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DEVELOPMENT AND ANTI-EROSION MEASURES IN URBAN HILLY AREAS: THE CASE STUDY OF KISENSO COMMUNE IN KINSHASA (DR. CONGO)

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Resumé

L'absence de techniques efficaces de lutte contre l'érosion ravinante dans la commune de Kisenso à Kinshasa, freine le développement communautaire. On veut savoir quelle est l'efficacité des ouvrages de rétention du ruissellement les plus couramment utilisés, compte tenu de leur emplacement et de leurs caractéristiques. L'objectif est de fournir des mesures de gestion appropriée et une protection efficace contre l'érosion. La méthodologie suit deux approches : la collecte de données de terrain (délimitation des zones contributives et inventaire des mesures de lutte contre l'érosion), et les analyses spatiales et statistiques. Ce qui a permis de caractériser l'occupation des sols, d'évaluer la capacité de rétention d'eau et de modéliser les volumes de ruissellement. Un plan d'aménagement a été élaboré, intégrant des ouvrages de rétention dimensionnés en fonction de la topographie locale et des déficits hydrologiques. Les évaluations hydrologiques ont révélé des volumes de ruissellement de 9 220,16 m³, 4 522,44 m³ et 1 872,28 m³ respectivement à Madimba, EP5 Livulu et Congo-Fort. Alors que les capacités de rétention actuelles sont limitées respectivement à 980,24 m³, 467,64 m³ et 321,5 m³. Le plan proposé prévoit des mesures supplémentaires retenant respectivement 948 m³, 904 m³ et 386 m³ dans les Zones contributives.

Mots clés : Commune de Kisenso, Zone contributive, Mesures de prévention, Erosion ravinante, Gestion des terres

Abstract

The absence of an effective preventive erosion control technique in the Commune of Kisenso (Kinshasa) hinders the progress of the community. The problem is how effective are the most commonly applied runoff retention measures in relation to their location and characteristics? The objective is to provide factual elements for the proper management and effective protection in the face of gully erosion. The methodology followed two main steps: field data collection involving the delineation of contributing zones (CZs) and the inventory of erosion control measures, spatial and statistical analyses. These analyses enabled the characterization of land use, the assessment of the water retention capacity of existing structures, and the modeling of runoff volumes. Based on these findings, a land-use plan was developed, incorporating retention structure dimensioned according to local topography and hydrological deficits. Hydrological assessments revealed runoff volumes of 9220.16 m³, 4522.44 m³ and 1872.28 m³ respectively in Madimba, EP5 Livulu and Congo-Fort, while current retention capacities are limited to 980.24 m³, 467.64 m³, and 321.5 m³, respectively. The proposed land-use plan includes additional measures capable of retaining 948 m³, 904 m³, and 386 m³ in the respective CZs..

Key words : Kisenso Commune, Contributing Area, Preventive Measure, Gully Erosion, Land Management

1. Introduction

During the second half of the twentieth century, gully erosion began to appear in rural areas as a result of cultivating arable land without plot-level land management (Roose et al., 2000). However, in Central Africa in particular, there has recently been a resurgence of geohazards (Wouters and Wolff, 2010; Vandecasteele et al., 2011), such as gully erosion, especially in urban environments (Tchotsoua, 2007; Vanmaercke et al., 2023; Ahadi Mahamba et al., 2023, Ndungutse et al., 2025; Ilombe Mawe et al., 2025). The cities of the Democratic Republic of the Congo (D.R.Congo) are striking examples of this (Makanzu Imwangana, 2014; Ilombe Mawe et al., 2025). The failure to incorporate preventive standards related to spatial planning or urban development regulations has created significant environmental and social vulnerability (Makanzu Imwangana et al., 2020).

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The commune of Kisenso, in the high town of Kinshasa, is a prime example of such occurrences. It is currently among the most severely affected areas by gully erosion. The absence of proper urbanization and adequate land-use planning (Zolezzi et al., 2018) has led to sprawling, unregulated construction. This is further compounded by the unregulated occupation of urban catchments in the hilly areas (Ahadi Mahamba et al., 2023), a housing crisis driven by rapid population growth, the lack of rainwater collection and drainage systems (Makanzu Imwangana et al., 2025a), and poor subdivision management - all of which are issues affecting the hilly and lowland areas of this commune. The rudimentary erosion control techniques used by the population in the contributing zones (CZs) are insufficient to eliminate this disaster (Lutete Landu et al., 2021; Lutete Landu et al., 2022), especially given the vulnerability factors in this part of the city of Kinshasa (Makanzu Imwangana, 2023).

More than 40 years ago, Van Caillie (1983) had already indicated that gully formation could be prevented by implementing measures to reduce runoff upstream of gully heads. In doing so, the progression of gullies could be halted before reaching their "natural" equilibrium state, governed by the decreasing size of drainage areas during the process of regressive erosion (Graf, 1977). Van Caillie (1983) examined rooftops and hardened surfaces within plots (courtyards) as critical runoff producers, but the role of runoff discharge from these surfaces in generating erosive runoff has never been thoroughly quantified or demonstrated (Makanzu Imwangana, 2014; Moeyersons et al., 2015). It is within this perspective that the present study situates itself, proposing a redevelopment approach for the hilly areas of this commune, which are currently undergoing disintegration.

The problem is how effective are the most commonly applied runoff water retention measures in relation to their location and characteristics? To what extent can runoff water retention measures significantly reduce peak runoff flows at the head of ravines? We believe that the runoff water management techniques used by the population in the site are insufficient and rudimentary. Retention basins and rainwater retention holes (sumps) can reduce peak runoff flows at the head of ravines to a certain extent, but not in large quantities, if the population has the culture to maintain these measures. Runoff water strategies that can be optimized in contributing areas are considerable support from the government by providing the municipality with a good disaster risk reduction policy in general and ravine erosion in particular.

The main objective of this study is to provide factual elements to the population or the necessary tools for the proper management and effective protection of the urban area in Kisenso in the face of the growing phenomenon of gully erosion. The goal is to offer a sustainable development perspective for this commune, considering its current condition. More specifically, the study aims to: (i) Map and identify the preventive measures used in Contributing zones that drain into specific gullies; (ii) Assess the effectiveness of these measures for each Contributing zone considered; (iii) Determine the reasons why some landowners refuse the installation of preventive measures on their plots and (iv) Propose a land-use plan that includes guidelines for better prevention of the gully erosion phenomenon in the commune.

The motivation behind this research stems from concern for the local population. The commune is landlocked and requires thoughtful consideration; this is why we were driven to conduct this study on the management of erosive zones.

2. Material and Method

2.1. Study area

The study area primarily covers the commune of Kisenso, located in the hilly zone in the southern part of Kinshasa. It is bounded to the west by the Matete River, which separates it from the commune of Lemba; to the east by the N'Djili River; to the south by the Kwambila River; and to the north by the commune of Matete (Fig.1). Geographically, it lies between 15°19'0" and 15°22'0" East longitude and 4°24'0" and 4°27'0" South latitude, at an average altitude of 370 meters. The commune covers an area of 16.6 km². It is located on a hilly site in the southeastern part of Kinshasa, characterized by sandy-silty textured soil, which is extremely erodible - aggravated by uncontrolled urbanization and the destruction of the original vegetation cover (Kayembe wa Kayembe et al. (2012). Kinshasa in general, and the Kisenso in particular, experience an Aw_4-type climate, with an average annual rainfall of 1,400 mm and an average daytime temperature exceeding 18°C. This means that the city receives this amount of precipitation on average each year. The month of November records the highest rainfall, with an average of 192 mm, whereas July is the driest month, with only 1 mm of precipitation.

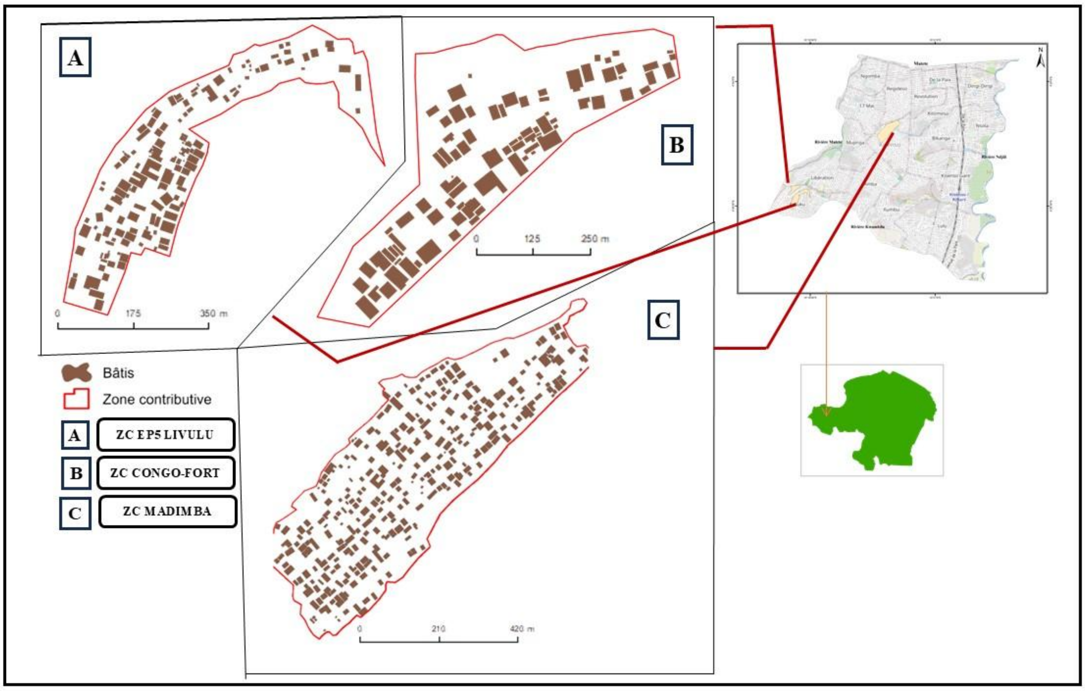

Fig. 1: Location of the Contributing zones of Congo-Fort (A), Madimba (B), and EP5 Livulu (C) within the commune of Kisenso, and Kisenso within the city-province of Kinshasa.

2.2. Material used

This study relied on a combination of field equipment (GPS device, measuring tape, KoboCollect mobile app) and digital tools (Google Earth Pro, ArcGIS 10.3, Microsoft Excel) to collect, process, and analyze data from the contributing zones to the heads of the three selected gullies of Kisenso commune.

2.3. Field Data Collection

Field data were collected in two phases, as follows:

a. Delineation of Contributing Zones (CZ): To determine the surface areas that drain water toward a gully, it was necessary to identify and mark the ridgelines using a GPS device. Starting from the gully head, the ridgeline was followed until it looped back to the starting point, thereby defining a CZ for that particular gully. In total, three contributing zones were delineated: 'Madimba', 'EP5 Livulu', and 'Congo-Fort' within the commune of Kisenso.
b. Inventory of Preventive Anti-Erosion Measures: This phase involved surveying each CZ street by street and plot by plot to record the measures implemented to reduce runoff and prevent further gully development. To facilitate data collection, the KoboCollect application was used. In this app, a customized form was uploaded, allowing for the localization of each retention measure per plot - serving as an alternative to GPS. The form also enabled the collection of detailed information about each measure (e.g., dimensions, installation date, installation cost, etc.) through direct questioning. Once the data collection was complete, the information was immediately uploaded to the KoboToolBox platform via an internet connection. The resulting database, built progressively with each entry, was then downloaded for data processing and analysis.

2.4. Data Analysis
2.4.1. Delimitation Data of the CZ

Using the gully polygons in the inventory provided by Lutete Landu (2019), we were able to upload them into Google Earth Pro along with the GPS points marking the boundaries of each Contributing zone (CZ). A visual analysis of the area, combined with local knowledge and field data, allowed for accurate delineation of each CZ. It should be noted that due to urbanization, the CZ no longer corresponds to what it would naturally be under undisturbed conditions (Makanzu Imwangana, 2014; Makanzu Imwangana et al., 2014), as the construction of roads has significantly altered its shape (Nyssen et al., 2002; Osmar et al., 2010 ; Zolezzi et al., 2018).

2.4.2. Inventory Data of Erosion Control Measures in the contributing zone (CZ)

Once the Kobo data on preventive measures were downloaded, the data were checked and organized using Microsoft Excel. This process involved grouping the various categories (type of measure, condition of the measure, exact count, and their proportion in each CZ: Madimba, EP5 Livulu and Congo-Fort).

2.4.3. Land Use Analysis

The Google Earth Pro platform was used to identify and characterize the main land use classes in each CZ through digitization. These classes - namely built-up areas, roads, and vegetation - were delineated, and their surface areas were calculated using ArcGIS 10.3. The ground surfaces within parcels (whether vegetated or not) were derived from the CZ.

Knowing the total surface area of the contributing zone (Sz), the area covered by roads (Sr), and the area covered by buildings (Sm), the no building parcel area (Sp) - previously unknown - was derived as follow:

Sp = Sz – Sr – Sm ………………………. (Eq.1).

2.4.4. Evaluation of Water Retention Capacity in the CZ

Based on the dimensions of water retention measures recorded during the field inventory, we estimated the static storage capacity of each type of measure installed in plots or along streets. Additionally, through modeling, Lutete Landu et al. (2024) simulated runoff generation scenarios for parcels and roads in the EP5 area, which was also included in this analysis and has the same caracteristics with Congo-Fort and Madimba contributing area. Thus, to estimate runoff, the approach used by Lutete Landu et al. (2024) was employed. Rainfall was determined from the Intensity-Duration-Frequency (IDF) curves for Kinshasa (Mohymont et al., 2004; Mohymont and Demarée, 2006), assuming a rain duration of 1 hour and a constant intensity. The rainfall height considered is 100 mm, equivalent to a return period of 75 years. This rainfall height was chosen because of its erosive nature (Moeyerson et al., 2015).

As the ground surfaces within parcels and road (whether vegetated or not) also have some capacity to retain rainwater through infiltration, the volume of infiltrated (Vi) water during a rainfall event was considered as 36% of the total intercepted rainwater (Lutete Landu et al., 2024). Since the amount of rainfall is known, it can be multiplied by the surface area of each type (plot and road) to determine the volume of water mobilized by each surface. Similarly, knowing the infiltration rates for each surface type, the volume lost through infiltration (Vi) can be subtracted from the mobilized water volume. The remaining volume, representing the runoff volume that would normally reach the gully head, can be calculated as follow:

Vg = (Vp + Vr) – Vi ………………………. (Eq.2).

Were Vg is the total volume of runoff that would normally reach the gully head; Vp is the runoff volume generated by parcels area; Vr is the runoff volume generated by roads.

Since we also know the volume of water that the existing anti-erosion measures are able of retaining, this can be subtracted from the runoff volume. This allows us to evaluate the effectiveness of the measures in limiting gully development. The same principle will also guide the design of water retention structures in our land-use planning proposal.

2.4.5. Proposed Land-Use Plan for the CZs

The land-use plan was developed based on observations made in the field. The proposed placement of water retention basins takes into account the contour lines (isohypses) of each CZ and is primarily located along the main roads within those zones. Meanwhile, rainfall retention pits were proposed for individual plots that previously lacked any preventive measures. The number of water retention basins and the number of rainfall retention pits varies from one CZ to another due to the differences in the size of each zone.

3. Results and Discussion

3.1. Cartographic Inventory

The cartographic results presented below highlight the main characteristics of the contributing zones (CZs), including their boundaries and the surfaces with different hydrological behaviors -such as built-up areas, roads, and plots in the various zones - as well as land management efforts, reflected by the mapped count of anti-erosion infrastructure.

In the Madimba CZ in particular, nearly every plot contains a preventive anti-erosion measure. A high concentration of houses is also noted in this zone, although they are generally small in size. The name ‘Madimba’ for this zone derives from the fact that the gully it feeds originates at Madimba Avenue, which receives runoff from three other avenues: Bukala, Matadi, and Tango. In the EP5 Livulu and Congo-Fort CZs, a low concentration of both buildings and preventive anti-erosion measures is observed. The EP5 Livulu gully originates at both Kivuvu Avenue and a portion of the EP5 Livulu School, which it threatens - hence the zone's name - even though it also collects runoff from seven other avenues: Bamba, Pangu, Kitambala, Kasanza, Malomba, Makabu, Muzengo, and Luadi. The Congo-Fort CZ, the smallest of all, receives runoff from just two avenues: Luadi and Congo-Fort, where the head of its gully is located.

The land use analysis made it possible to estimate the area occupied by each of the three selected classes, namely: buildings, roads, and parcels. Since the parcels had not been mapped, their surface area could simply be deduced by subtracting the combined surface areas of roads and buildings from the total area of the contributive zone. The results of this analysis, presented in Table 1, show that buildings represent the most extensive class across all CZs, covering 84.9% in the Madimba zone, followed by Congo-Fort at 68.7%, and EP5 Livulu at 64.3%. Roads account for approximately 5% of the surface area - specifically, 5.4%, 5.2%, and 4.4% for Madimba, EP5 Livulu, and Congo-Fort, respectively. Parcels, finally, represent one-third of the surface area in the EP5 Livulu zone, 26.9% in Congo-Fort, and 9.8% in Madimba. The latter is thus the CZ with the lowest proportion of non-built surface area.

Table 1: Area of land cover classes

Classes	Built-up area		No-built-up area				Total (m^2)
	m^2	%	Road		Parcel		
			m^2	%	m^2	%	
CZ of Madimba	86,559.5	84.9	5,492.1	5.4	9,952.4	9.8	102,004

CZ of EP5 Livulu	32,092.3	64.3	2,616.9	5.2	15,191.6	30,4	49,900.9
CZ of Congo-Fort	15,079.4	68.7	967.3	4.4	5,891.1	26.9	21,937.8
Total (m^2)	133,731.2		9,076.3		31,035.1		173,842.7

The cartographic results and land use distribution of the contributive zones (CZs) are presented in Figures 2a, b & c, respectively for Congo-Fort, EP5 Livulu, and Madimba.

Fig.2a: Location of structures and measures for erosion control in the contributing areas of Congo-Fort

Fig.2b: Location of structures and measures for erosion control in the contributing areas of EP5 Livulu

Fig.2c: Location of structures and measures for erosion control in the contributing areas of Madimba

3.2. Inventory of preventive measures

The measures recorded in the field (Fig.3) are presented in the various tables and graphs below. Figure 4 and Table 2a & b show the preventive measures implemented in the Congo-Fort, EP5 Livulu, and Madimba zones. In the Madimba ZC, retention basins are the most frequently used, with 62 occurrences representing 25.6% of all identified measures. These are therefore the most commonly employed techniques, unfortunately also the least maintained. In total, 242 measures were identified in Madimba, of which 54 were found to be in a very advanced state of deterioration. In the EP5 Livulu ZC, water storage tanks are the most frequently used preventive measures, with a frequency of 20, representing 17.7%. As for the Congo-Fort ZC, erosion control measures are generally neglected. Retention basins and retention pits in plots each recorded 8 observations, or 16.3%, making them the most frequently used measures in this area. They also show that aside from rainfall storage tanks and vegetation, all other preventive measures are partially degraded, and 37% of the plots lack any preventive measures - although some had them in the past, they are often not maintained.

Fig. 3: Examples of runoff water retention measures observed for the collection, storage, and infiltration of rainwater. a and g: Sealed underground masonry tanks; b: Underground metal tank; c and d: Plastic rainwater tanks (small and large capacity); e and f: Vegetation enhancing infiltration rates and preventing bottom clogging; h: Soakaway pit with concrete blocks; i and j: Infiltration trenches.

Table 2a: Number of preventive measures types in the 3 contributing zones

Types of preventives measures	Madimba		EP5 Livulu		Congo-Fort	
	Nb.	%	Nb.	%	Nb.	%
Sandbags along roads	2	0.8	0	0.0	0	0.0
Water retention basin	62	25.6	12	10.6	8	16.3
Water retention pit on plots/soakway pit	59	24.4	17	15.0	8	16.3
Small water retention dam	12	5.0	4	3.5	0	0.0
Rainfall storage tank	3	1.2	20	17.7	7	14.3
Sumps	0	0.0	12	10.6	5	10.2
Vegetation	8	3.3	8	7.1	4	8.2
No measure taken	96	39.7	40	35.4	17	34.7
Total	**242**		**113**		**49**	

Table 2b: Types of preventive measures and their condition in the 3 contributive zones

Types of preventives measures	**Number and size of measures**						**Number of preventive measures by condition**					
	Frequency			**Area (m^2)**			**In good order**			**Degradation**		
	Madimba	EP5	Congo-Fort	Madimba	EP5	Congo-Fort	Madimba	EP5	Congo-Fort	Madimba	EP5	Congo-Fort
Sandbags along roads	2			5			2					
Water retention basin	62	12	8	379.05	84.2	65	37	6	5	25	6	3
Water retention pit on plots/soakway pit	59	17	8	197.21	77.37	41.75	33	7	6	26	10	2
Small water retention dam	12	4		155.8	8		8	3		3	1	
Rainfall storage tank	3	20	7	6.7	96.72	36.1	3	20				
Sumps		12	5		40.78	9.44		8	3		4	1
Vegetation	8	8	4	87.5	47.8	79	9	7	5		1	
No measure taken	96	40	17			4.5						
Total	**242**	**113**	**49**	**831.26**	**259.11**	**235.8**	**92**	**51**	**19**	**54**	**22**	**6**

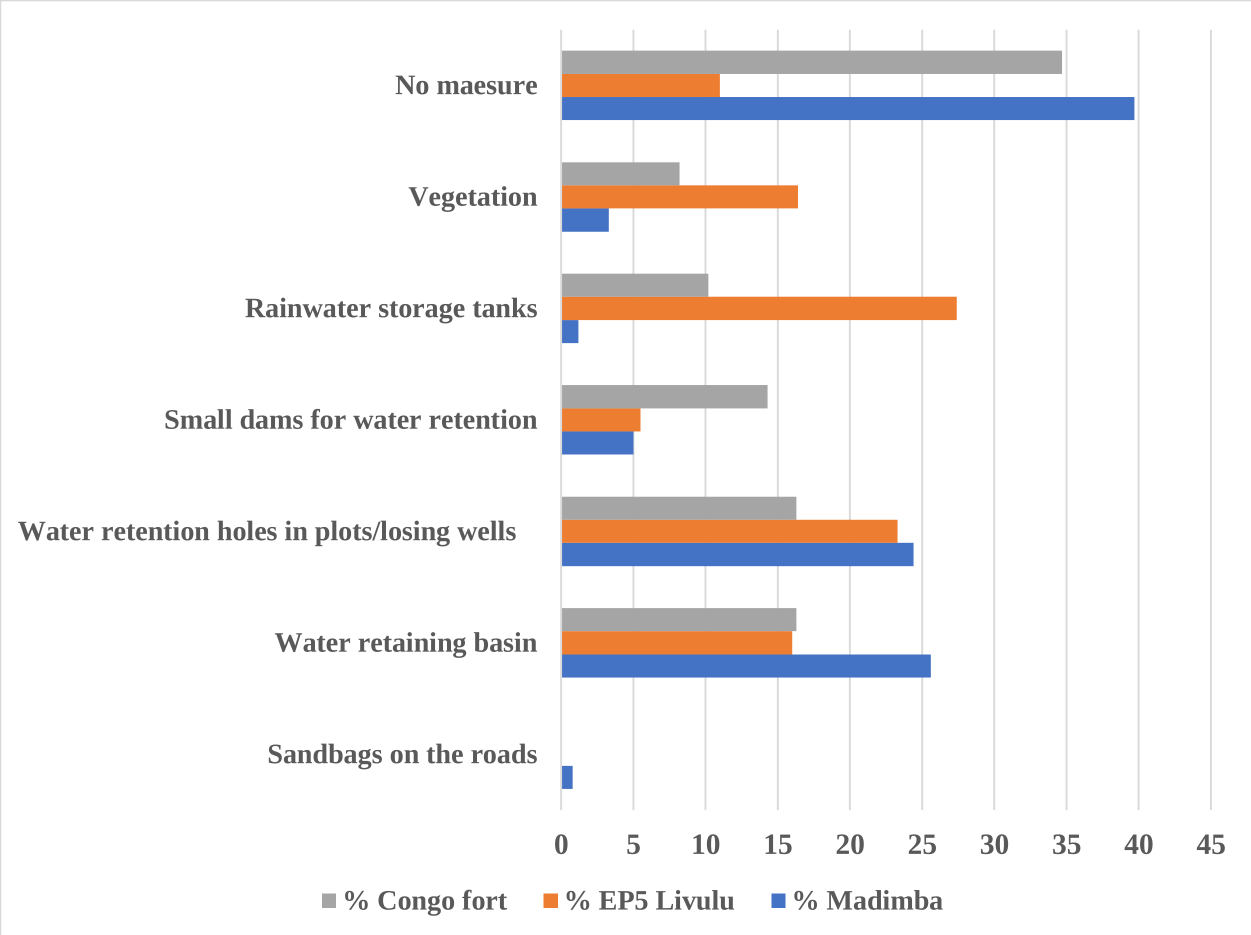

Fig. 4: Frequency of preventive measure types in the critical zones of Congo Fort, EP5 Livulu, and Madimba

The comparison of the condition of the measures shows that in the Madimba zone (Fig.5), the most frequently used measures are also those most degraded due to lack of maintenance; and that, apart from the water retention dams, the other less frequently observed measures show no signs of degradation. However, in the EP5 Livulu zone (Fig5), all observed measures are partially degraded, except for the one with the highest frequency - namely, the rainfall storage tank.

Figure 5 shows that in Congo-Fort, the moderately represented measures are the ones with some instances of advanced degradation. These include water retention basins, soak pits, and infiltration holes. Overall, it is also important to highlight that the Madimba zone has the highest number of parcels without any preventive measure - 96 parcels - followed by the EP5 Livulu zone with approximately 40 parcels (Fig.5), and finally the Congo-Fort zone with 17 parcels (Fig.5).

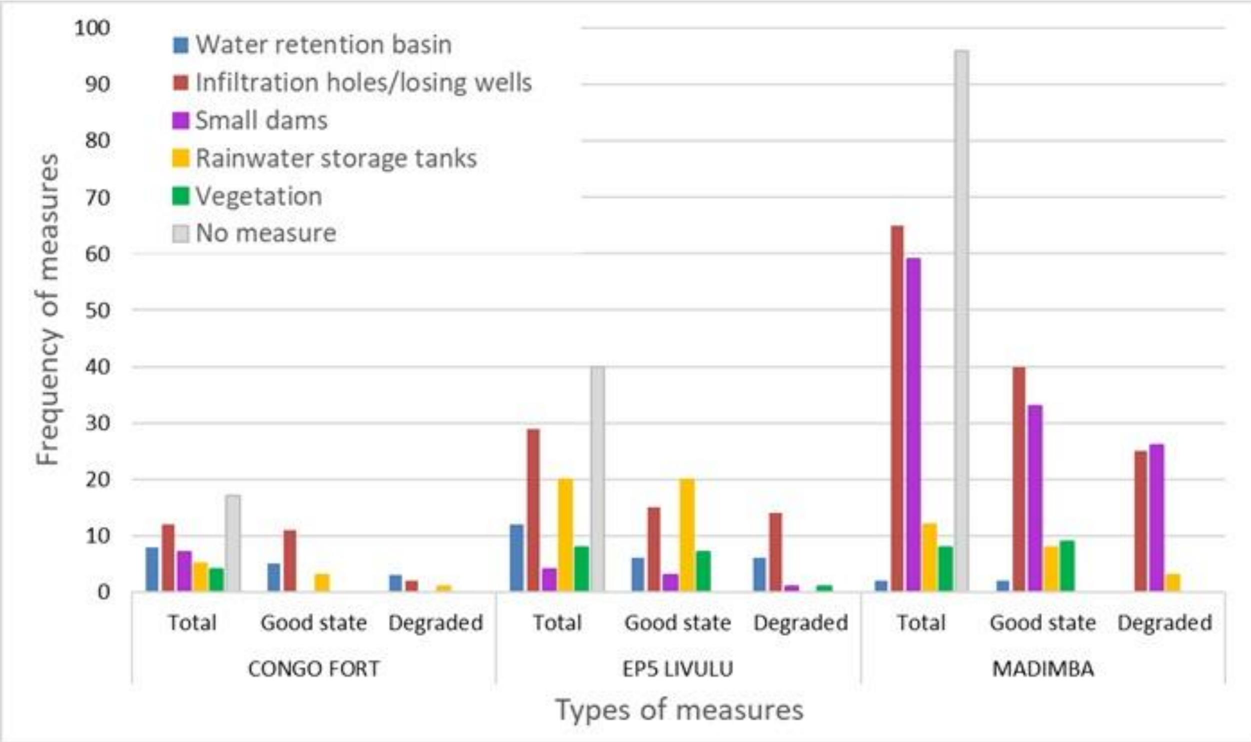

Fig. 5: Condition of preventive measure types in Congo-Fort, EP5 Livulu, and Madimba

3.3. Hydrometric Balance

Based on the dimensions obtained in the field, the volume of rainfall that the preventive measures installed in the CZs could retain was calculated for the three CZs. Table 3 shows the amount of rainwater retained by the different types of measures in each contributive zone.

Table 3: Rainwater retention capacity

Measure types	**Volume of water retained (m^3)**		
	Madimba	**EP5**	**Congo-Fort**
Water retention basin	485	187.2	181
Water retention pit in plots/soakaway pit	480.64	126.815	96.5
Rainwater storage tank	14.6	153.625	44
Total	**980.24**	**467.64**	**321.5**

Using modeling, Lutete Landu et al. (2024) simulated runoff production under various scenarios (different return period rainfall events, with or without mitigation measures, etc.) for plots in the EP5 Livulu area, which is also included in this analysis. Table 4 presents the runoff production for a rainfall event with a 75-year return period - i.e., 100 mm of rain over a one-hour duration - based on model data, considering the following average runoff coefficients for the zone:

- 60% of rainfall on roads becomes runoff;
- 64% of rainfall on residential plots becomes runoff;
- 36% of the rainfall infiltrates into the ground.

This estimate does not take into account the presence of runoff retention measures. If the heaviest rainfall, corresponding to a 75-year return period - that is, 100 mm/h - had occurred (Lutete Landu et al., 2024), the runoff volume produced will correspond to the table 4 as calculated using Eq.2. It also comes out of the last column of this table, the effect of the static volume of water stored or infiltrated by the measures in each parcel within the CZs during this rainfall event. The percentage of volume retained by the measures consists of a portion of the sum of runoff from parcels and roads (columns 3 and 4), from which the volumes infiltrated have already been deducted. After extracted the measures effects, the remaining runoff volume can be considered as the volume that runs off into the gully head.

The analysis of rainfall data obtained from CREN-K over an 11-year period, from 2010 to 2020, was essential for characterizing the rainfall patterns in the area. Observation of this data range revealed that the highest recorded rainfall in the commune reached a height of 501.39 mm. In Kinshasa, based on the data from Makanzu Imwangana (2014), average infiltration rates are estimated at 115 mm/h on unpaved roads, 160 mm/h in residential plots, and 250.7 mm/h in vegetated areas.

Table 4: Hydrological balance for different contributing areas

Site	**Dimensions**		**Parcels area**	**Roads area**	**Loss by infiltration**	**Total for the contributive zone**	**Effect of measures (basin or tank)**
Madimba	Area	**m^2**	96,511.9	5,492.1	-	102,004	
	Runoff volume	m^3	6,176.762	329.526	3,694.112	10,200.4	980.2
		%	60.6	3.2	36.2	100	15.1
EP5 Livulu	Area	**m^2**	47,283.9	2,616.9	-	49,900.8	
	Runoff volume	m^2	3,026.17	157.014	1,806.896	4,990.08	467.6
		%	60.6	3.1	36.2	100	14.7
Congo-Fort	Area	**m^2**	20,970.5	967.3	-	21,937.8	
	Runoff volume	m^2	1,342.112	58.038	793.63	2,193.78	321.5
		%	61.2	2.6	36.2	100	23.0

We observed that, despite the presence of preventive measures, the volume of runoff water remains excessive (Kisangala Muke et al., 2025; Makanzu Imwangana et al., 2025b). In their study entitled *'The Potential of Runoff Retention Structures as a Strategy to Control Urban Gully Erosion in Tropical Cities'*, Lutete Landu et al. (2024) highlighted this phenomenon in the Kimwenza neighborhood. Although retention structures were installed in that area, the volumes of water retained far exceeded their intended capacities, similar to the findings in our contributive zones. Our analysis indicates that the affected population lacks sufficient knowledge to appropriately size preventive measures, largely due to inaccurate hydrological estimations. Indeed, the volumes of water generated by urban plots do not align with the capacity of existing retention infrastructure, resulting in runoff volumes that surpass predicted levels. In response to this observation, we propose a land-use planning strategy below aimed at correcting these imbalances (Nowogoński, 2021). Land-use planning in areas contributing to gully heads should focus on reducing runoff and stabilizing the soil. This involves implementing measures like contour plowing, terracing, and re-vegetation to minimize soil erosion and water flow towards the gully head. Strategic land-use planning can also involve directing water away from the gully head through diversion channels or other hydraulic structures.

3.4. Proposed Land-Use Plans for the Contributive Zones (CZs)

Based on the foregoing, any urban planner would consider intervention in these zones necessary to correct the existing imbalances. It is therefore essential to propose a land-use plan for this study area in order to provide at least some support to the population living in these parts of the city of Kinshasa. This underscores the need for a forward-looking perspective for these zones, taking into account that preventive measures should be adapted to the actual volumes of runoff. Although this gully erosion phenomenon may not be entirely eradicated, if the local population adheres to such a land-use plan (LUP), they may find greater comfort during the rainy season and avoid the distressing scenes frequently experienced in recent years. According to Table 5, the volume of water running off into the gully is 15,614.88 m³. With such a volume, gully progression is highly likely to persist. We will therefore attempt to propose a land-use plan that would reduce the runoff volume to a level lower than this (Table 5).

Figure 6 illustrates the proposed land-use plans for the contributive zones of Madimba, EP5 Livulu, and Congo-Fort, where additional preventive measures are suggested. For example, Table 3 presents the proposed retention basins and water retention pits for the Madimba CZ. Considering the size of the CZ, the proposed number of retention basins is 20, while the number of retention pits is 51. These structures would have the capacity to retain approximately 540 m³ and 408 m³ of water, respectively. In the case of EP5 Livulu, the proposal includes 16 retention basins and 59 retention pits, which would allow for the retention of approximately 432 m³ and 472 m³ of water, respectively. For the Congo-Fort CZ, which is smaller in size, the plan suggests 6 retention basins and 28 retention pits, with estimated retention capacities of 162 m³ and 224 m³, respectively.

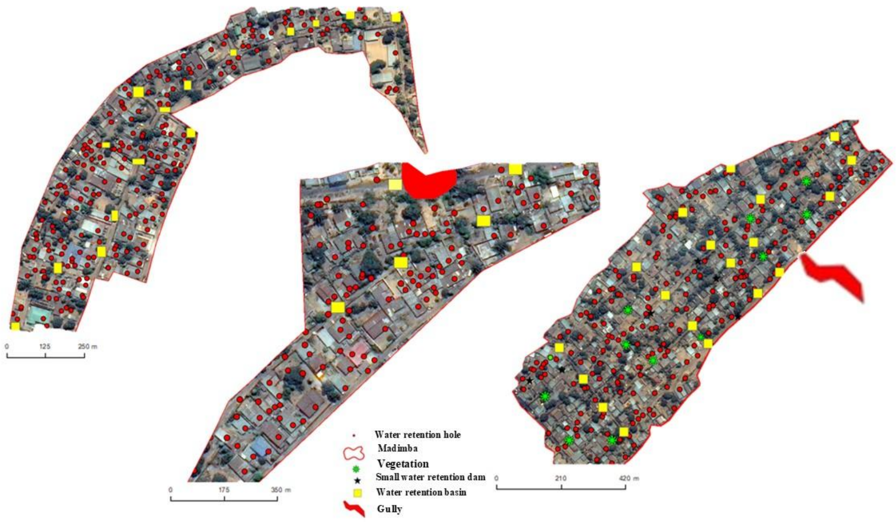

*Fig. 6: The land use plan map and its existing measures, along with the proposed measures for EP5 Livulu (**B**), Madimba(**C**), and Congo-Fort(**A**)*

Table 5: Proposed rainwater retention volume through preventive measures in the contributive zones of Madimba, EP5 Livulu, and Congo-Fort

Site	**Proposed measure type**		
	Dimensions	**Water retention basin (m^3)**	**Retention pit (m^3)**
Madimba	Length	3	2
	Width	3	2
	Depth	2	2
	Quantity	60	150
	Total Volume m^3	**3,960**	**1,200**
EP5 Livulu	Length	3	2
	Width	3	2
	Depth	2	2
	Quantity	48	177
	Total Volume m^3	**864**	**1,416**
Congo-Fort	Length	3	2
	Width	3	2
	Depth	2	2
	Quantity	32	56
	Total Volume m^3	**576**	**448**

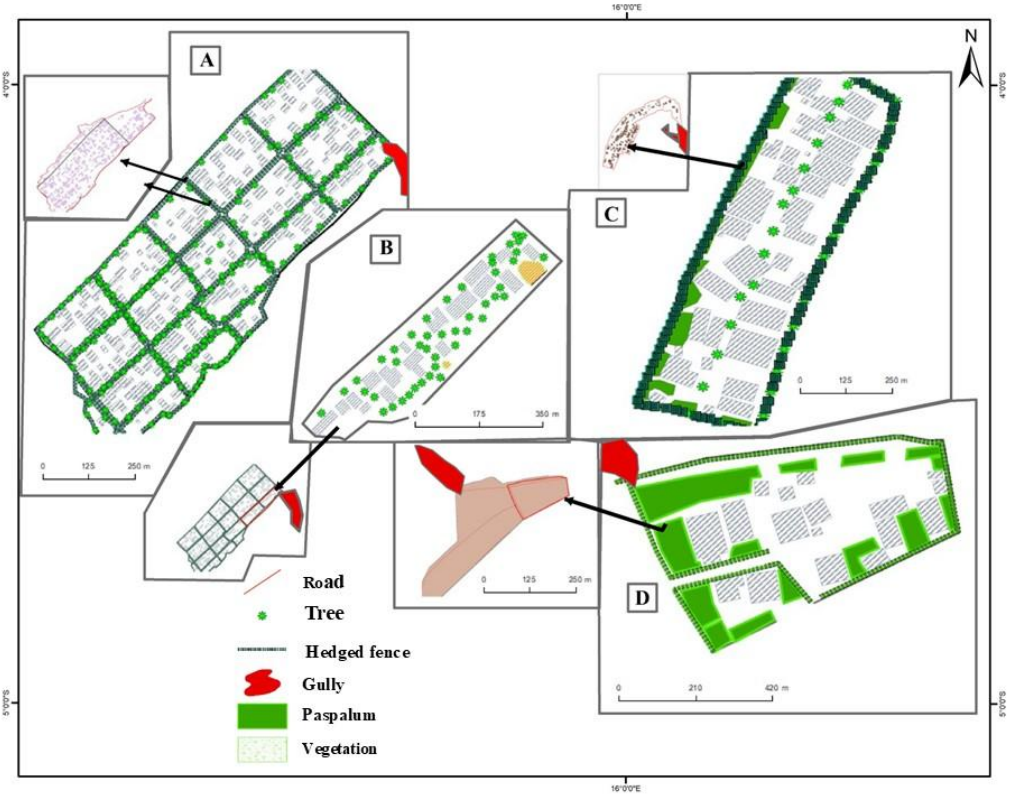

*Fig. 7 : A proposed Eco-district in a section of the contributive zones l'EP5 Livulu (**C**), Madimba(**A,B**), and Congo-Fort(**D**)*

Table 7 shows the volume of water retained by the two preventive measures that were proposed for the contributive zones (CZs). The volume of water flowing into the gully after infiltration through both the existing preventive measures and those proposed in the land-use plan (LUP). The proposed measures are concentrated in areas with isohypses, where the widths of major avenues were measured. This allowed for the placement of rainwater retention basins in these locations. Each basin was designed with a length, width, and depth of 3 meters. As for the rainwater retention pits, they were proposed for residential plots that lacked any existing measures. Figure 8 shows that 59% (9220.2 m^3) of the total runoff volume is found in the Madimba CZ, 29% (4522.4m^3) at Ep5 Livulu and 12% (1872.3m^3) in the Congo-Fort CZ. This reflects the proportion of runoff flowing into the gully after infiltration through the preventive measures (PM).

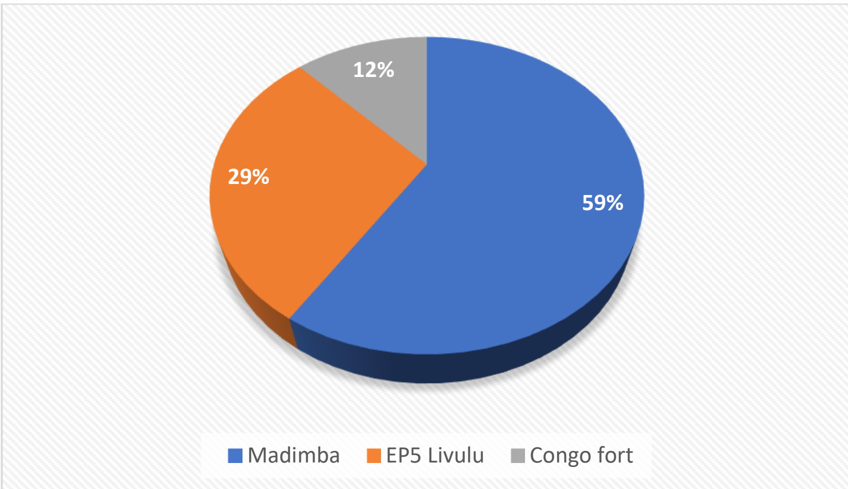

Figure 8: The proportional of the remaining water volume flowing into the gully in the 3 CZs

4. Conclusion

The main objective of this study was to provide factual elements to the population or the necessary tools for the proper management and effective protection of the urban area in Kisenso in the face of the growing phenomenon of gully erosion. This study identified seven types of preventive erosion control measures in the contributing zones of Kisenso. Among them, the water retention basin is the most frequently used (82 occurrences), although largely degraded. The current retention capacities - 980.24 m³ in Madimba, 467.64 m³ in EP5 Livulu, and 321.5 m³ in Congo-Fort - are insufficient in comparison to the observed runoff volumes, which reach up to 9,220 m³ in Madimba.

The proposed land-use plan, focused on the addition of retention basins and infiltration pits (totaling 5160 m³ in Madimba, 2280 m³ in EP5, and 1024 m³ in Congo-Fort), would significantly reduce runoff volumes, particularly by more than 10% in certain areas. It was also observed that the implemented measures are poorly maintained in these zones. There is a significant gap between the volume of water that flows into the gully and the amount that infiltrates through the preventive measures. Large concrete drainage channels should be built along the contour lines (isohypses) to direct rainwater to the valley or natural drainage paths (thalweg), where an energy dissipator should be installed.

If the local population were to implement a regular and effective maintenance system-such as cleaning out retention basins - the remaining runoff volume reaching the gully would be unlikely to cause damage. Therefore, it would be beneficial for neighborhoods to establish the following: (i) a community sanitation service with a weekly program to encourage residents to engage in erosion control and the upkeep of preventive and corrective measures; (ii) a network of appropriate drainage channels and collectors, from upstream to the outlet, to prevent gully formation; (iii) a community awareness unit to educate residents about the risks of gully erosion caused by poor rainwater management.

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