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BASES DE DATOS, PERCEPCIÓN REMOTA Y SIG APLICADOS A LA GESTIÓN AMBIENTAL

Mapping of great erosion in cities of Kinshasa and Brazzaville, Equatorial Africa.

Mapeo de la erosión a gran escala en las ciudades de Kinshasa y Brazzaville, África Ecuatorial.

Mapeamento de erosões de grande porte nas cidades de Kinshasa e Brazzaville, África Equatorial.

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Estudio de caso

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ABSTRACT

Since the 1980s, gullies have been a problem for the cities of Kinshasa and Brazzaville, whose research presents the case of 3 gullies located in the Congo River Basin in urban and peri-urban areas. The objective of the research was to present a digital model of elevation of urban gullies, with topographic data used in engineering projects for future recovery. The acquisition of topographic data was carried out through the Google Earth Pro software and the QGIS geographic information system, with data processing for visualization in the Golden Surfer software. The Laloux gully located in Kinshasa is one of the largest in the world, with a length of 1,100 m and a 3-way format. The mouth of the city of Brazzaville has a width of less than 40 m, but is more than 900 m long, in a densely populated area. The Buma gully in Kinshasa is an example of the development of the erosive process in a peri-urban area, with the expansion of one of the largest cities on the African continent, being induced by the existence of a road on a slope.

Keywords: gully, road, slope, topography

RESUMEN

Desde la década de 1980, los barrancos han sido un problema para las ciudades de Kinshasa y Brazzaville, cuya investigación presenta el caso de tres cárcavas ubicadas en la cuenca del río Congo en áreas urbanas y periurbanas. El objetivo de la investigación fue presentar un modelo digital de elevación de cárcavas urbanas, con datos topográficos utilizados en proyectos de ingeniería para su futura recuperación. La adquisición de datos topográficos se realizó a través del software Google Earth Pro y el sistema de información geográfica QGIS, con procesamiento de datos para su visualización en el software Golden Surfer. El barranco de Laloux, situado en Kinshasa, es uno de los más grandes del mundo, con una longitud de 1.100 m y un formato de tres vías. La desembocadura de la ciudad de Brazzaville tiene una anchura de menos de 40 m, pero tiene más de 900 m de largo, en una zona densamente poblada. El barranco de Buma, en Kinshasa, es un ejemplo del desarrollo del proceso erosivo en una zona periurbana, con la expansión de una de las ciudades más grandes del continente africano, siendo inducida por la existencia de una carretera en pendiente.

Palabras clave: cárcavas, carretera, talud, topografía

RESUMO

Desde a década de 1980, as boçorocas representam um problema para as cidades de Kinshasa e Brazzaville, cuja pesquisa apresenta o caso de 3 boçorocas localizadas na Bacia do Rio Congo nas áreas urbanas e periurbanas. O objetivo da pesquisa foi apresentar um modelo digital de elevação das boçorocas urbanas, com dados topográficos utilizados em projetos de engenharia para futura recuperação. A aquisição dos dados topográficos foi realizada através do software Google Earth Pro e do sistema de informação geográfica QGIS, com tratamento dos dados para visualização no software Golden Surfer. A boçoroca Laloux localizada em Kinshasa é uma das maiores do mundo, com uma extensão de 1.100 m e um formato de 3 direções. A boçoroca da cidade de Brazzaville apresenta largura menor que 40 m, mas possui extensão de mais de 900 m, em uma área densamente povoada. A boçoroca Buma em Kinshasa é um exemplo de desenvolvimento do processo erosivo em área periurbana, com expansão de uma das maiores cidades do continente africano, sendo induzida pela existência de estrada em declividade de encosta.

Palavras chave: boçoroca, encosta, estrada, topografia

INTRODUCTION

Soil erosion has become a major problem in equatorial and tropical areas after decades of deforestation and changes in land cover. Despite being a natural phenomenon, due to the seasonal rainfall, the intensity of soil losses is worrisome, since they can generate direct problems, such as: silting of rivers, damage to infrastructures and devaluation of real estate; and indirect problems, such as: reduced food production and expenditure of public resources.

In the field, soil losses are mainly notable with laminar erosion and loss of soil fertility, with the formation of small incisions called furrows on the slopes. In the city, soil losses are related to large-scale linear erosion, due to a higher concentration of rainwater in drainage channels present in public roads (roads and avenues, mainly). If urban erosion develops in a degraded area of a spring, the action of surface and subsurface waters leads to the formation of the most worrisome erosive form: the gully (Ionita et al., 2015).

As the gullies are linear erosive forms, modifying the terrain, mapping studies need to adopt the topographic scale in order to generate data for future urban erosion control projects and academic investigations to analyze the evolution of the phenomenon. From the topographic data of the area degraded by the gully, it is possible to generate models in geographic information systems for topographic scale mapping (Barrio et al., 2018).

Based on technological resources, with remote sensing images of high spatial resolution and the existence of geodetic equipment linked to the data of the global positioning system by satellite, the surfaces of the gullies can be represented in digital bases of geographic information systems, for the generation of models. Through models with high topographic scale resolution, analysis with topographic and cross-sectional profiles can be carried out, with data associated with information about soil and sediments (Walker et al., 2021).

Since the 1960s, soil erosion in geological formations dating back to the Quaternary in the Congo River Basin has been studied by De Ploey (1965 apud Lateef et al., 2010).

Imwangana et al. (2014) present the topographic data and morphometric analysis on the large linear erosions that were induced by urban roads in Kinshasa. With aerial photographs from 1977, 13 km of linear erosion perimeter were identified in Kinshasa. From the analysis of high-resolution remote

sensing images, 334 linear erosions (ravines and gullies) were identified, with a total perimeter of 102 km, in the urban area of Kinshasa.

In relation to the containment measures of the gullies in Kinshasa, the Laloux Gully presented problems of upstream erosion in 2009, with the destruction of the urban macro drainage systems; and the head of the gully was controlled with a work in 2012 (Imwangana et al., 2014).

Based on theoretical considerations, this work aims to present an updated analysis of the Laloux Gully in Kinshasa, and another gully located in the peri-urban area, with the inclusion of a third example of one of the largest gully in Brazzaville city.

Characterization of area

The Congo River Basin presents factors related to the trend of processes for soil losses, such as: precipitation in the equatorial climate with annual averages of 2,300 mm, geological substrate with sedimentary rocks dated to the Cenozoic and Quaternary; sandy and deep and homogeneous soils; deforestation since the nineteenth century with expansion of urbanized areas since the 1980s (Mushi et al., 2019).

Regarding the Physical Geography related to the development of gullies in Kinshasa, capital of the Democratic Republic of Congo, the characterization of Geology and the relations with the development of large-scale linear erosions, the Laloux and Buma gullies, from the city of Kinshasa, are located in sandstones of the Tendre Formation of the Inkissi Group, dated from the Cretaceous period. The sandstones of the Tendre Formation behave as unconfined aquifers, with the water table present at a depth of 8 m from the ground. The presence of subsurface waters of the unconfined aquifer favors the development of the gullies due to the action of internal tubular erosion (Lateef et al., 2010).

Regarding the urban expansion in Kinshasa, the rural exodus and the high fertility rate favor the increase of the urban fabric, whose metropolis exceeds 17 million inhabitants, with an area of approximately 500 km². The urban morphology in Kinshasa, since the time of colonization in the nineteenth century, has an orthogonal format with the existence of rectilinear avenues in the direction parallel to the slopes. Most of the urban roads on the outskirts of Kinshasa do not have asphalt and rainwater drainage (Wouters & Wolff, 2010).

About Physical Geography in the Republic of Congo, in the city of Brazzaville, the geological substrate is formed by sandstones of the Bateké Formation of the Inkissi Group. The geomorphology of the city of Brazzaville is formed predominantly by terraces dating from the Quaternary, with the formation of medium and small linear erosions. As a result of the slopes in watersheds and urban drainage due to the expansion of the city of Brazzaville, there is the development of gullies with approximately 300 m of extension on the slopes, with a very friable geological substrate dating from the Quaternary (Malanda et al., 2023).

The relief of the analyzed area is formed by the plateau of the Lower Congo River Basin with terraces composed of terrain susceptible to erosive processes, dating from the Quaternary and the Cenozoic (Mushi et al., 2019).

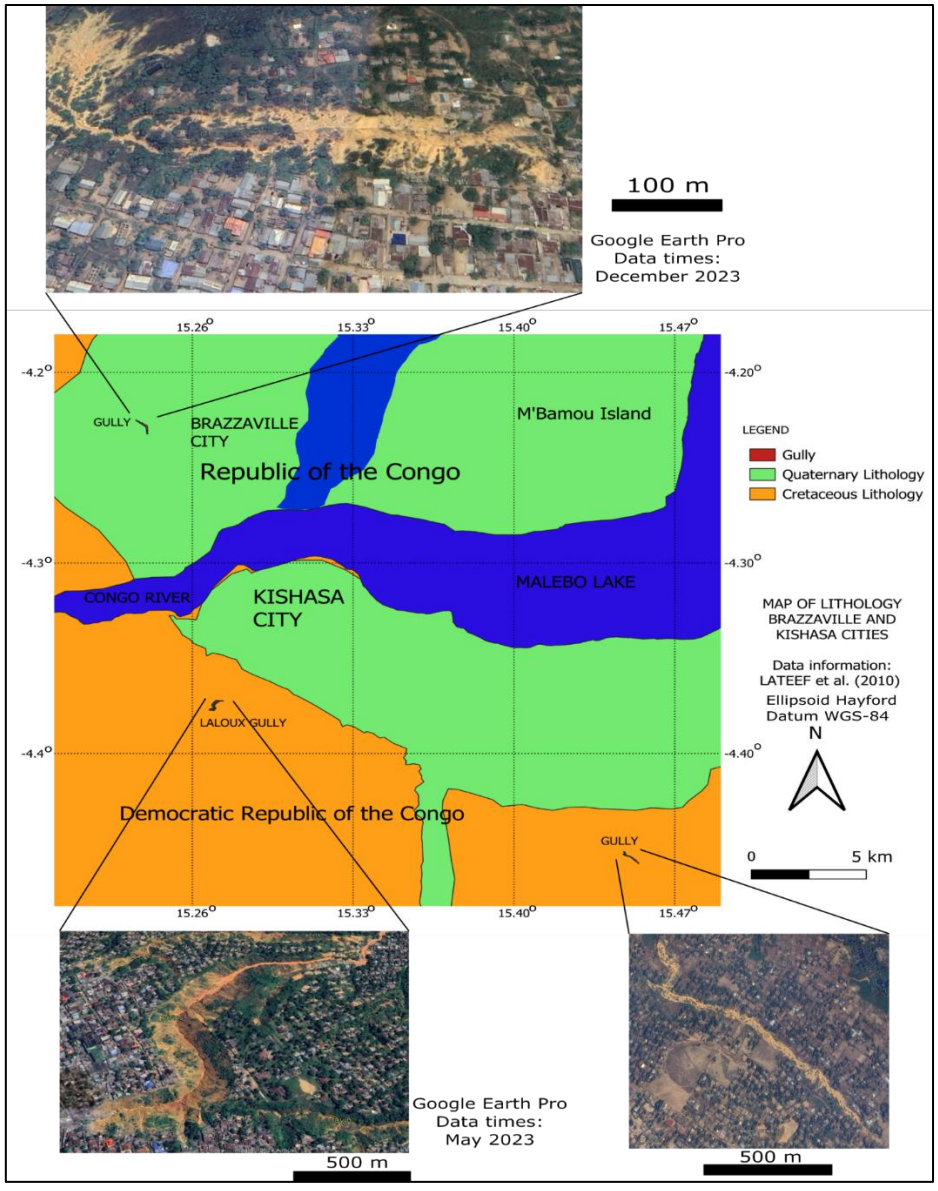
Regarding the susceptibility to erosion of the terrain of the urban site of Brazzaville, Kempena et al. (2016) highlighted that 4% of the soil is at high risk of loss, when considering erodibility. From the analysis of land cover conditions and the other factors of the Universal Soil Loss Equation, it was

found that 8% of the urban site of Brazzaville has a high potential for water erosion (Kempena et al., 2016).

Malanda et al. (2023) presented the risk of developing a bulge called Ngamakosso Erosion, with serious damage to the infrastructure of the Talangai neighborhood, northeast of the city of Brazzaville.

The map in Figure 1 shows the location of 3 major urban erosions studied, with their distribution in geological formations dated to the Quaternary and Cenozoic.

Figure 1. *Gullies in Brazzaville and Kinshasa with highlights in Geology Formation.*



Source: *Elaboration of author.*

The city of Brazzaville is located in a terrain with Quaternary sedimentary formations, highly friable with the presence of cliffs and dunes, with erosions of 400 m in length on average.

MATERIAL AND METHODS

The applied methodologies were derived from Geoprocessing, with the use of a geographic information system, software for image editing and acquisition of geographic data based on the Web.

In the acquisition of remote sensing images, Google Earth Pro was used, where the features were vectorized to generate files of the polygons of the mapped gullies.

To obtain the elevation dimensions, the terrain was activated in the Google Earth Pro view, with the annotation of the UTM coordinates and dimensions in a spreadsheet of rows and columns. In the Golden Surfer application, topographic maps of the gullies were generated, with the cartographic conventions of legends in hypsometry. To generate model terrain of gullies in software Golden Surfer used triangulation and linear interpolation method in spatial analysis.

Based on the geological map presented by Lateef et al. (2010), the geological formations were vectorized in the database of the geographic information system QGIS. In QGIS it was possible to define the datum and cartographic conventions, as well as the graphical scales.

When considering the topographic data of the urban basins, the rational method of maximum flow proposed by Pal & Pani (2016) was applied to estimate the flow in the gullies during voluminous rainfall of 30 mm.

In the Inkscape application, the editions of the cards were carried out with the insertion of images and symbology to represent the locations.

RESULTS

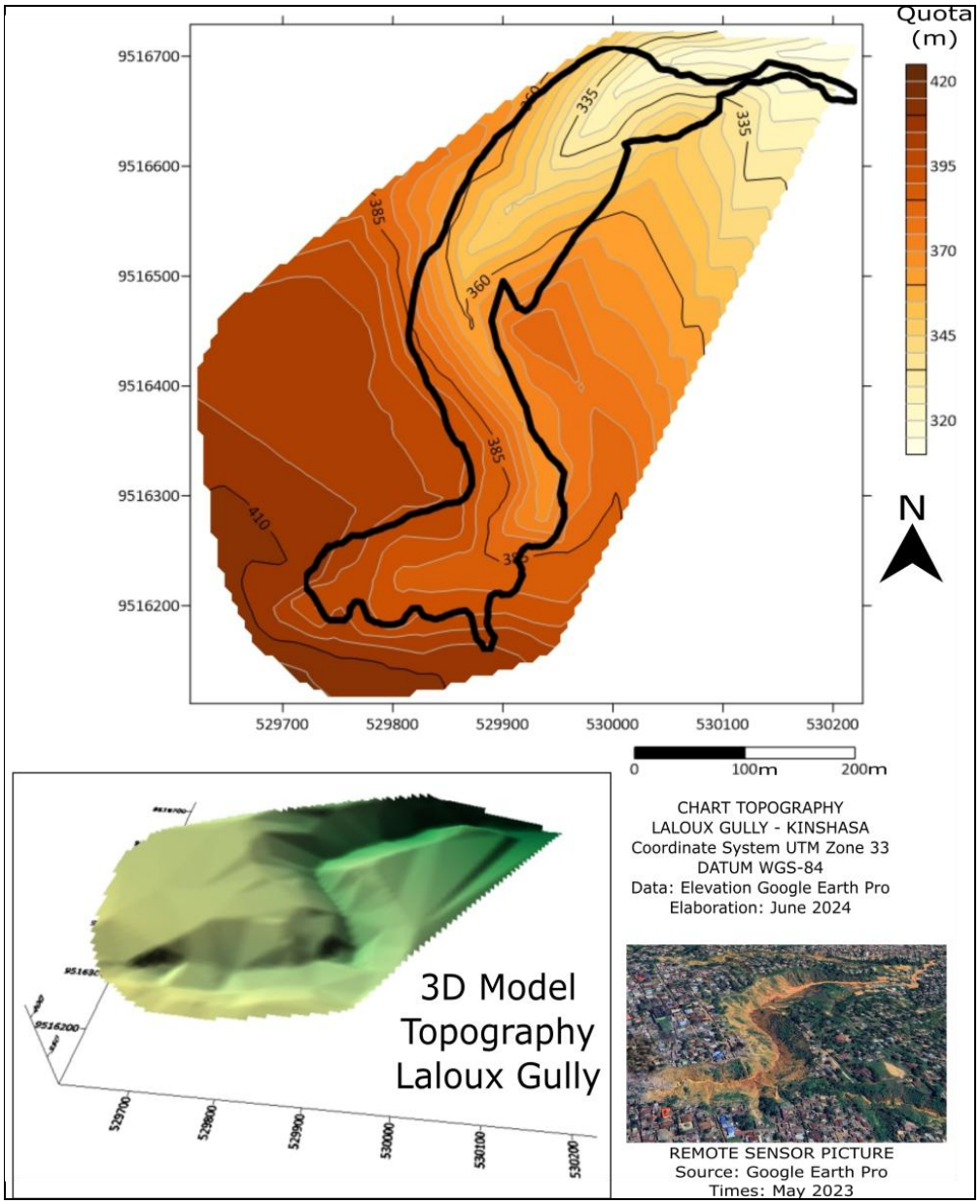
Urban erosion in Kinshasa

Probably, the Laloux gully is one of the largest in the world in urban areas. This erosive shape impresses with its shape and dimensions. Its format took 3 directions: first downstream with the bed of the watercourse, the second in the direction of the slope, and the third in the same direction as the Bolikango Avenue. According to remote sensing data, in 2004 the Laloux Gully had 850 m of long.

Currently, Laloux Gully is 1,100 m long, located downstream of Bolikango Avenue, located about 9 kilometers from the city center of Kinshasa. The area of the Laloux gully has approximately 10 hectares. The maximum width reaches 150 m, with an average width of 100 m.

The Laloux gully not only impresses with its dimensions but also stands out for its longitudinal shape in the letter S, with 3 directions of its bed. The head of the gully is located at an elevation of 420 m, exactly on the same bed as Bolikango Avenue, with a ramp at a maximum level of 447 m, 1,042 m long (slope of 3.5%). Figure 2 shows topography in area of Laloux gully, with levels of relief between 420 and 320 meters.

Figure 2. *Topographic chart of Laloux Gully.*



Source: *Elaboration of author.*

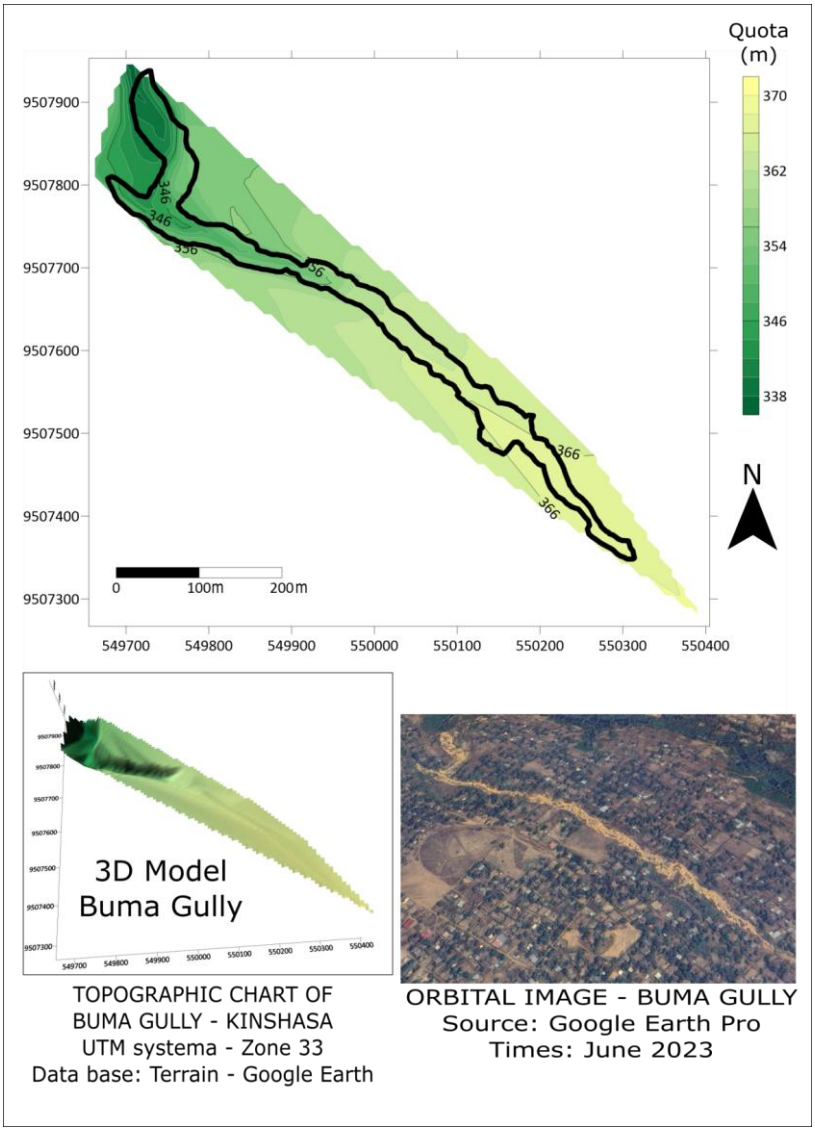
The contribution basin of the Laloux gully has an area of approximately 2.5 km, in urban density in the form of land use. Was estimated a maximum flow of 14.6 m^3/s in contribution basin's Laloux gully.

The gully of Buma district is located 22 km from the center of Kinshasa, being a peri-urban erosion. It is from a headwater of the tributary of the Ntshuenge River, one of the main urban tributaries of the Congo River. This urban erosion is 1,070 meters long, with an average width of 40 m.

About the genesis of this peri-urban erosion, in 2014 the gully was only 200 m long, arising from an upstream erosion of the headwaters of the Ntshuenge River. From 2016 onwards, the gully developed on the same bed of a public road that connects to a road, in the Buma neighborhood of the city of Kinshasa. In 2016, the gully was 500 m long. In 2018, in just 2 years, the gully expanded 375 m, reaching 875 m in length. In 2021 the peri-urban erosion reached its maximum length with

1075 m, with the development of its depth. Between 2018 and 2023, the gully expanded by only 135 m. The contribution basin of this erosion has an area of 550,000 m². Buma road, upstream of gully is 4.4 km long with an elevation between 432 and 380 m, with an average slope of 11.8%. Downstream and northwest, a branch of the Boma gully began in the same direction as the road. Figure 3 shows topographic conditions of terrain in area of Buma's Gully in Kinshasa.

Figure 3. *Topographic chart of Buma Gully.*



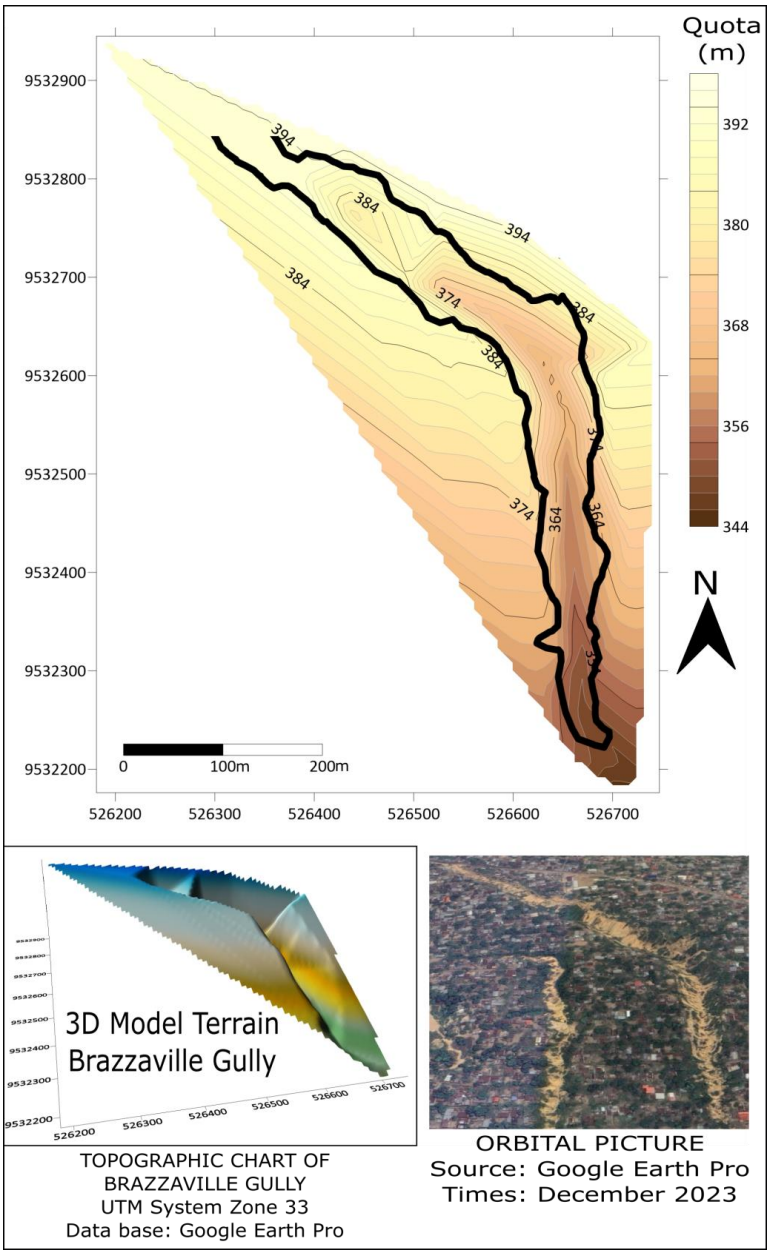
Source: *Elaboration of author.*

Urban Erosion in Brazzaville

The gully of P20 road in city of Brazzaville, in this text called Brazzaville Gully, has an area of 6 hectares with approximately 900 m of extension.

Despite having a shallower depth and width than the Kinshasa's gullies, the Brazzaville Gully has a large extension with 2 senses. Figure 4 shows the topography conditions in the degraded area of Brazzaville Gully.

Figure 4. *Topographic chart of Brazzaville Gully.*



Source: *Elaboration of author.*

The contribution basin of the Brazzaville Gully has an area of approximately 0.75 km, in urban density in the form of land use. Was estimated maximum flow of 3.7 m^3/s in contribution basin's Brazzaville gully.

The city of Brazzaville is located in a terrain with Quaternary sedimentary formations, highly friable with the presence of cliffs and dunes, with erosions of 400 m in length on average.

DISCUSSION

In summary, each gully analyzed in this research has its autochthonous characteristics.

The Laloux Gully, having several decades, has large dimensions in width, extension and depth, with a rear-stream erosion due to the bed of the Boukingo Avenue. Another aspect that hinders the control of urban erosion in the Laloux Gully is the absence of vegetation cover for stability, which is common in gullies over 20 years old. According to Imwangana et al. (2014), the government of the Democratic Republic of the Congo has implemented 2 macro-drainage builds to control the Laloux Gully, but the upstream erosion activity destroys the macro-drainage galleries. The conditions of precipitation concentrated in the equatorial climate and the implementation of asphalt in the urban roads of the city of Kinshasa were factors that maintained the upstream erosion at the head of the Laloux Gully. The densely populated area of one of Africa's largest cities makes it difficult to control urban erosion, due to the deposition of solid waste and rubble in the headwaters of the Laloux Gully.

The gully of the Buma neighborhood in Kinshasa is a classic example of peri-urban erosion that developed on the same roadbed. The morphology of the urban roads in the Boma neighborhood depends on the road located 20 km from the center, but the circulation road itself was destroyed by the action of soil degradation. The gully of the Boma was not extended only because the local topography reached a lower level of a lap of a headwater. Although the average width of the gully is 35 m, the most downstream part is more than 50 m wide with a depth that exposes the deep sandy and homogeneous soil, being easily eroded during the rains.

Brazzaville's Gully developed in a Quaternary substrate terrain, with high fragility. In addition to this natural susceptibility factor, the gully arose in an area that was landfilled for the urban expansion of an area close to the airport. In this case, the gully wasn't specifically developed due to induction by runoff through a public road (road, ex.), but by the drainage itself in an embankment area. In view of these aspects, Brazzaville's gully is hard to control due to the drainage of an old, grounded watercourse and a terrain highly susceptible to erosion. The only advantage from a perspective of gully's control is the existence of vegetation that has regenerated, unlike the other 2 examples.

In common, the 3 examples of the gullies analyzed, it is possible to notice the presence of a deep and homogeneous soil, of light color by the remote sensing images, with a tendency of high erodibility.

Regarding the morphology of the gullies, one direction in the valley of the Boma's Gully, 2 directions in the Brazzaville's Gully, and 3 directions in the Laloux Gully were highlighted in the geomorphological conditions; in which it would be interesting to study the characteristics of soil granulometry with local plots.

CONCLUSIONS

Soil erosion is a phenomenon, which in the case of gullies leaves marks on the landscape, with risks mainly in urban areas. Faced with this problem that affects poor regions in equatorial and tropical climates, the very important measure is to quantify and delimit the degraded area. Therefore, mapping on a local scale, with topographic data, is important for future projects to control urban erosion and possibly solve the problem.

The water erosion in urban and peri-urban areas needs to have studies on the conditions of land use and occupation in micro watersheds, in order to ensure the correct direction of rainwater and adequate works for urban erosion.

Recent technologies for the acquisition of geographic data with Geoprocessing contribute to the existence of maps and information for technical professionals in the elaboration of projects for urban erosion control and city planning. In the case of the African continent, the action of projects depends on external resources, with the importance of reports and articles to justify the erosion control proposal. Universities can produce knowledge through dialogue with technical professionals in the extension of activities in favor of society and the environment.

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