*International Journal of Earth Sciences Knowledge and Applications (2023) 5 (2) 168-181*

International Journal of Earth Sciences Knowledge and Applications
journal homepage: http://www.ijeska.com/index.php/ijeska

**Research Article** e-ISSN: 2687-5993

# Impacts of Recurrent Flooding and Erosion in the Municipality of Mususa (Butembo/Democratic Republic of the Congo) and Some Control Strategies

**Deogratias Anguandia Odhipio[1]***

[1]*Department of Geology, Université Officielle de Ruwenzori, Butembo, B.P. 560, Democratic Republic of the Congo*

**INFORMATION**

**Article history**
Received 28 July 2023
Revised 07 August 2023
Accepted 09 August 2023

**Keywords**
Flood
Erosion
Control strategies
Wayimiria River
Kimemi River

**Contact**
*Deogratias Anguandia Odhipio
odhipiang@gmail.com

**ABSTRACT**

In many parts of the world today, soil erosion is the major obstacle to mankind's future well-being. Combined with flooding, soil erosion is responsible for almost half of all deaths from natural disasters over the last 50 years, and almost a third of all economic losses worldwide. To prevent the Bubolese population from these disasters, it is necessary to identify the causes of recurrent flooding and erosion in the Municipality of Mususa in the City of Butembo and to propose solutions for the efficient prevention of these phenomena. Thanks to an approach based on a combination of several methods, notably documentation, fieldwork and the use of 'open street map' satellite data and the reference RGC database in the Democratic Republic of the Congo (DRC), flood-prone areas were identified and located around the Kimemi River. Whereas eroded areas are located along the Wayimiria River. Hence, after fieldwork, flooding in the Municipality of Mususa is the result of precipitation and inappropriate urbanization. Strategies to combat this phenomenon include (a) public awareness campaigns and (b) the use of tanks to store rainwater. In addition, erosion is caused by the regular mining of sand in the riverbed by the riverside population, and also partly by the nature of the soil. For this reason, the use of plants such as bamboo and public awareness campaigns would be the best solutions to these problems. Considering the urgency and gravity of the situation, the political and administrative authorities must get involved to stop these disasters, because prevention is better than cure.

## 1. Introduction

Of all the natural disasters that strike the world every year, floods are the most frequent, damaging and deadly (Maghsood et al., 2019; Ro and Garfin, 2023). They are the source of almost half of all deaths caused by natural disasters over the past 50 years and are responsible for almost a third of economic losses worldwide (Kundzewicz et al., 2014; Gasana, 2018; Krvavica et al., 2023; Li et al., 2023).

It is estimated that 2.9 million people have been displaced by the severe flooding in Central and West Africa (Kundzewicz et al., 2014; Oyedele et al., 2022) and the DRC is not exempt from this natural calamity. In December 2022, the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) reported that at least 169 people had died as a result of devastating rains in the capital Kinshasa (Lopanza et al., 2020). Furthermore, as predicted by (Cosoveanu et al., 2019; Shin et al., 2022; Yereseme et al., 2022; Manno et al., 2023), if climate change trends combined with an increase in the population living on flood-prone land, deforestation, the disappearance of marshland and rising mean sea levels, are confirmed in the coming decades, catastrophic floods are likely to be more frequent, and an increasing number of people should therefore be exposed to this phenomenon.

Faced with this well-founded warning, the issue of flood risk management is becoming increasingly important for governments and municipalities alike. This is the case for current concerns in the City of Butembo and especially for vulnerable entities located in low-lying areas.

**Copyright (c) 2023 Author**

This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License. The authors keep the copyrights of the published materials with them, but the authors is agree to give an exclusive license to the publisher that transfers all publishing and commercial exploitation rights to the publisher. The publisher then shares the content published in this journal under CC BY-NC-ND license.

As for erosions, they currently constitute the main evidence for explaining phenomena degrading the Earth's topographic surface, and these natural disasters have serious consequences for the environment (Chalise et al., 2019; Pandey et al., 2021; Chuma et al., 2022). Many books and publications have already been produced in these fields, and scientists are continuing with their research to provide detailed data on erosive phenomena around the world and their environmental consequences. According to Sahani (2012), it's not the climate that's behind the increase in runoff, but rather the impermeabilization of the Kimemi watershed.

Additionally, the degradation of the vegetation cover as a result of anthropogenic actions eliminates the delaying effect of rainwater concentrations and runoff that vegetation used to play (Rey et al., 2004; Kitakya, 2007; Wang et al., 2016) and urbanization intensified considerably between 1987 and 2004 (in $km^2$) in the Kimemi watershed (Sahani, 2012). This makes the soil surface impervious. In fact, according to the current mentality in the urban area of Butembo, a good plot is one where the entire courtyard is paved or cemented. This practice encourages runoff rather than infiltration.

That's why (Kundzewicz et al., 2014; Williams et al., 2018; Dong et al., 2023), believe that anthropogenic factors are the triggers of flooding phenomena. In addition, rainfall analyses carried out by (Sahani, 2012) reveal a downward trend. This supports the fact that the occurrences of flooding in the City of Butembo are not a result of the rains of recent years, as these are very normal. So, it's not the climate that's causing flooding in Butembo, but poor urbanization. This urbanization acts in two different ways (Lopanza et al., 2020). Firstly, it leads to an increase in the runoff coefficient, i.e., rainfall of the same intensity produces more surface water; and secondly, roads form privileged paths for runoff water. They increase watershed hydrological connectivity and transfer runoff to vulnerable areas in a short space of time. The massive inflow of water into the valley bottoms exceeds the drainage capacity of the valleys. This generates flooding.

These works of our predecessors are very similar to our research theme. Since most of them attempt to address some aspects of either flood or erosion risk management. That's why, in this study, we're going to draw on their results, especially those concerning methods of combating and preventing these natural disasters, to compare and discuss our findings.

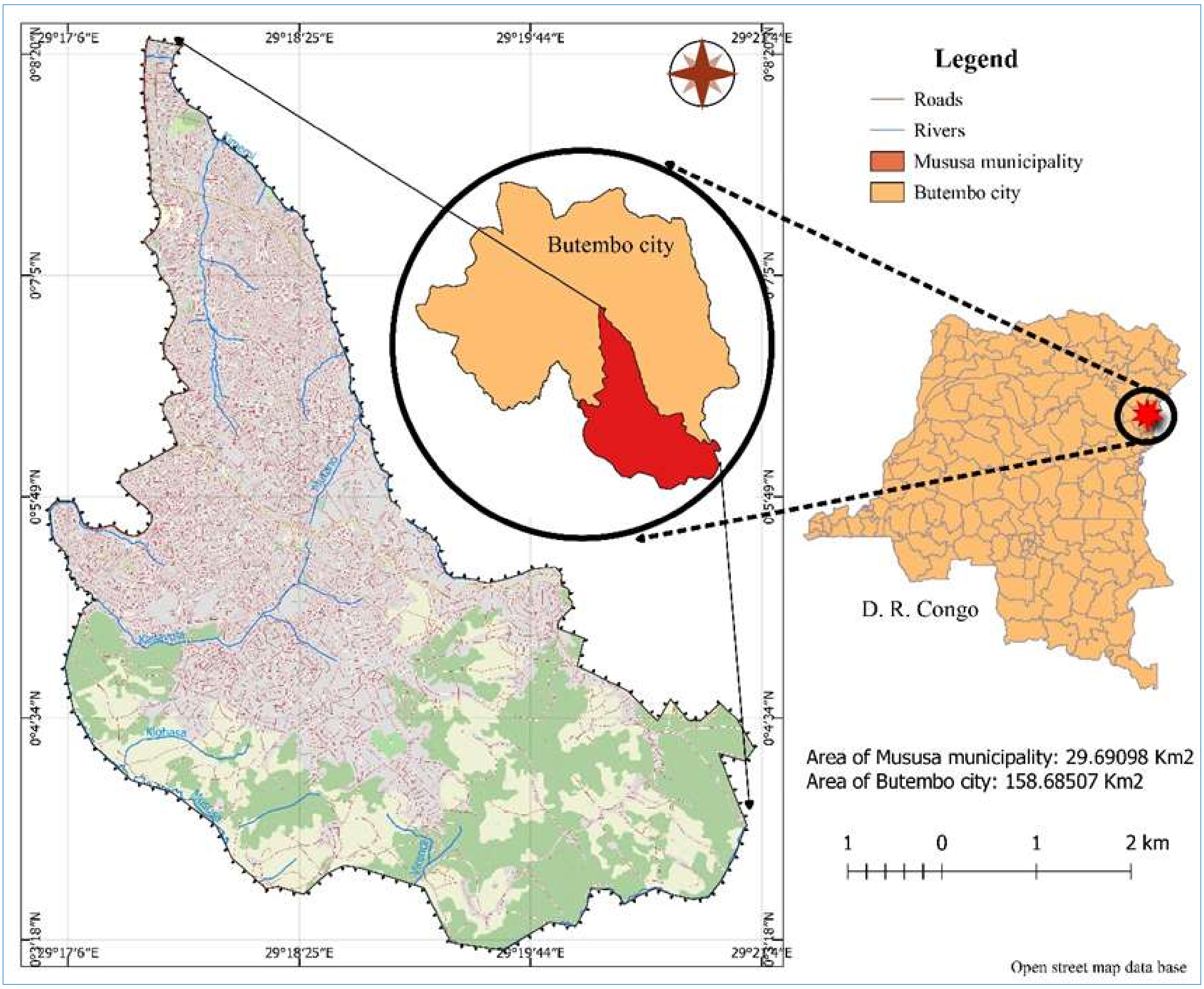


Fig. 1. Location map of the Municipality of Mususa, based on a combination of satellite data (Open Street Map) and the Common Geographic Reference (RGC) database

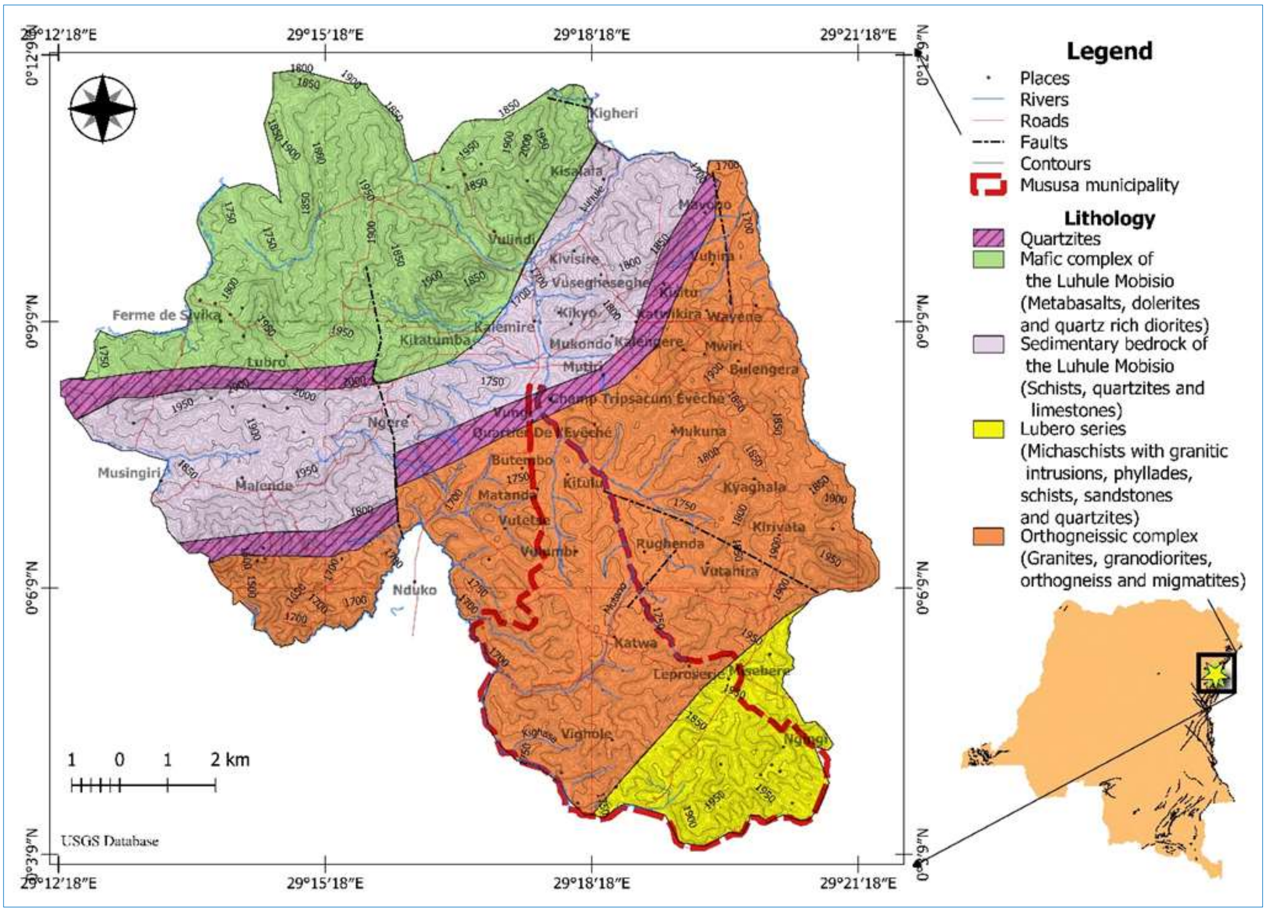


Fig. 2. Geological map of the City of Butembo according to BRGM geologists (Sahani, 2012; Odhipio et al., 2022)

However, this research attempts to solve two problems. The first problem or natural disaster identified in the Municipality of Mususa is flooding. After the field trip, the consequences (footprints) of this flooding phenomenon are very deplorable in the study area, especially in the areas located along the Kimemi River. The second problem identified in the Municipality of Mususa is erosion. The heads of these erosions, in certain cells of the Municipality of Mususa, are very advanced. This is because there are no anti-erosion practices in place, or those that do exist appear to be inefficient.

Given the above, it is worth asking the following questions: (a) What are the most vulnerable areas to flooding and erosion in the Municipality of Mususa? (b) What are the causes of flooding and erosion in Mususa? The anticipated answers to these questions are as follows: (a) the most vulnerable areas are located near the Kimemi and Wayimiria Rivers; (b) inappropriate urbanization and the absence of erosion mitigation practices are respectively the main causes of flooding and erosion in the City of Butembo. For this reason, the main objective of this study is to identify the causes of flooding and erosion in the Municipality of Mususa and to propose solutions for the efficient prevention of these phenomena. More specifically, this study aims to: (a) identify the most vulnerable areas to flooding and erosion in Mususa; (b) identify the causes of flooding and erosion in the Municipality of Mususa; and (c) propose some strategies for combating these problems.

## 2. Materials and Methods

### *2.1 Study Area*

#### *2.1.1 Geographical Frame*

The Municipality of Mususa, which is the focus of our study, is one of four municipalities of the City of Butembo. It occupies the southern part of the City of Butembo and extends between 0°03'10"N and 0°08'25"N latitude, and 29°17'45"E and 29°21'04"E longitude (Fig. 1). It is limited to the north by the Rawbank - CUGEKI Bridge Road, to the east by the Kimemi River, to the south by the Mususa River, and to the west by national road no. 2 ('Président de la république' Boulevards).

Butembo is one of three towns in North Kivu, in the northeast of the Democratic Republic of Congo. The urban area lies between 0°03'10"N and 0°12'08"N latitude and 29°12'18"E and 29°21'20"E longitude (Fig. 2). It is about ten kilometres north of the equator. It is located close to the western edge of the Albertine Rift. Butembo's geological substratum is very fragile and sensitive to erosion. The relief of the urban area of Butembo (Municipality of Mususa) is the result of Tertiary orogeny concomitant with the formation of the Albertine tectonic rift (Yamba and Boven, 1998). This gives the city a morphology consisting of an alternation of several hills and valleys, facilitating the accumulation of rainwater and its drainage in large quantities via the Kimemi River into the Congo River watershed. The soils in the Municipality of Mususa vary according to bedrock, texture, water and organic matter content. They are formed by a kaolinitic material characterized by a clay fraction dominated by kaolinite and free oxides (Bruneau and Katsuva, 1981). The oxides present in the soils are generally iron oxides, which give the soil its reddish or brownish tint, conferring on it the name of ferrisols (Zitong et al., 2000). The original vegetation of the Municipality of Mususa has disappeared as a result of human activity. It has given way to post-cultivation ruderal herbaceous weed groups and exotic woody species (eucalyptus, Grevillea, robusta...). For centuries, the region has been systematically deforested, to the extent that the climatic mountain forest survives only in a few underpopulated areas and on the few summits of isolated massifs.

Climatically, the Municipality of Mususa, like the whole city of Butembo, enjoys a humid subtropical climate tempered by mountains according to the Köppen-Geiger classification (Peel et al., 2007). The average temperature is 18 °C, with an average rainfall of 1.382 mm/year (Mahamba et al., 2022). There are two rainy seasons. The first begins in March-April-May, and the second in August-September-October-November. This climate is influenced by the passage of the intertropical zone (Fontaine et al., 2011).

*2.1.2. Geological Setting*

The geological substratum of Butembo is very fragile and sensitive to erosion (Sahani, 2012; Mahamba et al., 2022). The bedrock of the Precambrian basement underwent folding during the Paleozoic, and recent granite intrusions are thought to have been influenced by orogenic movements (Kawa et al., 2022; Odhipio and Kakule, 2022). Four main rock types are encountered in the City of Butembo (Fig. 2) and can be described from northwest to southeast as follows (Benjamin, 2022; Odhipio et al.,2022; Odhipio et al., 2023): 1) Maffic complex of the Luhule-Mobisio: Found around the Mubunge River. It consists of metabasalts, dolerites, diorites and quartzite islands. 2) Luhule-Mobisio sedimentary bedrock: composed of schists and quartzites with limestone intercalations. These schists date from the Lower and Middle Burundian, i.e., from around 1,235 ± 40 Ma. These schists, dark in colour and easily detachable in platelets, intercalated with large quartzite beds, are sound on interfluves and weathered at the bottom of hills and valleys. They are most notable at the bottom of the Lwamiso hill and on the hills west of the Kimemi. They form the floor of this river below the Biasa Bridge. 3) Orthogneissic complex: made up of laminated and retromorphosed granites and granodiorites, sometimes orthogneiss and homogeneous migmatites. This complex dates from the Antekibalian or Lower Kibalian. The Lower Kibalian dates from around 2,800 Ma. They are located in the centre and east of the town. Much of the urban area is built on this orthogenetic complex. 4) Lubero series: consisting of mica schists with granitic intrusions, phyllites, shales, sandstones and quartzites dating from the Lower Burundian. These rocks are located to the east of the town of Lubero.

### 2.2. Data Collection

This work is the result of an approach starting with a literature review and ending with the interpretation of results, via fieldwork. Not forgetting data processing and analysis. The literature consisted of consulting books and articles relating to the geology and geography of the study area, as well as to the causes of flooding and erosion in the municipality of Mususa, using 'Google Scholar and 'Mendeley' as search engines. The field equipment used included a compass, a GPS, a decameter, a phone (whose camera was used to take images) and a field notebook. During this investigation, we found that the most vulnerable areas to flooding and erosion are those located along rivers. The compass was used to determine the flow direction of the watercourses; the GPS helped us to take geographical coordinates (these coordinates were taken with a precision of 3m in UTM format); the decameter was used to measure the width of the watercourses and to estimate the average height of water in the minor and major bed respectively.

### 2.3. Data Analysis

Data were compiled and processed using QGIS (version 3.16) and Excel (version 2013). This enabled us to produce the various thematic maps used in this work. The data used to produce the location map came from a combination of 'open street map' satellite data and the RGC reference database for the DRC. On the other hand, the database used for the geology map (notably lithological and structural data) is available on the USGS platform.

## 3. Results and Discussion

### 3.1 Flood Risk Assessment in the Mususa Municipality

*3.1.1 Impacts of Floods and Vulnerable Areas*

In this report, we focus on the recent flooding of the Kimemi River on November 09, 2022. After a heavy rainfall lasting more than 4 hours, the river flooded the riverside neighbourhoods. Leaving footprints and damage after the flood. Using GPS and compass, respectively, we took the geographical coordinates of the site and the direction of the river's flow at each observation point (Table 1), making it easier to map the flooded area.

Table 1. Observation sites of the consequences of flooding in the Municipality of Mususa during the flood of November 09th, 2022

| Sites | Places | Geographical coordinates [in UTM format] | | | Flow direction | |
|---|---|---|---|---|---|---|
| | | Longitude [m] | Latitude [m] | Elevation [m] | from | to |
| Site 1 | Vungi | 756,096 E | 14,366 N | 1,722 | N183° | N003° |
| Site 2 | Vungi | 755,803 E | 14,195 N | 1,719 | N178° | N358° |
| Site 3* | Vungi | 755,851 E | 12,553 N | 1,721 | N120° | N300° |
| Site 4 | Vungi | 755,586 E | 14,858 N | 1,713 | N180° | N360° |

**The river flows in the same direction from N178° to N358°, the level of water on the road can easily reach 2 m at this point*


Fig. 3. Flooding of the Kimemi River on the Demobe Bridge and Kabakuli Bridge section (Quartier Vungi)


Fig. 4. Mososo quarter flooded after the heavy rains that fell on Kinshasa on April 01, 2023. Image UNDP-DRC

The consequences of this flooding include: (a) the abandonment of homes due to flooding: i.e., during the flooding, the waters of the Kimemi River reached the interior of the houses, forcing the inhabitants of the riverside areas to move and temporarily abandon their homes. (b) The flood waters killed several people during the flood, but their numbers were not communicated to us. These included vulnerable people such as the drunk, the very aged, the sick and children. (c) Not forgetting the loss of property and the destruction of homes, i.e., when the waters of the Kimemi River overflowed into homes, they affected their structure and strength. (d) On the other hand, the floodwaters (very dirty) reached some pharmacies located near the river and wetted several cartons of medicines. Unfortunately, after the floods had passed, the pharmacy owners simply cleaned and dried the medicines, and then resold them to the public. From a sanitary point of view, this was a big mistake, as these drugs were already contaminated. (e) Wastewater fills and pollutes drinking water wells. Due to a third external problem linked to the lack of drinking water and the insufficiency of REGIDESO taps, the local population always tends to replenish itself in these polluted wells. All of which lead to various illnesses linked to the consumption of dirty water.

In addition, floods have a serious impact on human activities and on biodiversity in the affected areas (Zhang et al., 2021). For example, some wildlife can be washed away, and vegetation can be uprooted. It is therefore clear that bank erosion along the Kimemi River is often due in part to recurrent flooding. For Oyedele et al. (2022), flooding often causes significant damage, in addition to long-term submergence of property and water pollution. The most sudden floods are the most dangerous for people's safety because they leave no time to evacuate flood-prone areas (Ji et al., 2018). The same reality is often experienced in the Municipality of Mususa, where neighbourhoods in downtown Butembo are submerged even when there is no rain in the downtown area.

Being a major collector for the city, the Kimemi River drains a very large area of the region. As a result, sudden floods often occur in the Vungi quarters. After the flood of November 09, 2022, the difficulties for users continued. Some communication axes, notably roads, remained cut off after the rain (Fig. 3).

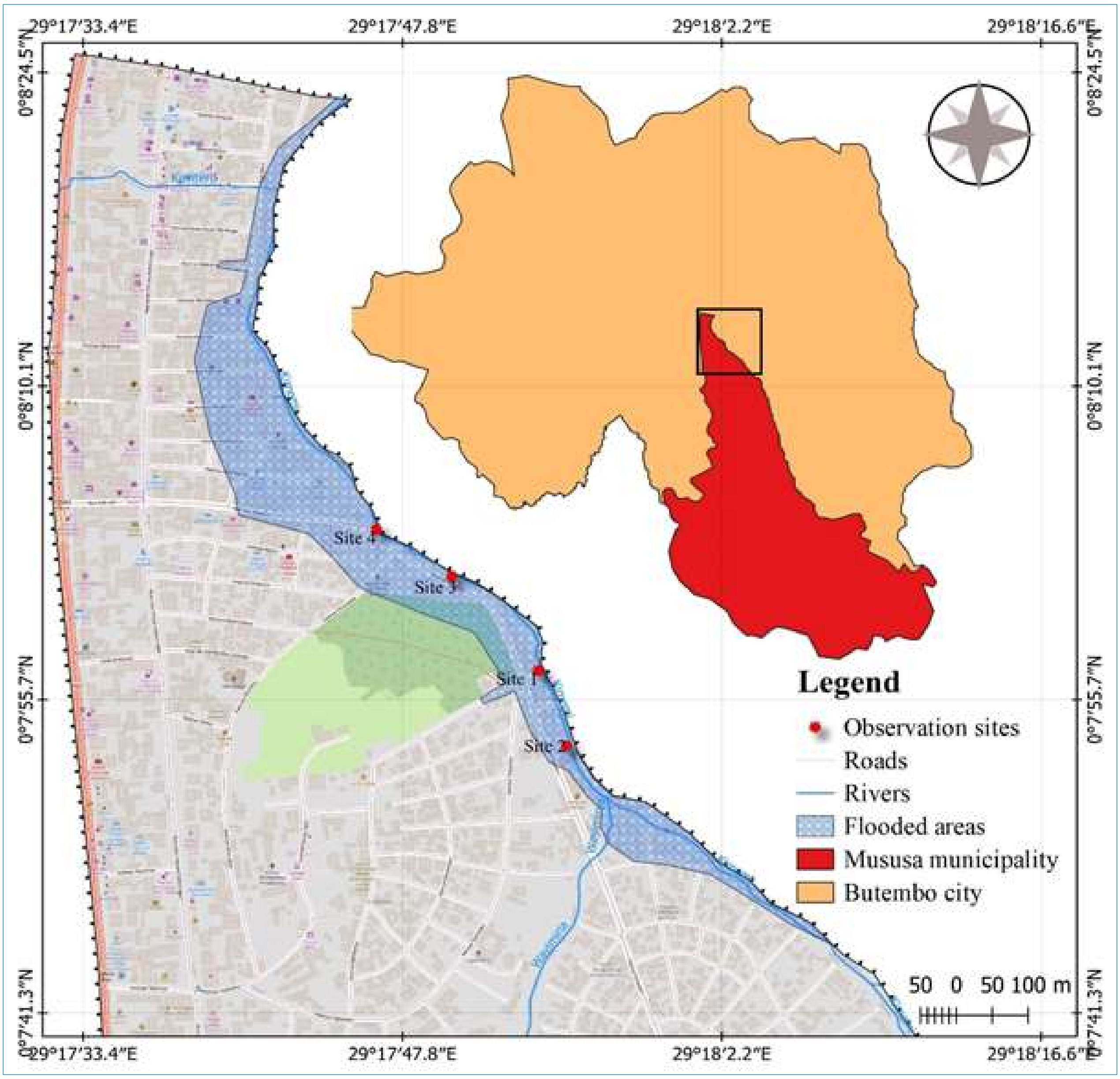


Fig. 5. Maps of flooded areas in the Municipality of Mususa in the City of Butembo after the rain of November 09th, 2022

For Rubinato et al. (2019) and Degeai et al. (2022), the risk of river flooding is increasing, with the massive arrival of water in a reduced concentration time due to the absence of obstacles, a consequence of the destruction of the bocage network (hedges, embankments, etc.). And that watercourses are undergoing a considerable deterioration in their physico-chemical quality, such as increased turbidity, pollution by phytosanitary products, increased eutrophication due to the use of soil improvers, and reduced substrate diversity. Silt transported by runoff also contributes to the obstruction of reservoir spawning grounds. Not to mention the risk of groundwater pollution, depending on its contact with the surface (in karstic environments, for example).

These disasters expose the population to epidemics (Gao et al., 2016; Huang et al., 2016), as some households lack sanitary facilities and prefer to defecate in the open air. Added to this is unmanaged garbage. This leads to water pollution, which constitutes the main impact of flooding in the city. The rise in water levels in residential, industrial and agricultural areas leads to numerous contaminations. Water pollution can also threaten human safety, particularly if hazardous substances are carried away by the waters, and potentially in contact with people. Moreover, Butembo is not the first Congolese town to experience the problems of flooding. Kinshasa (Fig. 4), the capital of the DRC, is one of the Congolese cities most affected by flooding (Wouters and Wolff, 2010; Lopanza et al., 2020).

Here is a cartographic representation of the areas flooded during this torrential downpour (Fig. 5). The Kimemi riverbed began to widen at the Henri Pierrard secondary school, where the waters no longer follow the normal riverbed. They overflow onto the riverside plots, entering houses and destroying everything in their path. With enormous damage downriver.

*3.1.2. The Causes of Flooding and Some Possible Solutions*

Although rainfall is the natural cause of flooding, human activities and inappropriate urbanization are the main causes of flooding in Butembo (Sahani, 2012; Mahamba et al., 2022). In addition, the lack of water pipes in certain quarters, the obstruction of water pipes by rubbish and anarchic construction remains the main causes of flooding in the city of Butembo. As previously stated, poor urbanization is one of the causes of flooding in Butembo, as it contributes to the waterproofing of the ground surface. The more buildings there are, the more infiltration diminishes to the benefit of run-off. The result is a successive increase in the volume of runoff, with significant consequences for low-lying areas, including the centre of Butembo.

In an attempt to solve the problem of flooding in the provincial city of Kinshasa, the Minister of State, Minister of Infrastructures and Public Works, at the 30th meeting of the Council of Ministers, speaking of the problem of post-rainfall flooding in the city of Kinshasa, mentioned that the causes of flooding in the city of Kinshasa (a city initially designed for 400,000 inhabitants, but now home to over 12 million due to demographic constraints), are: the lack of implementation of the various development plans, uncontrolled urbanization, the absence of an efficient waste management system in the city, leading to the discharging of solid waste into channels, collectors and watercourses, irregular maintenance of waterways and cleaning of collectors and watercourses, insufficient evacuation capacity of existing hydraulic structures, and climate change (with higher and more intense rainfall) (Muyaya, 2021).

For the Minister, solving this problem requires the application of a series of recommendations that call for substantial financial resources. These include Implementing the city's development plan, the Strategic Orientation Scheme for the Agglomeration of Kinshasa (SOSAK); Updating the mapping of the sanitation network; Planning systematic dragging and cleaning operations on the networks (hydrographic and sanitation); Efficient and rational solid waste management; Implementing the city's Flood Risk Prevention Plan (PPRI); Financing sanitation studies for the city; and the citizen awareness campaign (Muyaya, 2021).

These solutions are ambitious and require huge resources, which could handicap the implementation of these plans. However, raising public awareness through conferences and workshops seems simple and feasible. And it is the most efficient way, because in Butembo, as in most Congolese cities, waterproofing the entire surface of one's plot of land is a prestige. Changing this philosophy is a direct solution to the problem of flooding. As it is difficult to prevent the population from building and to impose a development model on the plot, the only solution available to effectively combat rainwater is to set up a water storage system on each plot. In this way, the quantity of water that falls on the plot remains stored in the tanks (Fig. 6). This has two advantages. Firstly, this practice helps to combat flooding by reducing runoff flows. Secondly, it combats water shortages, as the population will be supplied with large quantities of rainwater for laundry and household cleaning.

### *3.2. Erosion Risks in the Mususa Municipality*

*3.2.1. Impacts and Vulnerable Areas along Wayimiria Stream*

Erosion is defined as the detachment and transport of particles by rain when the soil is no longer able to infiltrate water (Bezak et al., 2021; Kinnell, 2021). It generally occurs on previously weakened soils, in the event of rainfall intensity exceeding the soil's infiltration capacity (particularly during violent storms), or on waterlogged soils (in autumn and winter) (Du et al., 2022).


Fig. 6. Images of some tanks for domestic rainwater storage


Fig. 7. Images of some eroded areas along the Wayimiria River

Table 2. Location of some eroded area along the Wayimiria Stream

| Sites | Places | Geographical coordinates (in UTM format) | | |
|---|---|---|---|---|
| | | Longitude (m) | Latitude (m) | Elevation (m) |
| Site 1 | Vichai | 756,046 E | 11,518 N | 1,762 |
| Site2* | Vichai | 755,992 E | 11,598 N | 1,746 |
| Site3* | Vichai | 755,836 E | 12,483 N | 1,739 |
| Site 4 | Vichai | 755,961 E | 11,652 N | 1,745 |
| Site5* | Vichai | 755,939 E | 11,824 N | 1,746 |
| Site 6 | Vichai | 755,828 E | 11,664 N | 1,745 |
| Site 7 | Vungi | 755,785 E | 12,890 N | 1,731 |

**The river flows in the same direction from N178° to N358°, the level of water on the road can easily reach 2 m at this point*

This more or less massive and rapid transport of water and soil can have major economic, human and ecological consequences, including a reduction in the agronomic potential of land, increased flood risk (mudslides, increased intensity and volume of river flooding), and the degradation of natural environments (Kundzewicz et al., 2014). These consequences can be serious both for biodiversity and for the safety of all those living in the direct vicinity of these environments (Zhang et al., 2021).

In the Municipality of Mususa, in the City of Butembo, for example, erosion of the riverside is observed along the Wayimiria Stream, with direct consequences for houses. Examples in sites 1, 2a, 4b and 5 (Fig. 7). These images (Fig. 7) show the degree of erosion evolution in the few observation sites in the Municipality of Mususa, along the Wayimiria Stream. Their geographic coordinates (Table 2) were very useful in drawing up the map of eroded areas in the Municipality of Mususa (Fig. 8). Besides, deforestation and agricultural practices have significant consequences for soil erosion and watercourses, notably through flooding and pollution (Mangaza et al., 2021). In addition, the APEL (Lake Saint-Charles and Northern Marshes Environmental Protection Association) reminds us that erosion also has local impacts on construction sites. It has a significant economic impact and improves working conditions on construction sites (Thibault et al., 2018).

*3.2.2. The Causes of Erosion and Some Possible Solutions*

Soil erosion, i.e., the mobilization of soil particles, is a complex phenomenon involving many factors. Soil is a collection of particles of varied sizes, constituting the basic unit of the soil (Kinnell, 2021). These particles are sometimes grouped in aggregates, or complexes, spaced by pores. One of the first factors likely to modify this structure is the "splash effect", which corresponds to the projection of particles following the impact of raindrops (Thibault et al., 2018). This effect depends on two parameters: (1) the bond strength between particles, and (2) particle size. A clay soil is made up of small (< 2 μm) but strongly bound particles. The impact of raindrops slightly loosens the aggregates. A sandy soil, on the other hand, is made up of bigger particles (between 50 μm and 2 mm) lightly bonded to each other, making it difficult for the splash to displace them. The most sensitive soils to splash are silty soils, whose particles are intermediate in size between clays and sands (Thibault et al., 2018). Complexes can therefore be dissociated, and particles mobilised by the impact of raindrops. Revised Universal Soil Loss Equation (RUSLE) is one of the erosion models developed by the United States Department of Agriculture (USDA) research program (Pandey et al., 2021; Chuma et al., 2022). Considering this model, the main factors influencing erosion are climate, mainly rainfall, soil types, topography land use or vegetation and more particularly cultivation practices (Pandey et al., 2021). In urban areas, all these factors can be grouped into two categories, namely: (a) factors related to ecological conditions (natural factors that are linked to the manifestations of erosion) among which can be distinguished: rainfall, soil type, topography and land use or vegetation cover; (b) factors related to socio-economic and political conditions including anthropogenic actions and urban planning policy (Lopanza et al., 2020).

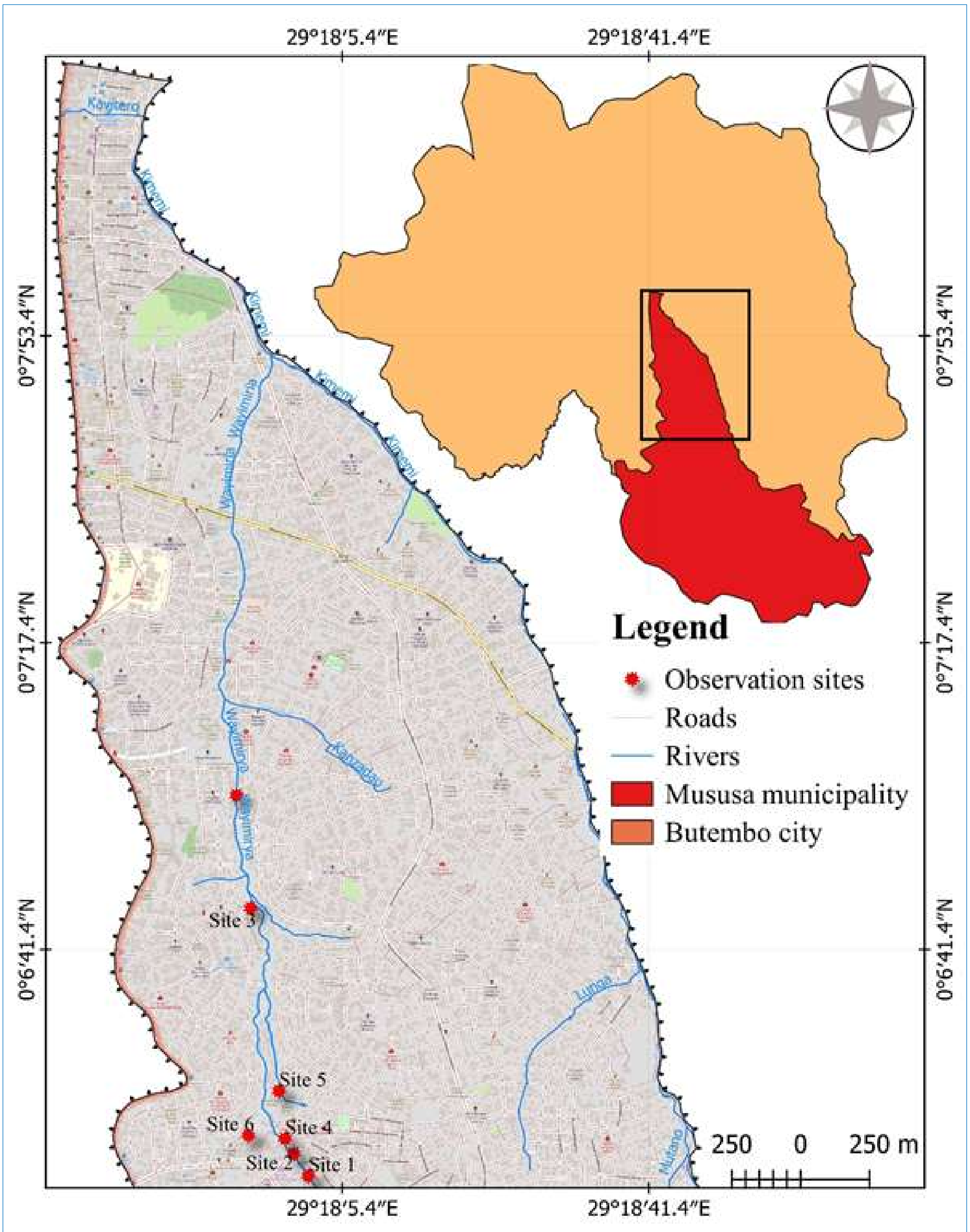


Fig. 8. Maps of eroded areas in the Wayimiria River watershed in the Mususa Municipality


Fig. 9. The main causes of erosion in the Municipality of Mususa in the City of Butembo

For Wouters and Wolff (2010), the causes of gully erosion can be deduced for each gully from a contextual analysis of satellite images and commented on using a field analysis (Wouters and Wolff, 2010). Then, the deduced causes are confirmed by an exhaustive geological survey of the gullies. In Kinshasa, for example, they observed four main causes of gullying using this method, namely: overflowing retention basins, broken collectors, paths created in the direction of the slope and silting-up and subsequent failure of lost wells. Many infrastructures have been unable to withstand the erosive nature of precipitation and the instability of the surface of sandy soils. Lack of maintenance and the absence of sites for the various wastes of the people of Kinshasa also played a role in the failure to control gullying.

Blais (2005), on the other hand, highlights the role of bedrock depth and old riverbeds in the development of internal foundation erosion (Blais, 2005). Thus, for a relatively classic alluvial soil (i.e., a clay layer covering alternating sandy-gravelly and silty layers), the area's most susceptible to internal foundation erosion are (a) areas corresponding to bedrock rises, (b) areas close to former river meanders, and (c) areas where human activity has modified the surface layer (agricultural use, borrow areas, etc.). He also assumes that in areas where the clay layer is weak, erosions are numerous but benign, whereas in areas where it is strong, they can lead to rupture.

However, in the case of the Mususa Municipality, the combination of erosion causes listed by Lopanja (2020) seems to be apparent in some of the observation sites. Notably in the Tarce Primary School valley (Fig. 9a) and in the Vichai Valley (Fig. 9b), where the main cause of erosion is the regular mining of sand in the riverbed by the riverside population. In Fig. 9c, the nature of the soil seems to be the cause of erosion.

Faced with this situation, many non-governmental organizations in the Democratic Republic of Congo have recently decided to combat erosion in Kinshasa by reinventing erosion control methods, the idea being to combine the construction techniques of the various infrastructures known to date with fast-growing vegetation and strong root systems (Wouters and Wolff, 2010).

According to Mietton (1986), today's erosion control methods can draw on a whole range of traditional techniques, the fruit of spontaneous farming initiatives. These range from mechanical processes (stone cordons, fascinage, grass or shrub planting) to biological or cultural practices (associated crops, mulching, ridging) (Mietton, 1986). On the other hand, Roose, et al. (1985) add that water and soil conservation will therefore be organized as a set of complex actions within the agrarian system aimed at bringing into play the interactions that exist between each of the resistance factors and especially the most efficient management of the soil. Not forgetting erosion control techniques such as ploughing, isohypse ridging, hedgerows or stop strips, which can reduce soil losses by 1/10, and some techniques for reducing the slope of the land, such as benches, trenches and pits (Roose and Sarrailh, 1989).

For example, INRA has demonstrated an 80% reduction in the transfer of sand and silt after a 3 m wide grass strip, and a 98% reduction after a 6 m wide strip, using soft hydraulic structures to control runoff and erosion such as grass strips, hedges, fascines and even weir ditches (Gésan-Guiziou et al., 2019). Dabney et al. (1995) and Barfield et al. (1975) obtained similar results by combining fascine, hedge and grass strip (Meyer et al., 2001).

Besides, Graf et al. (2003), encourage and advise the use of plant-based protective structures, qualifying the latter as "living construction", "plant technology", "biological engineering" or "ecological engineering". According to APEL, erosion control not only has positive effects on nature, it also has an economic impact (Graf et al., 2003). For this reason, effective erosion management will: limit the loss of soil and materials needed for development work around the building; reduce siltation of construction sites;

reduce sediment input into the municipal drainage system; reduce pollution of watercourses; reduce drainage system maintenance costs; prevent culverts from becoming blocked; prevent clogging and silting of rivers; eliminate gullying of sloping surfaces; prevent deterioration of bathing areas. Seeking to combat recurrent erosion along the Wayimiria River in the Municipality of Mususa, the vulnerable population uses the following techniques and methods. These include the use of vehicle tires as in Vungi near the confluence of the Wayimiria and Kimemi Rivers (Fig. 10a), wooden stakes used in the Vichai Valley (Fig. 10b), wooden stakes wrapped in bags used in the valley near the Vichai Elementary School (Fig. 10c), and mosquito nets supported by wooden stakes in the Vichai Valley (Fig. 10d).

Fig. 10. Some anti-erosion practices already applied to date by the riverside population along the Wayimiria River

Fig. 11. Images of bamboo to be used to combat erosion along the Wayimiria River in the Municipality of Mususa

Some of these anti-erosion techniques are very simple and are based on the use of affordable materials. The use of tires, for example, seems to be very successful in the Valley of Vungi. However, other erosion control techniques appear to be less efficient and unsustainable, such as the use of wooden stakes, wooden stakes wrapped in sacks, and mosquito nets supported by wooden stakes, etc. Despite their use, erosion continues to progress. This is why, instead of these, it would be preferable to use plants such as the bamboo, whose roots effectively help to stabilize the soil (Fig. 11).

Despite the use of all these techniques, it is important to raise people's awareness of the problem of erosion by informing them of the steps to be taken to minimize or simply avoid the formation and development of gullies. These include: (a) reducing the degradation of natural vegetation cover as much as possible, (b) sowing grass on every plot instead of waterproofing the entire surface, (c) using rainwater storage tanks as in the case of flood control, (d) avoid sand mining in riverbeds.

## 4. Conclusion

Responsible technicians today recognize that soil erosion in many parts of the world is the most significant obstacle to the future well-being of mankind. Combined with floods, they are the source of almost half the deaths caused by natural disasters over the last 50 years and are responsible for almost a third of economic losses worldwide. To prevent the Bubolese population from this scourge, it is necessary to identify the causes of recurrent flooding and erosion in the Mususa commune in the City of Butembo and to propose solutions for the effective prevention of these phenomena.

Thanks to an approach based on a combination of several methods, notably documentation, fieldwork and the use of 'open street map' satellite data and the DRC's reference RGC database, areas vulnerable to flooding were identified and located around the Kimemi River. Whereas areas vulnerable to erosion are located along the Wayimiria River. To reduce and/or eradicate the consequences of flooding and erosion as listed in this work, it is very important to know the causes of these disasters in the Municipality of Mususa.

Flooding in the Municipality of Mususa is caused by precipitations and their accumulation in the Wayimiria and Kimemi Rivers, but also by poor urbanization (waterproofing of the ground surface, which hinders infiltration in favour of run-off). To combat this phenomenon, here are a few strategies to adopt: (a) raising public awareness through conferences and workshops. This will directly change the behaviour of Bubolese people in the face of flooding, by combating the imperviousness of the entire surface of the plot. (b) The use of tanks for domestic rainwater storage. As it is difficult to prevent the population from building and to impose a development model on the plot, the only solution available to effectively combat rainwater is to set up a water storage system on each plot. In this way, the amount of water that falls on the plot remains stored in the tanks. This has two advantages. Firstly, it helps combat flooding by reducing runoff flows. Secondly, it combats water shortages, as the population will be supplied with rainwater in large quantities for laundry and household cleaning.

In addition, erosion in the Mususa commune is caused by the regular mining of sand in the riverbed by the local population, and by the nature of the soil. In some places along the Wayimiria River, the soil is clayey and very rich in organic matter (Vichai). This is why the use of plants such as bamboo, whose roots effectively help stabilize the soil, would be a good strategy. On the other hand, it is important to make the population aware of the problem of erosion by informing them of the steps to be taken to minimize or simply avoid the formation and development of gullies.

Considering the urgency and gravity of the situation, here are the actions to be taken by the political-administrative authorities: (a) rapidly provide the City of Butembo with development plans. These will enable the best possible organization of the already urbanized areas as well as those to be developed. (b) Install drainage systems along roads and clean them regularly, for example during weekly community work. (c) Set up a monitoring committee to check the water storage system in each household. For example, a committee made up of the heads of the cells and the heads of ten houses. (d) Organize campaigns to promote awareness and understanding of natural hazards (Cfr. Urban environmental services). (e) Formally prohibit the population from extracting sand from the riverbeds and streams draining the city. (f) Propose penalties and sanctions for recalcitrant offenders, to eradicate once and for all the practice of extracting sand from streams. Sand is less appreciated by construction experts because of its heterogeneous nature and grain size.

**Acknowledgements**
We thank the Faculty of Science and Technology of the 'Université Officielle de Ruwenzori' for providing us with the field equipment. And we would also like to thank the reviewers for their insightful remarks which enabled us to improve the quality of this article.

## Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

## References

Benjamin, M., 2022. Contribution á l'étude géologique sous aspect pétrographique et cartographique du site de l'Université Catholique du Graben (UCG/Butembo). Ann l'Unigom 12 (1), 20-33. https://www.pugoma.com/index.php/UNIGOM/article/view/171.

Bezak, N, Mikoš, M, Borrelli, P, Alewell, C., Alvarez, P., Anache, J.A.A., Baartman, J., Ballabio, C., Biddoccu, M., Cerdà, A., Chalise, D., Chen, S., Chen, W., de Girolamo, A.M., Gessesse, G.D., Deumlich, D., Diodato, N., Efthimiou, N., Erpul, G., Fiener, P., Panagos, P., 2021. Soil erosion modelling: A bibliometric analysis. Environmental Research 197, 111087. https://doi.org/10.1016/j.envres.2021.111087.

Blais, J-P., 2005. Typologie de l'érosion interne et érosion interne des digues fluviales : une courte revue bibliographique. Sci Eaux Amp; Territ. Sciences Eaux & Territoires, (Spécial Ingénieries-EAT-21), 65-70. https://revue-set.fr/article/view/6124.

Bruneau, J.C., Katsuva, K., 1981. Quelques aspects de la naissance et de l'impact du phénomène urbain dans le pays Nande au Nord Kivu (Zaire). Geo-Eco-Trop 5 (1), 139-162. http://www.geoecotrop.be/uploads/publications/pub_052_05.pdf.

Chalise, D., Kumar, L., Kristiansen, P., 2019. Land degradation by soil erosion in Nepal: A review. Soil Systems 3 (1), 12. https://doi.org/10.3390/soilsystems3010012.

Cosoveanu, F.S., Buijs, J.M., Bakker, M., Terpstra, T., 2019. Adaptive capacities for diversified flood risk management strategies: Learning from pilot projects. Water 11 (12), 2643. https://doi.org/10.3390/W11122643.

Chuma, G.B., Bora, F.S., Ndeko, A.B., Mugumaarhahama, Y., Cirezi, N., Mondo, J.M., Bagula, E.M., Karume, K., Mushagalusa, G.N., Schimtz, S., 2022. Estimation of soil erosion using RUSLE modeling and geospatial tools in a tea production watershed (Chisheke in Walungu), eastern Democratic Republic of Congo. Modeling Earth Systems and Environment 8, 1273-1289. https://doi.org/10.1007/s40808-021-01134-3.

Degeai, J.P., Blanchemanche, P., Tavenne, L., Tillier, M., Bohbot, H., Devillers, B., Dezileau, L., 2022. River flooding on the French Mediterranean coast and its relation to climate and land use change over the past two millennia. Catena 219, 106623. https://doi.org/10.1016/j.catena.2022.106623.

Dong, W.S., Ariffin, E.H., Saengsupavanich, C., Rashid, M.A.M., Shukri, M.H.M., Ramli, M.Z., Miskon, M.F., Feofry, M.H., Yunus, K., Ghazali, N.H.M., Noh, M.N.M., 2023. Adaptation of coastal defence structure as a mechanism to alleviate coastal erosion in monsoon dominated coast of Peninsular Malaysia. Journal of Environmental Management 333, 117391. https://doi.org/10.1016/j.jenvman.2023.117391.

Du, X., Jian, J., Du, C., Stewart, R.D., 2022. Conservation management decreases surface runoff and soil erosion. International Soil and Water Conservation Research 10 (2), 188-196. https://doi.org/10.1016/j.iswcr.2021.08.001.

Fontaine, B., Roucou, P., Gaetani, M., Marteau, R., 2011. Recent changes in precipitation, ITCZ convection and northern tropical circulation over North Africa (1979-2007). International Journal of Climatology 31 (5), 633-648. https://doi.org/10.1002/joc.2108.

Gao, L., Zhang, Y., Ding, G., Liu, Q., Jiang, B., 2016. Identifying flood-related infectious diseases in Anhui Province, China: A spatial and temporal analysis. The American Journal of Tropical Medicine and Hygiene 94 (4), 741-749. https://doi.org/10.4269/ajtmh.15-0338.

Gasana, J., 2018. Assessment of the impact of mining on the environment and health in drc (democratic republic of congo). Occupational & Environmental Medicine 75 (2) https://doi.org/10.1136/oemed-2018-icohabstracts.715.

Gésan-Guiziou, G, Alaphilippe, A, Andro, M, Aubin, J., Bockstaller; C., Botreau, R., Buche, P., Collet, C., Darmon, N., Delabuis, M., Girard, A., Grateau, R., Kansou, K., Martinet, V., Membré, J-M., Sabbadin, R., Soler, L-G., Thiollet-Scholtus, M., Tonda, A., Van-Der-Werf, H., 2019. Annotation data about multi criteria assessment methods used in the agri-food research: The french national institute for agricultural research (INRA) experience. Data in Brief 25, 104204. https://doi.org/10.1016/j.dib.2019.104204.

Graf C, Böll A, Graf F. 2003. Des plantes pour lutter contre l ' érosion et les glissements en surface. Notice Pour Le Praticien 37, 1-8.

Huang, L-Y., Wang, Y-C., Wu, C-C., Chen, Y-C., Huang, Y-L., 2016. Risk of flood-related diseases of eyes, skin and gastrointestinal tract in Taiwan: A retrospective cohort study. PLoS One 11(5), e0155166. https://doi.org/10.1371/journal.pone.0155166.

Ji, Z., Li, N., Wu, X., 2018. Threshold determination and hazard evaluation of the disaster about drought/flood sudden alternation in Huaihe River basin, China. Theoretical and Applied Climatology 133, 1279-1289. https://doi.org/10.1007/s00704-017-2257-8.

Kawa, G.N., Kabyemere, K.D., Kasekete, D.K.., Kayembe, GM., Odhipio, D.A., 2022. Géochimie du secteur de Vwandanze et ses environs (Nord - Kivu, R.D. Congo). Global Scientific Journal 10 (9), 1169-1179. https://doi.org/10.11216/gsj.2022.09.77792.

Kinnell, P.I.A., 2021. Technical note: Detachment and transport limiting systems operate simultaneously in raindrop driven erosion. Catena 197, 104971. https://doi.org/10.1016/j.catena.2020.104971.

Kitakya, A.P., 2007. Interactions Entre La Gestion Foncière et l'économie Locale En Région de Butembo, Nord Kivu, République Démocratique Du Congo. Université Catholique de Louvain, Louvain-la-Neuve, Belgique. http://books.google.com/books?id=c75395qdZFUC&pgis=1.

Krvavica, N., Šiljeg, A., Horvat, B., Panđa, L., 2023. Pluvial Flash Flood Hazard and Risk Mapping in Croatia: Case Study in the Gospić Catchment. Sustainability 15 (2), 1197. https://doi.org/10.3390/su15021197.

Kundzewicz, Z.W., Kanae, S., Seneviratne, S.I., Handmer, J., Nicholls, N., 2014. Le risque d'inondation et les perspectives de changement climatique mondial et régional. Hydrological Sciences Journal 59 (1), 1-28. https://doi.org/10.1080/02626667.2013.857411.

Li, C., Sun, N., Lu, Y., Guo, B., Wang, Y., Sun, X., Yao, Y., 2023. Review on Urban Flood Risk Assessment. Sustainability 15 (1), 765. https://doi.org/10.3390/su15010765.

Lopanza, J.M., Habaieb, H., Luboya, C.T., 2020. Erosions urbaines à Kinshasa : Causes, conséquences et perspectives. European Journal of Social Sciences Studies 5 (3), 147-169. https://doi.org/10.46827/ejsss.v5i3.878.

Maghsood, F.F., Moradi, H., Berndtsson, R., Panahi, M., Deneshi, A., Hashemi, H., Bavani, A.R.M., 2016. Social acceptability of flood management strategies under climate change using contingent valuation method (CVM). Sustainability 11 (18), 5053. https://doi.org/10.3390/su11185053.

Mahamba, J.A., Mulondi, G.K., Kapiri, M.M., Sahani, W.M., 2022. Land Use and Land Cover Dynamics in the Urban Watershed of Kimemi River (Butembo/D.R.C). Journal of Geoscience and Environment Protection 10 (06), 204-219. https://doi.org/10.4236/gep.2022.106013.

Mangaza, L., Sonwa, D.J., Batsi, G., Ebuy, J., Kahindo, J.M., 2021. Building a framework towards climate-smart agriculture in the Yangambi landscape, Democratic Republic of Congo (DRC). International Journal of Climate Change Strategies and Management 13 (3), 320-338. https://doi.org/10.1108/IJCCSM-08-2020-0084.

Manno, G., Azzara, G., Re C.L., Martinello, C., Basile, M., Rotigliano, E., Ciraolo, G., 2023. An Approach for the Validation of a Coastal Erosion Vulnerability Index: An Application in Sicily. Journal of Marine Science and Engineering 11 (1), 23. https://doi.org/10.3390/jmse11010023.

Meyer, L.D., Dabney, S.M., Kemper, W.D., 2001. Designing Research to Improve Runoff and Erosion Control Practices : Example , Grass Hedges. 10th International Soil Conservation Organization Meeting held May 24-29, 1999 at Purdue University and the USDA-ARS National Soil Erosion Research Laboratory. 449-453 In: D.E. Stott, R.H. Mohtar and G.C. Steinhardt (eds). 2001. Sustaining the Global Farm.

Mietton, M., 1986. Méthodes et efficacité de la lutte contre l'érosion au Burkina Faso. Cah ORSTOM, Série Pédologie 22 (2), 181-196. https://www.documentation.ird.fr/hor/fdi:24512.

Muyaya, P.K., 2021. Voici les causes des inondations post-pluviales dans la ville de Kinshasa. Lequotidien-RDC. Accessed July 10, 2023. https://lequotidien.cd/category/politiques.

Odhipio, D.A., Kakule, M.K., 2022. Influence of Regional Tectonics on The Geological Formations of The Locality of

Mabuku In Beni Territory. Indonesian Journal of Earth Sciences 2 (2), 236-246. https://doi.org/10.52562/injoes.v2i2.404.

Odhipio, D.A., Kakule, M.K., Wazi, R.N., 2022. Petrographic characterization of geological settings in the locality of Mabuku in the territory of Beni, DRC. Indonesian Journal of Earth Sciences 2 (2), 126-144. https://doi.org/10.52562/injoes.v2i2.406.

Odhipio, D.A., Tamelegu, J.Z., Mulekya, M.K., Kasekete, D.K., Kawa, G.N., Wazi, R.N., 2023. Geochemical Assessment of Mineral Occurrences in the Karibumba Region in the Territory of Beni, Democratic Republic of the Congo. Environmental & Earth Sciences Research Journal 10 (2), 41-51. https://doi.org/10.18280/eesrj.100202.

Odhipio, D.A., Daniel, I.A., Mukandala, P.S., 2022. Cartographie des formations latéritiques de Butuhe. Global Scientific Journal 10 (8), 831-845. http://eoi.citefactor.org/10.11216/gsj.2022.08.76608.

Oyedele, P., Kola, E., Olorunfemi, F., Walz, Y., 2022. Understanding Flood Vulnerability in Local Communities of Kogi State, Nigeria, Using an Index-Based Approach. Water 14 (17), 2746. https://doi.org/10.3390/w14172746.

Pandey, S., Kumar, P., Zlatic, M., Nautiyal, R., Panwar, V.P., 2021. Recent advances in assessment of soil erosion vulnerability in a watershed. International Soil and Water Conservation Research 9 (3), 305-318. https://doi.org/10.1016/j.iswcr.2021.03.001.

Peel, M.C., Finlayson, B.L., McMahon, T.A., 2007. Updated world map of the Köppen-Geiger climate classification. Hydrology and Earth System Sciences 11 (5), 1633-1644. https://doi.org/10.5194/hess-11-1633-2007.

Rey, F., Ballais, J.L., Marre, A., Rovéra, G., 2004. Rôle de la végétation dans la protection contre l'érosion hydrique de surface. Comptes Rendus Geoscience 336 (11), 991-998. https://doi.org/10.1016/J.CRTE.2004.03.012.

Ro, B., Garfin, G., 2023. Building urban flood resilience through institutional adaptive capacity: A case study of Seoul, South Korea. International Journal of Disaster Risk Reduction 85, 103474. https://doi.org/10.1016/j.ijdrr.2022.103474.

Roose, E., Sarrailh, J.M., 1989. Erodibilité de quelques sols tropicaux Vingt années de mesure en parcelles d ' érosion sous pluies naturelles. Cah ORSTOM, Série Pédologie 25 (1-2), 7-30.

Rubinato, M., Nichols, A,. Peng, Y., Zhang, J-M., Lashford, C., Cai, Y-P., Lin, P-Z., Tait, S., 2019. Urban and river flooding: Comparison of flood risk management approaches in the UK and China and an assessment of future knowledge needs. Water Science and Engineering 12 (4), 274-283. https://doi.org/10.1016/j.wse.2019.12.004.

Sahani, W., 2012. Le Contexte Urbain et Climatique Des Risques Hydrologiques de La Ville de Butembo (Nord-Kivu/RDC). Université de Liège. Accessed November 8, 2022. http://www.geoecotrop.be/uploads/theses/These_Walère_MUHINDO_SAHANI_2011.pdf.

Shin, E.T., Lee, S., Lee, J., Song, C.G., 2022. Effectiveness of an adaptive flood management strategy using riparian risk assessment and a tolerability criterion. Journal of Flood Risk Management 15 (1), e12756. https://doi.org/10.1111/jfr3.12756.

Thibault, L., Félix, L., Ayman, E.S., Frédéric, D., 2018. Quelques conséquences locales et régionales des changements d'usages des sols liés aux activités humaines - Planet-Terre. Planet Terre. Published online. 1-19. https://planet-terre.ens-lyon.fr/ressource/erosion-sols.xml.

Wang, Z.J., Jiao, J.Y., Rayburg, S., Wang, Q.L., Su, Y., 2016. Soil erosion resistance of "Grain for Green" vegetation types under extreme rainfall conditions on the Loess Plateau, China. Catena 141, 109-116. https://doi.org/10.1016/j.catena.2016.02.025.

Williams, A.T., Rangel-Buitrago, N., Pranzini, E., Anfuso, G., 2018. The management of coastal erosion. Ocean & Coastal Management 156, 4-20. https://doi.org/10.1016/j.ocecoaman.2017.03.022.

Wouters, T., Wolff, E., 2010. Contribution à l'analyse de l'érosion intra-urbaine à Kinshasa (RDC). Revue Belge de Géographie 3, 293-314. https://doi.org/10.4000/belgeo.6477.

Yamba, T.K., Boven, A., 1998. Evolution Pliocène et Quaternaire du remplissage sédimentaire dans le sud du bassin du lac Edouard, branche occidentale du Rift Est-Africain. Journal of African Earth Sciences 26 (3), 423-439. https://doi.org/10.1016/S0899-5362(98)00024-4.

Yereseme, A.K., Surendra, H.J., Kuntoji, G., 2022. Sustainable integrated urban flood management strategies for planning of smart cities: a review. Sustainable Water Resources Management 8, 85. https://doi.org/10.1007/s40899-022-00666-5.

Zhang, Y., Li, Z., Ge, W., Chen, X., Xu, H., Guan, H., 2021. Evaluation of the impact of extreme floods on the biodiversity of terrestrial animals. Science of The Total Environment 790, 148227. https://doi.org/10.1016/j.scitotenv.2021.148227.

Zitong, G., Zhicheng, C., Wenjun, Z., Hua, S., 2000. Classification of ferrallitic soils in chinese soil taxonomy. Pedosphere 10 (2), 125-133.