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RAINFALL VARIABILITY AND RAINWATER MANAGEMENT IN THE DJIRI WATERSHED IN BRAZZAVILLE (REPUBLIC OF CONGO)

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Abstract

The aim of this study is to analyze rainfall dynamics and stormwater management in the Djiri watershed, northeast of the city of Brazzaville. The methodological approach used is based on documentary analysis, data collection from the local SRTM-DM, rainfall statistics covering the period 1990-2023, field observations and socio-anthropological perceptions of SWM. These data were processed using Excel, ENVI and QGIS. The results show that the watershed, which has a KG=1.8, is elongated, rainfall is highly variable, with an upward trend, particularly in 2020, when the index reached its highest value of 0.35 since 1990, i.e. an average of 163.7 mm, and finally, the rainwater management is deficient. Under these conditions, rainwater that escapes infiltration is not domesticated by households, and uncontrolled by the lack of drainage systems, exploits the bare or waterproofed slopes of the hydrosystem, whose gradients sometimes reach 22% on a bedrock of almost 90% sand, to erode the soil. This phenomenon, whose direct consequences are 21 gullying and sedimentation, affects the environment, mankind, its activities and developments. The solution is treating gullies using biomechanical methods (gabion baskets and vetiver grass), install a weather station in the watershed to better monitor rainfall, raise awareness among the rainwater management population and, lastly, lobby the Congolese government to build an effective rainwater drainage system.

Keywords: *Watershed, Rainfall, RWM, Water erosion, Djiri*

Introduction

In Africa, rainfall variability manifests itself in significant spatial and temporal variations, sometimes in the form of abundant precipitation throughout the year, sometimes in the form of droughts of varying lengths and intensity. According to Dadoum Djeko (2018), it is a global phenomenon, the effects of which constitute a major obstacle to the socio-economic development of African countries. In Congo, this climate, which is felt throughout the country, exacerbates the environmental problems that threaten urban areas (flooding, erosion, rainwater stagnation, etc.) (Massouangui-Kifouala, 2022). Given that Congolese cities are indented by watersheds, the effects of rainfall variability on the environment appear to be cumulative with the consequences of poor rainwater management (RM) *in situ*. However, these hydrosystems are considered appropriate spatial references for the study and implementation of environmental policies related to water and material transfers in order to understand the consequences of current global changes (Dufour et Lespez, 2020); but poor RM disrupts geomorphological balances, with serious consequences (gully erosion). Kazi-Tani et al (2023) support this thesis, according to which autumn and summer rains directly cause slope erosion in hydrosystems. Runoff from roofs, which does not infiltrate, exploits the relief (slope) and erodes the soil (M'bouka-Milandou, 2023). However, for Mouanda-Lalamba (2021), the good RM by households protects both plots and urban roads from diffuse and concentrated runoff, which is responsible for water erosion and its consequences. The Djiri watershed, located between the Brazzaville city and the Kintelé Municipality, is facing this situation. This watershed has been subject to unregulated anthropization and a disruption of its morphogenetic balance (Ngatsé et al., 2017) for nearly three decades. Gully erosion degrades land, urban roads, buildings, and ecosystems (Mayima *et al*., 2019). The purpose of this work is to analyze rainfall variability and the consequences of poor rainwater management in the Djiri watershed from a sustainable urban development perspective.

Study Area

The Djiri watershed is located northwest of Brazzaville, between 4.012° and 4.212° south latitude and between 15.204° and 15.404° east longitude. It covers an area of approximately 885.97 km²and opens to the east onto the Congo River (Figure 1).

The Djiri basin is one of five watersheds that make up the Batéké plateau hydrosystem in southwestern Congo (Ngouala-Mabonzo, 2022). It cuts through an area of high hills 700 m high and valleys approximately 500 m. The dominant geological formations are the Batéké sands, composed of polymorphic sandstone (Ba1) at the base and ochre sands (Ba2) at the top (Sitou, 2008, Moueba, 2021, M'bouka Milandou, 2022). Strongly desaturated ferralitic soils have developed on these sands (Schwartz, 1985). The climate is tropical, characterized by a rainy season and a dry season (Samba-Kimbata, 1978). The dry season lasts four months (June to September) and the rainy season lasts eight months (September to May), with average monthly rainfall of 180 to 260 mm and temperatures ranging from 24 to 32°C. This BV is covered by gallery forests in the form of copses in the middle of shrub savannas, predominantly *Mitai laurentii, Hyparrhenia diplandra, and Hyparrhenia lecomtei,* with a light ground cover (Koechlin, 1961).

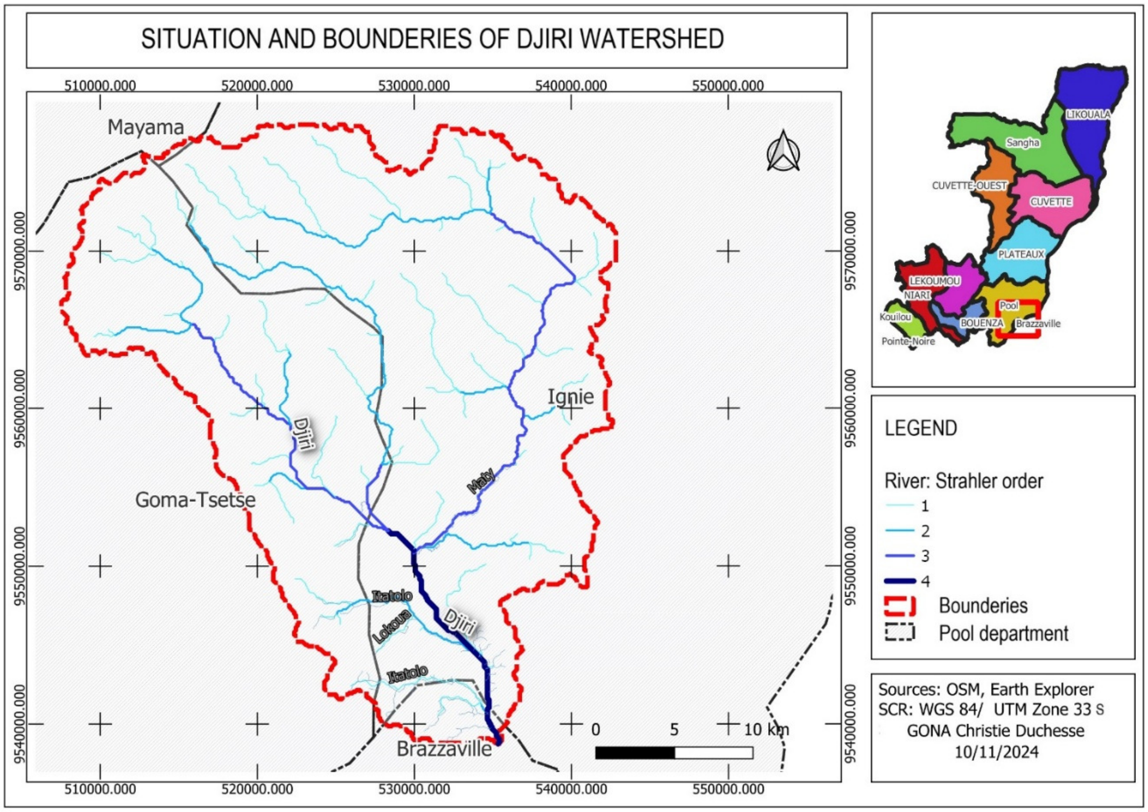

Fig. 1: Location and boundaries of the Djiri watershed

Methodology

Collection and Processing of Spatial, Climatic and Field Data

SRTM-DEM Data from 2000

This data was downloaded from landsat.usgs.gov/landsat-data-access.gov and processed using QGIS to generate the boundaries of the catchment area, calculate the surface area (S) and perimeter (P), and produce the altimetric map and slope map (%).

Climate data from 1980 to 2023

This data was obtained from the Brazzaville synoptic station, recorded on a monthly basis, and mainly concerns precipitation over a time scale ranging from 1980 to 2023. Descriptive statistics were used to determine the average monthly precipitation and reduced centred anomalies: (i) the simple arithmetic mean (SAM) and (ii) the reduced centred anomalies (RCA).

The SMA is defined as follows:

$$\bar{X} = \frac{1}{N}\sum_{i=0}^{n} Xi$$

Where: Xi is the variable in the series; n is the number of values in the variable; N is the total number of values.

The RCA is defined as follows:

$$RCA = \frac{(X_i - \bar{X})}{\sigma}$$

Where: RCA stands for Reduced Centered Anomalies; Xi is the variable in the series; σ is the standard deviation; X; mean.

Data from Social Surveys on Rainwater Management (RM) in situ

This data was used to analyze RM, behavior, and perceptions of people impacted by the geomorphological consequences of poor water management.

A random sample of 173 people was taken into account. Survey criteria: (i) households located up to 300 meters from the banks of the Djiri River, (ii) respondents are heads of households of both sexes (male and female), (iii) household categories: *households without gutters and households with gutters*. All data were processed using MS Office Excel 2010.

Results

Reduced centered anomalies 1980-2023: MAS and ACR

Figures 2A and 3B reveal that the rainfall pattern in Brazzaville and its surroundings is bimodal. It alternates between the rainy season and the dry season. The rainy season lasts 8 to 9 months, from September to May. October, November, and December are the rainiest months of the year, with the rainfall index reaching its highest value in November, at 1.2. However, January and February are a period of intra-rainy decline, with a decrease in precipitation. On the other hand, June, July, August, and September correspond to the dry season, with no precipitation. Figures 3A and 3B show the rainfall characteristics of the study area.

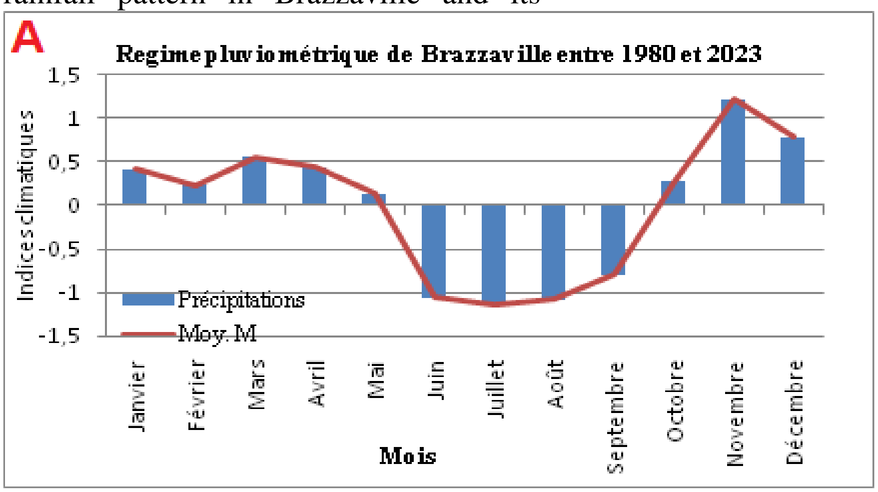

Fig. 2A: Precipitation patterns between 1980 and 2023

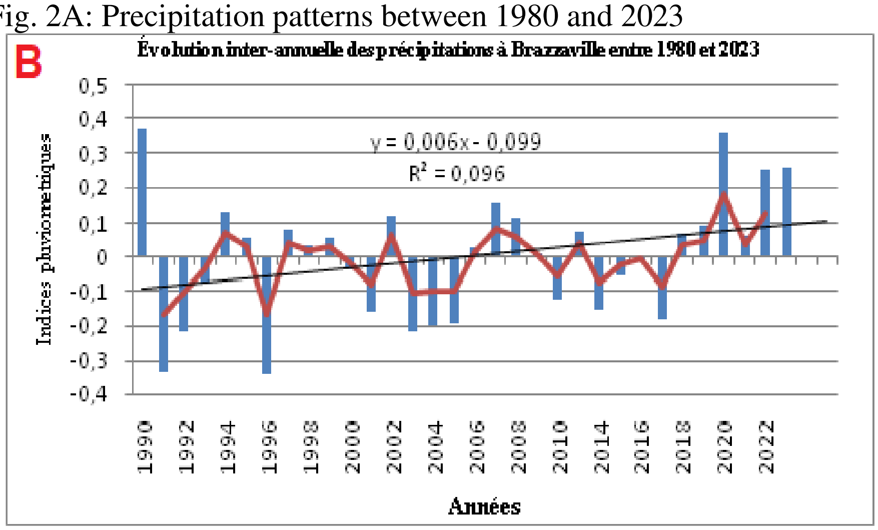

Fig. 3B: Interannual precipitation trends in Brazzaville between 1980 and 2023

The study of interannual precipitation variability in Figure 3 shows interannual changes in rainfall indices in the study area. Three (03) periods can be identified: a wet period characterized by above-average rainfall with very high rainfall runoff rates; a dry period characterized by rainfall deficits with low rainfall runoff; and finally, a more or less wet period where rainfall amounts are around the average value and runoff is less active. Of the entire study period, the decade 2010-2023 is the rainiest, with a rainfall index reaching 0.35 in 2020 and a tendency to increase. Finally, analysis of Figures 2, 3A, and B shows that the Djiri BV is characterized by a bimodal tropical climate. The monthly rainfall pattern shows that the year is divided into two seasons: a rainy season from March to October, during which more than 80% of precipitation is recorded, and a dry season from November to February, during which 20% of the annual rainfall occurs.

Rainwater management (RM) in the Djiri watershed

RM methods at the household level

Table 1 and Figure 3 (A and B) record and analyze RM in the Djiri watershed, based on random surveys conducted in a few households located around sites affected by gully erosion.

Table 1: Household RM in the Djiri watershed

Type of household	Rainwater management			Totals and percentages		
	Disposal	Domestication	Recycling	Totals	Grand total	Number (%)
Households with gutters	58 (66.67%)	18 (20.69%)	11 (12.64%)	87 (100%)	173	100
Households without gutters	64 (74.42%)	14 (16.28%)	8 (9.30%)	86 (100%)		

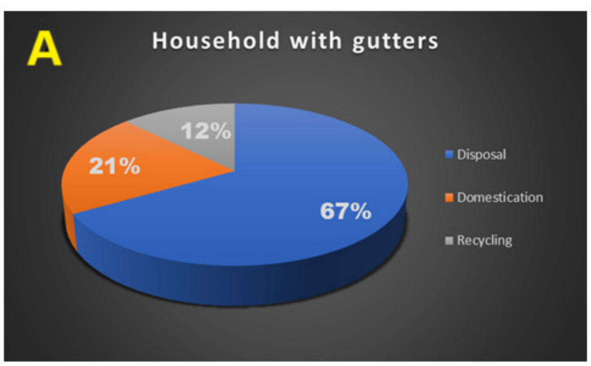

Fig. 3A: RM rates in households with gutters

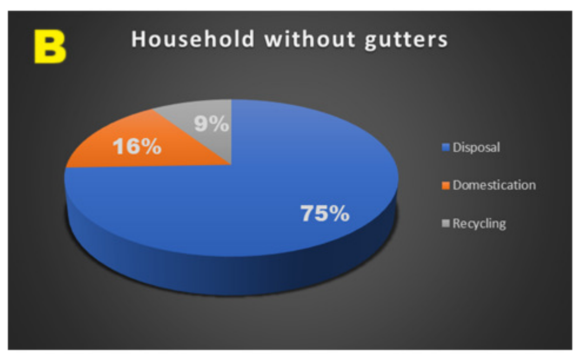

Fig. 3B: RM rates in households without gutters

According to these results, out of 173 households surveyed, 87 have gutters (MAG) and 86 do not have this equipment (MSG). In MAGs, 67% of households discharge water directly into urban roads where gutters end, 21% use it for domestic purposes, and 12% reuse it (laundry, washing dishes, bathing, etc.). In MSG households, 75% discharge water directly into urban drainage systems, 16% collect it without using it (cesspools), and 9% reuse it. A total of 122 (70.52%) households discharge water directly into the environment, 32 (18.50%) use it for domestic purposes without recycling it, and 21 (12.14%) reuse it for laundry, washing dishes, cleaning houses, and cleaning bathrooms. This clearly shows that in this watershed, households discharge more rainwater than they use for rational purposes. However, this almost insignificant management of rainwater by households contributes to the failure of the sanitation network in the watershed, which is the responsibility of the state. Runoff exploits the sensitivity of the soil and terrain to trigger runoff, which is responsible for water erosion in this BV. Most of this runoff is mobilized or collected by the roofs of houses.

RM method at the state level: liquid sanitation

After several surveys and observations carried out in the Djiri watershed, it was found that:

Only a few paved roads have liquid sanitation systems. However, these do not have good rainwater drainage capacity due to their poor design, in particular the shallow depth and width of the concrete structures and the lack of a slope in accordance with standard norms for draining water to the Djiri River, which is a natural outlet. As a result, rainwater stagnates in the gutters.

The liquid sanitation systems have become illegal dumps for all types of waste by the population along the main avenues and especially by businesses, which, every time they clean or tidy up, dump solid waste and sand into the gutters without a second thought. As a result, the gutters are constantly blocked, even in the dry season. During the rainy season, the gutters can no longer contain the water, leading to flooding due to poor drainage. Paved roads are severely affected.

There is no effective liquid sanitation policy in place by the state, through the municipalities of Djiri and Kintelé. The company AVERDA, now closed and replaced by a private Turkish company, was unable to manage this situation due to a lack of personnel and equipment to clean the gutters.

Due to poor RM by households and the failure of drainage systems on main roads, the Tsiémé BV is vulnerable to runoff and water erosion. Several studies show the influence of poor RM in Brazzaville and around the world. One such study is by Mouanda-Lalamba (2021), who believes that poor RM is partly responsible for water erosion in Congolese cities, as the Congolese government has failed in this policy. The lack of control over stormwater is now a real environmental problem in urban and peri-urban watersheds in tropical Africa.

Effects of poor RM in Djiri watershed

In the Djiri watershed, the direct effects of poor RM are soil erosion and the degradation of socio- urban infrastructure (schools, clinics, paved and dirt roads). The most affected neighborhoods are *Ihouémé (Kintelé), SOPROGI, Congo-chine, Itatolo, Académie militaire, and Impoh-Manianga*. The Gullies that currently affect this watershed began to form around 2017 and are also partly attributable to the heavy environment anthropization by humans in the late 2015s (Ngatsé *et al*., 2017). A total of 21 gullies have been identified in the basin, the six largest of which were measured by M'bouka Milandou. They take the form of pear-shaped channels that quickly develop into gullies, some of which are finger-like and others multi-lobed, with alarming dimensions (Table 2).

Table 2: Data from 6 ravines measured by Mayima *et al*. (2022) in the Djiri watershed

Code	Type of Gully	Total length (m)	Average width (m)	Average depth (m)	Volume (m^3)	Geographical coordinates
Gully 1		285	8.5	5.58	13,517.55	04°09'41" S/ 15°16'30" E
Gully 2	Lobe 1	340	11.33	3.77	14,522.79	04°09'13" S/ 15°16'25" E
	Lobe 2	348	2	1.50	1,044	04°09'14"S/ 15°16'26"E
Gully 3		150	15.30	8.66	19,874.70	04°08'24" E/ 15°17'13" S
Gully 4		80	10.30	4.88	4021.12	04°08'23" S/ 15°17'25" E
Gully 5		150	17.34	4.6	11,964.6	04°08'23" S/ 15°17'26" E
Gully 6		130	12.4	6.31	10,171.72	4°08'24" S/ 15°17'18" E

Source: Mayima *et al*. (2022)

Plate 1: Gully erosion in the Djiri watershed in Brazzaville
Photo 1: gully in Ihouémé (Kintelé), Photo 2: gully at the Don Bosco Institute, photos 3 and 4: gully erosion near the Itatolo CSI (Brazzaville), photo 5: gully in Casis (Brazzaville)
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Most of these gullies are over 100 m long with average depths and widths. This means that the largest gully has a volume of approximately 19,000 m³ (Gully 3), followed by Gully 2, with a single lobe reaching 14,000 m³, and Gully 1 in third place with nearly 13,000 m³ of these six ravines, the smallest (Gully 4) has an estimated volume of 4021.12 m³.These ravines are formed by rainwater collected from the roofs of houses and the *Itatolo* road, whose drains are blocked by sand and waste. Runoff flows through alleys and avenues perpendicular to the contour lines to reach the bottom of the steep slopes (gradients >5%) of the Djiri valleys, whose geological formations are dominated by fine sand. As these urban roads have no drainage system and have been compacted by humans, they are subject to heavy runoff, which causes gully erosion at the foot of the valleys. The forms of erosion are regressing towards the *Itatolo* road due to the increase in the amount of runoff. These morphoclimatic phenomena, which are dynamic in both time and space, are therefore aggravated by the relief and nature of the geological formations in place.

Role of relief and soils in the vulnerability of the environment

The relief of the Djiri watershed plays a decisive role in the development of diffuse and concentrated runoff, which is responsible for the aforementioned morphoclimatic phenomena. This relief was analyzed based on altimetric characteristics (Fig. 4A) and percentage slopes (Fig. 4B).

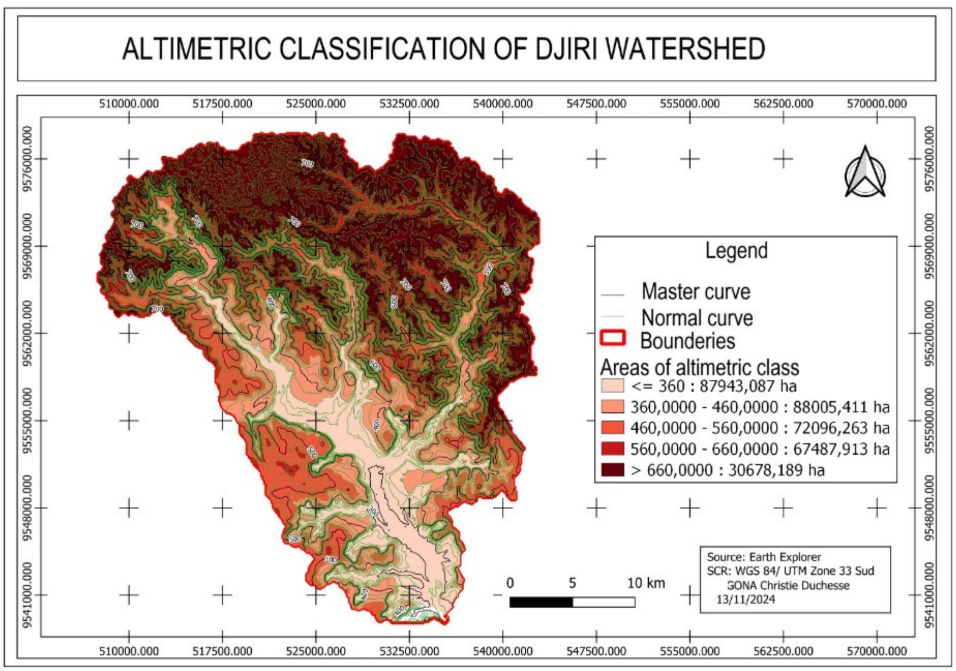

Fig. 4A: altimetric watershed map

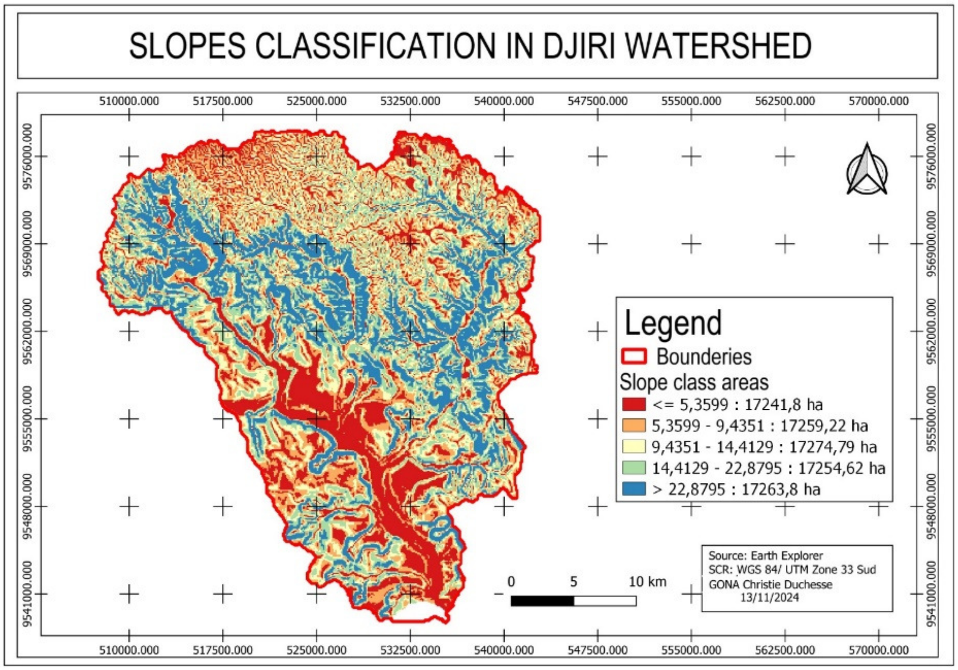

Fig. 4B: Slope watershed map

In Figure 4A, the 360-460 altitude class occupies the largest area in the Djiri watershed, covering nearly 88,000 ha. The altitude class above 600 m occupies nearly 30,600 ha. This is significant and reflects the presence of sandy hills and hollows within the basin, with steep slopes ranging from 5 to 22% (Fig. 4B). Here, the 9-14% slope class occupies most of the watershed with approximately 17,274 ha. This class reflects the sensitivity of the slopes due to their steepness and exposes the watershed to surface runoff, which causes water erosion.

Discussion

The results obtained at the end of this study show that precipitation in Brazzaville, where the Djiri watershed is located, increased during the study period. These results are consistent with those obtained by the UNDP (2010), the MDDEF (2011), and Ibiassi Mahoungou *et al*. (2019), which in turn confirm a constant change in rainfall in the Brazzaville city. This rainfall influences the development of diffuse and concentrated runoff in this peri-urban watershed. However, due to the lack of stormwater management policies by households and the state, the consequences are significant in terms of geomorphological phenomena, particularly water erosion and its consequences.

To this end, Mouanda Lalamba (2021) supports this thesis and believes that poor GEP is partly responsible for water erosion in Congolese cities, since the Congolese government has failed in this policy through the development of drainage and sanitation systems. Similarly, according to M'bouka Milandou (2023), the lack of control over rainwater is now a real environmental problem in urban and peri-urban watersheds in humid tropical Africa, and Congolese cities are no exception. However, according to Griffirhs *et al*.

(2000), a well-constructed drainage network facilitates the efficient and rapid collection and disposal of rainwater and wastewater. It also helps to maintain and preserve the environment, public health, natural water resources, and the planning of future maintenance activities. According to Foutou Matondo (2018), poor GEP is attributable to disorders observed in the land use process. According to Bokatolat Ekandza (2022), the method of wastewater disposal in Talangaï households is a considerable health risk factor. To this end, water erosion and its consequences observed in the Djiri watershed are aggravated by the physical vulnerability of the environment, particularly the sensitivity of the geologic formations characterized by the Batéké sand series with a thickness of 90 meters (Mabiala, 1973).

The sandy soils, which account for nearly 90% of the textures derived from these formations, are highly erodible when exposed, and their erodibility indices, as determined by Ngatse et al. (2017) and MAYIMA and al. (2016) in the northwestern part of Brazzaville, where the Djiri Wtershed is located, vary between 0.35 and 0.40 t.ha.h/ha.MJ.mm. These results are similar to those found by M'bouka Milandou (2022) in Kintelé, north of Brazzaville, and M'bouka Milandou and Mayima (2022) in Pointe-Noire. Under these conditions, with slopes reaching up to 22%, water erosion is inevitable when water is not channeled.

The slope values estimated in this basin are almost identical to those found in Masimou and Mayanga in Brazzaville by Kombo Kissangou et al (2018), and by Mondzali (2025) in the Pinaré watershed in Dolisie town. These slopes are due to altimetry values that reach nearly 660 m in some places. Throughout the northwestern part of Brazzaville, altitudes reach up to 700 m (Moueba, 2018).

Conclusion

Given the failure of land use planning and sanitation policies, runoff from precipitation exploits the sensitivity of sandy soils and the rugged terrain of the environment to accentuate the dynamics of geomorphological phenomena in the Djiri watershed, the direct consequence of which is gully erosion, which currently amounts to 21 gullies and ravines. The solution to this thorny problem lies primarily with the state, which must enforce laws on land use policies on the outskirts of the city and make efforts not only to clean up stormwater drainage systems, but above all to build them into a network in accordance with the physical conditions of Brazzaville in general and the Djiri watershed in particular (aggressive rainfall, sensitivity of soils and slopes to erosion risk). The population also has a responsibility to manage rainwater effectively through domestication techniques that can limit runoff in sandy alleys and avenues without drainage systems. Therefore, the municipality and environmental specialists must raise awareness among the population in this basin.

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