the speed of the water. The inclination of the slope acts directly on the speed of runoff (P. Dumas, 2010). The process of erosion is closely linked to the land use pattern, which is a major contributor to its aggravation or attenuation. Land use determines the degree of soil protection. The influence of vegetation cover on linear erosion is thus very important. The condition of the vegetation cover directly influences the roughness of the soil. This depends in particular on the number of stems per square meter. A plant cover composed of herbaceous plants with numerous stems will be more effective in protecting the soil from runoff than trees (Babrant, 2015).

The severely degraded sectors are located in the localities of Sinendé, Ina, Bembèrèkè, Gamia, Bouanri and Béroubouay. These sectors of strong degradation coincide with areas of friable and erodible lithology established on significantly steep slopes. It is a physical degradation due to water erosion of bare soil or very little natural vegetation. These are areas of very high density of roads, population and infrastructure. It contributes to the weakening of the soil structure inducing crusting, compaction, and erosion. This type of degradation affects about 28% of the land in the study area, i.e. 1,541 km² of land. The National Action Program to Combat Desertification (PAN/LCD) has located the extremely degraded soils in Benin in the regions of Boukoumbé and Ouaké. Their condition is due to water erosion and wind erosion caused by the scarcity of plant cover. Their surface area is estimated at 1,240 km² (MCDD, 2017).

Sectors subject to moderate degradation are located in agricultural land. These are areas of crops and fallow land, the main cause of deforestation. In these areas the uncontrolled use of herbicides and pesticides makes the soil friable and porous. The direct consequence of this state of affairs is an increase in surface runoff with probably an intensification of soil erosion (L. Bourguignon, C. Bourguignon, 2015). These areas of moderate degradation represent about 31% for the study sector, i.e. 1,699 km² of land concerned. They are mostly sectors subject to biological degradation marked by a decrease in organic matter and biomass. In 1996, moderately degraded soils in the central-eastern and north-western Sudanian zone were found in the regions of Segbana, Gogounou, Kérou, Péhunco, Sinendé, Bembéréké, Kalalé, Nikki, N'Dali and Parakou; they cover 24% of the area of the zone, i.e. an area of 8,600 km² (DAT, 1996 cited by Mama et al., 2020). Areas characterized by steep slopes, highly erodible substrate and low plant protection show a high potential for soil loss.

Land with low degradation corresponds to areas of low demographic weight with significant plant cover. They cover about 41% of the land, i.e., 2,253 km² of the midlands. In these sectors the density of roads and population is low and the proportion of cultivated land is lower than that of the vegetation cover. In the Sudano-Sahelian zone of the far north, they have been identified between Toucountouna and the Mekrou, between Bassila and Patargo, and to the east of the Parakou-Pèrèrè-Nikki road axis, with an area of 14,045 km² (DAT, 1996). Overall, in Benin, housing and other artificial land has increased from 56,000 ha in 2000 to 87,400 ha in 2010, an increase of about 56 percent in 10 years (CENATEL, 2017). However, extensive agriculture and mining remain by far the main cause of land degradation, particularly of plant cover. Indeed, about 96% of the forests, savannahs and wetlands that disappeared between 2005 - 2015 are the result of the extension of agricultural land, compared to only less than 2.05% that have been transformed into housing and infrastructure (OSFACO, 2019). The occupation of agricultural land increased from 90,800 ha, or 8% of the national territory in 1993 (DAPS/MDR 1994), to 453,100 ha, or 40% of the national territory in 2010 (MCDD, 2017). The area of agricultural land in 2010 (453,100 ha) is more than double the total area of land deemed cultivable, according to a study by the Ministry of Rural Development in 1994 (DAPS/MDR, 1994). However, more recent data indicate that only 17% of arable land is currently in use: this means that the current unprecedented expansion of agriculture in forests and other protected areas of the state is not the result of a lack of cultivable land but rather of poor farming practices dominated by extensive, mining and slash-and-burn agriculture (APRM, 2011). As an indication, the forest area in Africa has declined from 705 to 624 million hectares, according to data published by FAO. On the other hand, global warming contributes to soil acidification, loss of plant cover, forest fires and erosion in all its forms (Sinsin, 2018). All in all, it has been estimated that soil degradation and desertification would contribute up to 30% of global greenhouse gas emissions by reducing the capture by vegetation (Tharcisse Guedegbe, 2018).

In Togo, mapping of degraded land based on vegetation indices revealed different intensities of degradation unevenly distributed between very low (0.6%), low (3.5%), moderate (41%), high (44.7%) and very high (10.2%) (Koffi et al., 2019). Despite the numerous studies carried out, it is sometimes difficult to choose precisely the most appropriate spectral indices (Tchibozo & Toundoh, 2014).

Conclusion

Multi-criteria mapping of degraded lands in the communes of Bembèrèkè and Sinendé using the method of Atherton and allies and multi-criteria analysis has made it possible to highlight the sectors where degradation is strong, moderate and weak. The discrimination of the derelict sectors was based on the degradability relative to biophysical factors on the one hand and anthropic factors on the other. This study has allowed to better understand the main parameters that influence the phenomenon of land degradation. It also allowed to distinguish between natural and anthropogenic degradation with the RDPI and LUI index. Although deforestation contributes strongly to the environmental degradation of the study area, physical degradation due to natural factors is also very active in this area.

This qualitative model was based on simple parameters representing the main natural and anthropogenic factors of degradation such as slope, soil type and vegetation cover, as well as demographic weight, deforestation rate and density of roads and watercourses. These parameters, integrated in a Geographic Information System (GIS), in the form of thematic information layers, have been qualitatively reclassified according to an erodibility indicator prioritizing their contribution to the degradation process. A multi-criteria analysis of these information layers, carried out using a geographic expert system, then made it possible to design the land degradation mapping according to the three levels of degradation determined in a qualitative way (strong, moderate and weak). This work leads to a better understanding of the spatial distribution of degradation and allows a relative comparison between the communes in the study area. This type of cartographic product can be used as a decision support tool for sustainable land management and land use planning. More globally, this spatial analysis tool can be integrated at several levels in the management process of degraded sites. Finally, this work does not make it possible to identify the causes of degradation or to understand the dysfunction of these ecosystems and whether the risk of degradation is irreversible, which would require long-term analyses. Nevertheless, the proposed methodology, if included in a long-term monitoring system, could contribute to the management of land degradation.

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