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Dynamics of Land Use And Its Impacts In *Kintele* Urban Municipality: Degradation And Land Loss Through Gullying (Republic Of Congo)

I.A.W. M'Bouka Milandou¹,

¹ Humid Tropics Research Centre (CRTH), Faculty of Letters, Arts and Human Sciences, Marien Ngouabi University ¹

Abstract

The degradation and loss of land through gullying in Kintélé is largely due to the dynamics of land use. This study shows that in 30 years (1989 - 2019), land degradation and loss only started in 2016. In 1989, the bare/occupied land class was almost non-existent, but in 2019, with the influx of people from Brazzaville, it increased to almost 3,000 ha. This anthropic pressure on land is aggravated by 15 ravines unevenly distributed in 12 districts of the commune. The total volume of the void left is 2,800,000 m3, equivalent to 4,480,000 tonnes of land destroyed and lost. In this context, human settlements and activities are affected. But like the "land use" factor, the sensitivity of the physical environment plays an important role, due to the fact that the soils are erodible (K: 0.35 to 0.40 t.ha.h/ha.MJ.mm), the rains are aggressive (R: 7,000 MJ.mm/ha.h.year) and the topography of the site is uneven (slope \geq 15%). The solution to this thorny problem lies in the biomechanical treatment of the ravines and the use of effective preventive methods.

Résumé

La dégradation et la perte de terres par ravinement à Kintélé sont en grande partie dues à la dynamique de l'utilisation des terres. Cette étude montre qu'en 30 ans (1989 - 2019), la dégradation et la perte des terres n'ont commencé qu'en 2016. En 1989, la classe des terres nues/occupées était presque inexistante, mais en 2019, avec l'afflux de personnes en provenance de Brazzaville, elle est passée à près de 3 000 ha. Cette pression anthropique sur les terres est aggravée par 15 ravines inégalement réparties dans 12 quartiers de la commune. Le volume total du vide laissé est de 2.800.000 m³, soit l'équivalent de 4 480 000 tonnes de terres détruites et perdues. Dans ce contexte, les aménagements et les activités humains sont affectés. Mais à l'instar du facteur " occupation du sol ", la sensibilité du milieu physique joue un rôle important, du fait que les sols sont érodibles (K : 0,35 à 0,40 t.ha.h/ha.MJ.mm), les pluies sont érosive (R : 7 000 MJ.mm/ha.h.an) et la topographie du site est accidentée (pente \geq 15%). La solution à cet épineux problème réside dans le traitement biomécanique des ravins et l'utilisation de méthodes préventives efficaces.

1. Introduction

According to the United Nations, land degradation today affects nearly 2 billion people and concerns a third of the earth's surface, affecting around a hundred countries on all continents, but particularly in Africa **[1]**. Congo, located south of the Sahara, is not on the fringes of this situation, since the phenomenon of water erosion, which is the main agent of degradation and



land loss, affects many Congolese cities, particularly the urban commune of Kintélé, located north of Brazzaville. This commune is prey to water erosion which has been manifesting itself by gullying since 2016. This phenomenon, which also destroys the various man-made developments, is largely due to land use. Even before it was established as an urban commune, the Congolese state had launched major works to develop basic infrastructure (roads, university, sports complex, conference rooms, etc.) thus initiating the first major phase of land occupation. This was completed by the occupation of land by people from Brazzaville and elsewhere, for housing and socio-economic activities (leisure facilities, planting, livestock, etc.). But while the development of public buildings has been diligently pursued by the public authorities, sometimes without taking into account the risks linked to the sensitivity of the physical environment, the occupation of land by the populations, for its part, has not respected the master plan for land development and/or urban planning standards [2], including the subdivision before the sale of plots and estates to private individuals. To this end, the populations occupy areas at risk of erosion, which unfortunately manifests itself through dynamic gullying, of which land degradation is one of the most visible consequences in this young commune today. This study aims to analyse the land use in Kintélé from 1989 to 2019 and its impacts on the current degradation and loss of land through gullying, before proposing some possible solutions for the conservation of the said land.

2. Experimantal details

2.1. Presentation of the physical and man-made environment

Located in the Pool department, the town of Kintélé covers an area of approximately 154.60 km² (15,460 ha). It is bounded to the north and north-east by the administrative centre of Igné, to which it was attached as a village until 2016, before being erected as an urban commune in 2017 (Law No. 14-2017, of 16 March 2017), to the south by the Congo River, to the north-west by the sub-prefecture of Goma tsé-tsé and to the south-west by the department of Brazzaville (Figure 1).

The city's climate is tropical, hot and humid. It is characterized by an alternating 8-month rainy season (mid-September to mid-May) and a 4-month dry season (mid-May to mid-September) [3]. Annual rainfall totals are around 1,350 mm.

The pedo-geological complex is characterised by the series of Batékés sands with a power of 90 metres [4]. The soils or surface formations formed from this geological substratum are sandy and ferralitic. The topography is in the domain of the Mbé plateau. It is characterised by high, gentle hills that reach 700 m in altitude and valleys that are sometimes drained, sometimes deep dry, of about 300 m on the plateau and about 200 to 275 m on the Congo River, below the cliffs of Dover in the Stanley Pool [5].

Vegetation is dominated by groves on hilltops and along rivers and savannah, sometimes wooded, sometimes low and sparse on hillsides and valley slopes. Although still present in the small drained valleys and the few hill tops and slopes, the forests are very much under attack. The hydrography is dominated by the Congo River and the Djiri River, which acts as a catchment area for the eroded land in the city.

Kintélé, which is a booming urban area, has a population estimated in 2017 at around 10,952 inhabitants instead database of National Statistical Institute, unevenly distributed in 12 neighbourhoods, separated by vast expanses of semi-rural areas: Paul Ngambi (i), Stade de la Concorde(ii), Gaston Mpouiloulou (iii), Ngabamou(iv), Florent Ntsiba (v), Matensama souh (vi), Issouli (vii), Lifoula (viii), Université Denis Sassou Nguesso(ix), 1000 dwellings(x), Ihouemé (xi) and Ngambio (xii) (figure 1). The most popular activities are agriculture based on cassava cultivation, cattle breeding, fishing in the Congo River and commerce (terraces and hotels).



Figure 1: Situation and limits of the urban commune of Kintélé © I.A.W. M'BOUKA MILANDOU

2.2.Methodological approach

Data collection and processing, analysis and interpretation of the results were the different stages of this work.

2.2.1.Data collection and processing

Following the example of the documentation (dissertations, articles, etc.) dealing with the problem of land use (LU), (i) data consisting of satellite images of the study area and (ii) data related to land degradation by gullying and its consequences were collected and processed.

The first are ETM+ images from 1989, 1999 and 2009 and Sentinel and Landsat 8 images from 2019 downloaded from landsat.usgs.gov/landsat-data-acces. These images have been used for a spatio-temporal follow-up of the Kintélé LU, and have been the object of a supervised classification on the software ENVIE 4 and ArcGis 10.4. Some results were compared with the field data by supplementing those that were not uniform due to the resolution, others were compared using Copernicus images on GoogleEarth Pro.

In order to evaluate the spatial and temporal variations of the LU classes, a quantification was carried out using the statistical approach. The statistical reliability of the classifications was obtained directly from ENVI 4.4 software and the changes were assessed in three cases: progression (area gain), regression (area loss), and stagnation (classes that have not changed at all). Changes in the LU are then detected using the formula below:



S = S2 - S1(1)

S: area of change, S1: area in the initial year (1) and S2': area in the following year (2).

The variable considered here is the area of change (S). Positive values represent an increase in the area of the class during the period analysed and negative values indicate the loss of area between the two dates. Values close to zero indicate that the class remains relatively stable between the two dates. The rate of change (Rc) LU was calculated using the formula proposed by [6]:

$$Rc = \frac{(S_{n'} - S_n)}{S_n} x \ 100$$
 (2)

Rc: rate of change LU, Sn': area next year and Sn: area initial year

Positive values indicate progression, zero values indicate stagnation and negative values indicate regression.

The latter are data obtained in the field, relating to land degradation, during observations of the phenomenon of water erosion and its consequences. These consequences, which are none other than gullying and loss of land, have been quantified in order to assess their extent. The quantification consisted in (i) counting the gullying, (ii) cubing the forms of gullying in cubic metres, measuring their lengths, widths and average depths per section and finally (iii) evaluating the loss of soil in tonnes/year/ha. For the last two operations, the following empirical formulae were used:

$$V = \beta \left[\frac{(L.l.P)}{2} \right]_{(3)} \qquad Q_{t/year} = \frac{V.\int}{4}_{(4)} \qquad Q_{\frac{t}{year}/ha} = \frac{Q_{t/year}}{15\,460}_{(5)}$$

V: gully volume (m3); $\beta = 0.5$, coefficient attributed to the V-shaped gully [7]; L: Total length of a gully (m), l

: Average width of a gully (m), P : Average depth of a gully (m), Qt/year: amount of land lost (tons/year), Qt/year/ha: amount of land lost (tons/year/ha); J : apparent density (1 g/cm³ = 1 tonne/m³ in sandy soils of the Mbé plateau; 4: value expressing the 4 years corresponding to the average age of the Kintélé ravines since 2016; 15,460: surface area of the urban commune of Kintélé (ha).

3. Results and discussion

3.1. Land use mapping

Figure 2 illustrates the diachronic land use in Kintélé from 1989, 1999, 2009 and 2019, i.e. 30 years. The maps clearly show the change in the site when it was a grouping of small villages from 1989 to 1999. From 2009 onwards, the landscape was quite different from previous years thanks to the development of several tourist places (hotels, bars, etc.) without, however, the locality being erected as an urban commune. But in 2019, two years after the creation of the urban commune, the landscape changed with the dynamics of land use by the populations from Brazzaville and elsewhere (Igné, etc.).



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Figure 2: Diachronic evolution of land use at Kintélé from 1989 to 2019 © Idriss M'BOUKA MILANDOU

| LU | Surface area | | | | | | | |
|--------|--------------|-------|-----------|-------|-----------|-------|-----------|-------|
| Unit | 1989 | | 1999 | | 2009 | | 2019 | |
| | ha | % | ha | % | ha | % | ha | % |
| FSM | 3,837.43 | 24.94 | 3,151.20 | 20.47 | 2,744.72 | 17.76 | 4,688.38 | 30.42 |
| SS | 9,299.00 | 60,44 | 5,244.36 | 34.07 | - | 0.00 | - | 0.00 |
| HS | 1,908.36 | 12.40 | 6,015.14 | 39.07 | 9,366.69 | 60.61 | 4,548.34 | 29.51 |
| LF | - | 0.00 | 820.91 | 5.33 | 1,688.78 | 10.92 | 2,779.06 | 18.03 |
| BOF | - | 0.00 | - | 0.00 | 1,131.24 | 7.32 | 3,139.97 | 20,37 |
| WB | 318.32 | 2.06 | 139.93 | 0.90 | 139.93 | 0.90 | 224.30 | 1.45 |
| R | 23.11 | 0.15 | 23.11 | 0.15 | 380.79 | 2.46 | 29.80 | 0.19 |
| Totals | 15,386.22 | 99.99 | 15,394.65 | 99.99 | 15,452.16 | 99.97 | 15,409.85 | 99.97 |

Table 1: Land use areas in 1989, 1999, 2009 and 2019 in Kintélé

FSM: forest-savanna mosaic, SS : shrubby savannah, HS : herbaceous savannah, LF : leached floors, BOF : bare/occupied floors, WB : water bodies, R : road © I.A.W. M'BOUKA MILANDOU



Table 1 shows the evolution of the LU classes in hectare and percentage at Kintélé from 1989 to 2019. In 1989, Kintélé included a few small villages that were part of the sub-prefecture of Igné (Pool). There was no pressure on natural resources, despite the cutting of wood for heating, cooking and the construction of huts. As a result, the forest-savanna mosaic (FSM) still occupied 3,837.43 ha, i.e. 24.94% of the total area of the locality, and the SS occupied more space than other LU classes, since it is estimated at 9,299 ha, i.e. 60.44% of the area, thus explaining the domination of the Batékés sands in the pedo-geological complex of the area. The herbaceous savannah (HS) represented only 12.40% or 1,908.36 ha. The bodies of water characterised by rivers and streams occupied 318.32 ha, i.e. a representation of 2.06%, and finally roads only occupied 0.15%, i.e. 23.11 ha of the surface area, since only one road existed, that of the National Road 2 (NR2).

The year 1999 presents another reality. Since the herbaceous savannah (HS) progressed more than other classes, i.e. 39.07% of the total area equivalent to 6,015.14 ha, even surpassing the coverage rate of the shrubby savannah (SS) class which regressed to 34.07% or 5,244.36 ha, but occupying second place. The forest-savanna mosaic (FSM) occupies third place with 20.47% or 3,151.20 ha. It has not regressed too much 10 years ago. But this decade marks the appearance of a new LU class, which is none other than leached soil (LS), which occupies 5.33%, or 820.91 ha. The presence of its SL explains the destruction of the FSM and the SA for firewood needs, the construction wood of the huts and the charcoal that laid them bare. This exposure allowed rainwater to infiltrate these sandy soils, causing them to leach out and turn them into white sand. The bodies of water (WB) decreased by 139.93 ha, or 0.90%, due to their sedimentation, albeit weak from fine erosion. The class of roads has not changed, since the occupancy rate has remained the same (0.15%).

20 years later, i.e. from 1989 to 2009, the landscape continued to be 20 years later, i.e. from 1989 to 2009, the landscape continued to be modified by man, his activities and his developments. The data for 2009 show that the HS has continued to evolve, since it occupied 60.61% of the surface area, i.e. 9,366.69 ha. It is supported by the FSM, which fell sharply by 17.76% or 2,744.72 ha compared to the 20.47% it occupied 10 years earlier (2009) and 24.94% occupied 20 years later (1989). The SS class has disappeared because of the heavy exploitation of shrubs for firewood and charcoal production. This is visible even in the field. As for the leached soils, their rate has increased by almost 5%, or 10.92% of the occupied area, relative to 1,688.78 ha. The class of bare and occupied land (BOF) appeared in 2009, with 1,131.24 ha, or 7.32%. This year marks the beginning of land occupation by the population coming from Brazzaville and also the development of tourist sites. The rate of WBs has not changed since they have remained at 0.90% of occupied surface area. As for roads (R), they have increased by about 2%, i.e. a total of 2.46% of the surface area of 380.79 ha. It marks the expansion of the Road Natiobal 1 (RN1) and the tracing of other roads.

Finally the year 2019, two years after the creation of Kintélé as an urban commune and 30 years after 1989, the landscape has changed a lot. The BOF class has grown by around 13%, reaching 20.37% of the total surface area of the site, i.e. 3139.97 ha. This marks the dynamics of land use coupled with the urbanization of Kintélé. The classes of FSM and HS have almost reached the same occupancy rates, i.e. almost 4,500 ha, equivalent to nearly 30%. But here the FSM has evolved from nearly 2000 ha 10 years before (2009) where it occupied 2744.71 ha. On the other hand, HS has regressed by about 5,000 ha compared to 2009 when it occupied nearly 9,000 ha. The SS presents the same situation as in 2009, no change. LF continues to progress, especially in semi-rural areas, where it reached nearly 18%, or 2,779 ha. The BW rate increased slightly, with only 1.45%, or 224.30 ha. This still marks the sedimentation process that rivers undergo due to the gullies and ravines that erode the land and deposit them in the latter. As for the roads (R), they have regressed, since the occupancy rate is 0.19% or



29.80. This situation illustrates the advanced degradation of asphalt roads and earthen avenues.

Land use dynamics from 1989 - 1999

The period from 1989 - 1999 (10 years), represents a period when Kintélé was still a village in the sub-prefecture of Igné. It comprised a group of small villages along the Congo River. In this respect, analysis of land use between 1989 and 1999 shows that the study area has nevertheless undergone a change in landscape. This observation comes first from direct observation of the 1989 and 1999 LU maps (Figure 2). A visual comparison of the two classifications shows some changes. From a purely statistical point of view, we cannot conclude definitive results because the proportion of pixels obscured by clouds and their shadows is too high (Table 2, Figure 3).

Table 2: Evolution (S) and rate of change (Rc) LU (1989 and 1999)

| LU | Year/Area | | Evolution (ha) | Rate of change |
|-------|-----------|----------|----------------|----------------|
| Class | 1989 | 1999 | 1989-1999 | (RC) |
| FSM | 3,837.43 | 3,151.20 | -686.23 | -17.88 |
| SS | 9,299.00 | 5,244.36 | -4,054.54 | -43.60 |
| HS | 1,908.36 | 6,015.14 | 4,106.78 | 215.19 |
| LF | - | 820.91 | 820.91 | 0 |
| BOF | - | - | 0 | 0 |
| WB | 318.32 | 139.93 | 178.39 | -56.04 |
| R | 23.11 | 23.11 | 0 | 0 |



Figure 3: Overview of LU changes observed during the period 1989-1999 © I.A.W. M'BOUKA MILANDOU

There is a loss of area (regression) is observed for the FSM class, since S is equal to -686.23 ha. This regression is proportional to the Rc, which also has a negative value, i.e. -17.88% also expressing a regression. This situation is the same for the SS class, where S is -4054.64 ha and Rc is -43.60%, as well as for the WB class, where -178.39 ha represents the regressive evolution value and Tc is equal to -56.04%. The regressive evolution of the FSM and SS classes can be explained by the pressure exerted at that time by the rural population on natural resources, in particular the plant cover for firewood, wood for the construction of huts and for the manufacture of charcoal. Agricultural activities based on cassava were not too developed. As for the class of WBs characterised by rivers, streams and springs, they have regressed due to the drying up of certain springs, according to the testimonies of the populations. On the other hand, the HS class has evolved from 4106.18 ha, i.e. a Rc of 215.19%. This explains the colonisation of the herbaceous savannah instead of the forest-savanna mosaic and shrubby



savannah exploited by man. In these same areas where HS developed, due to the low density of grasses, the soil was washed away in 1999 with nearly 820.91 ha occupied.

The Rc is nil, thus explaining the stagnation of the said class. The BOF were very low to nil and there was no noticeable evolution during this period. As for the class of roads (R), it is characterised by a single main road which was the only exit to the north of the country (RN1) and other rural tracks allowing the populations of villages remote from the RN1 to access it. From 1989 to 1999 this class occupied only 23.11 ha, the evolution (S) was nil and the Rc also has a none value expressing stagnation. The loss of area (regression) is observed for the FSM class, since S is equal to -686.23 ha. This regression is proportional to the Rc, which also has a negative value, i.e. -17.88% also expressing a regression. This situation is the same for the SS class, where S is -4054.64 ha and Rc is -43.60%, as well as for the WB class, where -178.39 ha represents the regressive evolution value and Rc is equal to -56.04%. The regressive evolution of the FSM and SS classes can be explained by the pressure exerted at that time by the rural population on natural resources, in particular the plant cover for firewood, wood for the construction of huts and for the manufacture of charcoal. Agricultural activities based on cassava were not too developed. As for the class of IPs characterised by rivers, streams and springs, they have regressed due to the drying up of certain springs, according to the testimonies of the populations. On the other hand, the HS class has evolved from 4106.18 ha, i.e. a Rc of 215.19%. This explains the colonisation of the herbaceous savannah instead of the forest-savanna mosaic and shrubby savannah exploited by man. In these same areas where HS developed, due to the low density of grasses, the soil was washed away in 1999 with nearly 820.91 ha occupied. The Rc is nil, thus explaining the stagnation of the said class. The BOF were very low to nil and there was no noticeable evolution during this period. As for the class of roads (R), it is characterised by a single main road which was the only exit to the north of the country (RN1) and other rural tracks allowing the populations of villages remote from the RN1 to access it. From 1989 to 1999 this class occupied only 23.11 ha, the evolution (S) was none and the Tc also has a nil value expressing stagnation.

Land use dynamics from 1999 - 2009

The analysis of land use between the years 1999 and 2009 shows that the study area has undergone a change in landscape. This finding is based primarily on direct observation of the 1999 and 2009 LU maps (Figure 2). A visual comparison of the two classifications shows some changes. From a purely statistical point of view, we cannot conclude definitive results because the proportion of pixels obscured by clouds and their shadows is too high (Table 3 and Figure 4).

| LU | Year/Area | | Evolution (ha) | Rate of change |
|-------|-----------|----------|----------------|----------------|
| Class | 1999 | 2009 | 1999-2009 | (RC) |
| FSM | 3,151.20 | 2,744.72 | -406.23 | -12.89 |
| SS | 5,244.36 | - | -5,244.36 | -100 |
| HS | 6,015 | 9,366.69 | 3,351.55 | 55.71 |
| LF | 820.91 | 1,688.78 | 867.87 | 105.72 |
| BOF | - | 1,131.24 | 1,131.24 | 0 |
| WB | 139.93 | 139.93 | 0 | 0 |
| R | 23.11 | 380.79 | 357.68 | 1,547.72 |

Table 4: Evolution (S) and rate of change (Rc) LU (1999 - 2009)





Figure 4: balance of LU changes observed during the period 1999-2009 © I.A.W. M'BOUKA MILANDOU

But this period continues to mark the regression of the FSM, i.e. -406.48 ha and a Rc of -12.89%, followed by the SS which has practically disappeared and a regression Rc of -100%. This still explains the pressure exerted by the resident populations of the villages on the FSM and SS for the needs explained above. But during this period, it should be noted that several tourist sites were already beginning to emerge and these attracted many people for tourism but also for the purchase of estates and plots of land.... the aggressiveness on human resources was growing. But the herbaceous savannah continued to progress with 3351.55 ha in 10 years, occupying the spaces left by the FSM and the SS, with a Rc of 55.71%. The LF also progressed by 867.87 ha, i.e. a Rc of 105.7%. SNOs were noticed during this period, since, as announced above, the populations were already beginning to occupy the site. In 2009 this BOF class was 1131.24ha. As for the WBs, they remained stable from 1999 to 2009, with 139.93 ha occupied. Roads have increased by 357.68 ha or a Rc of 1547.79%. This reflects the development of roads and/or dirt tracks for access to tourist sites, in addition to the NR2 which already existed.

Land Use Dynamics 2009 - 2019

The analysis of the 2009 and 2019 LU maps shows a strong dynamic in the occupation of space (Figure 2). The visual comparison of the two classifications indicates significant changes. From a purely statistical point of view, we cannot conclude definitive results because the proportion of pixels masked by clouds and their shadows is too high. During this period a recovery of the FSM on nature was observed, with an increase of 1943.66 ha and a Rc of 70.81%. This reflects the abandonment of certain sites at risk of erosion by the authorities from 2017 onwards, when Kintélé was decreed an "urban commune" (Table 5, Figure 5). Those who acquired plots of land or estates abandoned them waiting to be exploited later. The SS disappeared and the HS regressed thanks to the many public building sites (sports complex, university, etc.) but also many private dwellings. The leached soils have again increased by 1090.28 ha, i.e. a Rc of 177.57%. They are coupled with the BOF, which also progressed by 2008, 73 ha, i.e. a Rc of 60.29%, thus explaining the strong urban growth, relative to the demographic growth of the commune.

| LU | Year/Area | | Evolution (ha) | Rate of change |
|-------|-----------|----------|----------------|----------------|
| Class | 2009 | 2019 | 1999-2009 | (RC) |
| FSM | 2,744.72 | 4,688.38 | 1,943.66 | 70.81 |
| SS | - | - | 0 | 0 |
| HS | 9,366.69 | 4,548.34 | -4,818.35 | -51.44 |
| LF | 1,688.78 | 2,779.06 | 1,090.28 | 64.56 |
| BOF | 1,131.24 | 3,139.97 | 2,008.73 | 177.56 |
| WB | 139.93 | 224.30 | 84.37 | 60.29 |
| R | 380.79 | 29.80 | -350.99 | -92.17 |

Table 5: Change (S) and rate of change (Tc) LU (2009-2019)





Figure 5: balance of LU changes observed during the 2009-2019 period © I.A.W. M'BOUKA MILANDOU

WBs decreased by 84.37 ha, or 60.29% of Rc. This situation reflects the disappearance of many rivers or their sedimentation. This phenomenon is due to the large amount of eroded land on the slopes and flanks that come to be deposited in the watercourses, with consequences that will be discussed below.

Synthesis of LU dynamics in 30 years, i.e. from 1989 - 2019

This synthesis shows the evolution and the rate of change in 30 years, from 1989 to 2019, in order to really analyse the progressions, stagnations and regressions of LU classes at Kintélé. Table 6 and Figure 6 show this trend.

| LU | Year/Area | | Evolution (ha) | Rate of change | | |
|-------|-----------|----------|----------------|----------------|--|--|
| Class | 1989 | 2019 | 1999-2009 | (RC) | | |
| FSM | 3,837.43 | 4,688.38 | 850.95 | 22.17 | | |
| SS | 9,299.00 | - | -9,299 | -100 | | |
| HS | 1,908.36 | 4,548.34 | 2,639.98 | 138.33 | | |
| LF | - | 2,779.06 | 2,779.06 | 0 | | |
| BOF | - | 3,139.97 | 3,139.97 | 0 | | |
| WB | 318.32 | 224.30 | -94.02 | -29.53 | | |
| R | 23.11 | 29.80 | 6.69 | 28.94 | | |

Table 6: Summary of evolution and Rc of LU (1989 - 2019)



Figure 6: Summary assessment of LU changes observed during the period 1989-2019 © I.A.W. M'BOUKA MILANDOU

The results show that in general, from 1989 to 2019, there has been more progress than regression and stagnation of LU classes. The FSM evolved from 850.95 ha, i.e. a Rc of 22.17%, thus showing a slight recovery of the forest-savanna mosaic despite the heavy occupation of the land in this commune, since if in 1989 the FSM area was 3837.43 ha, it evolved to 4688.38 ha.



This resumption of the FSM is due to the abandonment of areas at risk of erosion and areas already eroded in the town. It is also worth noting the planting of a few hectares of Eucalyptus which reinforces this FSM class. The shrubby savannah has regressed with -9299 ha and a Rc of -100% in 30 years. As for the HS class, it has progressed with 2639.98 ha, i.e. a Rc of 2639.98 ha, i.e. a Rc of 138.34% and is gradually replacing the SS class. As for the LF and BOF classes. The first one has progressed in terms of surface area, since they have gone from an average of 0 ha in 1989 to 2779.06 ha in 2019, a positive evolution of 2779.06 ha, but with a rate of change of 0%, explaining the stability until 2019. Often these areas are occupied by man or degraded by water erosion. As for the BOF class, it was practically none in 1989, since the villages were very small with small populations. But in 2019, it increased by 3139.97 ha, showing a strong occupation of the land by this urbanism phenomenon. But the rate of change (Rc) is zero...until 2019. WBs are being revised downwards, with the sedimentation phenomenon of several water sources and rivers. It has gone from 318.32 ha in 1989 to 224.330 ha in 2019, a regression of -94.02 ha and a Rc of -29.54%. As for roads, they have slightly increased by 6.69 ha, i.e. a Rc of 28.95%. This reflects the development of some asphalt and unpaved road sections, following the construction of the La Concorde sports complex, the International Conference Hall and the University.

3.2. Current degradation and loss of land at Kintélé

The land use evaluated in 30 years shows in a global way, a progressive evolution of the land use by man, his activities and his developments and a regressive evolution of the plant cover. This situation shows that the dynamics of land use will have an impact on land degradation from the year 2016 onwards. This degradation is driven by water erosion, which is manifested by unprecedented gullying. This gullying, which affects man, his activities and developments, degrades the land and contributes to its loss, thus changing the landscape of the commune of Kintélé. A total of 15 gullies have been counted. Although they are unevenly distributed in the 12 districts that make up the commune, since 2016 they have been causing significant land degradation, which moreover testifies to their loss through sedimentary transfer. The densely populated neighbourhoods are the most affected, compared to the sparsely populated neighbourhoods located in semi-rural areas.

Table 7, Figures 7 and 8 show the volumes of gullies and the loss of land, as well as the location of the different points of erosion.

| Gully | $V(m^3)$ | P(t) | P(t/year) | P(t/year/ha) | Geographical coordinates |
|----------|--------------|--------------|--------------|--------------|-------------------------------|
| Gully 1 | 350,518.98 | 560,830.37 | 140,207.59 | 96.03 | 4°07'07.62"S, 15°21'06.99"E |
| Gully 2 | 591,961.165 | 947,137.86 | 236,784.47 | 162.18 | 4°08'23.46"S, 15°21'37.55"E |
| Gully 3 | 56,557.765 | 90,492.42 | 22,623.11 | 15.50 | 4°08'56.09"S, 15°19'46.03"E |
| Gully 4 | 22,054.46 | 35,287.14 | 8,821.78 | 6.04 | 4°08'02.50"S, 15°20'43.03"E |
| Gully 5 | 36,373.415 | 58,197.46 | 14,549.37 | 9.97 | 4°08'05.56"S, 15°20'38.63"E |
| Gully 6 | 250,943.905 | 401,510.25 | 100,377.56 | 68.75 | 4°08'08.99"S, 15°20'10.01"E |
| Gully 7 | 777,166.085 | 124,3465.74 | 310,866.43 | 212.92 | 4°08'16.17"S, 15°20'40.86"E |
| Gully 8 | 423,771.27 | 678,034.03 | 169,508.51 | 116.10 | 4°09'26.87"S, 15°20'11.36"E |
| Gully 9 | 13,141.455 | 21,026.33 | 5,256.58 | 3.60 | 4°02'58.35"S, 15°22'18.80"E |
| Gully 10 | 130,459.77 | 208,735.63 | 52,183.91 | 35.74 | 4°00'24.25"S, 15°21'24.87"E |
| Gully 11 | 52,081.155 | 83,329.85 | 20,832.46 | 14.27 | 4°07'11.36"S, 15°21'09.46"E |
| Gully 12 | 36,409.622 | 58,255.40 | 14,563.85 | 9.98 | 4°07'12.71"S, 15°21'18.32"E |
| Gully 13 | 47,856.08 | 76,569.73 | 19,142.43 | 13.11 | 4°09'26.87"S, 15°20'11.36"E |
| Gully 14 | 2,351.195 | 3,761.91 | 940.48 | 0.64 | 4°07'09.35"S, 15°21'01.53"E |
| Gully 15 | 8,590.5 | 13,744.80 | 3,436.20 | 2.35 | 4°07'10.70"S, 15°21'00.75"E |
| Totals | 2 800 236,82 | 4 480 378,91 | 1 120 094,73 | 767,18 | 4°07'07,62''S, 15°21'06,99''E |

Table 7: Gully density, void volumes and amount of land destroyed and lost in tonnes/year/ha

V: volume of voids left by the ravines in 4 years (\mathbf{m}^3) , P (t): quantity of land lost in 4 years;

P(t/year): amount of land lost in tonnes per year, P (t/year/ha): amount of land lost per year and per hectare



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Figure 7: Volume of gully voids and amount of land destroyed and lost in tons/year/ha © Idriss M'BOUKA MILANDOU



Figure 8: Current location of the different erosion points at Kintélé in 2019 © Idriss M'BOUKA MILANDOU



This gullying is characterised by gullies, ravines and some overburdening of roads (alleys and avenues). But they are the result of a process triggered by a combination of a certain number of causes, namely: runoff that escapes infiltration and exploits the slopes by degrading the land, which is characterised much more by the Batéké sands. However, here, it is the major forms, notably the ravines, that have been taken into account, due to their density in the commune but also their destructive nature to the infrastructure of man and land.

Initially, these forms are piriform gullies that scour the soil (Photo 1), then, due to lack of treatment, they evolve into gullies (Photos 2 and 3). The gully evolves into a gully (Photo 4) which can be piriform, polylobate or not, when no treatment measures have been taken. Sometimes attempts at mitigation have been effective, but the quality of the treatment devices is either not effective or sometimes not maintained. This situation is at the root of the formation of the large ravines in Kintélé, according to testimonies from the living populations in the areas already affected.

These ravines are V-shaped (Photo 5), although some exceptions have been noted with a flat floor of less than 1 metre. However, this is due to the anthropisation of these ravines, transforming the floors into tracks or paths to access difficult places. The V-shaped gully shape is due to the dominance of the Batéké sands, which are loose rocks that cannot stabilise to facilitate the formation of a floor greater than or equal to 1 metre. The sandy nature of the rocks facilitates the transfer of sediment from the destroyed land.

The latter is deposited and accumulates in large quantities in the mostly drained shallows, thus we can observe the phenomenon of strong sedimentation that affects the watercourses of the municipality (Photo 6), with serious consequences on the environment, notably the reduction of the LU classes of the water bodies, by the clogging of springs and the sedimentation of rivers and streams (Photos 6 and 7).

These ravines also affect the habitat, the urban road system and some plantations in 5 districts (Figure 8): Issouli, Stade de la Concorde, Gaston Mpouiloulou, Ngabamou and D.S. Nguesso University. This gully density seems to be related to the population in these neighbourhoods, since those with lower populations are also less affected.



PLATE: FORMS OF DEGRADATION AND LOSS IN KINTELE LAND



Photo 1: gully scraping the soil from the plot to the alley, photos 2 and 3: gullies affecting the earthen avenues and endangering the habitat. It can be seen that in photo 2, there was an attempt to treat the shape with the bagged device filled with earth, but it was overflowed and dragged into the gully floor; photo 4: piriform gully; photo 5: giant V-shaped gully; photo 6: view of a giant gully and the alluvial plain showing the sedimentation of the river, in the 1000 housing estate; photo 7: sedimentation of a stream by the destroyed and eroded land upstream. © Idriss M'bouka Milandou, 2018-2019

The average volume of each gully is $186,682.46 \text{ m}^3$, the quantity of land destroyed and lost on average by excavation is 298,691.93 tonnes, equivalent to 74,672.98 tonnes per year, since 2016, i.e. 51.16 tonnes/year/ha. But the total volume of voids left by the 15 gullies is 2,800,236.82 m³, representing a total destruction and loss of land of 4,480,378.915 tonnes, equivalent to 1,120,094.73 tonnes per year or 767.18 tonnes/year/ha (Table 7).



The largest gullies are those with a void volume of more than 400,000 m³, namely Gul7, Gul2, Gul8, Gul1 and Gul6. They respectively have void volumes of 777,166 m³ for Gul7, equivalent to 212.92 tonnes/year/ha of land destroyed and lost, or a total of 1,243,465.74 tonnes since 2016; 591,961.165 m3 for Gul2, equivalent to almost 947,137.86 tonnes of land destroyed and lost since 2016, is equivalent to 162.18 tonnes/year/ha; 423,771.27 m³ for Gul8, for a destruction and loss of land of around 678,034.03 tonnes since 2016, or 116.10 tonnes/year/ha; 350,518.98 m³ of volume equivalent to 96 tonnes/year/ha since 2016, or a total of 560,830.37 tonnes; finally for Gul6, a volume of 250,943.905 m³ was recorded, for 401,510.25 tonnes of land destroyed and lost since 2016, or 68.75 tonnes/year/ha (Figure 7). Gully 10, which follows the first 5, has a volume of 130,459.77 m³ and has caused the destruction and loss of around 208,735.63 tonnes of land, i.e. 52,183.91 tonnes/year/ha (Table 7, Figure 7).

The rest of the gullies, a total of 9, have volumes of less than 100,000 m³ and land destroyed and lost per gully of less than 100,000 tonnes also, equivalent to less than 20 tonnes/year/ha since 2016 (Figure 7). This value exceeds several regions of the world, such as in the Sanguéré-Djalingo zone and Mbissiri in Cameroon, where land loss varies from 05 to 35 t/ha/year [8]. But this tonnage is also low compared to other regions of the world, such as in Montreal (Canada) where Jaramillo (2007) estimated annual sediment losses due to gullies at over 8,000 tonnes/year/ha and even in Algeria, where [9], cited by [10], estimated a loss of 90 to 300 tonnes/year/ha. But despite the fact that the rains are aggressive, the fragile soils, some slopes and hillsides entirely covered by vegetation are more stable than the uncovered slopes and hillsides. This is a good indication of the protective role of the soil by the plant cover against the action of rainwater, contributing greatly to the improvement of its infiltration capacity and significantly reducing splash, runoff, and thus erosion. But with the occupation of the soil, the site of Kintélé is experiencing a progressive degradation of the vegetation cover and the extension of the town which breaks the already sensitive morphodynamic balance of the site. Subdivisions in the commune have not been carried out with planning measures for an environment that is topographically rugged and prone to erosion. The same observation has been made in Kinshasa by [11], and in Brazzaville by [12]. On the whole, these forms strongly degrade the environment of Kintélé because they evolve rather quickly in time and space and sometimes surprise the populations when a heavy rain falls on the city.

However, the LU may or may not contrast with the density of current erosion patterns. This is why the analysis of the physical environment is essential in the discussion of the results obtained. This environment is characterised by the pedo-geological complex, the climate and the slopes which are the main factors triggering and accelerating erosion phenomena [13]. Outside Kintélé is established on a plateau broken up by valleys and hills shaped by erosion on a very unstable sandy geological substratum. This substratum is dominated by superficial formations whose sand content (fine, medium and coarse) varies from 90 to 98% of the total texture, with less than 7% of the fine fraction (clay and silt) as in Mayanga [14], in the Djiri watershed [15], and in the north of the sub-prefecture of Goma tsé-tsé [13]. These soils have very good permeability with a K index > 180 mm/h2 or 5.10-5 m/s, but are nevertheless very erodible, as the average erodibility index (K) varies between 0.35 and 0.45 t.ha.h/ha.MJ.mm [16]. These sensitive formations, thus denuded, are exposed by land use.



Under these conditions, the soils are exposed to concentrated runoffs generated by erosive rains, whose average erosivity index (R) north of Brazzaville is estimated at 7,000 MJ.mm/ha.h.yr. This index is twice as high as that found by [17] Mfumu et al (2012), i.e. 306.19 MJ.mm/ha.h.yr, in Kinshasa (DRC), more precisely in the Kemi river catchment area, but very low compared to the values of 10,071.84 MJ.mm/ha.h.yr, obtained in the Man catchment area in Haiti by [18]. As for runoff, they exploit the city's rugged topography in the different directions of the natural flow of water, which is itself dependent on slopes with values ranging from 5 to more than 15%, occupying almost 45% of the total surface area of the site [5], exposing the land to stripping and transport to the lowlands of the valleys that have been drained and are currently sedimented. The factor of slope on erosion is recognised by all soil physicists, including [9], who proved that soil loss due to soil erosion increases exponentially with slope variation.

Conclusion and recommandations

Land degradation and loss are phenomena that modify the landscape and affect the environment of the urban commune of Kintélé. Land use, which is very dynamic, with a progression of occupied or bare areas from almost 0% in 1989 to nearly 3,000 ha, or 20% of the surface area in 2019, is the first factor of land degradation and loss, driven by water erosion manifested by gullying. Nearly 15 gullies have caused the destruction and loss of nearly 4,480,378.91 tonnes of land, i.e. 1,120,094.73 tonnes/year since 2016 and 767.18 tonnes/year/ha. Although land is being destroyed and lost, it is worth noting that the population is severely affected as they lose their homes every rainy season. The state is also losing amenities and other public facilities (roads, buildings, electric masher, etc.). But the speed with which land is destroyed and lost is also due to the sensitivity of the physical environment (sandy and erodible soils, aggressive rains and very hilly topography).

The recommendations recommended at the end of this analysis are based on the different antierosion methods that make it possible to limit land degradation and loss. These methods are on the one hand curative, because gullying is dynamic in the area, and on the other hand they are preventive.

Among the curative methods, those that will be more effective are :

- The construction of gabions instead of large gullies, to stabilise the shape and control run-off water, especially if the excavation is located on the natural direction of water flow. It is a device consisting of stones and wire mesh, mounted on site, which is quite expensive. However, the availability of stones in the cataracts in Brazzaville and the availability of labour can reduce the cost of development. This mechanical method has already proved its worth in stabilising the large ravines in Brazzaville and its surroundings.
- The total filling of the ravine, followed by the construction of a large collector in place of the old treated form, taking into account the flow of run-off water, for drainage control. The spaces on either side of the canal can be planted with vegetarians to stabilise the soil. To this end, the communal authorities must ensure that the population does not degrade the vegetation. This so-called bio-mechanical method has already proved its worth in Brazzaville.

Among the most effective preventive methods are the following:

• The correction of deficiencies in the city's prior allotment. Plots of land and even estates have been sold to private individuals taking into account the rural environment



until 2016. But being a town, a lot of groundwork needs to be done to correct the deficiencies. That is to say, subdividing the areas before the sale, drawing the alleys and avenues parallel to the contour lines to break the run-off towards the slopes and building the water drainage systems to control run-off,

- Raising public awareness of the phenomenon of water erosion and its consequences or impacts on the environment.
- The implementation of laws by the public authorities to restrict the anarchic occupation of land in order to avoid putting the population at risk.
- The training of the population in the use of palliative methods of anti-erosion, which can delay the evolution of the forms, while waiting for the intervention of the public authorities.

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