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METHODOLOGY FOR EROSION RISK ZONING IN THE CITY OF BRAZZAVILLE STUDY OF CASE IN THE URBAN AREA

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ABSTRACT

The erosion phenomenon produces severe damages in the city of Brazzaville. Although it is difficult to stop it at a local scale, their after-effects can be mitigated. The forward-moving urban border in the steep terrains of the natural space, causes forest and savannah disappearance. This forest and savannah reduction causes intense soil erosion processes that conduct to a poor vegetative cover and increase the level of surface drainage capacity. The lack of an appropriate cartography makes difficult land use planning in the city of Brazzaville. This work takes into account an erosion risk model based on georeferred data which is easier to reproduce in developing countries with a few number of available cartographic layers. Slope, land cover/land use and soils are analyzed to establish the cartography model for erosion risk. This cartography showed areas occupied by different classes of erosion risk.

Keywords: erosion, land use planning, cartography, developing countries, risk.

1. INTRODUCTION

Really, one of the environmental problems of greatest concern is the question of land degradation. This problem under the specific name of erosion process is caused by a complex combination of various factors including climatic variations and is usually accelerated by anthropogenic action. Unfortunately, the terrestrial ecosystems are extremely vulnerable to over-exploitation and inappropriate land use. In Brazzaville city the largest areas currently subject to soil erosion processes are located in the mountainous areas generating significant impacts on the lives of local people, contributing to the marginalization and poverty in large parts of the population [1]. This work attempts to provide an assessment of the erosion risk for Brazzaville city considering a cartography model and using the Geographic Information System (GIS) for mapping areas subject to different level of the erosion risk.

2. THE STUDY AREA

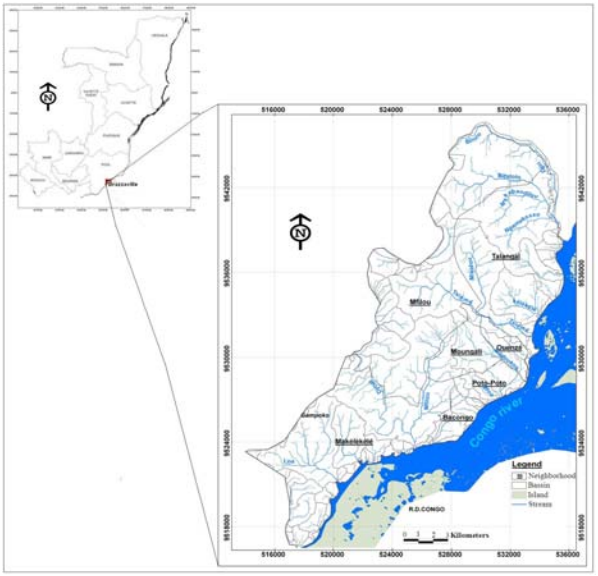

Figure-1. Study area.

Brazzaville city is the capital of the Republic of Congo and is located on the right bank of the Congo River which it shares with Kinshasa (capital of the Democratic Republic of Congo). Its stretch is about 30 km and has seven neighborhoods: Makélékélé, Bacongo, Poto-Poto, Moungali, Ouenzé, Talangaï and Mfilou. In 2008, the

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report of the National Center for Statistics and Economic Studies (CNSEE) revealed that more than one million people live in Brazzaville. That represents a little more than thirty percent of the total population of the Republic of Congo [2]. Physiographic features of Brazzaville are formed of hills, plateaus and plains where the plateaus are as belt surrounding plains [3]. These plateaus are converted to hills in the area of Nkombo and Massengo. Neighborhoods like Talangaï, Ouenzé, some areas of Moungali and Poto-Poto are located in the plains and subject to flooding during rainy periods [4].

Brazzaville city has a climate that is kind of "low Congo" with a rainy season from October to May and a long dry season from June to September which is interrupted by a short dry season between January and February [5, 6]. However, the lowest temperatures reach 19°C during the dry season in July while, the highest temperatures reach 30°C in November and April during the rainy season. Precipitation changes are relatively small and fluctuate between 800 and 1800 mm [7, 8]. Brazzaville city is dominated by savannah with typical species of sandy or clay soils. The plateaus contain groves and forests bordering streams [9]. Below the Batékés plateaus rich in water [10], Brazzaville city is watered by different rivers like Djiri in the north, then Tsiémé, Mfoa and Madoukou in the center, finally Djoué and Mfilou in the West, the eastern part is bounded by the Congo River, which has a flow of about 43000m^3/s [11]. Brazzaville soils in general are not very poor in clay and organic matter. They are called lateritic soils and being classified into four groups: podzols, ferralitic soils, hydromorphic soils and unsophisticated soils [12 and 13].

3. MATERIAL AND METHODS

A. Available data

The available data of the study area supplied variables related to erosion processes to implement a valid methodology. The basic information was collected during the fieldwork and complemented by some preexisting maps. They are the map of land use obtained from Landsat ETM+ images for the year 2012 [14]. Digital Terrain Model obtained from SRTM with 90 meter of resolution and soil map of the Geological Survey of ORSTOM. It was also used vulnerability map showing possible areas with different levels of vulnerability [15]. Cadastral map with Brazzaville city borders and the slope map obtained from the digital terrain model. These available maps were processed by Arc Gis 10.1 and one also used the Garmin GPS for points positioning.

B. Methodology

In spite of different models that exist to estimate the erosion process, the choice of one model implies its efficiency depending on the available data, the spatial and temporal scale. The current method to estimate the erosion risk must consider the main factors such as the relief, climate, soil, land use and land cover that affect the erosion [16]. In this work the lack of climatic data led to a qualitative assessment of the erosion risk. The Figure-3 shows the sequence of steps carried out for this study. To achieve the objective of this study one makes a simple analysis with emphasis on three variables that are closely related to the erosion risk like slope, soil, land use and land cover [16].

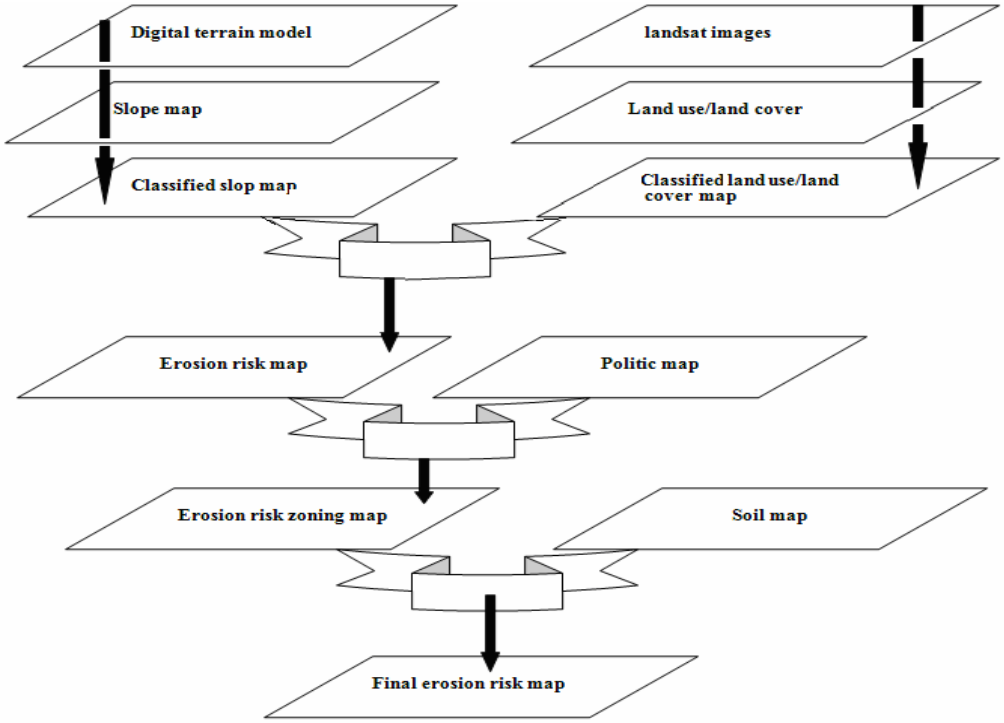

Figure-2. Cartography model.

Some importance was assigned to the slope factor for the discrimination of areas with a little or more sensibility to the erosion processes and the land use or land cover factor which determined the most affected areas (soils without vegetation) and more potential areas to be affected (soils with vegetation).

The slope map, soil map and land use or land cover maps were integrated into the Geographic Information System (GIS) to establish the erosion risk. So, each map provides information against erosion risk where it is divided into five classes (Table-1).

Table-1. Classes of erosion risk.

Classes	Erosion risk
1	Very low
2	Low
3	Medium
4	High
5	Very high

These classes are based on the conditions that affect the erosion processes which contribute to less or more soil loss. The slope map, soil map and land use/land cover maps are reclassified according to the Table-1. In order to reach our goal, different studies in different parts of the world on erosion processes have been consulted. This task has been complicated but simplified for the lack of climatic data and previous studies about the erosion risk in the study area.

By the combination of the two maps is obtained a 5 columns x 5 rows matrix of values representing the erosion risk given the slope, soil and land use/land cover. In order that the map obtained help establish the dialogue with the local people and political leaders, it will overlay with a political map which contains neighborhoods frontiers. The result of these maps combination respecting the established order in the Figure-3 is the erosion risk zoning map. The erosion risk is not only determined by the slope and land use but also by the soils or rocks resistance. So in the absence of rock in our study area, the only geological material subject to analysis was the soil classified into one category assigned to a greater erosion risk. The sum of the two maps produced a 5 columns x 1 rows matrix of values for the erosion risk taking into account the types of soils [17]. With that some values are increased by one and those yet maintain their risk of erosion. Finally, from this map it will suggest priority areas for action to reduce the erosion risk. Secondary data taken from various studies and the original data from the National Institute of Geography, ORSTOM were used to make the maps classification. This is an appropriate method that can be developed in a short time, with a relatively low cost and distinguishes areas with different classes of erosion risk. The slope map in percentages is the result of the digital elevation model processing that includes values from 0 to more than 35% (Table-2).

Table-2. Classes of slope.

Classes	Slope (%)	Erosion risk
1	0 - 3%	Very low
2	3% - 12%	Low
3	12% - 20%	Medium
4	20% - 35%	High
5	>35%	Very high

The slopes intervals are grouped into five classes related to their impact on the erosion risk [16]. This study considers that the influence of soil erosion depends on the slope angle. So, an increase in the slope angle causes an increase in the speed of runoff and the water kinetic energy causing the soil particles movement. The slope map was classified as follows: the class 1 refers to the slopes from 0% to 3% occupied generally by flat areas with insignificant losses of soil regardless of the use or presence of heavy rain, so the erosion risk is very low. The class 2 belongs to slopes from 3% to 12% considered as areas where the erosion that occurs is low and it can be controlled with appropriate management practices. The class 3 refers to the slopes from 12% to 20% where the erosion risk is medium and the types of land uses are already limited. The class 4 belongs to slopes from 20% to 35% and considered as the high erosion risk areas and is therefore not suitable for agriculture and other human activities because of the soil loss involved regardless of the type of soil and rainfall intensity. The class 5 refers to slopes greater than 35% being areas with a very high risk of erosion due to the high speed acquired by the water and therefore their greater kinetic energy resulting move particles. The slope map classification was obtained from the conversion of the digital elevation model into a slope map using the Arc GIS 10.1 software. Subsequently, the slope map obtained was classified into five classes defined above and shown in the Table-3.

Table-3. Classes of occupation and land use.

Classes	Land cover and land use	Erosion risk
1	Lake	Very low
2	Forest	Low
3	Savannah	Medium
4	Built	High
5	Bare ground	Very high

Land use map

As the land use and land cover map was already prepared, one analyzed the variability of the potential erosion for each type of land use or land cover, like this, not all types of land cover or land use could be in the same

degradation state. So, the erosion that occurs in a forest has not the same intensity as that produced in a savannah or one that occurs in a well conserved area or on bare ground, also that which occurs in areas with or without built conservation practices. Thus, the land use and land cover classes were determined and grouped into five classes (Table-3).

Land use and land cover assignation to each class of the erosion risk

The class 1 refers to the lakes, being the land cover that generates less risk of erosion because they are located in areas not favorable to erosion processes because their flat relief does not permit the erosion action on the ground. The class 2 refers to forest that is largely undisturbed by human activities and it is considered as the land cover that produces less erosion risk. In addition, it is an ecosystem more stable and with more planted trees. The Class 3 belongs to savannah located in the vicinity of the city which are areas subject to degradation for housing implementation, they are areas of easy access to houses construction after being occupied they begin gradually disappearing. This land use reduces both the soil retention capacity as the resistance and obstacles encountered by a drop of water on the ground that influences the speed of the drop impact on the ground, therefore being the erosion risk greater in savannah degraded than in a forest undisturbed [18]. However, the estimation of erosion between these two types of vegetation is currently being studied, because to date there is no available document that would establish baseline values for landscapes in the Republic of Congo.

More difficult is to estimate what type of land use, bare land or built protects more the soil from erosion pocesses. This decision depends notably on the state and the use made on them. It is currently part of the city of Brazzaville extension dedicated to the construction activities (bare land and built) that varies in a spectacular way in the demand or need for the people to build their own houses. This is defined as class 4 the houses built in hazardous areas, causing a very strong water flow after construction before plants sown to protect the ground when it is temporarily without or with a little vegetative cover. Moreover, in these areas there is a strong influence of human activities such as terraces, canalization poorly drained, garbage thrown away in water channels causing the disturbance of soil structure and therefore increases the erosion risk. With that the local people are at high erosion risk. The class 5 refers to the bare land or no vegetation in steep terrain because when the ground is bare the effect of soil degradation is more direct and severe each year because the soil lacks vegetative cover that protects it against the erosion.

Preparation of the erosion risk map

The erosion risk estimated by combination in a 5 columns x 5 rows matrix defines classes for the slopes and land use or land cover (Table-4).

Table-4. Erosion risk: Matrix of combination between slope and land use.

	Slope						
Land use	**Erosion risk**	**Classes**	**1**	**2**	**3**	**4**	**5**
	Very low	1	1	2	2	3	3
	Low	2	2	2	3	3	4
	Medium	3	2	3	3	4	4
	High	4	3	3	4	4	5
	Very high	5	3	4	4	5	5

The combination of values in the matrix is done as follows: when it matches the value of the two variables like slopes with land use and land cover, the final value of the erosion risk is the same as those of the variables. That is to say, when the slope is 1 and land use is 1 the erosion risk takes the value 1. Whenever possible, it assumes an intermediate value between the two variables in the case that the slope is 3 and the land use is 1, then the erosion risk is equal to 2. When there are several intermediate values, it is chosen the middle number with higher value like the slope is 1 and land use or land cover is 4, the possible intermediate values are 2 and 3, taking the highest intermediate value; the erosion risk value is 3. Finally, if there is no intermediate values between two variables the final value of the erosion risk coincide with the highest value of either variable. Thus, if the slope is 4 and the land use or cover is 5, the risk of erosion value is 5. With this fact is given the same importance to the two variables where the prevention principle is considered. The erosion risk map (Figure-3) is the result of the combination of the classified slope map and the map of land use/land cover.

Zoning erosion risk

The erosion risk map obtained was combined with the political map in order to produce the erosion maps which explain clearly the erosion behavior within the neighborhoods borders. This way the government and the local people will learn about the erosion risk distribution in the study area (Table-5).

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Table-5. Classes of soil sensitivity to erosion.

Code	Class	Degree of sensitivity	Type of soil
C	2	Low	Podzols and hydromorphic soils
B	3	Medium	yellow soils of plataus
A3	4	High	yellow soils of the hills
A2	5	Very high	lateritic soils

Erosion risk depending on soil erodibility

It is based on the description of different types of soil in Brazzaville already mentioned above. Relying on soils classification into four classes considering their sensitivity to erosion, once classified the soil map in four classes taking into account the erosion risk, the result is a matrix of 5 columns x 4 rows (Table-6) with values corresponding to the sum of the two variables considered (soil and risk of erosion). As shown in the Table-6, if the risk of erosion is very high (class 5) it is located in an area with the presence of sensitive soils (class 5), a new class of erosion risk is the class 6. As in all the work ones considered only five erosion risk classes and the class 6 is identified as class 5 too (very high erosion risk). The steps taken to achieve the erosion risk map begin with the classified soils map, then joined with the zoning map of erosion risk. Lastly, one obtained the final map of erosion risk (Figure-3).

Table-6. Matrix of the sum of erosion risk map and soil map classified.

	Erosion risk zoning map (slope+land use)					
Sols map (sensibility to erosion)	**Classes**	**1**	**2**	**3**	**4**	**5**
	2	2	2	3	3	4
	3	2	3	3	4	4
	4	3	3	4	4	5
	5	3	4	4	5	5

4. RESULTS AND DISCUSSIONS

The erosion risk distribution in the study area is shown clearly which is related to the dominant physiographic features that play an important role in showing the influence of many variables used in the cartography model on the erosion processes. One can appreciate that the slopes orientation intensifies the climate action on the ground, the properties and potential soil to generate biomass, determining even the forms of land use then the environment management. Many influences of the variables used for the cartographic model are seen from the Figure-3 which represents the percentages of areas occupied by each risk level and the slope for each class of sensitivity to the erosion processes.

Based on the Figure-3 it is clear that the areas with the lower risk are located in the plains, represented with dark green color and bright green on the erosion risk map, while those with high and very high risk are located in mountainous areas with steep slopes and sparse vegetation where the soil is more exposed to the erosion risk and make possible the runoff action to destroy the ground. The areas with medium risk are those areas located between plains and mountains represented with light yellow color (Figure-3).

In view of the results obtained (Figure-3), it is apparent that the erosion risk across the study area is significant. An important part of the area shows a high erosion risk (10%) or very high (19%). In addition, the areas occupied by medium erosion risk are 15%, low are 19% while those occupied with very low erosion risk are 37%.

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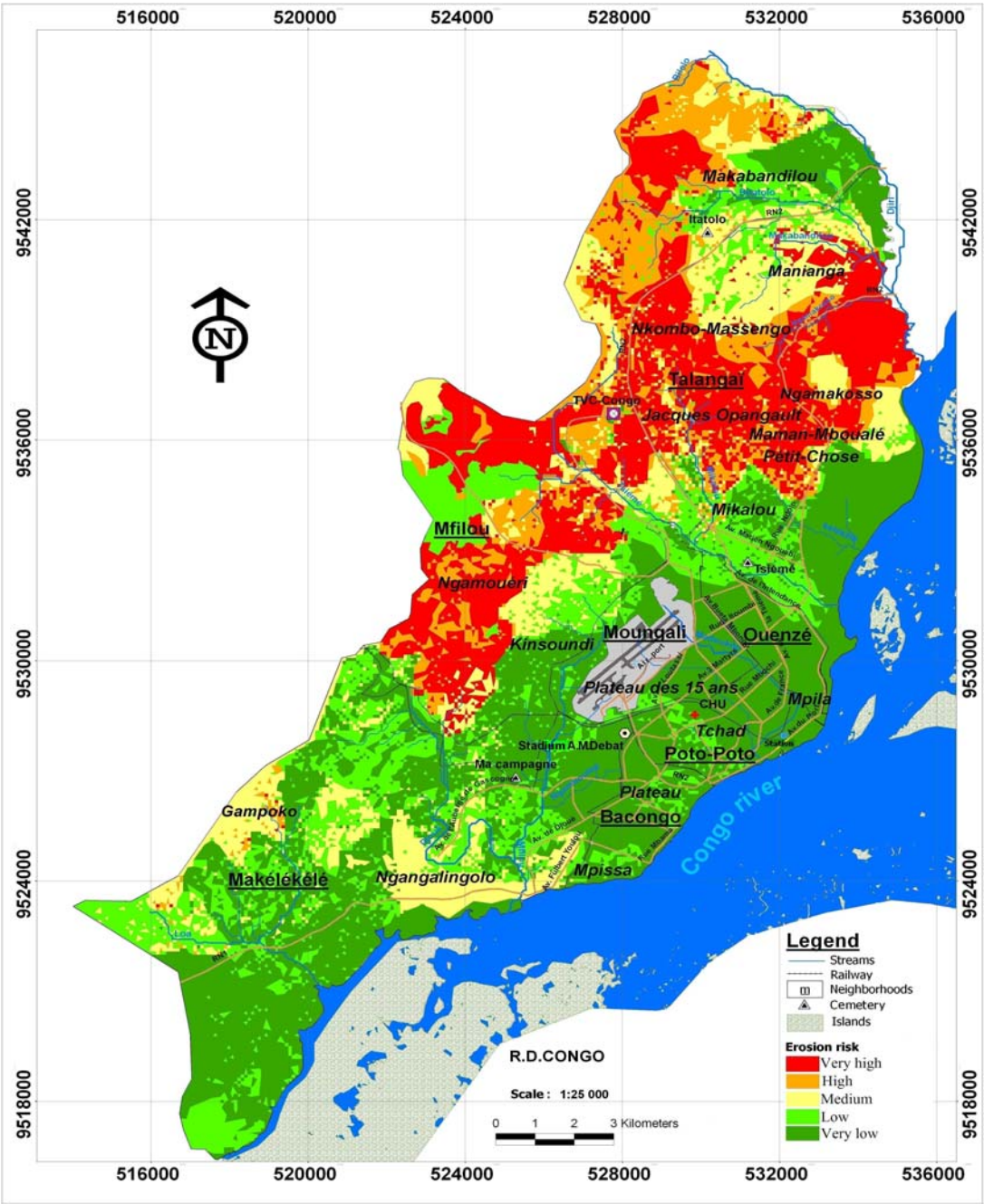

Figure-3. Erosion risk map.

These results are consistent if the slopes and types of land use are analyzed separately. Both factors have been taken into account to assess the erosion risk. The very steep slopes reached are mostly between 20% and 35% and over 35% (Figure-4). However, the flat or almost flat areas are common throughout the study area and are represented both intervals from 0% to 3% and 3% to 12% that represent a 60% in the whole area (Figure-4). An analysis of land use showed that the most widespread land cover in the city of Brazzaville is the vegetation (forest and savannah) with 70%. In addition to this an important part of the land that represents 27% is also devoid of vegetation (built and bare ground) as shown in the Figure- 5. That contributes negatively to increase the erosion risk along with the limited extent of the ground covered by vegetation. The combination of the steep slopes and land use that lead to erosion or conservative scarce land use shows that the erosion risk in the study area is generally high. Based on the erosion risk it is noted that neighborhoods like Mfilou and Talangaï are showing by far the largest area with high erosion risk (Figure-6). In other neighborhoods not predominantly by high and very

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high risk of erosion, although Makélékélé, Bacongo and Moungali are shown areas with a very high and high erosion risk, but in this case those areas with high and very high erosion risk do not occupy large areas like the neighborhoods Mfilou and Talangaï (Figure-6).

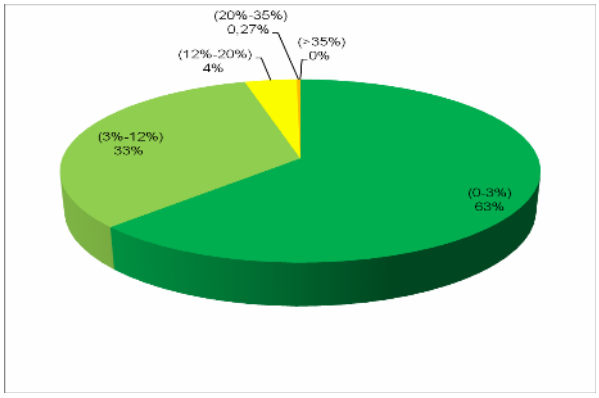

Figure-4. Slope variation in Brazzaville.

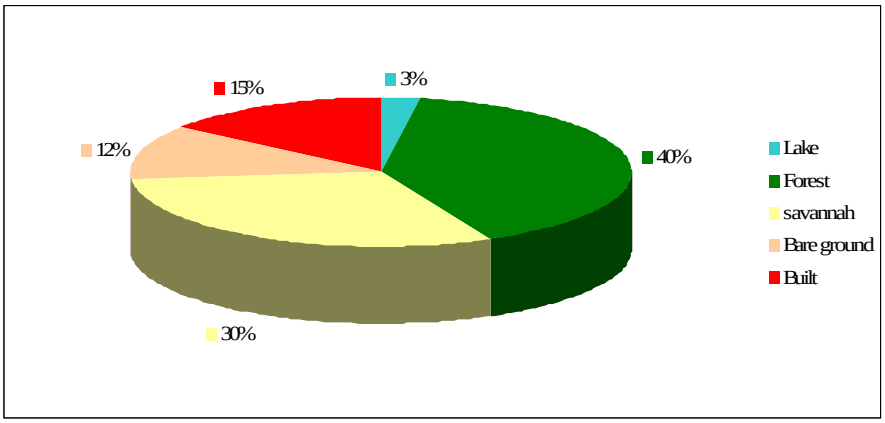

Figure-5. Slope variation in Brazzaville

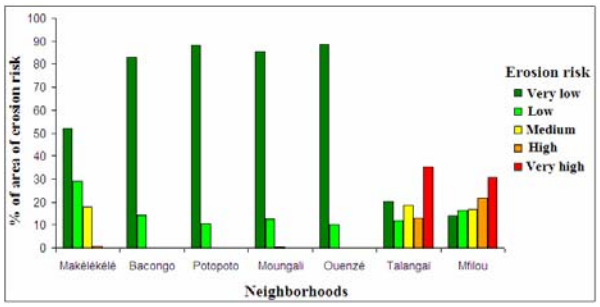

Figure-6. Erosion risk distribution by neighborhoods.

The GIS has been very important to study the erosion risk in the city of Brazzaville which has developed a simple model but efficient. It would be desirable for the future applications to change or increase criteria and vary classes for each criterion to assess the variation in the final result. Moreover, the method used to assess the erosion risk can be improved by including a number of other information, such as climate data, soil depth, soil texture, thus the results may fit closer to reality. However, the most accurate way to calculate the risk of erosion is the application of a quantitative model to provide numerical data on the amount of soil loss per unit of time and space [19]. The lack of information in the study area about factors that significantly influence the erosion processes makes that the application of a quantitative model is not feasible in the near future but promising projects will obtain data to characterize these factors.

5. CONCLUSIONS

The compilation of existing maps and field georeferred information prove a low cost and represent a useful database to start a debate in Brazzaville about decision-making in the natural spaces management. The sequence of steps presented may be applied in a short time based generally on available data, or data obtained easily. The method also shows that even if with limited data we can assess the risk of erosion in an area without making the quantification of the erosion processes. In view of these results, the erosion risk in the study area can be transformed into a direct threat to the local people. For this reason, we propose some control systems and practices to mitigate the soil erosion.

Based on this work, the control measures of soil loss most effective and appropriate for the city of Brazzaville could be the planting of trees, infiltration trenches, construction of terraces and bench terraces with stone and vegetation. This practice is recommended for areas with higher slopes between 20 and 35%. Despite the existence of marked differences in the erosion risk

between one neighborhood and others, in general neighborhoods like Mfilou and Talangaï show areas affected by high and very high erosion risk, almost 50% of each of these neighborhoods showed medium to high erosion risk. This is due to the conversion of the vegetation to residential areas held by the local people. These actions are caused by the implementation of houses in hazardous areas. The soils are eventually exposed and it is going to intensify the erosion process.

The consequences of the erosion processes are not confined into the higher areas, but the most serious effects move downstairs areas. Therefore, due to the hilly terrain aspect of the neighborhoods Talangaï and Mfilou, it is important to preserve the primary vegetation left.

The analysis of all the work is concluded that the integral city of Brazzaville shows a concerned erosion risk by the conjunction of several circumstances like the high degree of deforestation, especially in the young neighborhoods, the steep slopes and the heavy rainfall produced in a short time.

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