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Article

# Analysis of the impact of urban sprawl on vegetation cover in Central African cities: Case of Brazzaville, Republic of Congo

**Innocent Joachim Emvoulou[1,2,*], Reisch Vanel Attipo[1], Madinatètou Takili[3], Ndorane Allarane[2], Tak Youssif Gnongbo[3]**

[1] Regional Center of Excellence on Sustainable Cities in Africa (CERViDA-DOUNEDON), University of Lomé, Lomé 01 BP 1515, Togo
[2] African School of Architecture and Urban Planning Professions (EAMAU), Lomé BP 2067, Togo
[3] Geography Department, Research Laboratory on the Dynamics of Environments and Societies, University of Lomé, Lomé 01 BP 1515, Togo
*** Corresponding author:** Innocent Joachim Emvoulou, ijemvoulou@gmail.com

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**Abstract:** Growing urbanization in sub-Saharan Africa, with its attendant degradation of natural vegetation, is a real scourge. It takes the form of urban sprawl, with its corollary of native vegetation degradation. The aim of this study is to assess the impact of urban sprawl in Brazzaville and the related degradation of the vegetation covering on the urban site. The methodological approach was based on the collection of documentary and field data, as well as the analysis of Landsat satellite images from 2002, 2012 and 2022. The results show a regressive evolution of natural plant formations in favor of urbanization. The area of vegetation cover fell from 17,523 ha in 2002 to 8355.5 ha in 2022, representing a regression rate of 52.32% in 20 years. At the same time, the urban area has grown from 12,164 ha in 2002 to 29,892 ha in 2022, an increase of 145.74%. This deterioration in vegetation cover is reflected in water erosion, resulting in silting-up and flooding of homes and sanitation facilities.

**Keywords:** urban sprawl; vegetation cover; erosion; flooding; Brazzaville

## 1. Introduction

The rapid urbanization of the world appears to be a major issue for those interested in the interactions between population, urbanization and development (Fodé et al, 2020). Considered a major phenomenon of the 20th century, urbanization is profoundly transforming the African continent. Since 1990, the number of cities in Africa has doubled, from 3300 to 7600. Their combined population has increased by 500 million people (BAD, 2022). This exponential demographic expansion has led to a spatial dynamic characterized by the absorption of peri-urban and rural space. The regression of natural spaces has been at the origin of global movements that have led to the implementation of international conventions for the protection of natural resources (Gansaonré et al., 2020). In sub-Saharan Africa, plant-based natural resources are considered one of the components of biophysical cover and constitute the subsistence support for the majority of the population (Curtis, 2014; Tankoano et al., 2015). However, they are affected by numerous anthropogenic actions as well as natural factors giving rise to social, economic and environmental problems (Rani et al., 2015). African metropolises are growing inexorably at the expense of plant cover. With this in mind, Polorgni et al (2015) show that the green spaces which were inseparable from the city of Lomé did not survive in the face of its spatial extension, and many have even disappeared.

In Congo, one of the crucial scourges facing urban development stakeholders is controlling urban expansion. Urban populations are growing exponentially, and this phenomenon is accompanied by peri-urbanization. Dziwonou (2001) shows that urban centers in sub-Saharan Africa welcome 2.5 million new city dwellers per year.

In the Republic of Congo, the capital Brazzaville is part of the same dynamic. Since the late 1970s, it has grown steadily. Its population rose from 300,000 inhabitants on a surface area of 6500 ha in 1974 (RPGH, 1974) to 400,000 inhabitants on a surface area of 7200 ha in 1980 (SDAU, 1980), then to 856,000 inhabitants on a surface area of 12,000 ha in 1996 (RGPH, 1996). Following the politico-military disorder between 1997 and 2000, punctuated by civil wars, the decades of 2002, 2012 and 2022 are characterized by peace and tranquility, a driving force for development. These years were marked by a rapid increase in its population, the population grew rapidly, from 1,051,145 in 2002 to 2,000,000 in 2020 (PLU, 2022) and 2,145,783 in 2022 (RGPH-5, 2023), representing a relative growth rate of 104.14% in twenty years. This rapid population increase has led to considerable spatial expansion of the city. Compared to the national population which is 6,142,180 inhabitants, it represents 34.94%, or more than a third of the country's population. This is the most important spatial and demographic change in the history of the country. The area of urban land has increased from 12,164 ha in 2002 to 29,892 ha in 2022, an increase of around 145.74%, and this expansion of urban space is taking place at the expense of natural space (Amontha et al, 2015; Atchade et al., 2023; Nganmo and Priso, 2022; Yang, 2024). At the same time, this leads to a significant reduction in vegetation cover in favor of housing, market gardening and equipment (Sène, 2018). Compared with the city's current boundaries, the area of vegetation cover has fallen from 17,523 ha in 2002 to 8355.5 ha in 2022, a regression of 52.32%. The city is sprawling to meet the high demand for housing, while continually mortgaging peri-urban space. This phenomenon is taking place in total disregard for urban planning and land use standards. Brazzaville's galloping and uncontrolled urbanization is thus at the root of the degradation of the urban environment (Mayima et al, 2022). The city's demographic growth plays a central role in changes to biodiversity through habitat loss. This loss endangers animal and plant species (Koua Oba, 2019). Indeed, its physical setting of Boardaus, hills and plains, stripped of vegetation, exposes the city to natural risks and disasters.

Djangbedja et al. (2017, p. 76) emphasize that the strong demographic pressure in the surroundings of the city of Lomé has led to a very significant regression of the plant cover and "deteriorated the physicochemical qualities of the hydrosystem". Thus, the abundant vegetation, composed, among others, of Pista stratiotes, Typha australis, Nymphea lotus, Adansonia digitata, Borassus aethiopum, is destroyed daily. In this context, Bawa (2017) shows that every year in the northern outskirts of Lomé, beyond 25 km, a large proportion of agricultural land, i.e., 26%, is converted into buildings, and this mutation, according to the author, is a sequestration of carbon, a destruction of biodiversity and a deregulation of temperature and flood risks. This phenomenon is visible in Cotonou, and according to Danvide (2015), the urbanization of Cotonou is taking place for the benefit of marshy areas, and the populations residing there are destroying the aquatic flora and carrying out partial embankments. These practices, according to the author, degrade and weaken the natural ecosystem. With this in mind,

Tchamiè and Badameli (1997) show that the expansion of the city of Lomé threatens the disappearance of local plant species in wetlands, unlike exogenous species such as Blighiasapida, introduced which have become more important.

The degradation of its natural heritage has become so worrying that demographic pressure has led to its extension into non-edificandi areas. In recent years, populations have occupied areas that are strictly off-limits to construction, such as the Talangaï and Djiri hills to the north and the M'filou hills to the west, either for market gardening or for housing (Koua Oba, 2019). The growing need for building land has led to a rapid expansion of the urbanization front, resulting in the regression of vegetation cover in favor of residential areas. The threat of extinction of plant cover and biodiversity in Brazzaville's peri-urban area is a palpable reality. In the absence of an urban housing policy in favor of social housing, low-income populations are settling in peri-urban neighborhoods along the valley bottoms and on the hillsides, resulting in the accelerated degradation of these sites (Mayima et al., 2022; Mambou and Elenga, 2023). This situation is not only a constraint for the population, but also a hindrance to the sustainable development of the city, in light of the socio-economic and environmental consequences recorded.

The aim of this article is therefore to assess the dynamics of land use in Brazzaville and its impact on vegetation cover through the analysis of satellite images. To achieve this, an appropriate research methodology was adopted through field data collection and processing, which led to satisfactory results.

## 2. Materials and methods

### 2.1. Geographical location of the study area

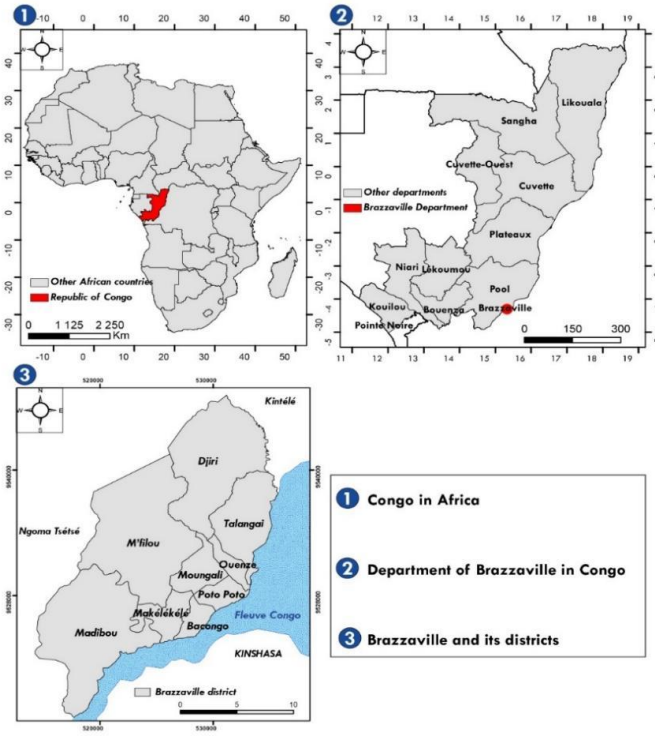


**Figure 1.** Location map of the city of Brazzaville.

Source: Emvoulou, 2023.

Brazzaville is the capital of the Republic of Congo and its main metropolis. It is located on the right bank of the Congo River, with geographic coordinates of 4°16′10″ south latitude and 15°16′16″ east longitude. It is bounded to the north by the Djiri River, to the southeast and east by the Congo River, and to the northwest, west and southwest by the Pool Department (**Figure 1**). **Figure 1** shows the geographical location of the city of Brazzaville.

The Brazzaville site features a contrasting landscape juxtaposing two (02) types of relief: plateaus and step-shaped plains, sloping NW-SE. It is made up of high areas at altitudes of between 350 and 650 m in the north and north-western parts, medium areas at altitudes of between 290 and 350 m and low areas at altitudes of between 220 and 290 m, mostly alluvial plains to the east and in the watersheds of the main rivers (**Figure 2**). The climate is humid tropical, characterized by an alternating rainy and dry season (Samba-Kimbata, 1978). The rainy season lasts around eight months (October to May), with rainfall averaging over 1400 mm/year and an average monthly temperature of 25 °C. The original vegetation covering the urban site and its periphery consisted of Pentaclethra eetveldeana forests on desaturated soils, dry hills and valleys and Loudetia savannahs with Annona arrenaria and Hymenocardia acida that grow on hillsides and hilltops with predominantly sandy soils and low water-holding capacity (Kimpouni et al, 2018; Makany, 1976).

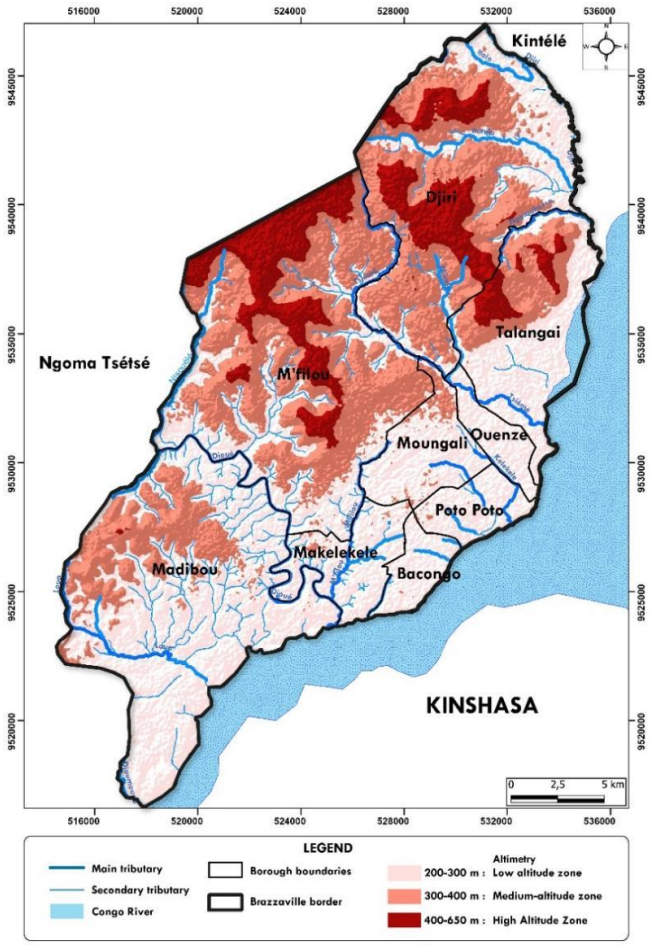


**Figure 2.** Relief of the city of Brazzaville.

Source: Emvoulou, 2024.

## 2.2. Materials and working methods

The cartographic process undertaken is based on a scientific and rigorous methodology, taking advantage of modern cartographic and geomatic tools. This method is based on cartographic analysis of the degradations highlighted and field observation.

Initially, cartographic analysis was carried out by exploring the Brazzaville urban area using Google Earth software. This enabled a comparative analysis of urban dynamics from both a historical and contemporary perspective. Following this analysis, geo-spatial data were acquired using this software, facilitating the digitization of key elements of the urban fabric.

Secondly, cartographic processing of the data, including delineation of the urban area and vegetation cover for the years 2002, 2012 and 2022, identification of erosion and flood zones and other urban irregularities, was carried out using QGIS software and field observations. The maps obtained provide a basis for calculating changes in land use. These changes over time were assessed by examining variations in surface areas and drawing up cross-matrices by combining use maps taken at different times (Mayima et al., 2018).

To obtain an accurate digital terrain model (DTM or DEM), the ASTERGDEM generator was used through the Global Mapper software, enabling a topographic model of Brazzaville with a resolution of 30 meters represented in the UTM 33 south system for WGS 84 reference ellipsoid. In addition, ArcMap 10.8 software was used to refine the elevation analysis by generating contour lines, slopes and the relief of Brazzaville, all at a scale of 1/125,000. To ensure optimum graphic quality, final processing of the GIS maps was carried out using Adobe Illustrator.

Finally, for a more in-depth interpretation of the urban phenomena observed, statistical processing was carried out on the geographical data collected using Excel software. This comprehensive and integrated methodological approach produced accurate and reliable results, essential for understanding and effectively managing Brazzaville's urban territory.

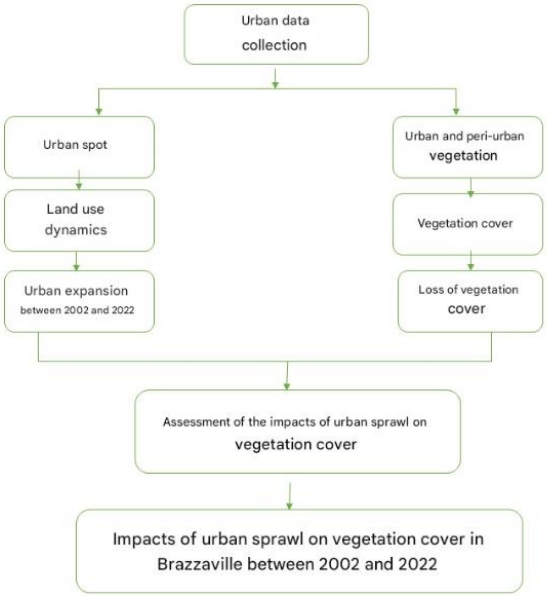


**Figure 3.** Methodological diagram.

We quantitatively assessed the impacts of urban expansion on vegetation in the city of Brazzaville using QGIS software. First of all, we calculated urban land areas at several scales (neighborhood, area, arrondissement). We then quantified the dynamics of urban sprawl in the city of Brazzaville between 2002 and 2022, using changes and growth rates in urban land area. Moreover, we determined the different types of impact on vegetation, i.e., positive and negative impacts. Finally, we calculated the areas of positive and negative impact in the city to determine the impacts of urban sprawl on vegetation cover in Brazzaville. This whole process is summarized in **Figure 3**.

## 3. Results

This section deals with the state of land use, land dynamics and the consequences of the destruction of vegetation cover on the environment.

### 3.1. Land cover dynamics

(1) From 2002 to 2012

**Table 1** shows that the dynamics of land use between 2002 and 2012 are marked by a substantial increase in urban sprawl and a significant decline in vegetation cover. The surface area of the urban spot rose from 12,164 ha in 2002 to 18,845 ha in 2012, an increase of 6681 ha (+54.92%). At the same time, vegetation cover fell from 20,026 ha to 13,636 ha, a decline of 6,390 ha (−31.91%). Whereas in 2002, the development of the built-up area was contained within the official limits of May 2011, in 2012 it had overrun these limits by 291 ha in the south-western part.

**Table 1.** Variation in surface area over time from 2002 to 2012.

| | **Area in ha** | | **Change in surface area** | |
|---|---|---|---|---|
| **Land use unit** | **2002** | **2012** | **ha** | **Rate (%)** |
| Urban spot | 12,164 | 18,845 | +6681 | +54.92% |
| Plant cover | 20,026 | 13,636 | −6390 | −31.91% |
| Watercourses and unvegetated areas | 450 | 450 | - | - |
| Habitat outside official boundaries | - | 291 | - | - |
| Official area* | 32,640 | 32,640 | | |

Source: Emvoulou, 2023.
Legend: (-) regression, (+) progression, (*) Law n°12-2011 of May 17, 2011, on the boundaries of the Brazzaville municipality.

(2) From 2012 to 2022

**Table 2** shows the trend in land use dynamics between 2012 and 2022. The urban area continues to grow, increasing by 11,047 ha (+54.92%). Vegetation, on the other hand, decreased by 5623 ha (−58.76%). There has also been a significant increase in residential areas outside the city limits, rising from 291 ha in 2012 to 3,325 ha in 2022, an increase of 3034 ha (+1042.61%). These overflows of built-up area can be seen to the north-east (1023 ha) and south-west (2302), as shown in **Figure 4**.

**Table 2.** Temporal variation in surface area from 2012 to 2022.

| | Area in ha | | Change in surface area | |
|---|---|---|---|---|
| **Land use unit** | **2012** | **2022** | **ha** | **Rate (%)** |
| Urban spot | 18,845 | 29,892 | +11,047 | +54.92 |
| Plant cover | 13,636 | 5623 | −8013 | −58.76 |
| Watercourses and unvegetated areas | 450 | 450 | - | - |
| Habitat outside official boundaries | 291 | 3325 | +3034 | +1042.61 |
| Official area* | 32,640 | 32,640 | | |

Source: Emvoulou, 2023.
Legend: (-) regression, (+) progression, (*) Law n°12-2011 of May 17, 2011, on the boundaries of the Brazzaville municipality.

(3) From 2002 to 2022

The data in **Table 3** shows that, overall, from 2002 to 2022, Brazzaville's urban area increased from 12,164 ha to 29,892 ha, with a spillover outside the official city limits of 3325 ha. At the same time, vegetation cover fell from 17,523 ha to 5,623 ha, a decline of 67.91%. In 20 years, the built-up area has grown from 12,167 ha to 29,892 ha, an increase of 145.74%.

**Table 3.** Variation in land area over time from 2002 to 2022.

| | Area in ha | | Change in surface area | |
|---|---|---|---|---|
| **Land use unit** | **2002** | **2022** | **ha** | **Rate (%)** |
| Urban spot | 12,164 | 29 892 | +17,728 | +145.74 |
| Plant cover | 17,523 | 5 623 | −11,900 | −67.91 |
| Watercourses and unvegetated areas | 450 | 450 | - | - |
| Habitat outside official boundaries | - | 3325 | +3325 | - |
| Official area* | 32,640 | 32,640 | | |

Source: Emvoulou, 2023.

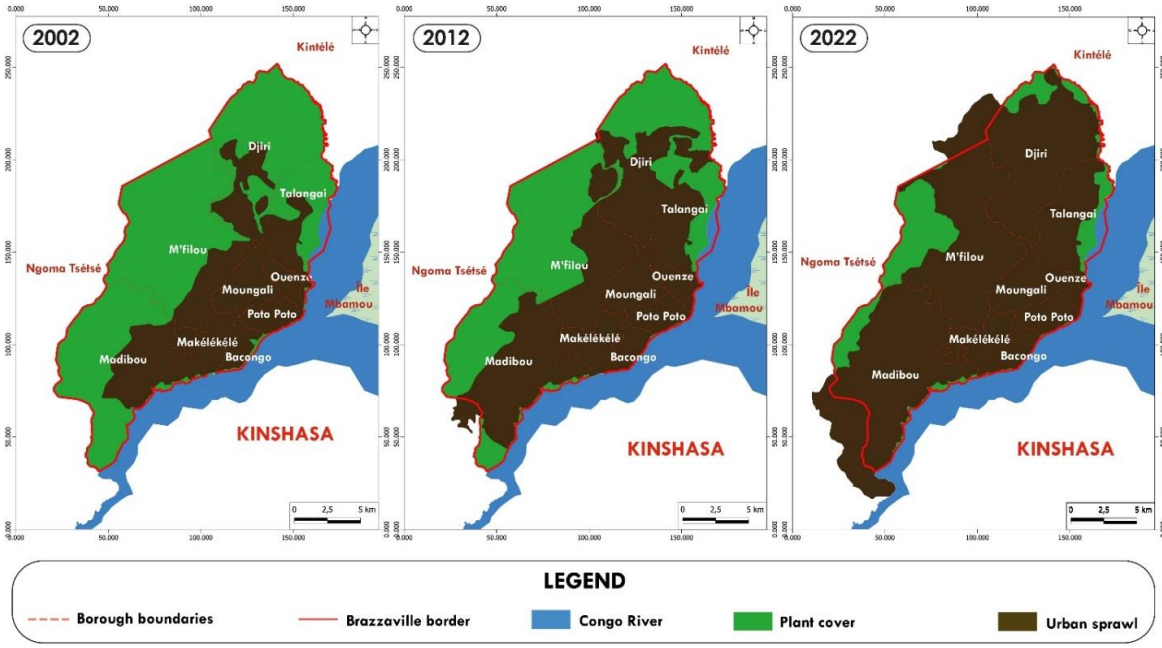


**Figure 4.** Contrasting trends in vegetation cover and built-up areas from 2002 to 2022.
Source: Emvoulou, 2023.

**Figure 4** illustrates the opposing dynamics of vegetation cover and built-up area. Analysis of these two processes, based on images from 2002, 2012 and 2022, shows that vegetation cover has been declining over the last twenty years. From 2002 to 2022, vegetation cover has been regressing in favor of built-up areas, as a result of human pressure on the natural environment (**Figure 5**). But this expansion of the built-up area is anarchic, the result of uncontrolled urbanization.

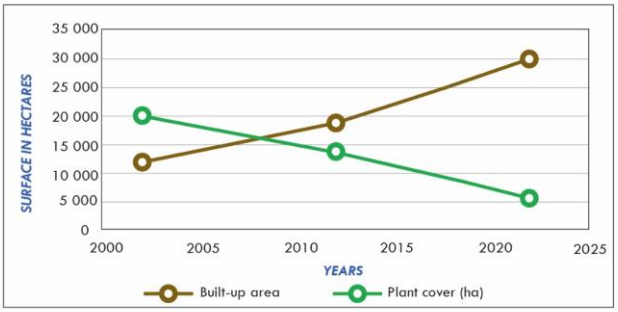


**Figure 5.** Comparative evolution of urban area and vegetation cover from 2002 to 2022.
Source: Emvoulou, 2023.

Like **Figures 4** and **5** illustrates the opposing dynamics of linear changes in urban sprawl and vegetation cover.

## 3.2. Land use and development from 1980 to 2022

The Master Plan for Development and Urban Planning (SDAU) of 1980, drawn up for a 20-year period, established the city's boundaries, which remained stable until 1991, when government control over land development was abolished. From then on, state-owned land reverted to private property belonging to individuals, families and communities. The latter, in a quest for gaiety sustained by exponential demographic growth, embarked on subdivision operations without respecting the urban planning standards laid down by the 1980 SDAU.

Spatial development in Brazzaville after 1991 took place under the exclusive control of landowners, without the supervision of the public authorities, in a context of total disregard for urban planning rules. This state of affairs has led to self-construction in terms of spatial planning, i.e., the production and development of building spaces, the construction of buildings and roads, without a legal planning framework. The result is an irregular urban fabric, with construction in non aedificandi zones, i.e., exposed to possible natural hazards such as flooding, erosion, landslides, subsidence, quicksand and others. In 2011, new city limits were set, but they began to be exceeded in 2012, more than ten years after 1991. This was a period of land anarchy, marked by informal allotments and above all, the occupation of non aedificandi zones, in defiance of the relevant urban planning standards. The period from 2012 to 2022 is characterized by the densification of the urban fabric and the occupation of hilly areas at altitudes ranging from 350 to 650 m. An analysis of the city's spatio-temporal evolution between 2002 and 2022 shows that 72.8% of its territory is located in the upper part, at altitudes ranging from 300 to 650 m, of which 60.91%, from 300 to 400

m and 11.9%, 400 to 650 m, with very pronounced inclines and slopes, in excess of 10% (**Figure 6**).

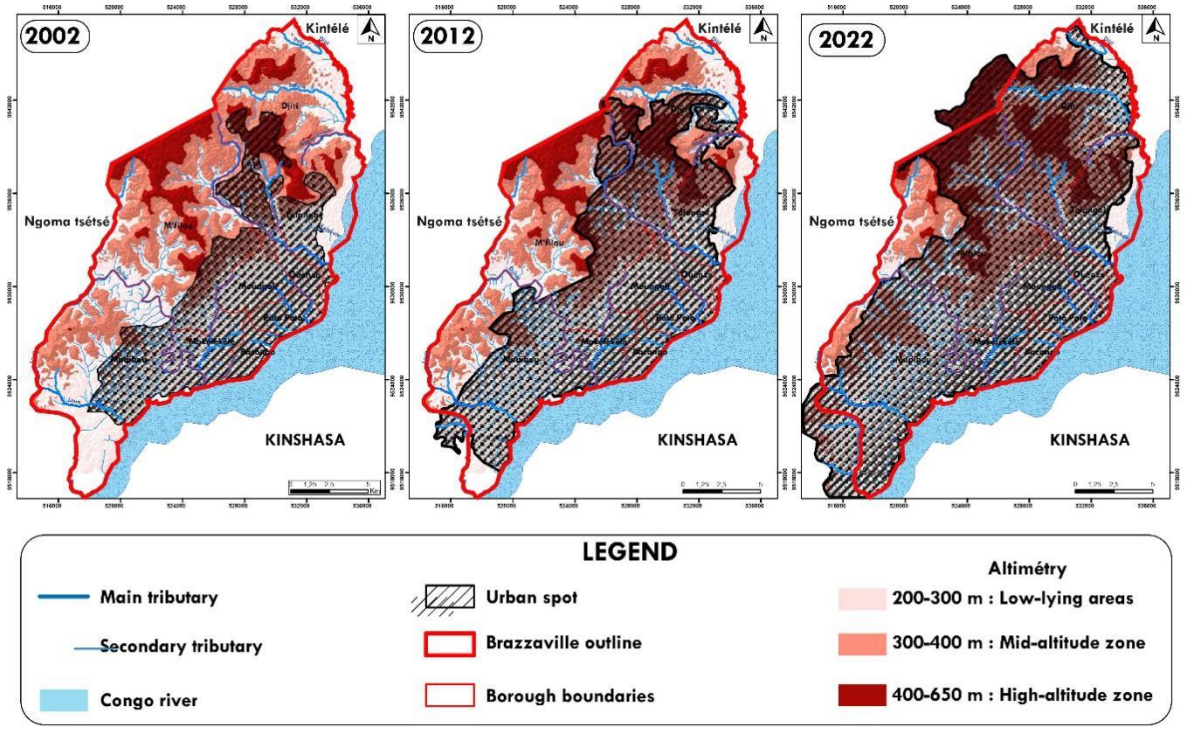


**Figure 6.** Change in land use from 2002 to 2022.
Source: Emvoulou, 2023.

**Figure 6** shows how the constant extension of the built area led to the occupation of the upper part of the territory, at altitudes ranging from 300 to 650 m.

## 3.3. Temporal spatio-demographic evolution of Brazzaville 2002 and 2022

The city of Brazzaville has experienced a rapid increase in its population over the last twenty years. It has increased from 1,051,145 inhabitants in 2002 to 2,145,783 in 2022 (RGPH-5, 2023), an increase of 104.14% (**Figure 7**). This explains the extraordinary spatial extension. The area of inhabited areas increased from 12,164 ha in 2002 to 29,892 ha in 2022, an increase of 145.74%. These results make population growth one of the major factors in the regression of vegetation cover in the urban and peri-urban perimeter of Brazzaville.

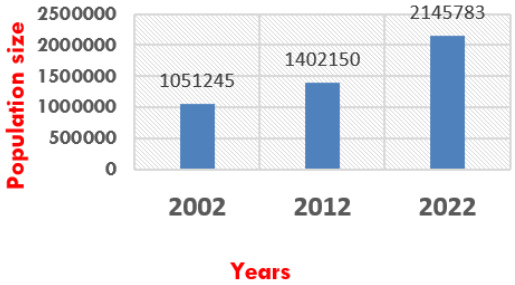


**Figure 7.** Brazzaville population trends from 2002 to 2022.
Source: RGPH 5, 2023.

**Figure 7** shows how from 2002 to 2012 and from 2012 to 2022, the population is constantly increasing.

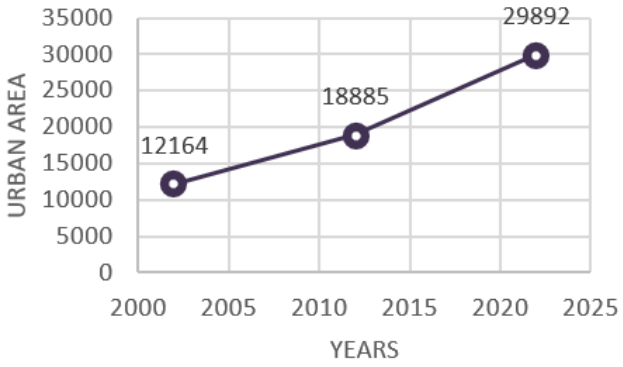


**Figure 8.** Change in urban land area from 2002 to 2022.
Source: Emvoulou, 2023.

**Figure 8** shows how from 2002 to 2012 and from 2012 to 2022, the urban task is constantly increasing.

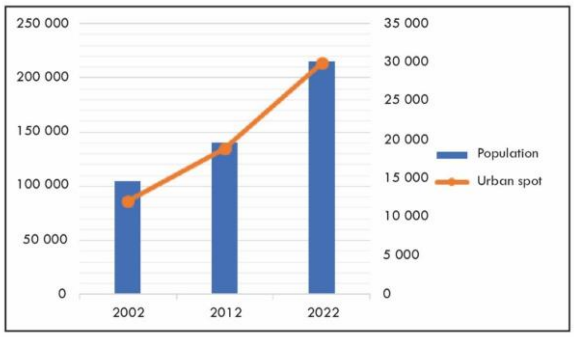


**Figure 9.** Evolution of the surface area of the agglomeration and the size of the population.
Source: Emvoulou, 2023.

Analysis of **Figure 9** shows that the evolution of the urban area is similar to that of the population, with increases of 145.74% for one and 104.14% for the other. In the same periods, plant cover increased from 20,476 ha in 2002 to 14,086 ha in 2012 and 6073 in 2022, a decline of 67.91%. We then see that, when the number of the population increases, the area of plant cover decreases (**Figure 10**).

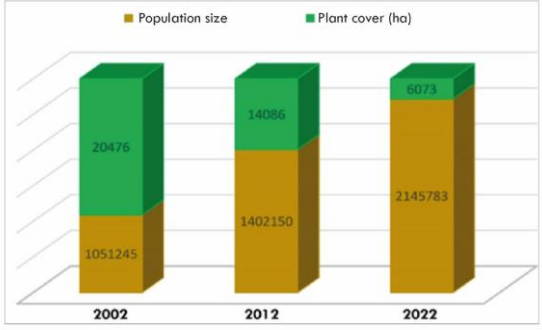


**Figure 10.** Explosive urban expansion at the expense of vegetation cover.
Source: Emvoulou, 2023.

**Figure 10** shows how rapid and permanent urban expansion has reduced vegetation cover by more than half in 20 years. It went from 20,476 ha in 2002 to 6073 ha in 2022, a decline of 70.34%.

### 3.4. Vegetation cover destruction and environmental problems in Brazzaville

The destruction of the plant cover leads to the alteration of the protective function of the soil of the latter. It has resulted in the occurrence and development of many environmental problems. Among these, water erosion in urban areas, which appears to be one of its most obvious consequences. In Brazzaville, the continuous increase in population and the consequent extension of the urban space have pushed the populations to settle in high altitude areas (400 to 650 m) with slopes of more than 15%. But this appropriation of the natural space and its transformation into a habitat is done by destroying the vegetation. Urbanization, whether controlled or uncontrolled, I always to the detriment of natural areas. As a result, unprotected land is exposed to the hazards of natural phenomena such as climate. Indeed, bare, unprotected soil is subjected to the aggressiveness of rainfall, resulting in water erosion and its corollaries of siling and flooding. Erosion, which is at the root of the formation and development of gully erosion, causes significant human and environmental damage. It occurs in six of the nine arrondissements and is one of the major environmental problems facing the city (**Figure 11**).

**Figure 11.** Destruction of dwelling by erosion.
Source: Emvoulou, shooting, December 2023.

The photos in **Figure 11** illustrate the extent of the evolution of the Don Bosco ravine in Itatolo, in district 9 Djiri.

It is the cause of a lot of material and human damage. According to Ngazzi (2017), for example, it was estimated that for 157 ravines and gullies identified, the loss of 33,603.90 t/ha/year of land at an estimated cost of 40 billion CFA francs. Between December 2022 and October 2024, the Don Bosco ravine alone in Itatolo has progressed by 216 m for an estimated loss of land at a volume of 14,256 $m^3$ (**Figure 11**). Land erosion is the cause of much of the destruction of homes, as shown in the images in **Figure 12**. These sufficiently illustrate the extent of the problem and the damage.

One of the consequences of water erosion in Brazzaville, which is a form of soil degradation, is the silting up of buildings. Soil erosion, as mentioned above, is the process of detachment, transport and deposition of soil, by runoff, from a point located at the top of the slope to a lower point. Thus, all the earth torn up in the hilly areas is deposited below, in the valleys, shallows, talwegs and river beds. Everywhere in Brazzaville, these sensitive places are occupied and developed, without taking into account of their vulnerability and without the slightest consideration of the physical characteristics of the place (**Figure 12**). This resulted in the invasion of sand from roads, homes and sanitation works. We most often end up with buildings totally submerged in sand. This spectacle of desolation is very common in M'filou, in the La Base district and in Talangaï, in the Kélékele basin, in districts 607, 608 and 609, 610.

**Figure 12.** Image of houses and roads swallowed up by sand in M'filou and Talangaï.

These photos show the engulfment of buildings by sand in the La Base district, in district 7 M'filou district.

## 4. Discussion

Several research works (Samba et al, 2008; Sautter, 1966; Tchitembo and Moundza, 2017; Vennetier, 1991) addressed the question of the uncontrolled dynamics of urban growth and its socio-economic implications (quality of housing, security and access to basic social services) in Brazzaville. On the other hand, these studies have not sufficiently taken into account the effects of the latter on the vegetation cover, which expose the populations of the areas concerned to the risks of environmental disasters. This study on the sprawl of Brazzaville and its impact on the vegetation cover shows that the exponential population growth of the city is occurring to the detriment of the vegetation cover and the natural space. Between 2002 and 2022, its population increased from 1,051,145 to 2,145,783 inhabitants, an increase of 104.14%. At the same time, the area of inhabited areas has increased from 12,164 ha in 2002 to 29,892 ha in 2022, This is an increase of 145.74%. These results are similar to those of Amontha et al. (2015), Sène (2018), Folega et al. (2019) and Nganmo and Priso (2022), obtained in the analysis of the urban growth of the cities of Bignona in Senegal and Douala in Cameroon, Addae and Oppelt (2019) in the analysis of the spatial dynamics of the Greater Accra metropolis in Ghana and Koua Oba (2019) in Brazzaville. In this work, the authors demonstrate that population growth is one of the

major factors in the regression of vegetation cover in the urban and peri-urban perimeter of the cities studied.

The work of Djangbedja et al. (2017) shows that the strong anthropization of plant formations in the lower Zio valley in Lomé leads to the significant loss of microphanerophytes (75.80%) and Guinea-Congolese species (37.77%) and a high value of Shannon diversity index, i.e., 3.175 bits. Tampo et al. (2015) demonstrate that anthropogenic activities have deteriorated the physicochemical and water qualities of the hydrosystem of the Zio River basin and significantly disrupted the pollution gradient. Thus, the stations downstream of the Zio basin corresponding to the Zio valley in Greater Lomé have lower dissolved oxygen contents of up to 0.6 mgO2/L in contrast to the good quality of water upstream of the valley. of Greater Lomé where dissolved oxygen levels are very high, ranging from 6 to 14.6 mgO2/L. For Takou (2015), artificialized surfaces due to the density of buildings have exploded in Lomé to the detriment of vegetated surfaces. Dense buildings which occupied 27% of urban space in 1986 increased to 55% in 2011 and 88% in 2013, an increase of 61% between 1986 and 2013; discontinuous buildings increased in the same period from 40% to 4%, a reduction of 36% to the disadvantage of landscaped space.

This relationship between urbanization and regression of vegetation cover is evoked in the work of Yang et al. (2024), Atchade et al. (2023) and Folega et al. (2019), who place particular emphasis on the effectiveness of green spaces in urban areas. Bare and fragile soils such as those in the northern and northwestern areas of Brazzaville are exposed to the aggressive action of rainfall. In a dynamic of often uncontrolled spatial occupation, this leads to the appearance and development of water erosion that is rampant in Brazzaville. This relationship between spatial occupation and erosion is also demonstrated in the work of Bawa et al. (2019), Mayima et al. (2019) and Nzila et al. (2020), in their work on the same phenomenon in Lomé,Kintélé and Brazzaville. Water erosion and its corollaries, silting up and flooding, are the phenomena of soil degradation that the city has experienced over the last twenty years (Attipo et al., 2023; Emvoulou et al., 2024; Mambou and Elenga, 2023). These results are in line with the work of Tchotsoua and Bonvallot (1997) in the city of Yaoundé and Van Caillie (1990), Wouters and Wolff (2010) in the commune of Kinshasa, Mutungu Kuleta et al. (2021) in the town of Kikwit, in the Democratic Republic of Congo and M'bouka Milandou (2022) and Mayima et al (2022) in Brazzaville.

The results of this research are consistent with those of Tao et al. (2023). Urban growth had far greater negative effects than the positive effects on vegetation in the HBOY region between 2000 and 2020. The areas of vegetation negatively and positively affected by this expansion were 403.9 $km^2$ and 169.4 $km^2$ respectively. Thus, the negative impacts were 2.4 times higher than the positive impacts. Moreover, in the different categories of cities, the negative effects on vegetation far outweighed the positive effects.

## 5. Conclusion

The demographic explosion that the city of Brazzaville has experienced over the past twenty years (from 2002 to 2022), has led to an unprecedented spatial extension. It results in an uncontrolled occupation of peri-urban space, with the consequences,

among other things, of the destruction of plant cover. The development of these bare spaces, with irregular relief and unstable ground, is at the root of the environmental problems that have been observed. Most of them boil down to water erosion, resulting in silting, landslides and flooding. These soil degradations are caused by the present need for space for the construction of housing, roads, urban infrastructure and service facilities in the area studied. The damage caused by these natural disasters is significant and is not only a major constraint for the sustainable development of Brazzaville, but also a challenge for policymakers and local government managers. This study demonstrates the cause-and-effect links between population growth, spatial extension and environmental degradation observed in the city. It recommends the implementation of responsible policies in the occupation and development of sensitive and non-aedificandi areas, as recommended by articles 2 and 20 of Law 06-2019 of 5 March 2019 on the Urban Planning and Construction Code in the Republic of Congo and the orientations of the 2016 Urban Planning Master Plan (SDU) and the recommendations of the 2022 Local Urban Planning Plan (PLU) of the city, focused on the creation of forest areas in areas exposed to erosion water and along the city's waterways. It proposes the implementation of urban restructuring projects in order to respond to the problems posed by informal land use and development.

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