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Original Research Article

Conceptual Model Aimed at Limiting the Effects of Rainfall on Buildings and Urban Infrastructure in the Republic of Congo

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Abstract

Reports on precipitation and rainfall data show that Congo has a tropical climate characterized by heavy rainfall for eight (08) months out of twelve (12), with volumes reaching up to 225 mm in November and April. Land use and the construction of various structures by the population do not take into account the runoff caused by heavy rainfall. This situation poses serious problems for the architectural quality of buildings and the environment. As a result, human settlements are extremely precarious and unsanitary. Each rainfall causes damage to roads, flooding of plots, silting and soil pollution. Field observations and data from recent newspapers and publications have identified demographic and rainfall characteristics as well as phenomena that cause damage to the urban environment. This study highlights the need to develop a national building standard that takes into account heavy and intense rainfall in the Congo. The main conclusions show that rainfall is one of the key factors influencing the quality of the built environment, that is to say buildings and infrastructure. The anti-erosion development model proposed in this study uses eco-parceling to strengthen the resilience of buildings in the face of natural events. The implementation of such development plans could help engineers and public authorities in the urban crisis linked to natural disasters.

Keywords: Rainfall, Water runoff, Erosion control, Soil pollution, Urban sanitation.

1. INTRODUCTION

Housing and roads are priority social issues that determine people's quality of life and well-being, as well as their environment. Territorial well-being and resilience are measurable [1]. Housing is an essential aspect of material living conditions. It must both meet basic needs, in particular by providing shelter from the elements, and give individuals a sense of security and privacy. Housing conditions also play a key role in individual health and human development. This excerpt clearly demonstrates the essential role that housing plays in improving the social conditions of the population. Road infrastructure also fits into this same social perspective. The design and construction of houses and engineering structures in a given environment influence the social and economic conditions of households. The condition of housing and roads has an impact on current and future generations. With this in mind, they must be sized and designed to fit easily into the cultural and social environment of households, taking into account their expected lifespan: 50 to 100 years for buildings and more than 25 years for roads [2]. In order to ensure their sustainability, these structures must be built from durable materials that are available locally or imported. Housing and roads are among the 'determinants of health' [3]. In this regard, the deterioration of urban roads due to poor management of runoff, wastewater and valves is one of the greatest challenges for urban mobility and public health in Congo [4]. Poor sanitation infrastructure limits local development, exacerbating poverty through the constant rise in food costs on the one hand and the loss of labor productivity on the other. According to UNHabitat data [5], access to sanitation networks is one of the shortcomings of the sub-region (state of cities). The 2023 General Population and Housing Census (RGPH-5) [6] indicates that, according to population typology, 97.70% of inhabitants spent the reference night in their household, while 2.30% spent it elsewhere for various reasons. It reveals significant spatial disparities in terms of land use within the country. The departments of Brazzaville (3,646.81 inhabitants/km²) and Pointe-Noire (665.7 inhabitants/km²) are overpopulated in terms

of land use. The General Population and Housing Census (RGPH-07) [7] indicates that in Congo, domestic wastewater is mainly discharged onto plots of land (48.3%) or into the streets (30.3%). Only 6.3% of households have septic tanks. In Brazzaville and Pointe-Noire, access to the sewerage system remains very low (9.8%). More than half of Congo's urban population does not have access to adequate sanitation (RGPH-07). At least 1 to 5 people die every time it rains due to traffic accidents, flooding and silting of land and streets. During heavy rains, people and vehicles are often swept away by the pressure of runoff water [8]. This reality is all the truer given that, as Musabwamana (2021) [9] points out, 'heavy rainfall is the cause (...) of loss of life'. Despite the Republic of Congo's commitment to development goals, particularly SDG 6 on water and sanitation, in 2020, 73.2% of the population had access to at least basic drinking water services and 20.2% had access to at least basic sanitation services (PND, 2022) [10]. Currently, people living in precarious neighborhoods face the threat of erosion, as concrete responses to this problem are still lacking. Indeed, slums or precarious neighborhoods in Congo are a clear manifestation of poor planning and management of urban areas, and in particular of a dysfunctional housing sector and urban road network. Several studies conducted in the field of sanitation in the Republic of Congo have identified poor wastewater and stormwater management as a major factor in the degradation of the urban environment and basic infrastructure [11-12]. According to UNICEF Congo [13], less than 11% of households use an appropriate wastewater disposal system, including 15% in urban areas and less than 2% in rural areas. Furthermore, despite the implementation of sanitation infrastructure projects in the cities of Brazzaville and Pointe-Noire, and erosion control projects by the public authorities in 2011, controlling the effects of rainfall on buildings in urban areas remains a major topic of scientific and public debate today. Wastewater and stormwater management, as well as solid waste management, are among the main challenges of the Republic of Congo's 2022-2026 National Development Plan. The aim of this work is to propose a functional anti-erosion development model capable of integrating the link between urbanization, housing and roads. The basic idea is to incorporate an ecological vision into urbanization plans and appropriate urban construction, thereby improving the resilience of the living environment.

2. MATERIALS AND METHOD

2.1 Description of the study area

2.1.1 Climate of Congo

The Congo has two rainy seasons during the year: a long rainy season from October to December, with high temperatures ranging from 25°C to 35°C and frequent rainfall. A short dry season from January to February, with no rainfall but high temperatures. A rainy season from March to May with high temperatures and frequent rainfall, and a long dry season from June to September. In general, cities in Congo experience eight months of rainfall ranging from 120 mm to 260 mm. The highest rainfall is recorded in November and April (Fig. 1).

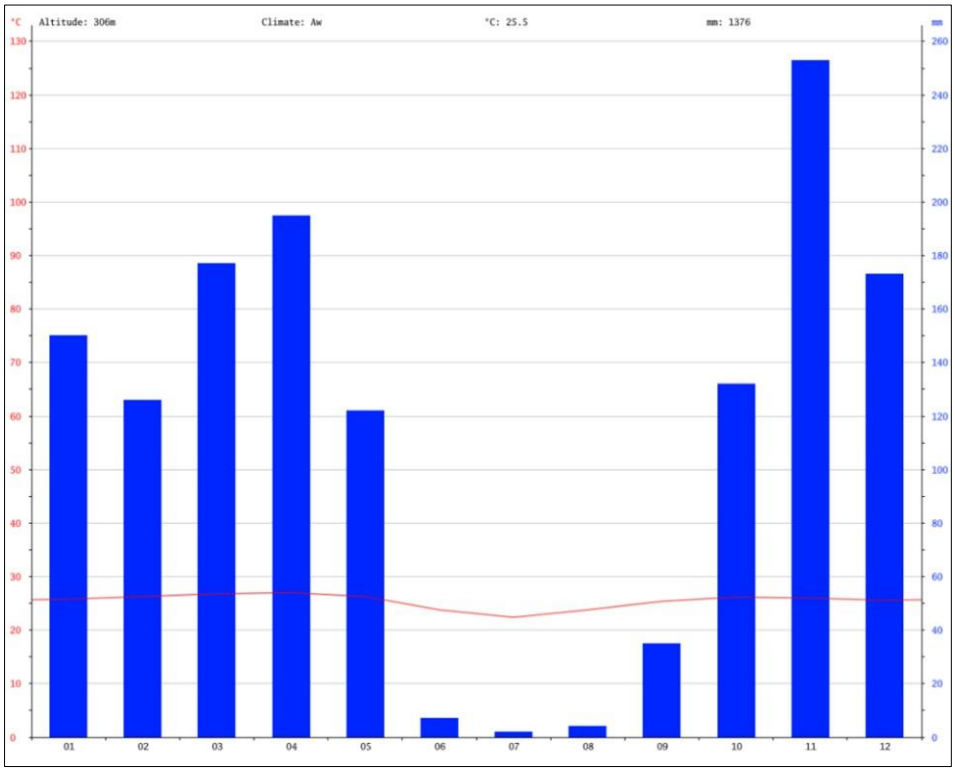

Fig-1: Climate chart for Brazzaville and Pointe-Noire [14]

2.1.2 The urban setting of the Congo

Founded by Europeans during the colonial period, Congolese cities are undergoing rapid urbanization thanks, on the one hand, to the massive influx of migrants who have left their villages. And on the other hand, to the phenomenon of delinking, whereby city dwellers who live with relatives and wish to become independent seek to build a new life elsewhere. The creation of urban agglomerations is not a matter of chance. In the north, they are located along rivers, which have long been the only practical means of transport: Makoua, Owando (e.g. Fort-Rousset), Boundji, Ewo, Gamboma, Ouesso, Impfondo, Mossaka, etc. In the south-west, on the other hand, it was the railway that led to the development of settlements around stations, such as Mvouti, Loudima, Madingou, Mindouli, etc. In addition, the creation of an administrative post also promoted the development of urban areas such as Djambala, Oyo, Boko, Kinkala, Mouyondzi and Mossendjo. Of the four major cities in Congo, three are connected by transport routes: Brazzaville, the terminus of navigation on the Congo River; Dolisie, an important locomotive depot since 1934; and Pointe-Noire, the coastal terminus of the CFCO and the former 'federal road' (caravan route) connecting Chad to the Atlantic.

The coastal terminus of the CFCO and the former 'federal road' (caravan route) connecting Chad to the Atlantic. Nkayi (formerly Jacob), on the other hand, developed around a large sugar cane plantation and an industrial complex. The choice of these sites reflects a desire to provide the population with certain climatic, health, economic and aesthetic advantages, thanks to their location at altitude, on a plateau, on the banks of a river or on a hill. The cities of Djambala, Brazzaville, Makoua, Gamboma, Boko, Mouyondzi, Nkayi, etc. are examples of this. Two types of neighborhoods have formed in the urban landscape of these cities:

- The European town or administrative town;
- African villages or 'working-class neighborhoods', populated exclusively by African nationals and the local population.

The European city (administrative city) comprises administrative buildings, shopping centers, industrial and residential areas. It benefited from a concerted urban planning scheme, providing for wide avenues, large roundabouts and extensive green spaces. The most popular type of housing was the villa surrounded by lawns and modestly sized buildings. It is also equipped with a rainwater drainage system, which is still in use today. In recent years, buildings comprising hundreds of flats have been constructed (homes without borders 'TCHICOBO' in Pointe-Noire, Camp Clairon, Camp August 15 and the Mpila dredging accommodation in Brazzaville).

Pointe-Noire, Camp Clairon, Camp 15 Août and the Mpila dredging accommodation in Brazzaville). African villages (working-class neighborhoods), with their grid layout, had a dense network of streets dividing them into hundreds of 'blocks', each of which was divided into fenced-off plots (8 to 10), or even 12 to 16 in the following season. They all look the same everywhere. Traditional housing remains the most widespread. Despite efforts by property developers to modernize working-class neighborhoods with projects such as Bacongo Chic, Tahiti, Plateau 15th Anniversary in Brazzaville, Chic neighborhood and Tié-Tié market in Pointe-Noire, the results are still not tangible. Working-class neighborhoods are established and developed without any urban planning. There is no rainwater drainage system. The city, once very shady, has now lost its reputation as 'green Brazza'. The population no longer has anywhere to plant trees. These 'ground-level' agglomerations, considered to be urban sprawl, pose serious transport problems, both for intra-urban public services and for the inhabitants themselves. Indeed, many people lose a considerable amount of time on long and tiring journeys. The other most intractable problem is that of collective technical infrastructure, which is controversial in terms of design, construction and maintenance (roads, water and electricity distribution, sewage disposal and valves). The infrastructure needed to cover all neighborhoods represents too heavy a burden on the municipal budget. Private investment is not profitable for operators, as a large proportion of the customer base has low incomes. From five neighborhoods in 1961 with 135,000 inhabitants, Brazzaville now has nine, with a population of 1,373,382 in 2007 (RGPH – 07), Figure 2.

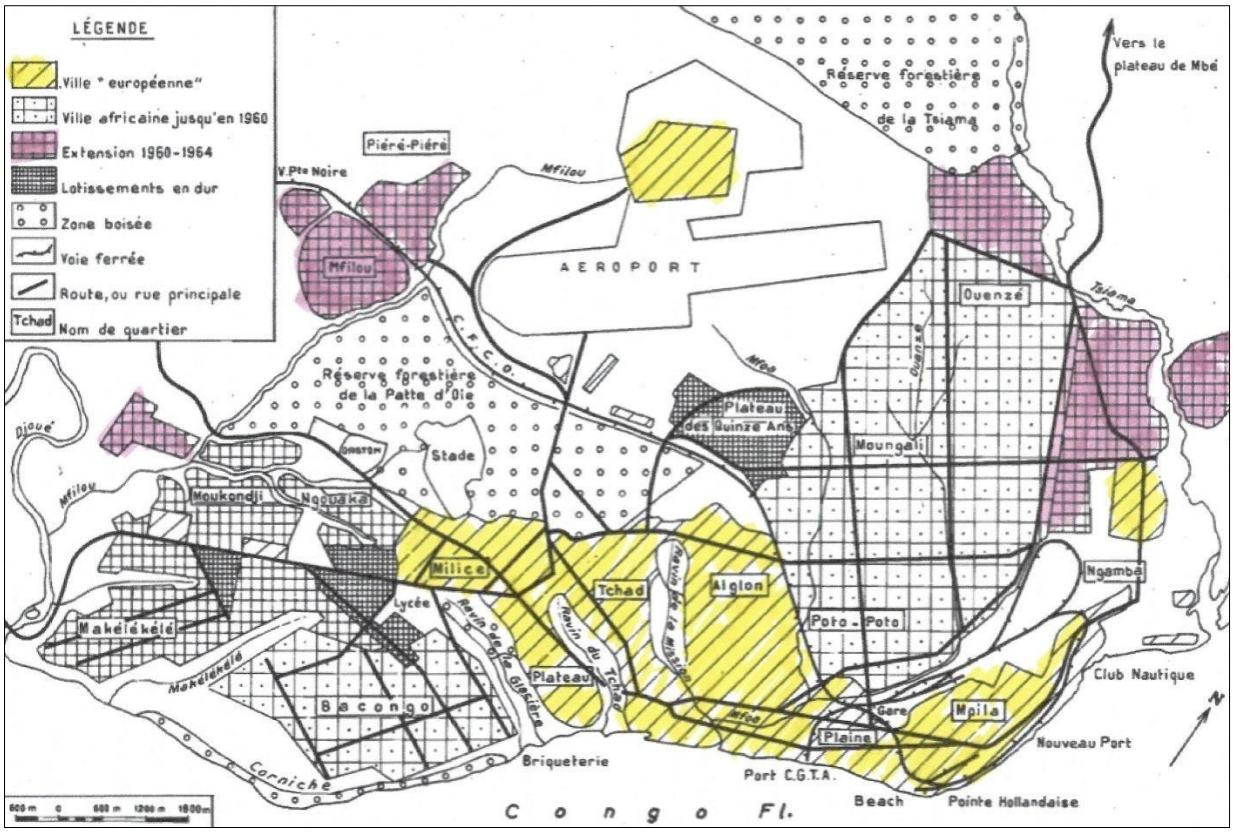

Fig-2: Schematic map of the city of Brazzaville (1960 – 1964) [15]

2.2 Observations on the deterioration of living conditions in Congolese cities

Field observations and information obtained from experts in the fields of roads and various networks, as well as newspapers, have revealed certain impacts of poor wastewater and rainwater management on habitats and roads in urban areas of Congo's two main cities (Brazzaville and Pointe-Noire). Across the sanitation sector as a whole, an inventory of existing infrastructure and equipment in urban areas in terms of excreta, wastewater, current rainwater drainage systems and areas of erosion or flooding reveals institutional weaknesses in terms of coordination between civil engineering disciplines during the construction of the city [11,16]. On this basis, the most significant impacts of rainfall in Brazzaville and Pointe-Noire are reflected in particular in soil erosion phenomena with the collapse of habitats, the degradation of infrastructure (roads, industrial buildings, etc.), flooding, etc. Figure 3 shows cases of erosion recorded on 18 November 2019 in the estate area, District 9 Djiri in Brazzaville, and in June 2025 in the Mayanga area, District 8 Madibou. The depth of this erosion is estimated at between 15.3 m and 17 m.

Fig-3: Erosion in Domaine (Djiri) and Mayanga (Madibou)

This erosion phenomenon often begins with the simple removal of a layer of topsoil following rainwater runoff on open dirt roads, then spreads with increased rainfall and the development of new construction on undeveloped land. In fact, in the new so-called peripheral areas (Ngamakosso, Massengo, Kombo-Matari, Mama Mbouale, JacquesOpangault, Mikalou, Emeraude, Casis, Kahounga, Mfilou or Moukondo, Mouhoumi, Sadelmi, Kinsoundi, Moukoundji-Ngouaka, Mayanga, etc.), due to population growth, the city's development has not followed any urban planning (Mambou and Elenga, 2023) [17]. This has led to significant land movements causing human and material losses, as well as incalculable social welfare costs for public authorities through various humanitarian action projects, such as the Lisungui 2 project. Faced with this natural insecurity and in order to prevent the erosion from worsening, residents use sandbags, used tires and household waste as a means of containment and backfilling. Figure 4 shows the silting up of an Afric' petrol station and a house in February 2019 in the Base area, 7 Mfilou district of Brazzaville.

Fig-4: Silting up of the petrol station and a house in the Base area, Mfilou district

From these images (Fig. 4), we can see the absence of inadequacy of urban drainage systems and road infrastructure capable of stopping landslides during rainfall. These shortcomings can also be explained by the lack of up-to-date technical studies of the terrain at the time of construction. Figure 5 shows cases of flooding of houses and roads in Pointe-Noire and Brazzaville between 2020 and 2025. It should be noted that flooding is a topical issue and of public interest, particularly during the rainy seasons in Congo. The case of Pointe-Noire can be explained by the ageing road infrastructure and the fact that the drainage channels have become insufficient given the increase in the number of habitable roofs. The case of Madibou in Brazzaville can be explained by the overflowing of the Congo River following the increase in rainfall frequency in recent years.

Fig-5: Effect of rainfall on habitats and roads in: a) Pointe-Noire, 8 and 9 November 2020; b) Brazzaville, Madibou, 2025(source: VOX TV actuality)

The problem of urban sanitation in Congolese cities can also be explained by undersizing, poor slope when installing rainwater and wastewater drainage pipes, and lack of maintenance. These factors are largely responsible for the obstruction of gutters and the deterioration of paved roads. An illustration of these facts is presented in Figure 6.

Fig-6: Condition of the road surface on Etoumbi Street in Brazzaville

3. RESULTS

Analysis of the damage observed on buildings and infrastructure in Brazzaville and Pointe-Noire shows that the severity of damage caused by land erosion varies from one geological soil formation to another. Water erosion depends on several factors (18]: rain erosion, infiltrability, slope of the land and land use (vegetation cover, farming practices). It is very alarming on soils composed of loose sand or silty sand and moderate on clay soils [19-21]. Naturally, water stagnates on flat land and flows on sloping land. On a watershed with a given slope, a quantity of water at a certain speed strips the soil to form deposits downstream. The solution to the phenomenon of erosion involves controlling the amount of water generated by the plots and roads located in the watershed. Flooding, on the other hand, depends on how watercourses are integrated into urban development plans. The case of the Madoukou River in districts 3 Poto-Poto and 4 Moungali is a good example of flood-resilient development. Below, we present a suitable proposal for urban development that prevents soil erosion.

3.1 Eco-parceling plan for erosion-resistant land use planning.

Figure 7 shows an eco-parceling plan for urban areas aimed at controlling erosion in Congolese cities. New neighborhoods created in Congo's major cities do not have drainage systems for runoff, wastewater and floodgates. Each plot discharges its water onto unpaved dirt roads. The development model proposed in this study is an antierosion eco-parceling of plots located on hills or in watersheds with slopes that are prone to erosion (Figure 7). The dimensions of the plot (20 m x 25 m) allow households to build an 80 to 120 m² building, topped by a 2 m sanitary belt to ensure ventilation and natural lighting in the living areas; 100 m² of unpaved space for planting a tree or garden, to allow a certain amount of rainwater to infiltrate; a 3 m by 20 m strip for storing rainwater. This natural system for collecting and storing rainwater on the plot (natural catchment area) will enable the street to manage its own water, thus preventing erosion.

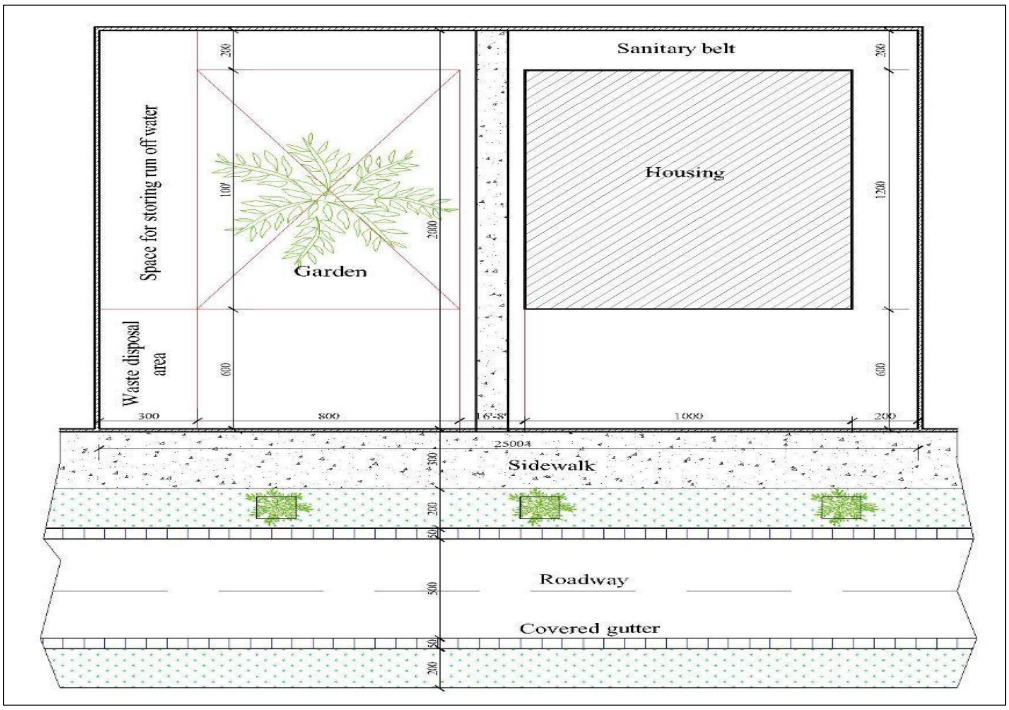

Fig-7: **Development through eco-parceling of Congolese cities**

3.2 Erosion management plan for the urban road right-of-way

Figure 8 shows the characteristics of urban road rights-of-way that ensure better rainwater drainage. This will involve reviewing existing road rights-of-way on certain avenues to ensure good mobility for users, with the possibility of planting trees or grass in front of each plot. In this way, some of the runoff from the roads will be absorbed by the plants and grass.

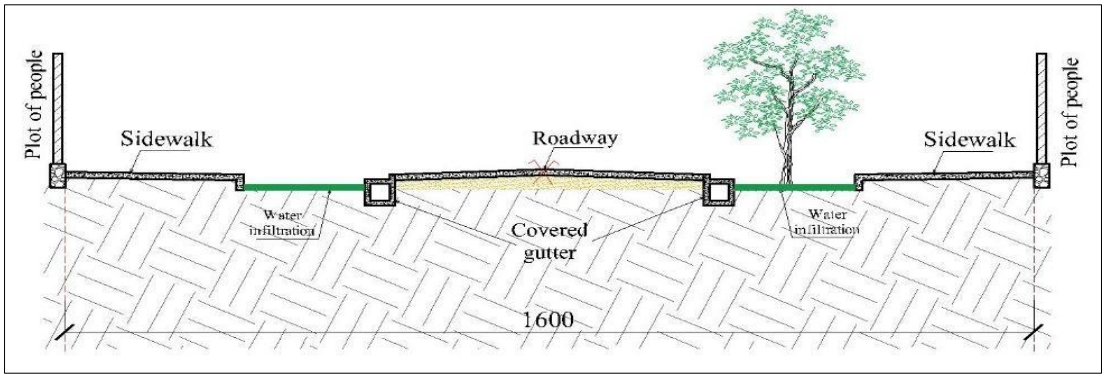

Fig-8: Typical erosion control Measures for urban road rights-of-way in Congolese cities

4. CONCLUSION

The objective of this study was to assess the damage caused by rainfall to buildings in Congolese cities in order to propose an appropriate model for urban development. The study showed that plot size, road layout and road rights of-way are the cause of erosion, precariousness and unsanitary housing in the urban areas of Brazzaville and PointeNoire. Urban planning and building regulations, which represent the building and infrastructure sector, are merely a reflection of a country's economy, its beliefs and the lifestyles of its population. It is in this environment that girls and boys, the future leaders of our country, grow up.

Currently, problems of erosion, substandard housing and the condition of roads in urban areas are factors that influence children's education and the effective participation of working-age residents in the national economy. This study examines the current situation of roads and land threatened by erosion, as well as that of households affected by precariousness and poverty, focusing on two (2) aspects in particular:

- The choice of plot size for the management of household waste, rainwater and sanitary wastewater ‘at home’.
- The layout of roads, rights-of-way and areas likely to ensure adequate sanitation in neighborhoods and the city, taking into account rainfall in the Congo.

The study shows that housing intended for large households of five (5) or more people on a plot of land measuring 20 m x 20 m (400 m²) or 10 m x 20 m (200 m²) can only be unsanitary, unhealthy and a source of environmental problems. Analysis of the phenomenon of erosion in Congolese cities has shown that the public authorities and the population have not yet found a sustainable alternative to solve the problems of erosion and flooding in Congolese cities at a lower cost. The new dimensions of plots that can accommodate decent housing for an average Congolese household of five (5) people can be 20 m x 25 m (500 m²). This area will allow:

- Build a house with a floor area of between 80 and 120 m².
- Create a buffer zone of 1.50 m to 2.00 m around the house to ensure ventilation and natural lighting in the rooms.
- Plant a tree with a diameter of 6 to 10 m (or a garden of 60 to 10 m²).
- Create sufficient space for rainwater infiltration and storage.
- Properly manage wastewater and valves, as well as household waste.

Public road space must be designed taking into account the slope and materials that make up the watershed.

The recommended dimensions for urban roads in Congo are 16 m and above. These dimensions allow the urban population to:

- Plant 1 to 3 trees in front of their plots to absorb some of the runoff;
- Create gutters to drain rainwater into streams and rivers;
- Move freely by car (four wheels), bicycle or motorbike (two wheels) and on foot.

This work will continue in order to incorporate the design component of pavement thicknesses suitable for Congolese urban roads into the calculation of structures that retain ground movements.

Declarations

Conflict of Interest: The authors declare that they have no conflicts of interest.

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