Method Article

Design, characterization and geospatial analysis of physical and socio-economic indicators of anthropogenic pressures on protected areas in Africa

Abstract

In Africa, the predominance of agropastoral activity and poverty in rural areas lead to strong anthropogenic pressures on protected areas and to their quick degradation. Efficient conservation of protected areas and sustainable exploitation of natural resources require therefore adaptive and dynamic management that integrates peripheral socio-economic interactions with regard to their changing spatial and temporal dimensions. They also call for the deployment of appropriate management indicators capable of translating all the issues raised into concrete and practical terms. To this end, a new conceptual and analytical approach to assess pressure indicators is needed to take into account the oscillation or the spatio-temporal mobility of the area of socio-economic dependence that must henceforth provides the basis for sustainable management of protected areas in the context of adaptation to climate change. The present study responds to this concern through rigorous conceptualization, characterization and validation of original peripheral pressure indicators focusing on a global and dynamic spatial and socio-economic framework. The method used consisted of an interpretative analysis of the theoretical bibliographic data, measurements and field observations using GPS and ArcGIS 10.1 software and semi-structured interviews for the characterization of the defined pressure indicators and their validation on a protected area of reference. The five physical and socio-economic pressure indicators designed and applied on the basis of the criteria of direct dependence on protected areas were the *coefficient of asymmetry* (K_c)*, the periphery* (Ψ)*, the dependent population* ($D\pi$)*, the distance-access time (DAT) and the field daily working time (FDWT)*. The approach and pressure indicators were successfully applied to the Rusizi National Park (Burundi) for the period 1984-2015. The results showed that the park has a coefficient of asymmetry (K_c) of 2.64 which represents a three times higher level than its circular equivalent, a periphery Ψ of 13.23 km radius composed of 35 localities characterized by distance access times (DAT) of 0 to 2 h30 and field daily working times (FDWT) ranging from 7 to 11 hours. They revealed that nearly 70% of the peripheral population are concentrated within 6 km of the boundaries and have an distance access time of less than one hour. The peripheral dependence on the protected area reaches 100% for woody resources, 97% for livestock products, 88% for agricultural resources and 83% for animal protein products. The modeling of potential pressures and field observations showed that peripheral localities are the more threatening that they are more dependent, more populated and closer. As a consequence, the important anthropogenic pressures observed led to a very significant degradation of the park during the study period.

Keywords: *Protected area, Pressure indicator, Coefficient of asymmetry, Periphery, Dependent population, Distance-Access Time, Field daily working time*

1. Introduction

As a key for biodiversity conservation strategies and safeguarding of socio-cultural values [1-4], protected areas have multiple interests according to the categories of actors [5-8] and face severe exploitation pressures, particularly in the tropics [9]. These pressures are as more worrying as the climate change has already affected 89% of the world's natural systems [10-12, 3]. They are also annoying because the world system of protected areas provides one of the most effective solutions for mitigation and population adaptation [3]. For effective conservation of degraded or threatened ecosystems and sustainable exploitation of natural resources, protected areas have to be managed in an adaptive and dynamic way [13, 11]. Such requires priority for research and reliable data on the management and evaluation of protected areas [1, 3]. This should be the case for African countries where several factors lead to overexploitation of natural resources, quick degradation of protected areas and deforestation [14, 15, 3]. Specifically, participatory management approaches are designed to address the central problem of natural resource exploitation at or around the periphery of protected areas [8, 16]. Indeed, protected areas and their peripheries have multiple and complex interactions [17, 15, 18, 8, 19] that generate a dynamic spatialization of social relationships [20-21] and inevitably lead to think of conservation as a gradient of situations ranging from strict protection areas to surrounding agricultural areas [22]. The omnipresence of social issues around protected areas [23] makes it necessary to analyze the impact of peripheral socio-economic interactions on the dynamics of protected areas by considering a wide spatial and temporal scale [17]. These observations resolutely pose the problem of the definition and delimitation of the "periphery" or the “socio-economic extent zone" of a protected area as a central parameter that makes it possible to draw objectively the spatio-temporal framework of the socio-economic interactions between "Protected Areas” and their “Dependent Zones" which determine the exploitation and evolution of the protected resources. The real periphery is therefore more extended than the classical and static buffer zone of 500 to 1000 m which is theoretically destined to absorb peripheral conflicts to secure central protection zones [24-25].The design, the characterization and the spatial analysis of physical and socio-economic pressure indicators are based on the key and various criteria considered for the creation, the management and the evaluation of protected areas [26-28, 19]. Up to now, no thorough research has been conducted to conceptualize and determine the periphery of protected areas and associated indicators in a rigorous manner in their socio-economic and spatial realities. This article was specifically designed to analyze the management of African protected areas in a perspective that places them within a wide spatial and socio-economic framework for land planning.

2. Methodological approach and methods

The methodology used consisted of three stages, that are namely: (1) interpretative synthesis of bibliographic theoretical data and specialized scientific articles, (2) conceptualization and characterization of physical and socio-economic pressure indicators and (3) field measurements, observations and interviews for the probatory or validation test. The required data for the biophysical and socio-economic characterization of the periphery of the tested protected area were collected using: (1) semi-directive individual interview guides, (2) semi-structured interview guides in focus groups, (3) GPS site surveys, (4) guided field observations and (5) random observations of product traces in the sites.

2.1. Theoretical arguments and analysis

Among the biophysical criteria used for creating protected areas and that represent in some way the ecological value of ecosystems, we find the size and shape that determine exposure and vulnerability to human threats [29, 27]. Ideally, shapes that maximize concentration and minimize the length of boundaries are preferable to others. However, the great majority of African protected areas have been established mainly or exclusively on the basis of their tourist interest by targeting strategic hunting areas and endemic species [30-31, 6, 2]. They rarely meet this standard and are largely exposed to peripheral pressures which are often justified and aggravated by: (1) the socio-economic interest of these areas that often coincide with wetlands and have the most suitable lands for crops and pastures [24], (2) the exception or the African rule of "protected areas without inhabitants" and the predominance of protected areas of management categories I to IV which often result in land dispossession and population expulsion [32-34], (3) the strongly restrictive conditions for population integration [35] and the low impact of ecotourism on the population economy [36-37], (4) the new global sorting and selective conservation strategies that lead to a relegation of the population socio-economic interest [38, 6, 39-41] and (5) the historical contentious related to the creation or extension of protected areas and the destruction of crops, properties and people by wild animals [24, 2, 15]. As a result of these conservation policies and practices, the peripheries of protected areas where expelled local populations are concentrated become areas of open population hostility and rebellion [24, 6, 2] from which regular forays are conducted for farm lands, pastures, wild animals, food and wood resources as African protected areas have become "food pantries surrounded by hunger" [42]. As buffers established to satisfy peripheral socio-economic interest are most of the time recovered for the extension of protected areas, the periphery is each time pushed back and the populations doubly sequestered forced to put more pressures on protected areas because of a lack of credible socio-economic alternatives. This is easily to understand since it is known that the African internalization and ownership of international policies of participatory management are at odds with the conditionalities of external financing that are increasingly "closed" to protected areas that are more and more “open” to local communities. This is the real dilemma of the conservation in many African countries. Thus, the efficient and sustainable management of African protected areas requires a rigorous redefinition and deployment of appropriate management, monitoring and evaluation indicators that can translate all the issues raised into concrete and practical terms. Traditionally based on participatory and adaptive management plans [43-46] and regular evaluations of the management effectiveness [47, 26, 48], it must now be extended beyond the physical limits of protected areas by integrating new pressure indicators that underpin sustainable management in the context of climate change that leads to a spatio-temporal dilatation of the periphery or the area of socio-economic dependence. This theoretical conception of protected areas with spatio-temporal mobility is openly opposed to the imposition of precise geographical limits [49] which does not take into account the fluidity of the zones of extension and peripheral influence for socio-economic purposes. Contrary, it is supported by other authors who consider that one of the best methods of global studies of protected areas for the evaluation of the effectiveness management is the study of the changes undergone by natural vegetation to the inside and outside of their boundaries [3]. In this perspective, the traditional management plans must from now on cover both the protected area and its socio-economic periphery, whose spatio-temporal oscillation have to be integrated into the management and evaluation schemes. The protected area's management and assessment model that we considered for the definition, characterization and geospatial analysis of the pressure indicators we have designed is DPSIR [50]. In this model, the pressures of interest for our study are related to the quantification and the distribution of populations, agricultural activities and infrastructure in and around protected areas [51].

2.2. Design and characterization of pressure indicators

In our study, new concepts and pressure indicators were defined, characterized and applied for the assessment of protected area's pressures with regard to their periphery and conservation objectives. With reference to the definition and nature of environmental indicators that are intended to demonstrate the evolution of specific attributes of a protected area with respect to the conservation objectives [26, 52], the pressure indicators we used are all physical and socio-economic by nature.

2.2.1. Coefficient of asymmetry of a protected area (K_c)

The coefficient of asymmetry is a physical indicator that we define as "the ratio between the perimeter of a protected area and the circumference of a circular protected area that would have the same area". The definition of this indicator is based on the theoretical approach of the ideal shape of protected areas which should maximize concentration and minimize the length of boundaries [29]. The more the coefficient of asymmetry of a protected area is close to one (1), the more its shape is picked up and approaches a circle and vice versa. Elongated and irregular shapes increase the exposure of protected areas to peripheral threats and constitute the first indicator of vulnerability, particularly in rural, poor and populated environments that are characterized by low densities of preventive and dissuasive surveillance. In the analysis of potential pressures on protected areas, the coefficient of asymmetry completes the protected area accessibility map model, which theoretically quantifies the potential pressures by the population in relation to the barriers or facilities of protected areas access by considering the topography and land use [53]. In the model or the vulnerability matrix, large values are attributed to obstacles (rivers, mountains, hills) and small values to easy crossing areas (savannahs, grasslands).

2.2.2. Periphery of a protected area (Ψ)

The periphery of a protected area is a hybrid concept that is at the same time spatial, socio-economic and temporal. We define it as "the space-time of mobility of the socio-economic dependence of populations and localities on the natural resources of a protected area". Intuitively and practically speaking, it is a spatially and temporally oscillatory space whose thickness or horizon depends on the socio-economic and climatic constraints and opportunities that can be internal or external to the protected area. This dynamic conception of the area of peripheral influence is obviously more appropriate than the classic and static term "shoreline" from which derives the adjective "riparian" often attributed to the neighboring populations that are economically depending on protected areas for their life.

2.2.3. Dependent populations (D_π)

The spatial and temporal concept of periphery is indissolubly linked to the concept of "peripheral or dependent populations" of a protected area. We define it as "all inhabitants who depend totally or partially on one or more natural resources of the protected area, by direct access or through intermediaries, at any time of the year. This means that the concept has four fundamental dimensions, namely: (1) a spatial dimension that determines the thickness of the geographic area of dependence or the periphery, (2) a socio-economic dimension that corresponds to the type of dependence to the protected area, (3) a governance dimension based on the direct or indirect mode of access to natural resources and (4) a temporal dimension that indicates the annual period and duration of dependence on the protected area.

2.2.4. Distance-Access Time (DAT)

To the concept of periphery of a protected area, we add the concept of "Distance-Access Time" which translates both, for a given locality and a given peripheral community, "a distance to the protected area" and "a time associated pathway " that is necessary for local populations to reach the protected area and exploit its resources, along the shortest route; by assuming the absence of any physical and administrative constraint. The "Distance-Access Time", expressed in "walking hours" in the African context, completes the anthropogenic and agricultural pressure indicators used to characterize and classify a country's protected areas [51]. The weakness of these indicators lies on the spatial and temporal references which consider a uniform buffer or a fixed periphery of 30 km and a travel time of 3 hours, without taking into account the heterogeneities within this geographical space.

2.2.5. Field Daily Working Time (FDWT)

The concept of "Field Daily Working Time" is a spatialized socio-economic concept that is fundamentally related to the concepts of "Periphery" and "Distance-Access Time". For a population and a predominantly agricultural locality located at a given DAT that is doing illegally agropastoral activities in a protected area, we define the "Field Daily Working Time" as "the maximum daily working time calculated on the basis of a daily time of 12 hours divided between the work and the return or walking journeys from and to home, by considering one hour for 6 km. The more a locality has a significant DAT, the lower its FDWT is and the less it will be threatening the protected area and vice versa.

2.3. Methods for the determination of pressure indicators

2.3.1. Coefficient of asymmetry of a protected area

The coefficient of asymmetry is determined by the formula $K_c = 0.28P_a / (\sqrt{S_a})$ in which P_a and S_a respectively designate its perimeter (km) and its area (km²). The formula is obtained by expressing the perimeter of the protected area P_a as a function of the radius of the equivalent circle R_c which is calculated by the relation $R_c = \sqrt{S_a / \pi}$ (1) in which S_a represents the common surface of the protected area and of the equivalent circle. By combining the relation (1) with the formula of the coefficient of asymmetry by definition, $K_c = P_a/P_c$ (2) where P_c is the circumference of the equivalent circle, we arrive at the proposed formula, knowing that $P_c = 2\pi R_c$ (3). The area S_a and the perimeter P_a of a given protected area are determined using any mapping software like ArcGIS or QGIS from their shapefile.

2.3.2. Periphery of a protected area

The delimitation and characterization of the periphery is based on spatial analysis of socio-economic activities and demography. They are related to: (1) the spatial location and distribution of peripheral villages and markets directly dependent on a protected area, (2) the identification and characterization of the main socio-economic activities of peripheral villages depending on a protected area, (3) the qualitative identification and characterization of the natural resources taken by peripheral villages and (4) the spatial distribution and evolution of the peripheral population depending on the natural resources of a protected area. The location of peripheral villages and markets is carried out through systematic pathways directed by the territorial administration officers and the protected area’s managers, based on the criteria of socio-economic direct dependence. The geographical coordinates of the various sites are registered with a GPS and used for mapping after their projection in the WGS 1984 system, and appropriated UTM Zone with any mapping software. The characterization of the socio-economic activities of the peripheral villages and the dependence on natural resources is carried out on the basis of the technical and management reports, direct observations and individual and focus group semi-directive interviews with administrative officers, protected areas’ managers and the populations concerned as well. Through the analysis of fraudulent or illegal activities thanks to the management reports and field observations (nature of the seizures and penalties, geographical origins of the offenders), natural resources needs and extractions are easily identified and described. Peripheral populations at different periods are determined by extrapolating data from general countries population censuses in specified years and from entities administrative censuses.

2.3.3. Modeling of Threats and potential peripheral pressures

The modeling of threats and peripheral pressures or the theoretical assessment of threats and potential pressures of peripheral dependent localities on a protected area is based on the prevailing socio-economic status, the distance-access time, the field daily working time and the dependent population. For identical demographics, a locality will be more threatening than another on the protected area that it is closer to it. For identical distances or the same distance, a locality will be more threatening than another that it is more populated. According to our model, localities will be the more threatening for a protected area that they are more dependent, more populated and closer.

2.3.4. Distance-Access Time (DAT)

For a given peripheral locality, the distance X is measured in km with the measurement tool of any mapping software like ArcGIS or QGIS, from the distribution map of peripheral localities. The measured distance is then converted into corresponding access time (AT), by delimitating concentric geographical areas offset by 30 minutes of walking for 3 km distance.

2.3.5. Field Daily Working Time (FDWT)

For each sector thus delimited and each peripheral locality, the FDWT is calculated using the formula: $Y = 12-2\ (X/6) \Leftrightarrow Y = 12- X/3$ where Y is the FDWT expressed in hours and X the distance of the locality to the protected area in km. In the application of the formula, the duration of 2 ways trip X/3 is rounded up to the nearest unit or half-unit.

2.4. Application to the Rusizi National Park

2.4.1. Coefficient of asymmetry K_c

The area and perimeter of the Rusizi Park determined by the ArcGIS 10.1 software being 106.73 km² and 97.68 km, the radius and circumference of the equivalent circle determined by calculation are respectively 5.83 km and 36.61 km. The coefficient of asymmetry K_c corresponding to these values is 2.64; which represents a remarkably high level of asymmetry as shown in Figure 1. In practice this means that the total length of the park's borders is almost 3 times greater than it would be if it were circular in shape. In other words, the highly asymmetrical nature of the protected area provides dependent peripheral populations a level of exposure to the fraudulent intrusion of 3 times higher; anything else remaining equal.

2.4.2. Periphery and socio-economic indicators

The Burundian periphery of the Rusizi National Park is made up of 35 dependent localities which are between 0 and 13.23 km far from the borders. These distances correspond to access times of 0 to 2h30 for a normal foot walk (Figure 1). All the localities are characterized by a high rural and agropastoral activity. The proportion of peripheral localities that are involved in agriculture and livestock, agriculture, livestock and fishing and small business represent respectively 73%, 9%, 6% and 12% (Figure 2). Like many African protected areas, we note that most of peripheral localities are involved in agropastoral activities. Indeed, 88% of them are depending on agriculture and livestock.

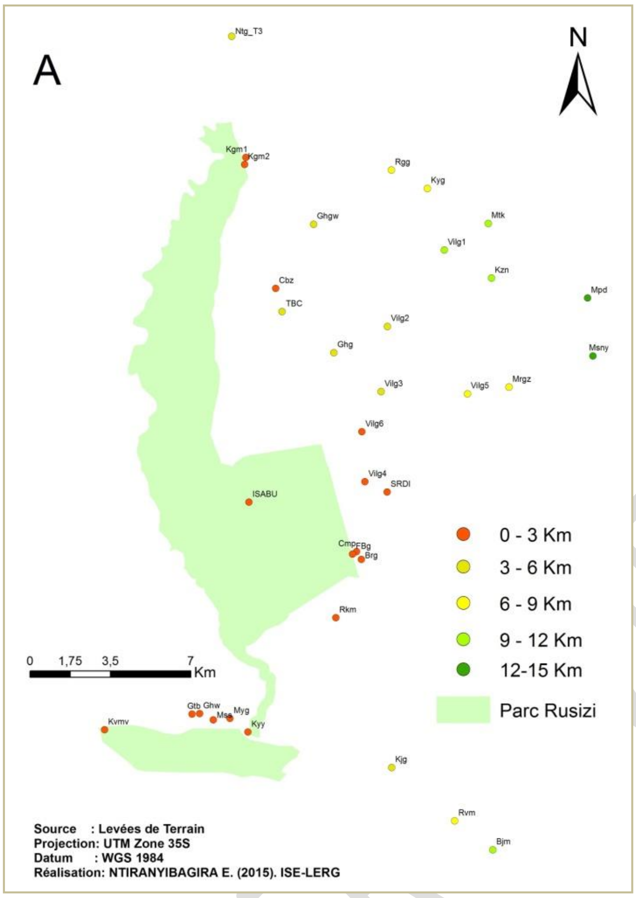

Figure 1: Spatial distribution of Burundian peripheral villages

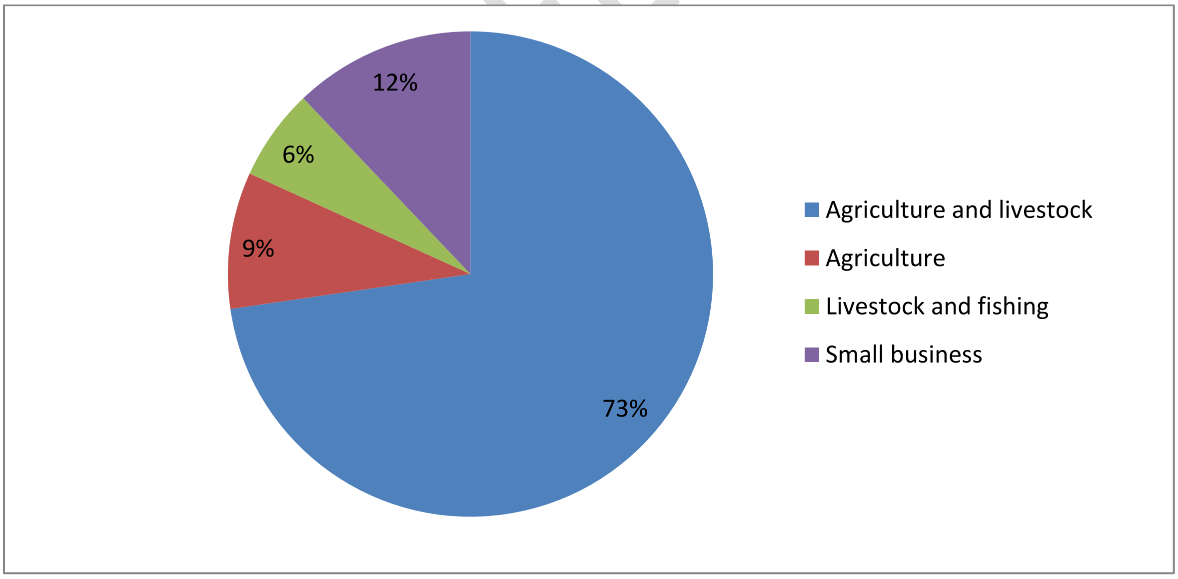

Figure 2: Socio-economic characteristics of peripheral villages

The dependence of peripheral localities on the protected area reaches 100% for woody resources, 97% for livestock products, 88% for agricultural resources and 83% for animal protein products as shown in Figure 3. All of these communities have markets for the purchase and sale of various wood and non-wood forest products taken from the protected area; 69% of them being fraudulent and 31% authorized by managers. The population socio-economic dependence to the park for these natural resources is extended to the whole year even if it is increased during the dry season that is taking place from May to October.

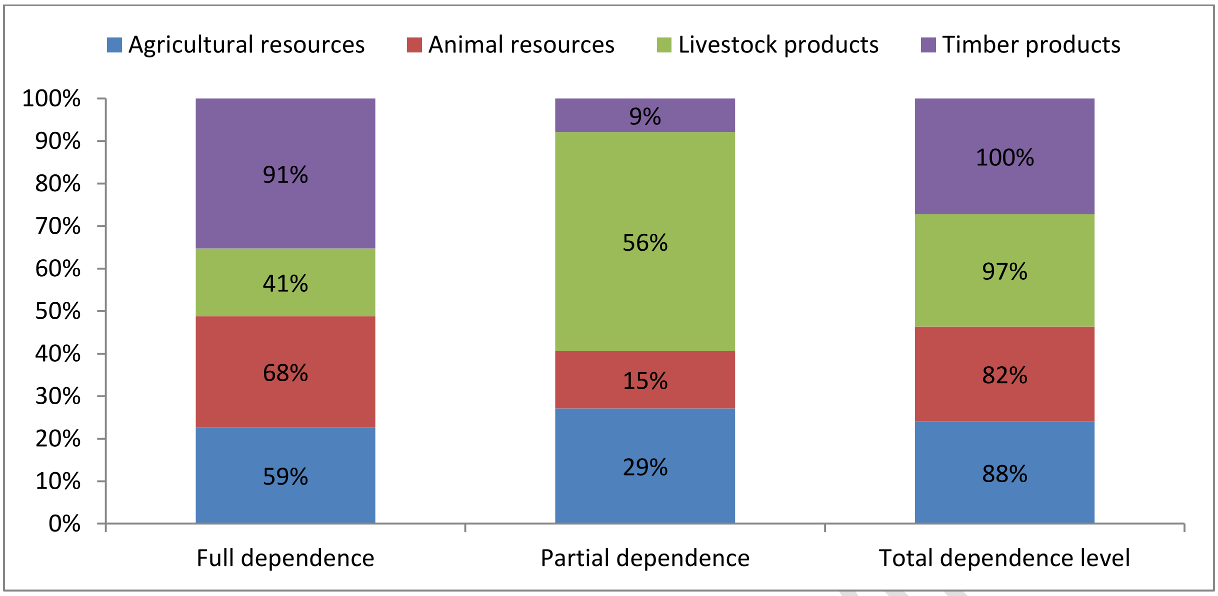

Figure 3: Type and levels of socio-economic dependence to the park

The peripheral dependent populations on the protected area increased from 30 190 inhabitants in 1980 to 146 799 inhabitants in 2015. This represents respectively 58% and 76% of the total population of the surrounding districts.

2.4.3. Levels of peripheral threats and pressures

In terms of spatial distribution, the cartographic analysis showed that the proportion of peripheral dependent localities located at distances of up to 3 km, 6 km, 9 km, 12 km and 15 km from the borders represent respectively 48.6%; 68.6%; 82.9%; 94.3% and 100% of the total. With regard to the access time of peripheral populations to the protected area, these distances correspond respectively to 30 mn, 1h, 1h30, 2h and 2h30 travel times, as shown in Figure 1. In other words, 70% of the peripheral dependent populations take a maximum of one hour to access the protected area and extract natural resources.

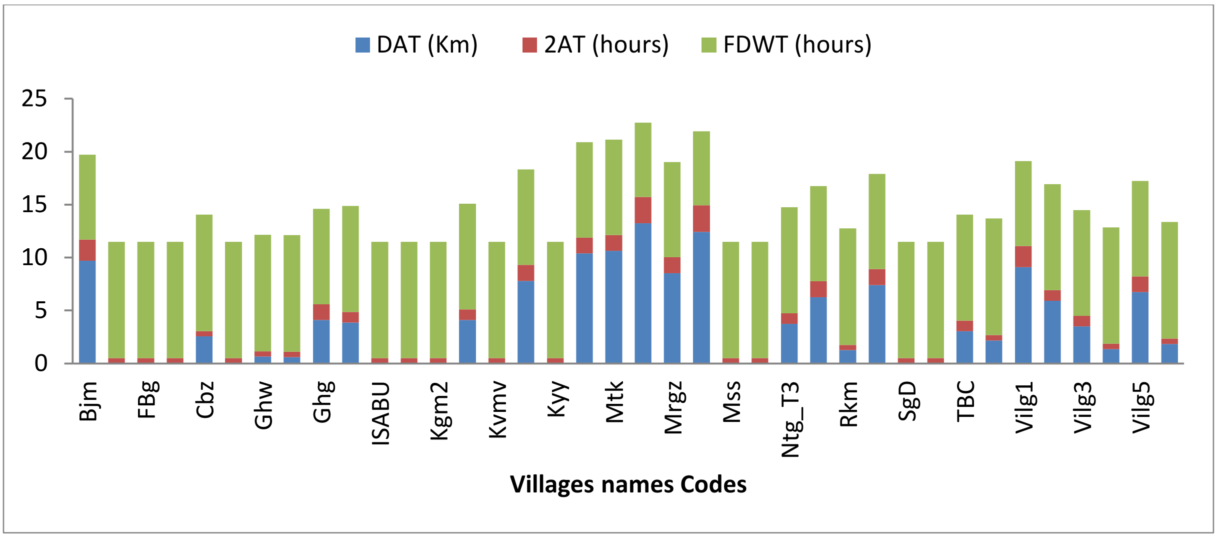

Figure 4: Values of key indicators of potential threats and harms

The Figure 4 shows that the FDWT from the different localities are characterized by Distances - Access Time (DAT) and Return Access Time (2AT) that oscillates between 7h for localities located far from the park like Mpanda and Musenyi and 11h for nearby towns like Gatumba, Buringa, Rukaramu, Village 4 and Kagwema. The results of field observations and interviews showed that the peripheral localities that put the greatest pressure on the protected area are concentrated in the northern part of the park, within 1 km from the borders. These are mainly Rukaramu, Buringa, villages 1 to 6, Cabiza, Kagwema 1 and Kagwema 2. These localities are characterized by DATs of 0 to 9 km, a 2AT of 3 hours maximum and FDWT ranging from 8h to 11h. As a strategy to face long distance and high access times, people living in the localities with a high DAT are often used to contract with population living in localities that are close to the park for illegal farming activities against payment, especially in the rainy season.

2.4.4. Strategies of spatial occupancy at the periphery (Ψ)

In terms of spatial strategies, the analysis of the localities distribution between 1980 and 2015 shows that new localities have concentrated near the park (Figure 5). The majority of the new localities were created between 1990 and 2000. They were established between 0 and 3 km on one hand and between 5 and 10 km, on the other hand, focusing particularly at less than 1 km from the limits of the protected area (Figure 5).

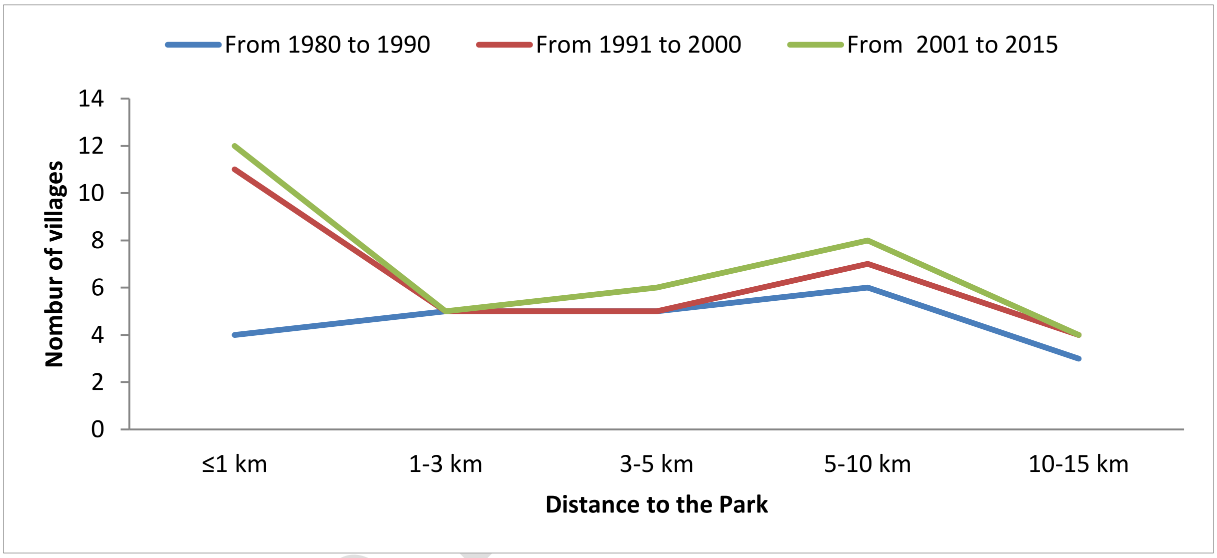

Figure 5: Spatial and temporal evolution of peripheral villages

The increase in the number of localities was accompanied by a decrease in their average distance to the park (Figure 6). The average distance to the park evolves according to a logarithmic linear regression model with y = -7.704lnx +46.876 and a coefficient of correlation R^2 = 0.87. In fact, the number of peripheral dependant localities increased from 23 up to 35 between 1984 and 2015. Contrary, their average distance to the park decreased from 4.78 km to 3.64 km during the same period. The new villages created between 1990 and 2011 (2015) are increasingly concentrated near the Park (Figure 6). This dynamic constitutes a double indirect pressure, numerical and spatial, which is accentuated with another pressure, this one direct; that is to say the demographic pressure.

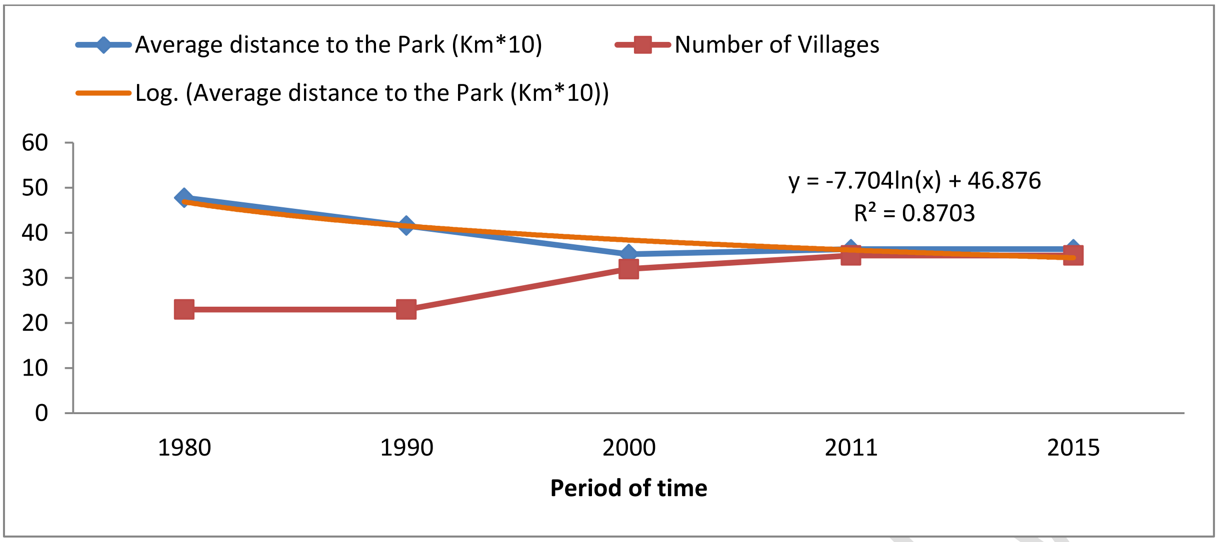

Figure 6: Comparative evolution of number and distance of peripheral villages

The Figure 7 shows that the spatial distribution and densification of dependent populations follow the digital and spatial densification of peripheral localities. The peripheral populations are concentrated between 0 and 3 km on one hand and between 3 and 5 km on the other hand, with a particularly strong concentration within 1 km from the park. The peripheral population growth was much marked during the periods 1990-2000 and 2011-2015 (Figure 7). The demographic evolution has been steadily increasing between 1 and 5 km radius. That is to say between 1 and 3 km on one hand and between 3 and 5 km on the other hand. The proportion of the peripheral dependent populations on the park increased from 58% in 1980 to 76% in 2015.

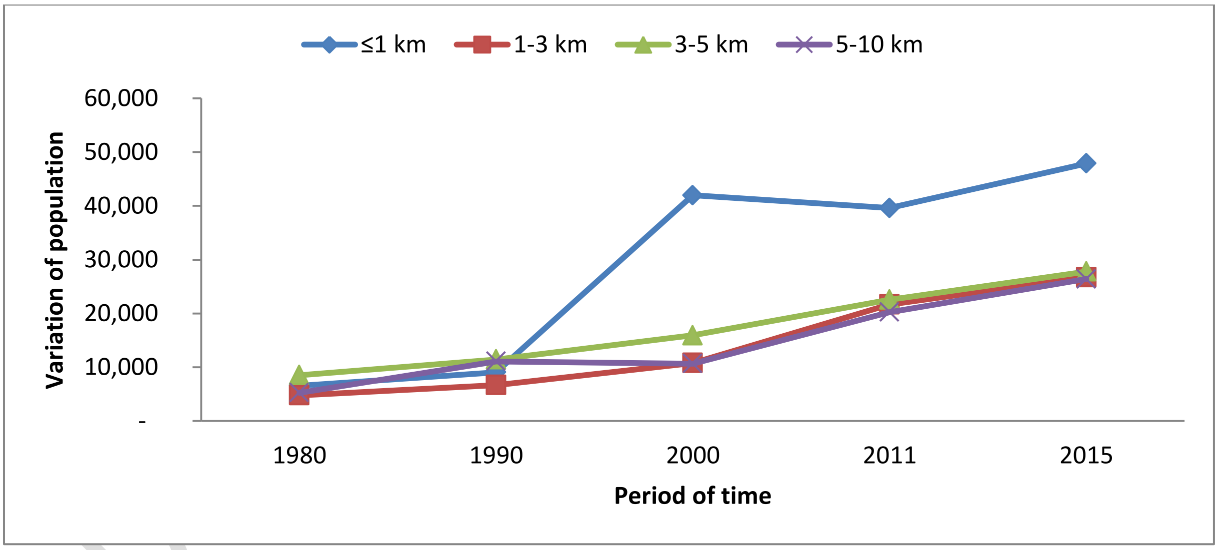

Figure 7: Spatial and temporal evolution of peripheral populations

As a result of the important peripheral socio-economic interactions and threats, the Rusizi national Park has experienced a very quick and advanced degradation between 1984 and 2015. The regression in vegetation cover, the progression in vegetation cover vegetation, the non vegetation involving conversions and the overall stability are respectively representing 55%, 14%, 23% and 8% of the total area (Figure 8). We note that as a result of increased socio-economic interactions and human pressures, the park undergone a very important degradation that has affected more than 50% of the protected area during the study period.

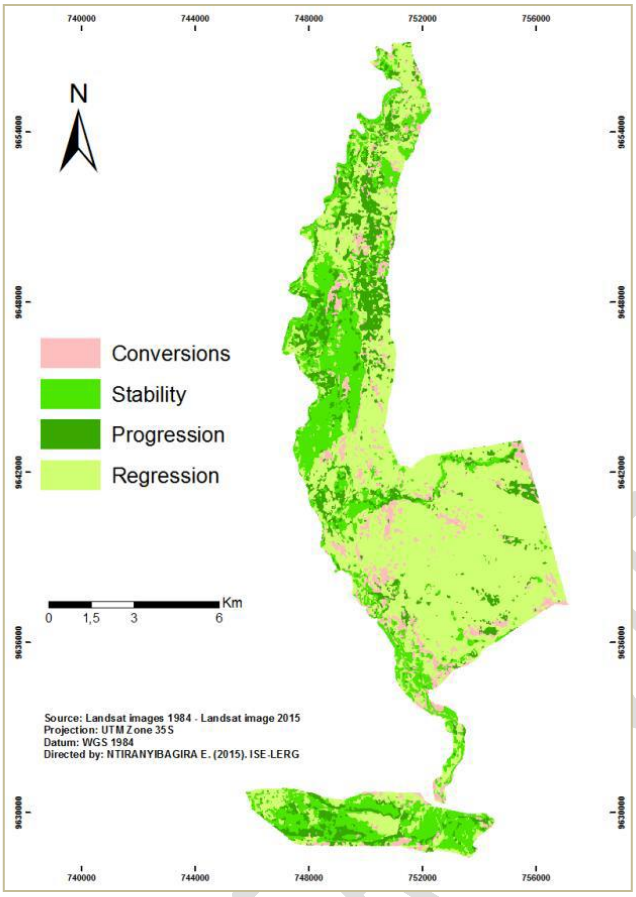

Figure 8: Aggregated land cover dynamics between 1984 and 2015

3. Conclusion

In the African context, we have shown that protected areas are under severe exploitation pressures and rapid degradation due to several factors with combined effects. The objective of the study was to design, characterize and validate a number of physical and socio-economic pressure indicators on protected areas that are likely to best reflect and integrate spatial issues, temporal and socio-economic posed by the oscillatory nature of the periphery conceived and defined as the zone of spatio-temporal influence or socio-economic dependence. In the context of rural poverty and community adaptation to climate change marked by the spatial, temporal and socio-economic dilation of the zone of dependence, a precise knowledge of these indicators is essential for an adaptive, dynamic and sustainable management of protected areas. Thanks to an appropriate methodological approach combining theoretical aspects, field data and validation test to a protected area of reference, the study led to interesting results, particularly with regard to the characterization and the practical operationalization of the complex concept of periphery that extends well beyond the classical and static buffer zone that is often recovered by protected areas managers and subtracted from socio-economic uses. It has also made it possible to highlight the interest of an integrated analysis of the protected area management which places them in an encompassing and dynamic spatial and socio-economic framework. In this sense, the results obtained will enable decision-makers and managers of African protected areas to have new tools for sustainable management and planning, in the context of climate stress and increased human pressures.

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