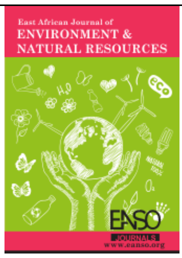

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Original Article

Gully Erosion associated with Peri-Urbanization: Focus on the Catchments around Kimwenza in the South of Kinshasa (DR. Congo)

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ABSTRACT

The catchments draining Kimwenza, a small plateau in Southern Kinshasa town (DR Congo), are undergoing rapid and extensive peri-urbanization with limited planning. This research focuses on gully erosion processes associated with different infrastructures. The objectives are to characterize the morphometry of the catchments, describe the surface water flow network, assess the runoff rates, and propose an appropriate drainage solution to collect runoff. It appears that these basins have a high drainage density, ranging from approximately 1,800 to over 11,000 m/km², with a general average of around 6,570 m/km², as determined through field and laboratory investigations. In addition, all the basins in this area are somewhat rounded in shape and modest, which means they are more likely to have rapid rainwater concentration and response times. As a result, runoff flow can be torrential, especially since 80 % of this sector has slopes greater than 8%. The peak rate of surface runoff can exceed 650 l/s/ha, according to an analysis of active showers and their intensities. Due to the incoherent soil structure, mainly composed of sand, 30 gullies were mapped with an average length of 560 meters, a width of 27 meters, and a depth of 10 meters. Under these conditions, mitigating the gully phenomenon requires significantly reducing runoff flows.

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INTRODUCTION

Gully erosion has emerged as a pressing urban management issue, posing a significant barrier to urban development in numerous cities across the Global South (Vanmaercke et al., 2023). This environmental phenomenon demands immediate and comprehensive attention, akin to other global disaster risks. In the Global South, the strategies employed to combat this issue often fall short, are largely ineffective, and are occasionally rudimentary (Lutete et al., 2022). These approaches lack a solid foundation in the root causes of gully erosion (Lutete et al., 2024; Ilombe Mawe et al., 2024; Makanzu Imwangana et al., 2015; Makanzu Imwangana, 2014), underscoring the need for a more informed and proactive response.

Before 1967, the town of Kinshasa was confined exclusively to the plain, a historical fact that shapes its current urban planning challenges. From the pre-colonial era to the present day, legal texts have existed. The government has compiled legal texts on the Regulatory Status of Urban Planning (MATUH and CPCAI, 2013). While regulations were followed and respected in the past, this is no longer the case today. Rural exodus, rapid population growth, and the housing crisis have led to an urban-rural expansion onto the hills to the west and southwest of the town. Customary chiefs established this land anarchy due to administrative laxity and the complicity of certain government officials, who legitimized the de facto situation in peri-urban areas under the false pretext of respecting ancestral and customary ownership. Law No. 73-021, published on July 20, 1973, stipulates that land belongs to the state, which should manage it. In the urban centre, the occupation of marshy and flood-prone areas on the plain has followed the disregard for regulations evident in the high town.

The Kinshasa urban development master plan, which initially proposed a linear expansion of the agglomeration eastward beyond Ndjili Airport, was quickly overshadowed by the town's rapid and unplanned spread onto the hills. The first to be affected were Ngaliema, then Kisenso in the 1970s, and later many other hills, which were eventually invaded by self-built housing. This uncontrolled urban expansion, starting in the late 1960s, led to gully erosion on the slopes of steep, sandy hills, followed later by flooding.

It is a well-established fact that the peak convexities of Kinshasa's hills, particularly those with low slopes, have been primarily shaped by splash erosion. Field experiments using tracer sands have shown that gently sloping soils are only slightly susceptible to runoff action. However, these areas must have undergone significant ablation due to splash effects. In a convex relief form, gully erosion only appears following landscape modifications (soil degradation), leading to water concentration, particularly along roads. Kinshasa's high town has been grappling with dramatic gully erosion for over half a century. Observations from Google Earth imagery highlight new gullies appearing after each rainy season. These images reveal badland landscapes isolating entire neighbourhoods from the rest of the town. This isolation sometimes makes basic social infrastructure inaccessible; in the worst cases, they are destroyed by gully erosion. This problem poses serious socio-economic and environmental challenges for Kinshasa, and its long-term nature underscores the severity of the issue.

Two major complementary studies have presented their findings over the past decade. The first, conducted by a group of urban planners, is presented by Kayembe wa Kayembe (2013), and the second, by a group of geomorphologists, is presented by Makanzu Imwangana (2014). From an urban planning and development perspective, thanks to a holistic and multi-scalar geographic approach to physical and human factors (combining the interpretation of very high-

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resolution satellite images, fieldwork (observations, interviews, DGPS surveys), and GIS use), this study has demonstrated that intra-urban gully erosion is a complex phenomenon with multiple causes. These include the orthogonality of road networks on hill slopes, trails laid out along steep slopes, construction techniques on loosened and weeded terraces offering no resistance to runoff, soil impermeabilization in upstream residential areas, inadequate drainage networks failing to reach outlets, poorly maintained or nonexistent anti-erosion measures, lack of public space appropriation, and delayed intervention. This delayed intervention exacerbates poor living conditions in low-income neighbourhoods while accelerating gully erosion, causing it to branch out and take on spectacular dimensions. From the perspective of dynamic and applied geomorphology, Moeyersons and Trefois (2008) noted that in a tectonically and climatically stable zone, gully erosion due to Hortonian runoff (Horton, 1945) begins following an increase in peak discharge induced by a rise in the runoff coefficient, caused by urbanization, which alters the hydrological regime and basin morphology. Roads and drainage ditches disrupt natural drainage conditions and can lower a location's critical intensity threshold. Particularly in areas where urban infrastructure is now severely damaged, the triggering of road-related gullies is highly frequent, as they develop rapidly (Jungerius et al., 2002; Nyssen et al., 2002; Osmar et al., 2010). Based on the above, gully erosion in Kinshasa's high town results from road openings without sufficient and adequate drainage. This situation is confirmed by comparing gully locations with the natural topography and the shape of these gullies with preexisting urban infrastructure. Findings reveal that 91% of these mega-gullies developed along and on artificial drainage lines, primarily anthropogenic runoff channels such as roads, ditches, sewers, drains, and tracks (Makanzu Imwangana, 2014; Makanzu Imwangana et al., 2015).

The situation in our study area does not differ from what these authors confirm. It should be noted that this site is located between two hills (Mont-Amba and Mont-Ngafula), which have been invaded by self-construction, without prior development of rainwater drainage networks, responsible for soil erosion. Therefore, this site requires modernization using urban fabric development and sanitation techniques. To achieve this, it would be necessary to have a good understanding of its geomorphological and hydrogeomorphological dynamics and surface flows.

This research aims to assess the necessary activities to stop the advance of gully erosion surrounding the Kimwenza mission. These interventions aim to mitigate runoff flow path issues that cause erosion in the town, despite the challenge of controlling this phenomenon due to limited knowledge of the causative parameters, the fragile nature of the soil, and the particularly steep topography of the target area. Specifically, this research aims to (i) describe and analyze the soil, identify and characterize the main erosion sites in the study area; (ii) describe, analyze, and characterize the topography and hydrographic network of the study area; (iii) analyze and evaluate runoff discharges, the primary driver of gully erosion, and estimate the drainage system; (iv) assess the impact of erosion and the vulnerability of the area; (v) identify suitable and practical solutions to reduce gully erosion in this part of Kinshasa.

STUDY AREA

The town of Kinshasa is built on a vast plain surrounded by hills. Several authors, such as Lelo Nzuzi (2008), compare the site's general morphology to an amphitheatre. The hills form the southern edges of this amphitheatre. The study area includes parts of Mont-Amba and Mont-Ngafula. The section located on Mont-Amba includes the COGELOS neighbourhood, which is adjacent to the University of Kinshasa campus. Meanwhile, the section on Mont-Ngafula encompasses the Kindele neighbourhood (upstream of the Funa Stream), the Kimwenza Mission neighbourhood (administratively referred to as Kimbuta), and the Kimwenza-Gare

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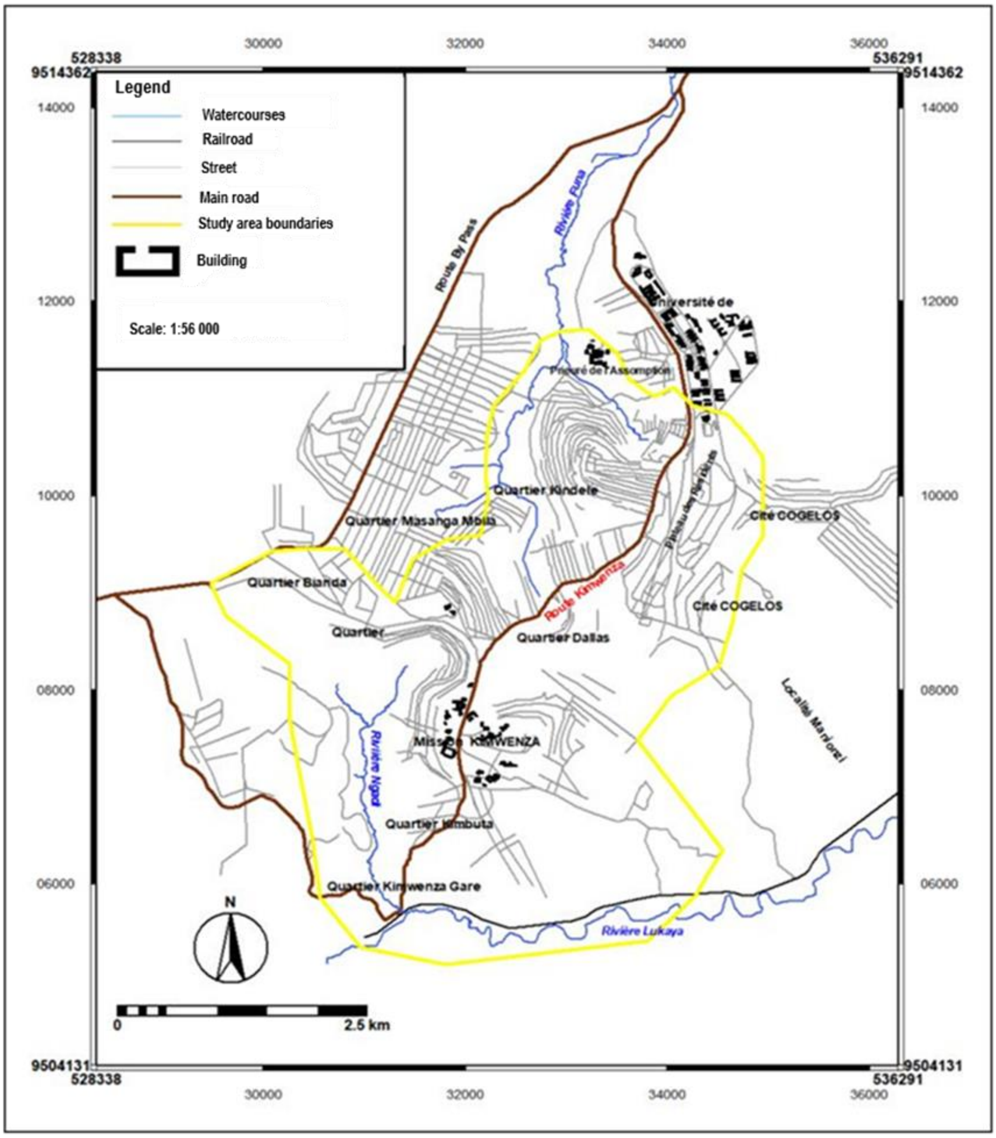
neighbourhood (Figure 1). The study area is undergoing self-construction without urban planning standards and without a runoff drainage network, yet it rains heavily, on bare, non-cohesive soils and on steep slopes.

Figure 1: Map of the Study Area, Locating Kimwenza Mission and Kimwenza Gare Squares (S), the University of Kinshasa (NE), and the Damaged Kimwenza Road Joining the Two Entities in Southern Kinshasa Town.



The Kimwenza Mission and its surroundings are built on a small plateau of the same name, which serves as the contact zone between the Pool Plain (average altitude: 310 m) and the southwestern extension of the Batéké Plateau (average altitude: 413 m). This small plateau, eroded by fluvial processes, is characterized by valleys separated by elephant-back interfluves and connected to rounded hilltops through steep slopes, forming an amphitheatre-like relief. With predominantly flat bottoms, these valleys are drained by relatively small rivers, including the Funa to the north, the Lukaya and its tributaries to the south, and the Bumbu to the southwest (Figure 2).

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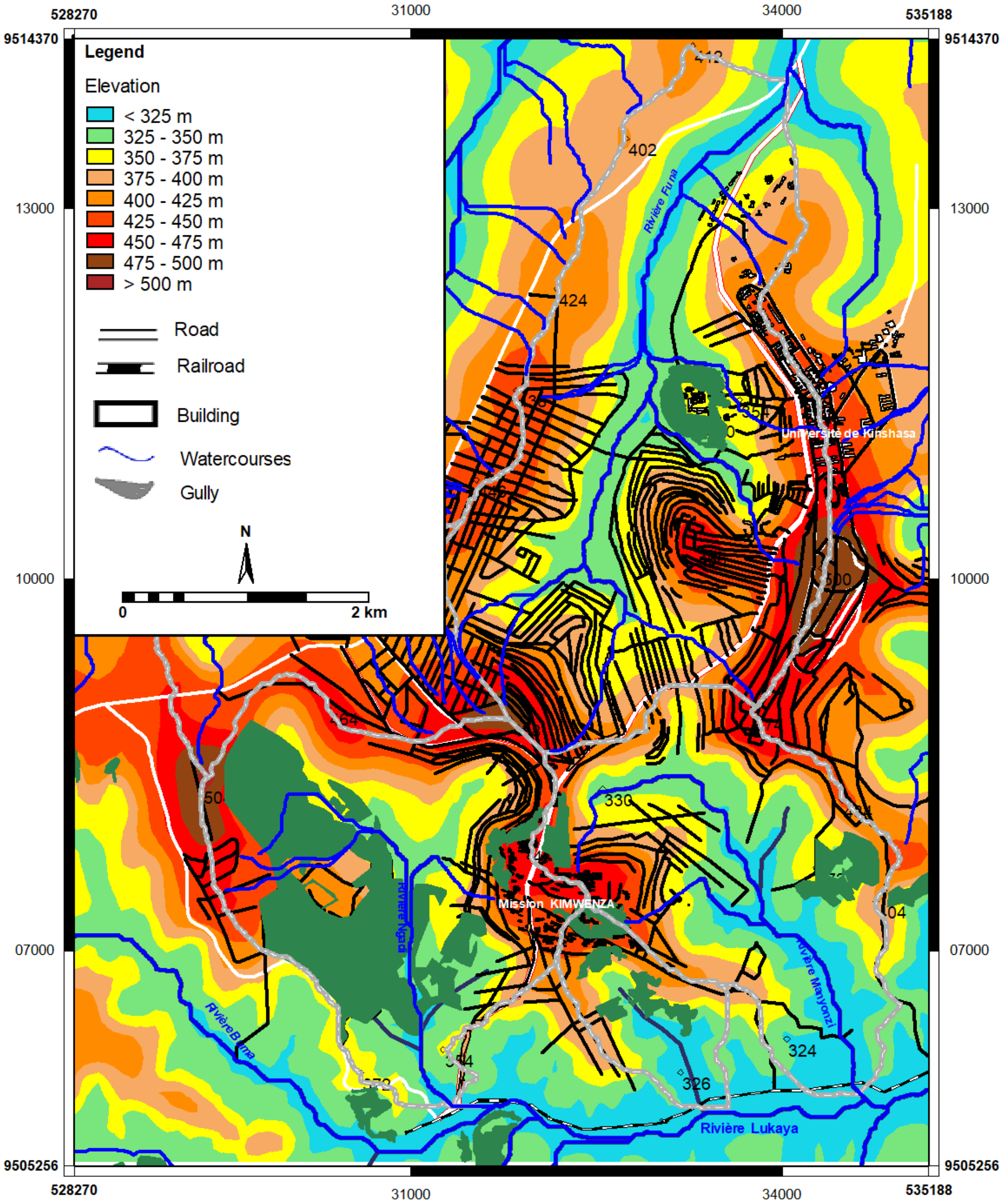
Figure 2: Elevation Map of Kimwenza Mission and Its Surroundings Showing Hills Ant and Flat Areas



The slopes of this small plateau, once classified as *non-aedificandi* zones (prohibited for urban development), are now occupied by self-built neighbourhoods, as shown in Figure 1. Kinshasa, in general, and the study area, 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 (Figure 3).

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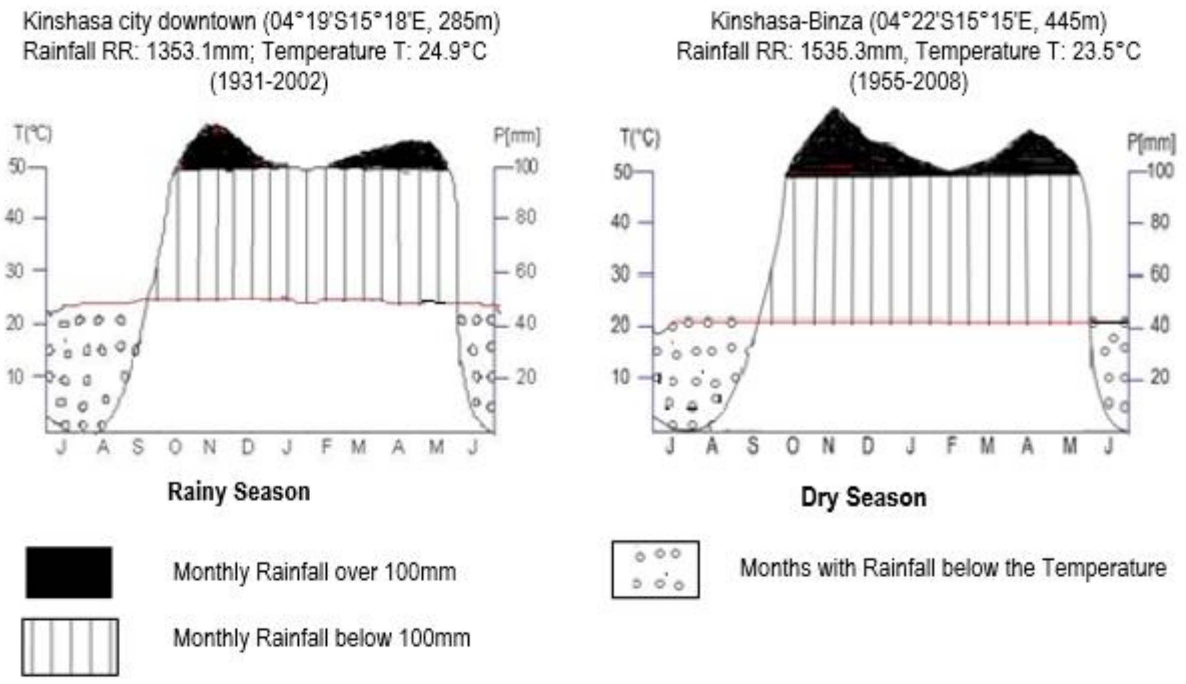
Figure 3: Umbrothermal Diagram of Kinshasa (1932-2008) from Pangu Sanghy (2011)



From a spatial perspective, this town today spans nearly 1,000,000 hectares, covering only 650 hectares in 1919 and expanding to 5,500 hectares (almost tenfold) by 1960 (Crabbe, 1980). This rapid expansion in surface area is a direct consequence of the demographic surge driven by a massive rural exodus, itself triggered by a multifaceted crisis that includes economic decline, rural impoverishment, poor governance, political instability, and fratricidal conflicts, among other factors. Naturally, the relentless search for housing and the struggle for survival, exacerbated by this crisis, have led to the proliferation of informal activities and the development of numerous spontaneous urban settlements (Pangu Sanghy, 2011; Lelo Nzuzi, 2008; Luboya, 1997). These settlements have ultimately encroached on hillside slopes and major riverbeds. As a result, in the absence of an effective urbanization policy, especially after independence, the widespread disruption of the overall surface water drainage system has become a persistent issue in Kinshasa. This situation has led to several significant problems, including worsening gully erosion, encroachment of major riverbeds by housing, transformation of rivers into waste disposal sites, disorganization of drainage channels, and an increase in both the frequency and intensity of flooding (Pangu Sanghy, 2011).

MATERIALS AND METHODS

Materials

- To measure infiltration capacity in the field and collect soil samples, a ring infiltrometer made of a PVC tube, as described by Moeyersons (1989), was used. The diameter of the tube is 7.8 cm, giving a cross-sectional area of 48 cm². Such a ring allows for the collection of undisturbed soil samples. This tube is inserted to a depth of 5 cm, allowing a volume of 240 cm³ to be collected by gently rotating the tube while lifting it slightly. If part of the soil remains at the bottom of the hole after sampling, the convexity of the lower part of the sample is manually retrieved using a trowel or spatula. The sample is then stored in a plastic bag for the laboratory. This procedure requires that measurements in areas with abundant roots be excluded (Moeyersons et al., 2015).

- Other instruments used for the field research include a GARMIN 62S GPS to position all sample collection points on a map, a digital camera to photograph profiles and horizons

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where samples were collected, and a measuring tape to measure the thicknesses and depths of various gullies and horizons where infiltration measurements were to be made.

- The pedological coverage was subdivided into homogeneous volumes. Depths vary from 38 to 150 cm and are explicitly expressed in detail through distinct aggregates, constituents forming the matrix, and pedological features. Due to their vertical dimensions, from centimetres to meters, the horizons are directly identifiable to the naked eye in the profile. Each horizon is a volume. The average characteristics observed at different sampling sites have already been well described by Wouters and Wolff (2008), Baert et al. (2009), and Makanzu Imwangana et al. (2018). The pedological section characteristic of this environment is described macroscopically in its dry state; it is important to note that colours become very distinct after rainfall. It includes:

  - Horizon A, 10-30 cm thick, is composed of fine sand (greyish) rich in grassroots, but the concentration decreases with depth.

  - Horizon B_{W1}, with a thickness of 30-80 cm, consists of a more coherent sandy texture than the previous horizon; with depth, there is an increase in fine sand. It is greyish-yellow in colour, contains a few rare roots, and becomes friable upon drying.

  - Horizon $B_{W2.1}$, with a thickness exceeding one meter, is yellow and moist, even during this period in July, consisting of fine sand with some silts and blackish spots, which may indicate the activity of soil fauna.

Methodological Approach

Description and Determination of Soil Hydraulic Conductivity

- The technique involves measuring in situ the dynamics of water infiltration into the soil by determining the permeability of each horizon in several pedological profiles along the slopes of gullies that cut through the Mont-Amba and Mont-Ngafula to deduce their behaviours. For this purpose, the walls of the gullies were cleared using a spade from top to bottom of the profile to refresh and visualize the horizons, which differ by their colouration. This choice was arbitrary for all observation points. Five field trips were made to collect soil samples and conduct in situ permeability and laboratory tests. The choice, although arbitrary, is based on the number of sub-catchments, five in total, due to a single transect per sub-catchment. A total of 15 samples were selected for granulometric analyses and infiltration tests in the laboratory, with three samples from each of the five chosen transects. At each of these sampling points, we performed in situ soil permeability tests using a simple ring, 20 cm in length, with 5 cm of the ring embedded in the soil (Figures 4 and 5).

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Figure 4: *In situ* Soil Permeability Test at the Mont-Amba site.

Figure 5: *In situ* Soil Permeability Test at the Mont-Ngafula Site.

- The portion embedded in the soil has a volume of approximately 240 cm³. This technique is preferred over the double metal ring for practical reasons, mainly its ease of transport and low water consumption. The infiltration capacity is given by Darcy's law (1856) by timing the drop in the water level in the tube according to the following equation from Lambe and Whitman (1979):

$$k = \frac{2{,}3 * a * L * \log_{10}(h_0)}{A(t_1 - t_0) * h_1}$$
……………………………………………..…(1)

where,
k = permeability in cm/s[1]; a = the cross-sectional area of the tube (48 cm² here); L = the thickness of the tested sample (5 cm here), the depth at which the infiltrometer is embedded in the soil; A = a = the cross-sectional area of the tested sample, which is 48 cm²; $t_1 - t_0$ = time in seconds between the water levels, h_0 (= 20 cm) and h_1 (= 5 cm) In the tube. For the PVC tube used as the ring infiltrometer, the infiltration capacity k becomes:

$$k = {6{,}93}/{(t_1 - t_0)}$$
………..……..……………………………………(2)

Watershed delineation and determination of physical and morphometric parameters

The watershed, which is the area where precipitation is collected and rivers are fed, is partially defined by the surface, bounded by ridgelines, and calculated through planimetry. Starting from the digital terrain model created from a drone survey with a spatial resolution of 0.5 m in 2020, the ArcHydro tool in ArcMap was used to calculate and extract sub-watersheds and establish the hydrographic network of the study area. This method yielded all the shapes, physical parameters, and indices used in this study.

Calculation of Runoff Flows

- Faced with the lack of field data from the Kimwenza station or any other station within the watersheds, we resorted to using data from the Regional Center for Nuclear Studies of Kinshasa (CREN-K) station, located approximately 5 km from the Kimwenza Mission Centre. Its daily rainfall chronicle spans 14.5 years (2007–2021). These data were correlated with those from stations of Kinshasa/Binza and Kinshasa/N'djili and then homogenized.
- The lack of data on the duration of rainfall at the reference station of the CREN-K station (4°25'04.79''S/15°18'34.68''E; alt. 481.16 m), we relied on historical data and previous studies based on observations from the Kinshasa/Binza station (4°22'14''S/15°15'17.62''E; alt. 445 m), where unfortunately, data recording was interrupted over 5 years ago due to a lack of

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rain gauges. This station, of rank 1 (WMO), is located approximately 10 km north of the Kimwenza Mission (4°27’10.49’’ S, 15°17'16.83’’ E; alt. 476 m).

- In drainage engineering, the distribution of maximum intensities based on duration is crucial for designing road drainage systems and small-scale street infrastructure projects. Rainfall intensity has a velocity dimension, but in drainage engineering, it is translated into specific discharge and expressed in litres per second per hectare (l/s/ha) to estimate runoff flows. The most intense rains are often the briefest. It is observed that during a prolonged rainfall event, high-intensity phases are generally short. Without more recent data, we resorted to analyzing the available pluviograms from METTELSAT, covering the period from 1977 to 2000. Their analysis enabled the calculation of maximum intensities for durations of 5, 10, 20, and 60 minutes.

- As part of this study, only the pluviograms with the highest rainfall amounts were retained. This limitation was dictated by the fact that the heaviest rains rarely last longer, and most precipitation in a rain event is typically collected within 90 minutes (Kalombo, 2001). The moving sums determined the maximum contribution for each rainfall event within a given period. This distribution of occurrences based on the contribution will allow cumulative occurrences to be calculated. These cumulative occurrences were graphically represented by their decimal logarithms on the y-axis and their contributions on the x-axis. The distribution of representative points for a given time is thus approximately a straight line, at least for most of the data. Analytical fitting is, therefore, possible using the least squares method. The equation of the sought-after fitting line is in the general form:

y = bx + a (3)

- The parameters a and b will be derived from the "eyeball" fitting of the Gumbel (1958) distribution. The Gumbel double exponential distribution is a frequency model commonly used to predict extreme events in hydrology. Its cumulative distribution function F(x) is given by the following form:

$$F(x) = \exp\left[-\exp\left(-\frac{x-a}{b}\right)\right] \quad (4)$$

With the reduced variable u such that:

$$u = \frac{x-a}{b} \quad (5)$$

Where a and b are the parameters of the Gumbel model.

The distribution is then written as follows: $F(x) = \exp\left(-\exp(-u)\right)$ (6)

and $u = -\ln\left(-\ln(F(x)\right)$ (7)

We then understand that the expression for a quantile becomes linear, such that xq = a + b*uq (8)

- In practice, the goal is primarily to estimate the non-exceedance probability F(xi) that should be assigned to each value xi. There are several formulas for estimating the cumulative distribution function using empirical frequency. All of them rely on sorting the series in descending order, allowing the assignment of a rank r to each value. Simulations have shown that for the Gumbel distribution, the empirical frequency of Hazen should be used:

$$F = \frac{r-0{,}5}{n} \quad (9)$$

where r is the rank in the data series sorted in ascending order, n is the sample size, and x[r] is the value at the rth rank.

- In the effort to develop a tool for predicting erosion, Makanzu Imwangana (2014) evaluated the relationship between rainfall intensity Ri and the runoff coefficient CR in Kinshasa-West:

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$$Y = 0.7533X - 6.1169 \quad (R^2 = 0.8011) \qquad (10)$$

With X representing the rainfall intensity I [mm/h] and Y representing the runoff coefficient CR [%].

To identify the contributing areas of the main gullies, a flow simulation over the entire area was carried out using the Land and Water Information System (ILWIS 7.6) software to map the land flow path organization of runoff in the study area.

Cartographic Inventory of Gullies and Their Characterization

The gullies were mapped through photo-interpretation on Google Earth Pro (Sheppard & Cizek, 2009) using ArcGIS 10.2 and Quantum GIS in the laboratory. Data on the measurements and dimensions of the gullies were obtained through automatic calculations on ArcMap 10.2. The width data represent averages estimated using automatically obtained areas. The slope of gullies' walls in Kinshasa ranges from approximately 25° to 45°. Data on depth and volume were derived from the width of the gullies and calculated by considering an average flank slope of 35° for a triangular section (Makanzu Imwangana et al., 2015).

Field Data Collection Campaign and Vulnerability Assessment

A small field data collection campaign (Survey Form) was organized with the help of two Geomatics students and two Junior Researchers during the first half of May 2021. It enabled the collection of ground control points using a Garmin 62S GPS from various gully erosion sites. This facilitated the creation of a geographic database in GIS form. This GIS allows the mapping of the study elements.

During the data collection campaign, the gullies and their impact on the terrain were directly observed to understand the situation. A survey was conducted among the local population based on a questionnaire developed in KoboCollect and administered via an Android mobile phone. The goal was to identify the underlying factors that led to the situation and understand the causes of the ravaging, its impacts, and the measures taken to combat it. This fieldwork also helped approximate the drainage area of runoff at the heads of the gullies, enabling an assessment of the vulnerability of infrastructure, such as roads and houses, while considering the potential progression of the gullies.

RESULTS AND DISCUSSION

Description of the Soil at Kimwenza and Its Hydraulic Conductivity (Permeability)

In the Kinshasa region, soils are generally poor, and their acidity is pronounced, a primary characteristic of tropical soils. Although chemically poor and thus sterile, these soils are regularly watered for eight to nine months during the year. They contain a certain proportion of clay. Thus, in some areas, the soil is a mixture of clay and sand. It is in these places that they provide the best agricultural yields. However, the heavy rainfall leaches these soils, causing a total hydrolysis of these elements. This phenomenon leads to their laterization. Lateralization is the final phase of the hydrolysis of soil materials.

The granulometric analysis results of soil samples show a soil type composed, on average, of 84.2% sand, 10% silt, and 5.8% clay. It is a sandy loam soil made up of coarse sand. This type of soil is susceptible to water erosion when exposed, given that at least 83% of slopes are greater than or equal to 10°. It is also worth noting that, in general, these soils had an average water content of 27% in their initial state. It is observed that schistous sandstones yield yellow or light brown clayey sands that are low in fertility and sufficiently permeable. The soils of the arable layer have an average granulometric composition of about 3.4% clay, 5.6% silt, and 91.0% sand, with an apparent density of about 1.25 (Kasongo et al., 2010).

It should be noted that in this catchment, the soils are permeable and poor, except in the alluvial and colluvial formations, where they are fertile. The type of soil found is Haplic Acrisols, which cover nearly the entire catchment. These are sandy, very deep, leached soils with almost no clay on the surface. That is the type of soil found in our study area. High proportions of clay or even clayey soils

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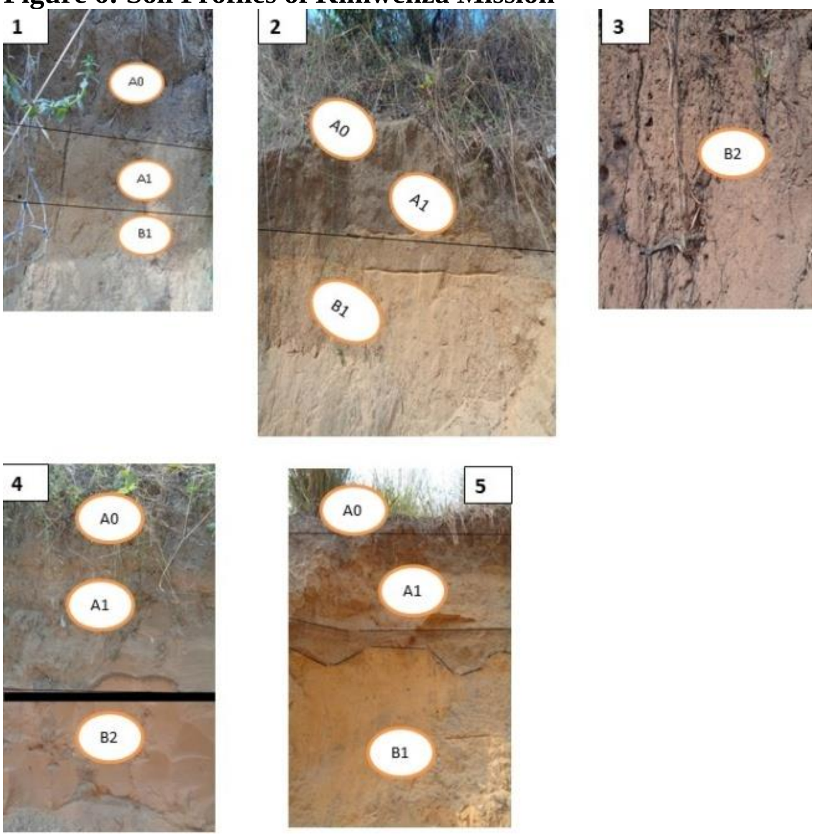
are found in deep valleys. Moreover, natural drainage is disrupted when settlements and other land uses replace the forest. An artificial drainage network predominates, driven by the presence of footpaths, streets, and roads in the landscape. As a result, it is observed that water erosion cuts into the sandy relief at the tops of the highest hills and on the slopes of deep valleys. This phenomenon constantly rejuvenates the profile, highlighting the slight fertility and good hydraulic conductivity of these soils. Additionally, in this landscape, a thin layer of organic matter in the form of lichens delays water infiltration into the soil and promotes runoff. Table 1 presents the main characteristics of the horizons of typical soil profiles in the study area (Figure 6).

Table 1: Description of the Soil Pedological Profiles of Kimwenza

Places	Geographical coordinates	Characteristics of soil profiles
Profile 7 km Photos 1 & 2 (Fig.6)	04°25′49.7” 015°17′21,0” 448m	• Horizon A0: Black soil (Humus) rich in organic matter with variable thickness. • Horizon A1: Black soil with brown patches. • Horizon B1: Yellow soil with a thickness ranging from 10 to 30 cm depending on the location.
Profile Kimwenza Gare Photos 3 & 4 (Fig.6)	04°28′14.7” 015°16′58,4” 323m	• Horizon A0: Black soil (Humus) rich in organic matter with variable thickness. • Horizon A1: Black soil with brown patches. • Horizon B2: Red soil, clayey in the valley bottom with the presence of iron oxide.
Profile Kimwenza Mission Photo 5 (Fig.6)	04°27′31.7” 015°17′17,9” 440m	• Horizon A0: Black soil (Humus) rich in organic matter with variable thickness. • Horizon A1: Black soil with brown spots. • Horizon B1: Yellow soil that can reach depths of several meters.

Figure 6: Soil Profiles of Kimwenza Mission



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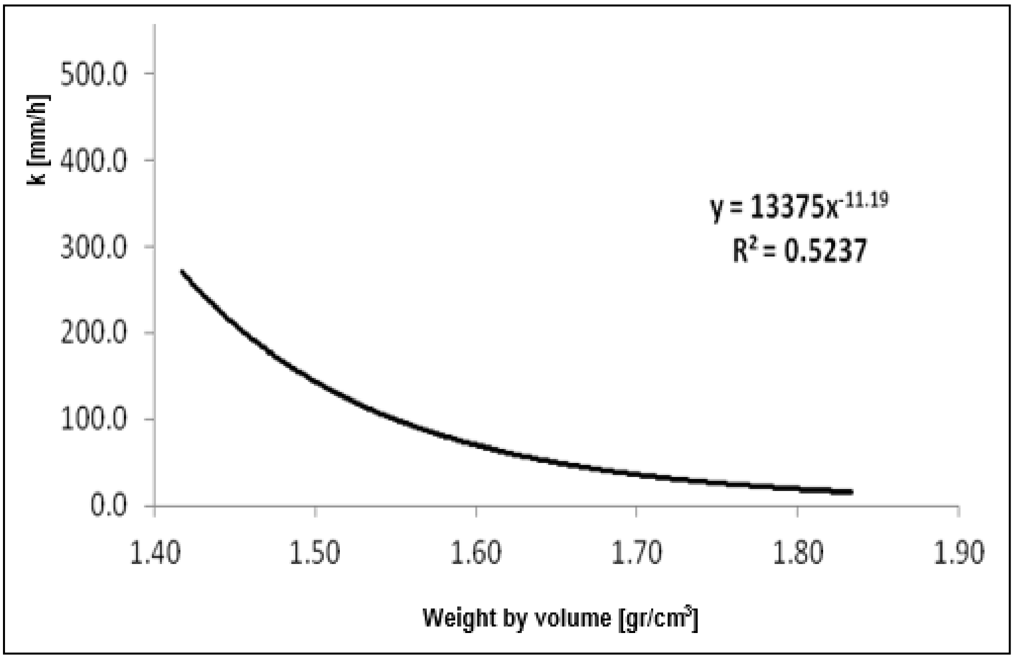
Regarding other analyses and observations obtained, it appears that the average permeability (hydraulic conductivity of the soil) in the field is 551 mm/h (Min.: 11 mm/h and Max.: 2096 mm/h), while in the laboratory, it is 108 mm/h (Min.: 3 mm/h and Max.: 779 mm/h). The difference is substantial between the two methods. The field measurements partially account for the soil suction. Since we did not measure the dry bulk density of the soil, its water content, or saturation in the field, we prefer to retain the permeability found in the laboratory. The advantage here is that we work under a saturated system. With such a magnitude for the average permeability, it is evident that we are dealing with sand. With a soil bulk density of 1.85 g/cm^3, infiltration reaches its limit and results in runoff (Figure 7). This soil impermeabilization occurs in urban areas due to soil compaction caused by the frequent passage of vehicles and pedestrians. This compaction follows the opening of roadways and specific vegetation covers (*Cynodon dactylon, Paspalum notatum,* and others) when they almost completely cover the soil. At such a coverage rate, these types of vegetation act like bare, complex, and compacted soils.

Figure 7: Permeability of Soils in Kimwenza Mission.



Hydrographic Network of Kimwenza and Its Surroundings, Morphometric and Topographic Parameters

The study of gully erosion is closely related to surface runoff, making it essential to understand the origin of all hydrological processes within the catchment. The Kimwenza site is primarily drained by the Funa and Lukaya rivers (with tributaries Manyonzi and Ngadi), whose valleys feature steep slopes (Figure 8a, b, and c). Figure 8 shows that over 61% of the developed land on the Kimwenza site has slopes exceeding 8%, while relatively flat terrain makes up only about 10%. In short, the region is dominated by steep terrain.

The processing of the digital terrain model allowed for the generation and/or calculation of the main parameters characteristic of the catchments of the upper Funa, Manyonzi, Ngadi, upper Bumbu, and the Kimbuta neighbourhood valley (Table 2). Self-construction, even anarchic development, heavily disturbs the environment, with many streets oriented along the slope, as seen in Figure 9b, leading to an extreme densification of the drainage network.

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Figure 8 : **(a) Watersheds Boundaries; (b) Slope Map : 0-2% Flat Land, 2-8% Medium Slope and > 8% Steep Slope; (c) Slope Frequency Histogram in the Kimwenza Region.**

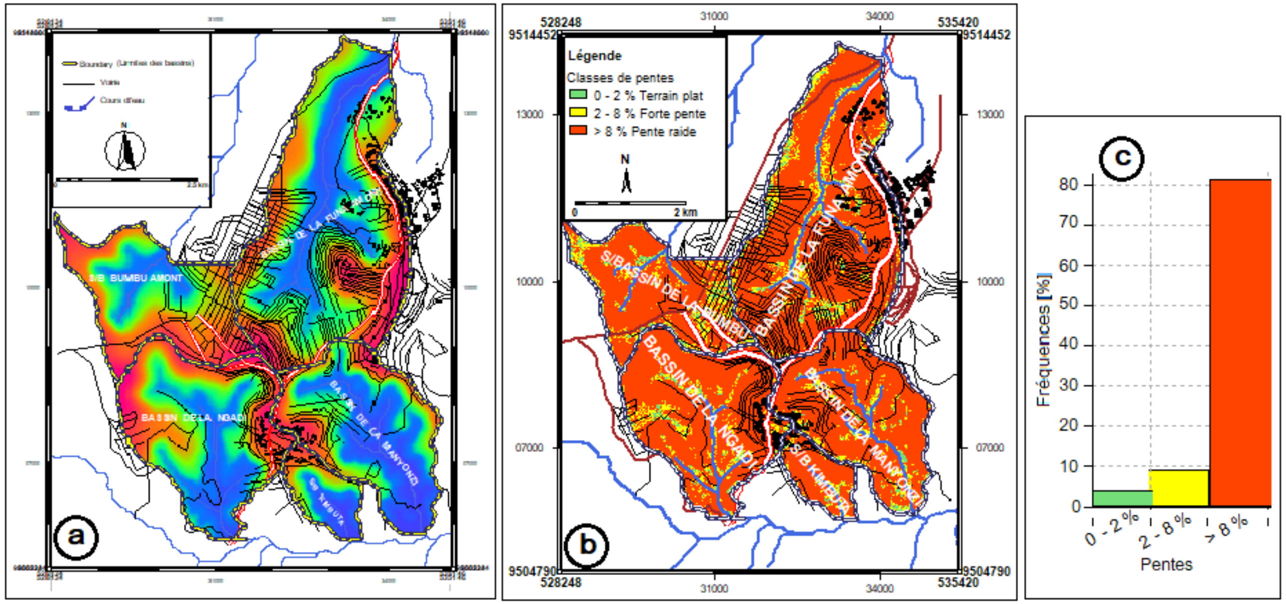

Table 2: Morphometric Characteristics of the Watersheds of the Kimwenza Site and Surroundings

ID	Catchment Name	Perimeter [km]	Area [km²]	Total Drainage Length [km]	Drainage density [m/km²]	Longest Flow Path Length [km]	Longest Drainage Length [km]	Upstream Elevation Average [m]	Downstream Elevation Average [m]	Slope along drainage Average [%]	Slope Drainage Straight Average [%]	Sinuosity Average	Total Upstream along dranage length [km]	Center Drainage	Center Catchment
1	Funa amont	16,14	11,43223	13,2083	11554,11	7,087	7,485	384,3	340,6	7,65	8,66	1,142	131,6074	(532605.00,9510903.00)	(533070.63,9511445.00)
2	Manyonzi	11,268	5,70922	18,627	3262,77	5,071	5,025	366,6	325,9	7,2	8,47	1,197	17,801	(533287.00,9508371.00)	(533617.42,9507481.00)
3	Ngadi	12,535	6,64247	35,4672	5339,46	4,31	4,557	386,1	341,4	7,56	8,87	1,167	34,8369	(530837.00,9507863.00)	(530917.75,9507479.00)
4	Kimbuta	5,608	1,33083	2,391	1796,63	2,592	2,391	348,9	311,2	6,75	8,28	1,112	6,0054	(532211.00,9507027.00)	(532921.50,9506626.00)
5	Bumbu amont	13,009	4,863752	52,927	10882,09	2,952	2,818	398,8	360,4	7,49	8,43	1,142	52,871	(529465.00,9509695.00)	(530091.50,9509854.00)
	TOTAL	58,56	29,9785	122,621											
	AVERAGE				6567,01	4,4024	4,4552	376,94	335,9	7,33	8,542	1,152	48,62434		

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Indeed, Table 2 shows that all the catchments in the Kimwenza area and surroundings have a very high drainage density, ranging from about 1,800 m/km² in the Kimbuta sub-basin to more than 11,000 m/km² in the upper Funa basin, with an overall average of nearly 6,570 m/km². It is also noted that the sinuosity of the foremost collectors is very low, with an average below 1.2. That means most drains' (talwegs) geometry is nearly straight, confirming that the exceptional drainage density observed on this site results from several street gullies. Furthermore, all the basins in this area of Kinshasa are relatively compact in shape and of modest extension (Table 3). This reality means that the catchments in the Kimwenza area and surroundings are predisposed to have a short concentration time for rainwater, leading to a relatively quick response time. Consequently, it can be concluded that the runoff flows in this area can only follow a torrential regime, especially considering that most (80%) of this sector of Kinshasa has slopes exceeding 8%.

Table 3: Morphometric and topographic characteristics of the catchments in the Kimwenza area and surrounding areas

No	Catchment	Perimeter [km]	Area [km²]	Gravelius Compactness index	Equivalent Rectangle Length [km]	Vertical Drop [m]	Global slope Index [m/km]
1	Upstream Funa River	16.40	11.43	1.3	5.036	133.0	0.026
2	Manyonzi River	11.27	5.71	1.3	3.448	136.0	0.039
3	Ngadi River	12.54	6.64	1.4	4.018	133.5	0.033
4	Upstream Bumbu River	12.54	4.86	1.6	4.580	121.0	0.026
	Whole watershed	52.49	28.64	1.4	8.888	155.0	0.017

Description of the Surface Water Drainage Network in the Kimwenza Mission and Surrounding Areas

The morphology of the study area, as presented in Section 4.2, primarily encompasses four small catchments located on the Kimwenza plateau. After simulating the runoff across the entire study area, the drainage areas of the main gullies identified trace the organization of the flow paths of surface runoff in the area (Figure 9). Figure 9 allowed the delineation of the sections of the road most exposed to runoff flows. In the Funa catchment, it is noted that along the UNIKIN – Kimwenza section, significant flows discharge onto the road. These water masses primarily come from the Residents' Plateau, the COGELOS, and the Dallas neighbourhoods. In the Manyonzi catchment, the road is affected by flows from the northwest and those following the road. Along the Kimwenza Mission and Kimwenza Gare section, the most dangerous flows come from the Kimwenza neighbourhood and those following the road from the Mission in the Ngadi catchment. It is particularly noteworthy that these runoff flows, which are very aggressive due to the often steep terrain slopes and the destruction of vegetation, carry large amounts of sediment produced by soil erosion.

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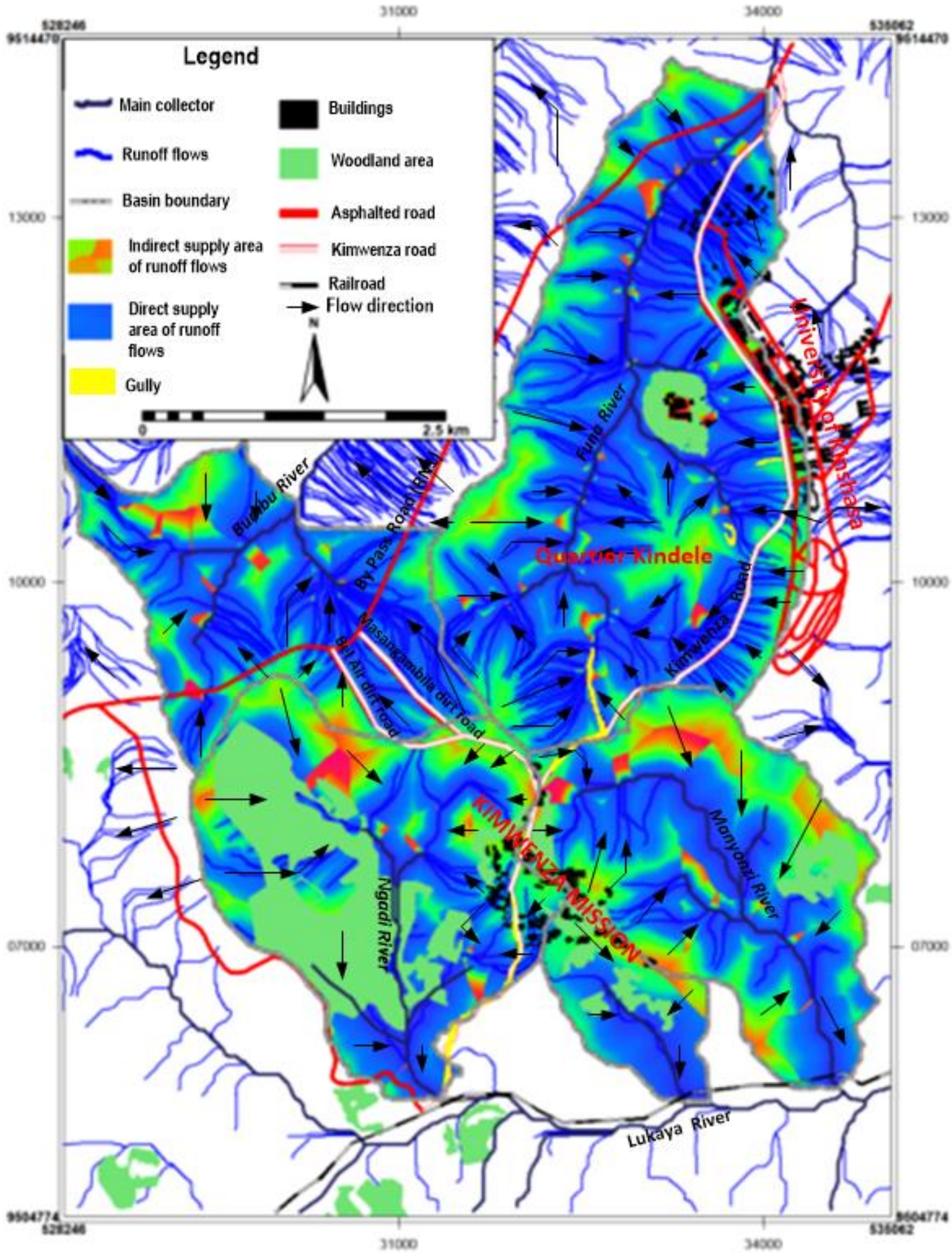
Figure 9: Simulation of the Land Flow Paths of Runoff in the Kimwenza Region in Kinshasa



Runoff Discharge Evaluation

Rainfall

Figure 10 shows that during the last decade, the highest monthly rainfall amounts were recorded in April 2007 (399.2 mm), November 2007 (389.0 mm), and October 2019 (381.8 mm). The highest daily rainfall maximum occurred on November 16, 2017 (123.5 mm). Unfortunately, there is no information on the temporal sequences of this rain as the CRENK-K station only has a totalizing rain gauge. However, analyzing this storm would have

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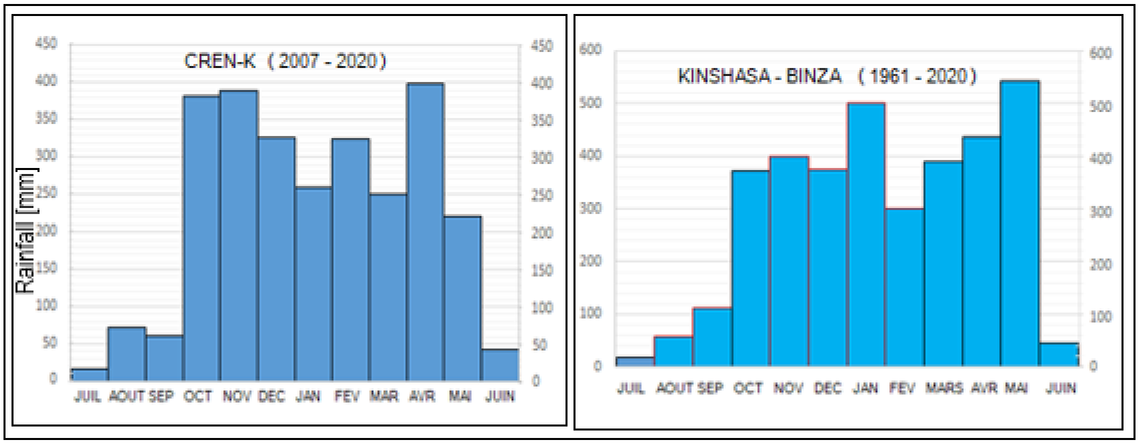
helped determine the variation in its intensity. At the Kinshasa/Binza station, the highest monthly maxima were observed in May 1974 (545.3 mm), January 1974 (501.5 mm), and November 1988 (399.8 mm), while the highest daily maximum was recorded in May 2001 (212 mm).

Figure 10: Maximum Rainfall at the CREN-K and Kinshasa-Binza Stations (1961 - 2020).



Analysis of Active Rainfall

Pain (1975), Crabbe (1980), Van Caillie (1983), Makanzu Imwangana (2014), and other authors almost unanimously state that the rainfall intensities in Kinshasa generally range between 12 and 100 mm/h, with an average of 51 mm/h for daily rainfall of about 25 to 119 mm, and the daily average fluctuating around 66 mm (Table 4).

Table 4: Rainfall Intensities for Erosive Rains in Kinshasa-West (Binza) from 1975-2005.

Date	P (mm)	I_{30} (mm/h)	Date	P (mm)	I_{30} (mm h^{-1})
4/04/1979	76	47	13/11/1991	57	31
20/04/1983	54	36	19/01/1992	104	54
10/11/1983	58	26	9/05/1993	55	25
27/03/1984	67	70	23/05/1995	60	55
24/04/1984	25	31	3/04/1998	79	48
16/03/1986	61	80	12/04/1998	119	86
14/04/1986	56	44	14/11/1998	46	19
6/05/1986	58	68	20/03/2001	55	42
16/05/1986	101	70	20/04/2002	57	34
29/10/1986	103	67	6/05/2002	97	98
8/02/1990	82	100	7/11/2002	41	12
9/12/1990	41	37	19/04/2005	33	36

Source: *Makanzu Imwangana (2014).*

Based on this data, the author performed a frequency analysis that revealed that half of the rains responsible for gully erosion have an intensity ranging from 21 to 50 mm/h, and a quarter come from those with an intensity between 51 and 70 mm/h. The duration of these rains varies from 45 minutes to 15 hours and 18 minutes, with an average of 6 hours and 47 minutes (Figure 11).

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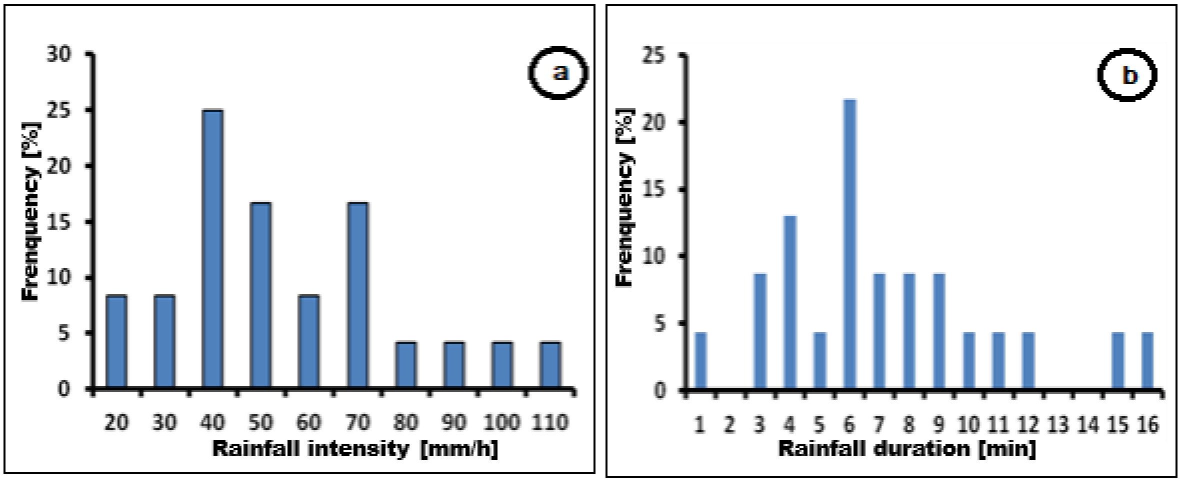
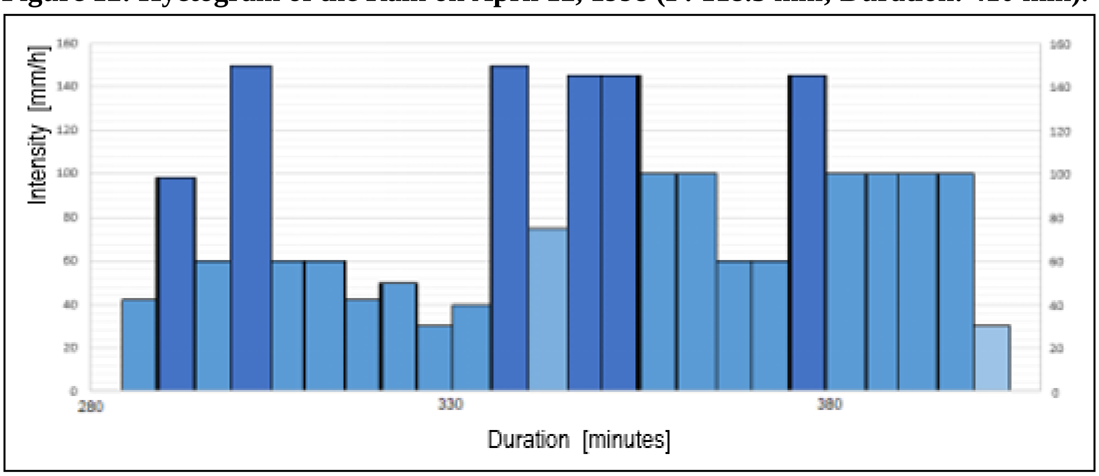
Figure 11: (a) Frequency of Erosive Rainfall Intensities (b) Frequency of Their Observed Duration in Kinshasa-Binza During the Period 1975-2005 (Source: Makanzu Imwangana, 2014).



The maximum intensities of rainfall phases range from 10 to 300 mm/h and last between 1 to 30 minutes. The average maximum intensity is 93 mm/h for 8 minutes and 48 seconds. Approximately 70% of the maximum intensities of these rains range from 60 to 150 mm/h, and 13% of them reach 300 mm/h. The time it takes for erosive rain to reach its maximum intensity is estimated between 5 minutes and 6 hours and 28 minutes, with an average of 1 hour and 40 minutes. For illustration, the rainfall phases of the torrential rain on April 12, 1998, have been described in detail on the hyetograph presented in Figure 12.

Figure 12: Hyetogram of the Rain on April 12, 1998 (P: 118.5 mm; Duration: 410 min).



From the analysis of the rainfall event shown in Figure 13, the previous statement falls within the study area of very intense rains with significant variations in intensity. In this case, several sequences are noted where the intensity is greater than or equal to 100 mm/h (for a short duration). If this intensity persists for 5 minutes, it will produce a specific flow rate of (100,000 litres/ha)/(560 s) = 178.57 litres/ha/s. Finally, the frequency analysis of active or critical rains led to the forecast model of Imax, with its return period presented in Figure 13.

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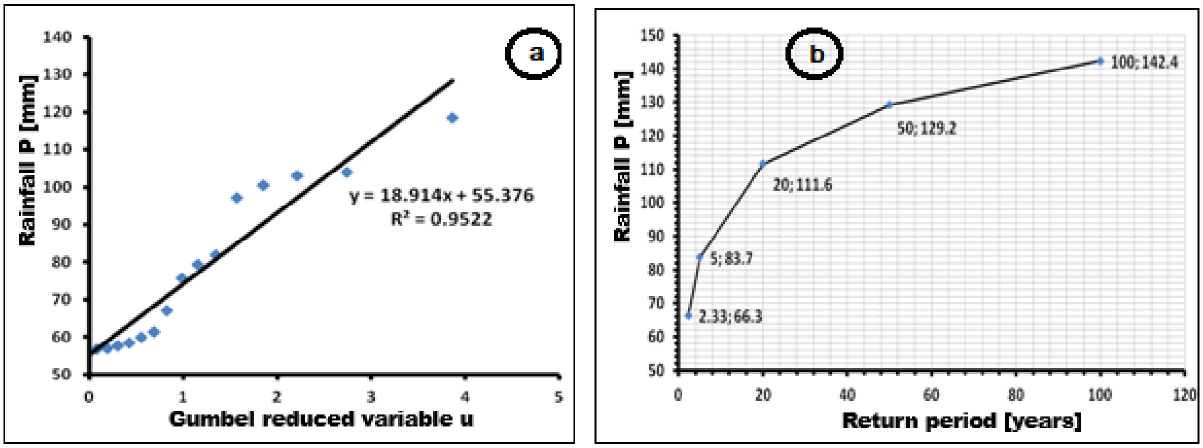
Figure 13: (a) Frequency Analysis of Active Rains and (b) Fitting of Active Rain Intensities (Imax) at Kinshasa/Binza Using the Gumbel (1958) Method (Source: Makanzu Imwangana, 2015).



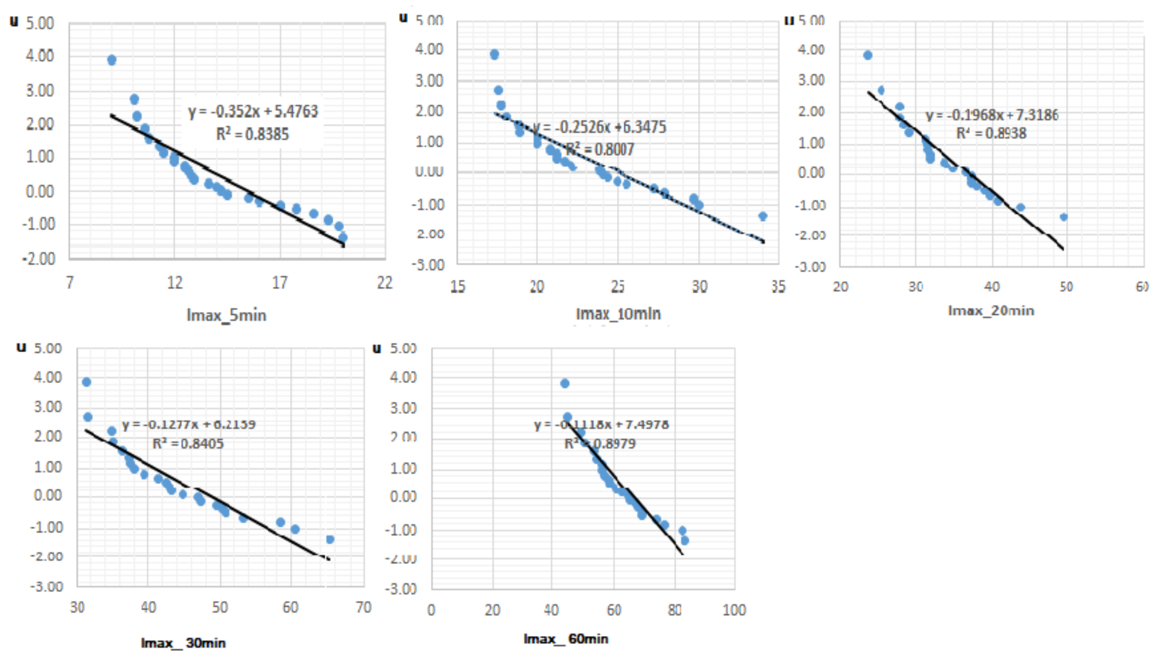
Among the sites subjected to sampling are the Cogelos Road (CR = 3%) and ERAIFT (6.1%), which are located within the study area. According to a survey by the same author, the height of the minor critical shower with annual occurrence is 24.9 mm. Based on this information and the simulations of the maximum rain intensities adjustment model (Fig. 14), a summary of the results has been compiled in Table 5.

Table 5: Occurrence of Active Rains in Kinshasa-East (1975-2005)

Rain [mm]	24.9	66.3	83.7	111.4	142
Return period [years]	1	2.33	5	20	100

Figure 14 presents the analysis of the maximum rainfall intensities in Kinshasa/Binza (1977-2000).

Figure 14: Graphical Fitting Lines of Gumbel (eye-fit) for the Maximum Rainfall Intensities in Kinshasa/Binza.



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Estimation of peak runoff flows in Kinshasa-West (1977-2000)

For the maximum rainfall intensities over 5 minutes, the adjustment line is

y = -0.352x + 5.4763, the resulting occurrences are:

- The contribution reached twice in one year is obtained by replacing y with log10;

log10 = 1; 1=-0,35x+ 5.47636 and x It will then be equal 12.71676 mm/5'.

The intensity is then $\frac{12,71676x10000}{5'x60''} = 423,892 liters/s/ha$

- The contribution encountered once every 5 years is y = log 1 ; log 1 = 0 ; 0 = -0,352x + 5,4763 et x equals: 15.5577mm /5min ;

The intensity is: $\frac{15,5577x10000}{5'x60''} = 518,589 liters/s/ha$

- The contribution reached once every 10 years is y = log0.5; log0.5 = -0.30103; x = 16.41287mm/5min.

The intensity is: $\frac{16,41287x10000}{5'x60''} = 547,096 liters/s/ha$

- The occurrence input for 20 years is y = log0,25 ; log0,25 = -0,602 ; x = 17,26807mm/5'

The intensity is: $\frac{17,26807x10000}{5'x60''} = 575,602 liters/s/ha$

- The occurrence input for 30 years is y = log0,125 ; log0,125 = -0,903 ; x = 18,12327 mm/5'

The intensity is: $\frac{18,12327x10000}{5'x60''} = 604,1089 liters/s/ha$

- The occurrence input for 50 years is y = log0,03125 ; log0,03125 = -1,505 ; x = 19,83366 mm/5'

The intensity is: $\frac{19,83366x10000}{5'x60''} = 661,12216 liters/s/ha$

After calculating the respective occurrence inputs for 1, 5, 10, 20, 30, and 50 years for the maximum intensities in 10, 20, 30, and 60 minutes using the same procedure, the results presented in Tables 6a and 6b were obtained.

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Table 6a: Occurrence of Maximum Rainfall Intensities [mm/h] Observed in Kinshasa-West (1977-2000)

	Return period of Imax in mm/h.					
Duration	**1 an (2 times)**	**5 years**	**10 years**	**20 years**	**30 years**	**50 years**
5 min	12.7	15.6	16.4	17.3	18.1	19.8
10 min	21.2	25.1	26.3	27.5	28.7	31.1
20 min	32.1	37.2	38.7	40.2	41.8	44.8
30 min	40.8	48.7	51.0	53.4	55.7	60.4
60 min	58.1	67.1	69.8	72.4	75.1	80.5

Table 6b: Occurrence of Peak Rainfall Flow Rates [liters/s/ha] Observed in Kinshasa-West (1977-2000).

	Return period of Qp in liters/s/ha					
Duration	**1 year (2 times)**	**5 years**	**10 years**	**20 years**	**30 years**	**50 years**
5 min	423.9	518.6	547.1	575.6	604.1	661.1
10 min	352.8	418.8	438.7	458.5	478.4	518.1
20 min	267.6	309.9	322.6	335.4	348.1	373.6
30 min	226.8	270.3	283.4	296.5	309.6	335.8
60 min	161.4	186.3	193.8	201.2	208.7	223.7

Since drainage infrastructure, such as gutters, is rare and often destroyed, it will be assumed that there is no drainage network in the study area. Table 6b determined the peak rainfall flow rates that will guide engineers in efficiently sizing their structures. Thus, the central collector will be calibrated according to the peak flow rate Qp of 661.1 liters/s/ha, while the flow rates Qp of 518.1 liters/s/ha to 223.7 liters/s/ha can be used for hierarchically sizing the secondary structures (Figure 15). Kisangala et al. (2025), working on all maximum daily rainfall between 1970 and 2021 in a neighbouring area, found that the expected rainfall quantities under climate change will be greater than 220 liters/s/ha. The difference with our research lies in the rainfall that Makanzu Imwangana (2014) called as active rainfall because not all rainfall causes gully erosion.

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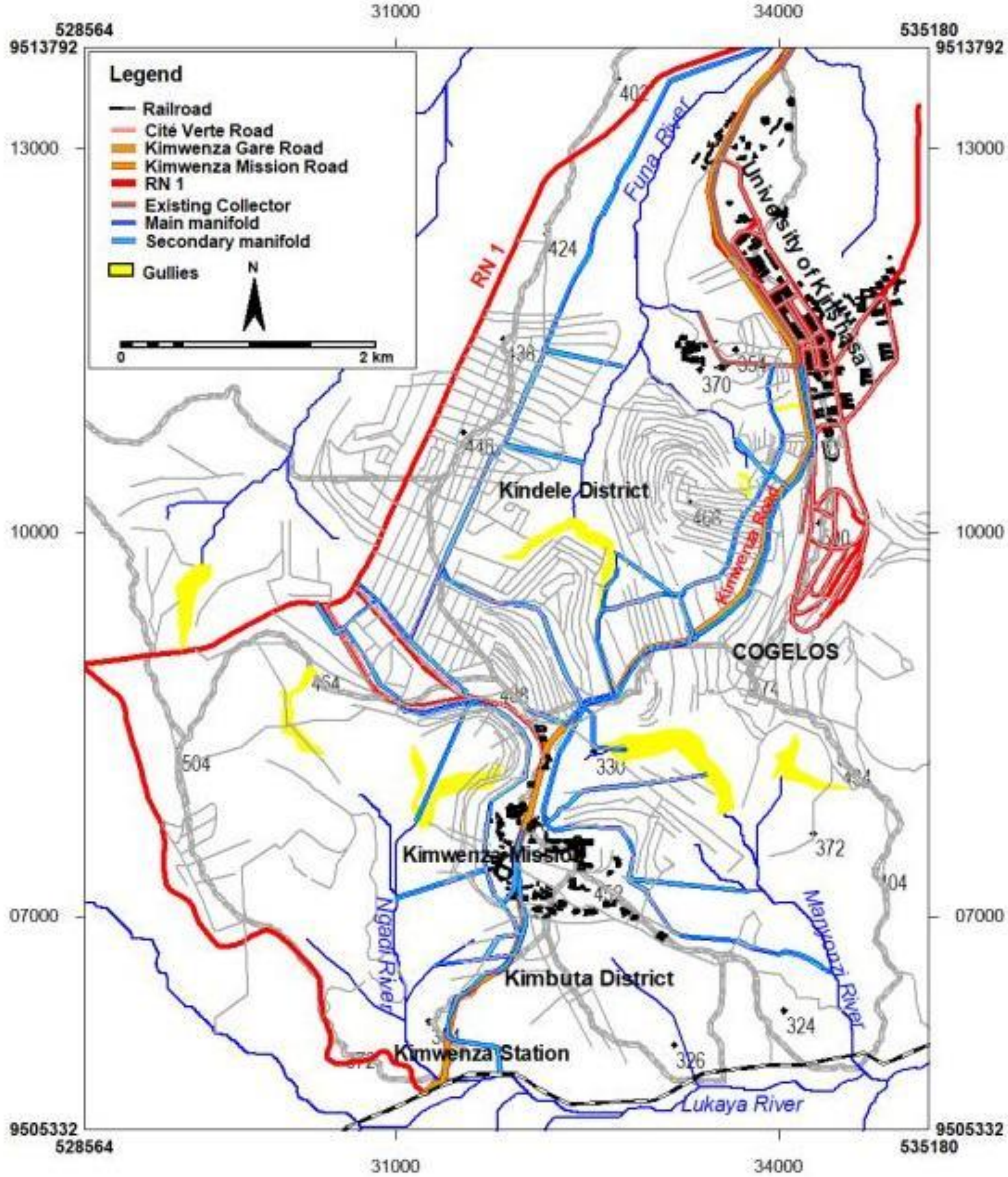
Figure 15: Map of the Rainwater Drainage Network Project in the Kimwenza Mission and Its Surroundings.



Mapping and Characterization of Gully Erosion Areas

The mapping of gully erosion areas is shown in Figure 16. In this figure, some gullies are too small to be easily seen due to the map scale.

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Figure 16: Location of Gullies In and Around Kimwenza Mission: All Gullies Appear to be Artificial and Colonize the Hillsides Occupied by Informal Settlements.

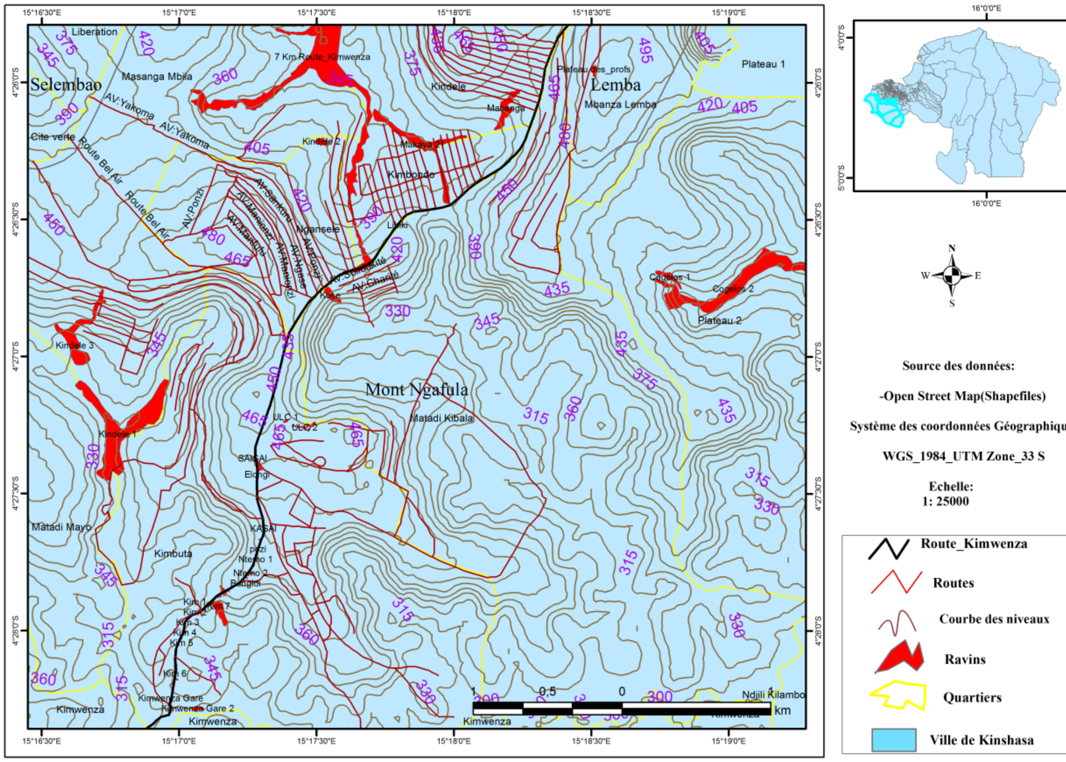

Table 8 presents the measurement and dimension data for 30 gullies mapped on Google Earth Pro in 2021. These dimensions were obtained through automatic calculations using ArcMap 10.8. Table 8 shows that the longest and largest gully is the Kimwenza Km7, Kimwenza 1 is the smallest gully based on length, and Ntemo 1 is the smallest gully based on the volume of eroded materials.

Table 8: Dimensions of Thirty Gullies Located on Google Earth Pro in 2021 and Measured on the Kimwenza Mission Site and Its Surroundings.

N°	Name	Length (m)	Avg Length (m)	Avg.Depth (m)	Surface (m²)	Volume (m³)
1	Arrêt SAISAI	33,5	9,2	3,2	307,4	493,8
2	Avenue KASAI	102,1	6,0	2,1	614,4	647,2
3	Bungidi	73,4	8,5	3,0	620,5	918,1
4	Cogelos 1	220,3	25,1	8,8	5529,7	24301,6
5	Cogelos 2	1377,5	72,0	25,2	99156,7	1249475,9
6	Elongi	248,6	17,0	5,9	4214,2	12504,7
7	Kimwenza 1	18,3	8,5	3,0	155,1	230,0
8	Kimwenza 2	73,6	13,2	4,6	972,9	2252,5
9	Kimwenza 3	109,8	7,4	2,6	816,8	1063,4
10	Kimwenza 4	35,1	13,4	4,7	471,1	1107,6
11	Kimwenza 5	75,1	5,5	1,9	410,7	393,3
12	Kimwenza 6	177,2	15,8	5,5	2802,2	7758,9

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N°	Name	Length (m)	Avg Length (m)	Avg.Depth (m)	Surface (m^2)	Volume (m^3)
13	Kimwenza 7	177,5	15,8	5,5	2802,2	7742,5
14	Kimwenza 7 Km	2599,5	104,3	36,5	271100,9	4949182,7
15	Kimwenza Gare 1	80,6	7,9	2,8	639,0	886,2
16	Kimwenza Gare 2	88,4	20,6	7,2	1815,8	6532,2
17	Kindele 1	806,8	130,7	45,8	105450,7	2412814,2
18	Kindele 2	82,9	40,9	14,3	3388,5	24241,6
19	Kindele 3	453,3	79,2	27,7	35893,2	497486,7
20	Kose Cogelos	141,0	37,3	13,1	5259,1	34331,8
21	Libiki	126,0	7,4	2,6	934,6	1213,4
22	Mabanga	331,6	43,8	15,3	14529,7	111436,4
23	Makaya	709,2	54,8	19,2	38883,6	373190,6
24	Ntemo 1	47,9	4,7	1,6	223,7	182,7
25	Ntemo 2	98,3	11,4	4,0	1124,7	2252,9
26	Plateau des Profs	91,8	22,2	7,8	2034,9	7893,7
27	Pozi	69,8	5,0	1,7	347,4	302,8
28	ULC 1	32,2	14,7	5,2	473,6	1220,5
29	ULC 2	163,6	16,7	5,9	2733,8	7997,2
30	Yakoma	42,3	7,2	2,5	303,4	380,5
	Total	**8687,2**			**604010,5**	**9740435,6**
	Minimum	**18,3**	**4,7**	**1,6**	**155,1**	**182,7**
	Average	**560,5**	**27,5**	**9,6**	**38968,4**	**628415,2**
	Maximum	**2599,5**	**130,7**	**45,8**	**271100,9**	**4949182,7**

Field Survey Results

A total of 18 gullies have been identified (e.g. Figures 17-22). These eighteen gullies, represent 60 percent of the total identified in the study area, surveyed were selected for their easy access and for safety reasons, but they are also the most emblematic gullies, called ‘mega-gullies’(Makanzu Imwangana et al., 2015).

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Figure 17: Head of the Main Gully on the Kimwenza Road at Km 7, Dated May 12, 2021.

Figure 18: Km5: Failure of the Work Initiated by a Chinese Company Responsible for Resurfacing the Road.

Figure 19: Poor Drainage of Rainwater Causing Streets Erosion.

Figure 20: A Typical Case of Erosion Starting at the Intersection of a Street and the Main Road.

Figure 21: A Typical Case of the Threat of a Power Pole Falling by SNEL Along the Eroded Road.

Figure 22: Landslide of Gully Walls Along the Road Shows Evidence of Undermining at the Base and/or the Presence of Clay.

The analysis of the field survey results provides the following information:

- ***Factors of erosion***: The survey reveals that 17 out of 18 cases, i.e. 94.4 percent are due to the lack of rainwater runoff drainage, and one is caused by the rupture of the RÉGIDESO pipeline (Figures 23 & 24).

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Figure 23: Cause of Erosion and Number of Buildings Destroyed.

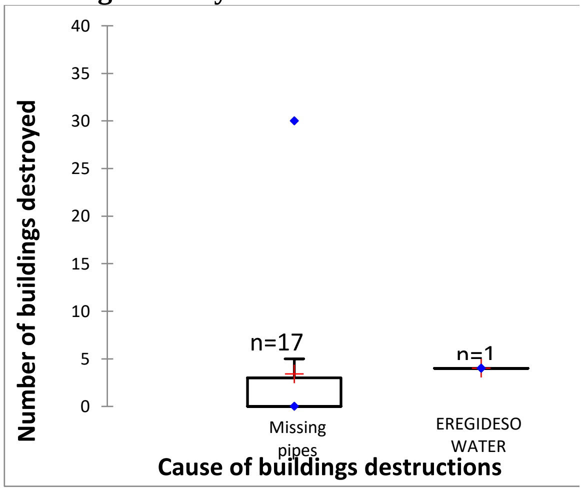
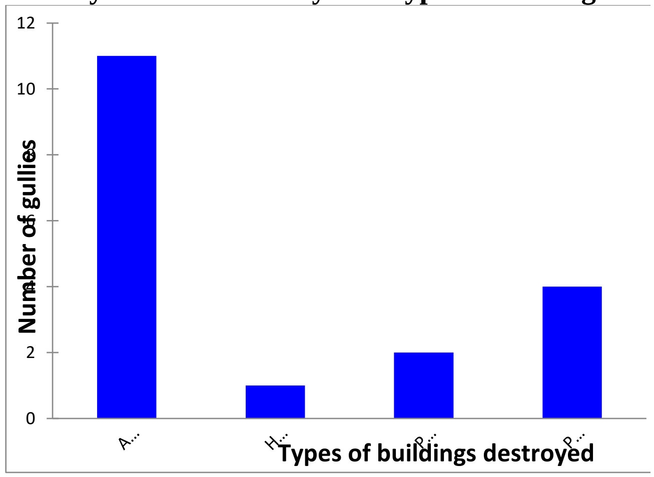


Figure 24: Number of Gullies That Have Destroyed or Not Destroyed a Type of Building.



- ***Measures to combat gully erosion***: The community is attempting to mitigate gully erosion. They primarily use sandbags, household waste, metal sheets, tarps, and vegetation. All these measures are applied within the gully. However, this hole is a consequence, and addressing it does not solve the real issue, which is the cause of the erosion beyond their control. Nevertheless, a few rare plots have constructed small drains to reduce the water at the gully's head. This water is responsible for the erosive runoff in the neighbourhood (Figure 25). Otherwise, the effectiveness of their measures remains very low (Figure 26).

Figure 25: Number of Measures at the Head of all Gullies.

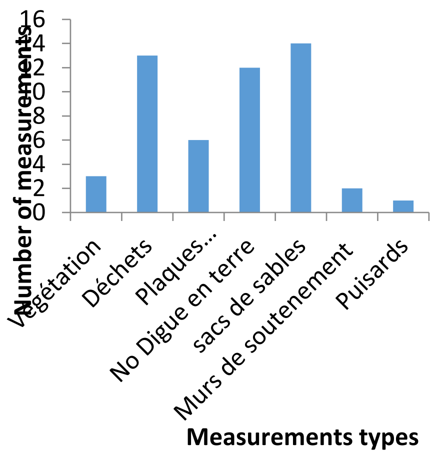
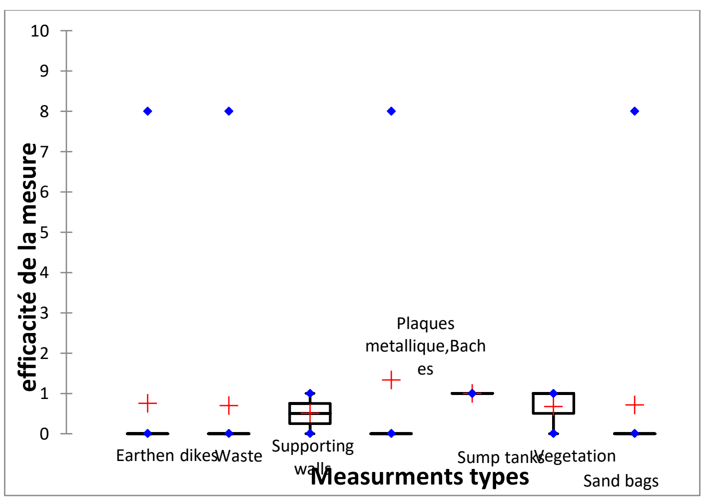


Figure 26: Effectiveness of Erosion Control Measures.



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Impacts of Erosion and Vulnerabilities

According to the results of the survey, there have been human losses, with two people killed due to the advance of the gully at Km7. Although most gullies did not destroy buildings, more than 40 percent destroyed residential and commercial homes. Over 300 houses were destroyed by the gully at Km7. In the Cogelos Plateau, one gully destroyed 15 houses. That leaves the owners with a significant socio-psychological impact due to the lack of housing and/or a reliable source of income (Figures. 27 and 28).

Figure 27: Number of Losses Caused by the Gully Erosion.

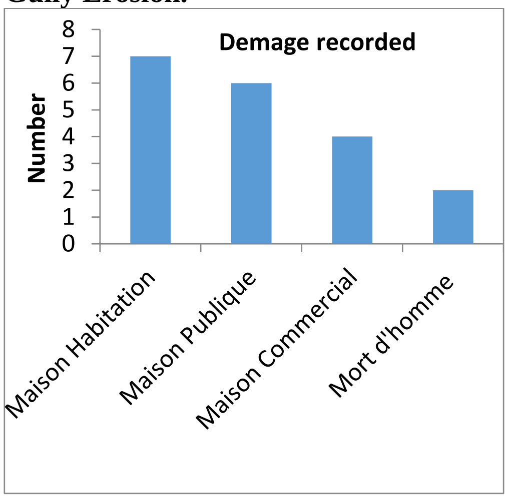
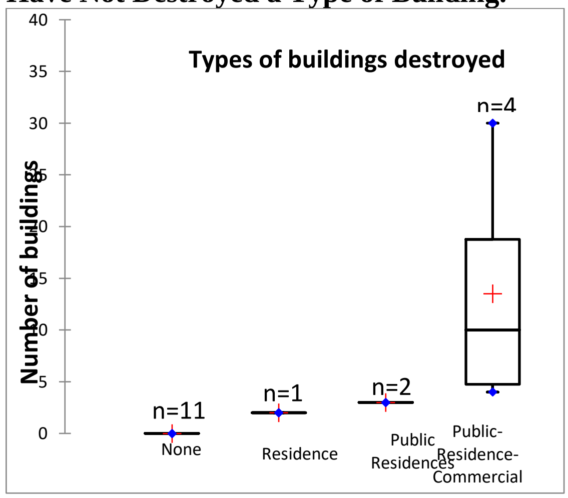


Figure 28: Number of Gullies That Have or Have Not Destroyed a Type of Building.



From the perspective of vulnerability and considering the potential progression of gullies in the drainage or contributing areas of erosive runoff, Table 9 shows the total number of houses, streets, and lengths that would be destroyed if each of these gullies were to progress. Based on the number of houses and the fact that the average household in poor neighbourhoods of Kinshasa (Kayembe wa Kayembe et al., 2016) consists of 7.3 people, this table also displays the total number of people who would be affected by the erosive runoff drainage areas at the heads of the gullies. This population would be directly vulnerable. In total, nearly 900 houses would be affected, 60 streets would be cut off, worsening the isolation of neighbourhoods, approximately 2,500 meters of the road would be exposed, with 80 percent of the main road impacted, and more than 6,500 people would lose their homes.

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Table 9: Potential Impacts of a Possible Evolution of the Kimwenza Gullies.

Gullies' names.	Nb. Exposed houses.	Nb. Exposed roads/streets.	Length of exposed roads (m).	Nb. Exposed inhabitants.
Arrêt SAISAI	61	3	648	445
Avenue KASAI	19	3	-	139
Bungidi	6	0	0	44
Cogelos 1	18	2	0	131
Cogelos 2	36	2	0	263
Elongi	61	3	-	445
Kimwenza 1	10	0	0	73
Kimwenza 2	10	0	0	73
Kimwenza 3	12	0	0	88
Kimwenza 4	17	1	152	124
Kimwenza 5	17	1	-	124
Kimwenza 6	39	1	133	285
Kimwenza 7	10	2	0	73
Kimwenza 7 KM	74	5	188	540
Kimwenza Gare 1	23	0	0	168
Kimwenza Gare 2	12	3	0	88
Kindele 1	50	O	O	365
Kindele 2	20	2	0	146
Kindele 3	31	3	0	226
Kose Cogelos	9	1	138	66
Libiki	66	7	229	482
Mabanga	32	3	50	234
Makaya	89	7	313	650
Ntemo 1	5	0	0	37
Ntemo 2	6	0	0	44
Plateau des Profs	13	2	514	95
Pozi	11	1	69	80
ULC 1	61	3	-	445
ULC 2	61	3	-	445
Yakoma	15	2	11	110
Total	894	60	2443	6526

P.S.: The dash in the table means the measurement has already been accounted for in another gully, which is often nearby. For example, the length of the roads in the ULC 1 & 2 gullies is included in the measurement of the Kimwenza Km7 gully.

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Identification of Suitable and Effective Solutions for Reducing Erosion Risks

To reduce the risk of gully erosion, we propose four types of solutions, which are:

- Reducing runoff by digging vegetated parcel soakaways and setting up rainwater collection and storage systems (Short-term solutions). The population of youth associations of the community can organize such works during the weekends, with the support of religious communities such as the Society of Jesus established there and Loyola University in Congo;
- Diverting and draining runoff waters at the head of the gullies through the construction of a masonry drainage network from the ridge to the valley (Medium and long-term solutions). These types of works require the intervention of significant financial resources, so it would be better if the Congolese state were involved through the provincial government of the city of Kinshasa;
- Stabilizing non-road gullies using bio-engineering techniques like terracing, particularly with vetiver or other soil-stabilizing plants (Short-term solution). With some financial and technical support, local communities in general and particularly youth associations in the study area can carry out these works well;
- As for the eroded Kimwenza road (Medium and long-term solutions), this requires the intervention of the Congolese state:
    - Equipping with appropriate drainage structures (cf. Solution 2);
    - Implementing waste removal measures in case of waste dumping;
    - Backfilling;
    - Lowering embankments to raise the roadbed;
    - Constructing crossing structures, culverts under roads, and others;
    - Vegetating embankments with plants like vetiver;
    - Construct the road with rigid pavement.

These techniques will not only reduce runoff but also sedimentation in watercourses.

CONCLUSION

Throughout this research, it has been demonstrated that the gullies invading the Kimwenza landscape, which have swept away significant infrastructure of all kinds, including several kilometres of paved roads, numerous homes, schools, and others, have been caused by poor management of rainwater runoff. The analysis of active rainfall and its intensities revealed that the peak runoff flow can reach more than 650 l/s/ha. The topographic analysis of this area showed that the slopes are primarily steep (> 8%), and the soil is of low cohesion, primarily composed of sand. The watersheds covering this part of Kinshasa have a very high drainage density because, beyond the particularly steep lands, these watersheds are entirely occupied by self-built neighbourhoods that have decimated the vegetation cover, with many streets turning into ditches during rainfall. Nearly 90% of rooftops lack gutters, and most plots have no rainwater retention systems. Under these conditions, mitigating the gully phenomenon requires substantially reducing runoff flows. Our future research will focus on assessing the effectiveness of gully control measures employed by local communities, assessing the impact of runoff reduction in new housing developments and older neighbourhoods, and quantifying runoff sediments to gain insight into the specific degradation of catchments in peri-urban areas.

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