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Cartography of environmental vulnerability to soil erosion of the urban area of Brazzaville using Geographic Information System (GIS)

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Abstract

Urban areas are recognized as important regions by their fragilities and dynamic. The study area is located in the Brazzaville city and it is well known by strong anthropogenic action on it. This research has generated maps of natural and environmental vulnerabilities to soil erosion from base maps of soils, slope, occupation and land use. From these maps it is possible to recognize sensible areas from environmental problems, by allowing recommendation toward best advantage for control and environmental management. The maps elaboration aims to show the intensity and the distribution of vulnerability, mainly considering the stability related to topographic and soil aspects. The methodology consists of a logical integration and processing of different available data to create a georeferenced database in Arcgis 9.3.1 program. This computer program allows an efficient analysis of different information layers taking into account the vulnerability of each environmental elements submit to analysis.

Keywords: Environmental vulnerability, natural vulnerability, soil, GIS, Brazzaville.

Introduction

In 1972, during the United Nations Conference of Environment in Stockholm, Sweden has emphasized the idea that the man at the end of the twentieth century became the most important co-agent in the overall earth evolution, able to significantly intervene in the ongoing transformation of our planet. From this concern, the evolution of several environmental impact studies has been conducted in order to assess and protect areas with greater sensitivity to changes.

The pressures of occupation and land use of urban areas around the world, its effect on the balance of ecosystems have been a frequently discussed topic in the scientific literature[1, 2]. Urban areas are constantly affected by natural morpho dynamic factors such as slope angle, runoff, among others that abruptly changes a local morphology[3].

The industries development also contributes to the ecological destruction that causes land degradation and increases natural disasters[4]. The industrialization and urbanization have some consequences that can affect negatively ground water in some areas where the aquifer is a main source of drinkable water[5]. That is to say ground water receives industrial or municipal waste that has a negative impact on the environment by adding pollutants into ground water and soil; this affects not only the environment but also the human health[6, 7].

The soil erosion is accelerated by the removal of vegetation like plants and shrubs in tropical forest areas. Then, the soil erosion is a consequence of deforestation where the ground losses its stability and it is exposed to erosion agent like rainfall. The deforestation involves the process of disappearance of woodland and forest due to the anthropogenic action such as farming, logging for industrial needs and agriculture by using pesticides to stop insects[8]. These human activities have negative impact for water by producing contaminants like mercury (Hg), arsenic (As) and lead (Pb)[9].

On the other side, the urbanization has an advantage on the growth of cities and the construction of new houses which sometime are placed on fertile soil. This causes the lost of agriculture land, destroying the micro flora and micro fauna[10, 11].

While, the Brazzaville city has faced many problems related to irrational occupation and land use of the environment. Till now there are no studies focused on land use planning in Brazzaville city. However, the city suffers consequences especially in the rainy season where it is noticed that people living in vulnerable areas face erosion risk. That is to say people have obligation to make a good choice for implementing houses in order to avoid negative effects caused by erosion process.

In order to comply with the provisions of the city of Brazzaville, concerned about the significant increase in problems related to the misuse of the physical environment and public pressure, the city of Brazzaville is in interest to prepare a Master Plan for Urban Municipality and Environment.

The study presented here gave important information for the steps taken in the development of the Master Plan for Urban Development and Environment of Brazzaville and aimed to add information about the physical environment (compiled and produced) in one document generating cartographic database that will afford in the future a development of a more extensive system with addition of physical and socioeconomic information.

Material and Methods

Study Area: Brazzaville city is located on the right bank of Congo River which it shares with Kinshasa city. Its extension is about 30 km and has seven neighborhoods as shown in figure-1. According to the report of the National Center for Statistics and Economic Studies in 2008[12], more than one million people live in Brazzaville. This represents a little more than thirty percent of the total population of the Republic of Congo. The relief of Brazzaville has a very varied aspect. It consists of hills, plateaus and plains[13]. The plateaus are as belt surrounding plains. These plateaus are converted to hills in the area of Nkombo and Massengo located in Talangaï and Mfilou neighborhoods, respectively. Some areas of Talangaï and parts of Ouenzé, Moungali, Poto-Poto (figure-1) are located in the plains and are submit to flooding during rainy periods[14].

The climate of Brazzaville is kind of “Bas Congo” with a rainy season from October to May and a long dry season from June to September. It has also a slowing down of rainfall between January and February[15]. The mean of lowest temperatures recorded is 19°C during the dry season in July. The mean of highest temperature is 30°C during the rainy season. Precipitation changes are relatively small and fluctuate between 800 and 1800 mm[16].

Brazzaville city is characterized by savannah including typical species of sandy soils. The plateaus contain grove and gallery forests bordering streams[17]. Below Batékés plateaus rich in water, the city of Brazzaville is covered by different rivers such as Djiri in the north, then Tsiémé, Mfoa and Madoukou in the center and finally Djoué and Mfilou in the West[18]. The eastern part is bounded by the Congo River, the second largest river in the world after the Amazon which has a flow about 43000m^3/s[19] (figure-1).

In general, Brazzaville soils are very poor in clay and organic matter. They are called lateritic and classified into four main groups: podzols soils, ferralitic soils, hydromorphic soils and unsophisticated soils[20, 21].

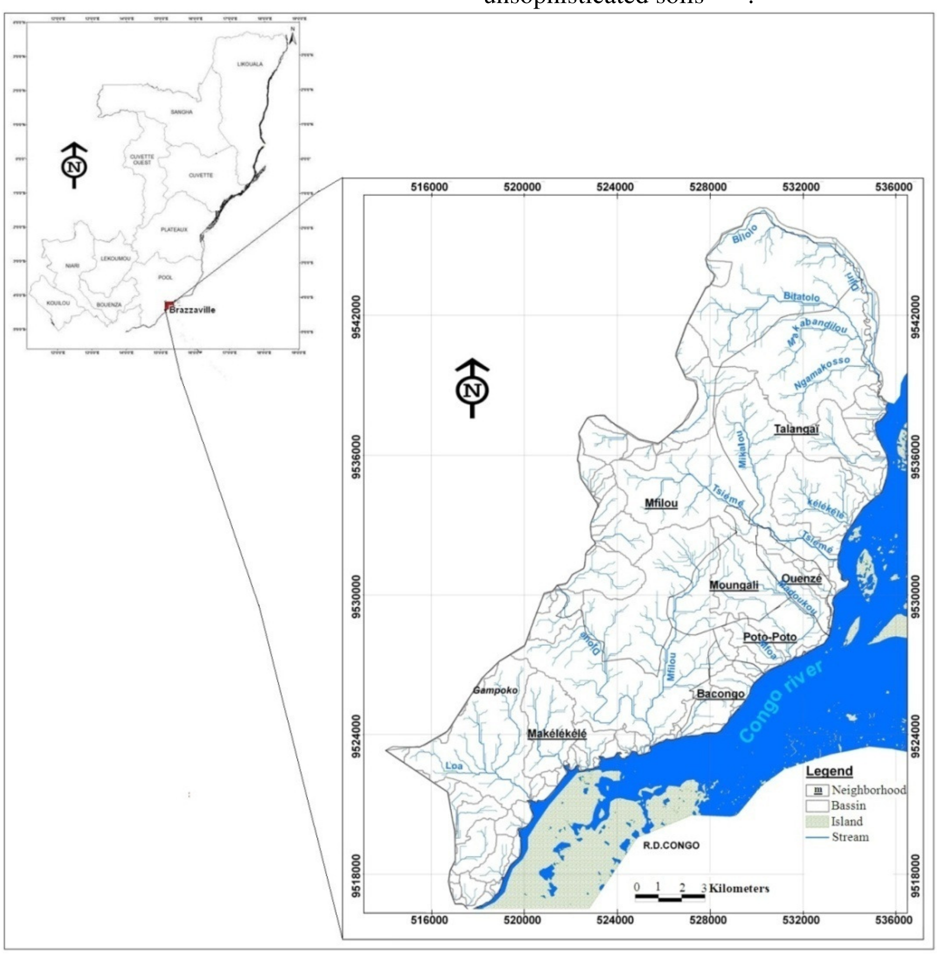

Figure-1
Location map

Available data: The basic information was collected during the field work in the study area. This is complemented by the following preexisting maps: Map of vegetation and land use obtained from two Landsat ETM+ images from year 2012 (end of the dry season), soils map prepared by the Geological Survey of ORSTOM, political map prepared by the National Institute of Geography of the Republic of Congo and cadastral service[22, 23], slope map produced from the Digital Terrain Model made from SRTM with 90 meter of resolution obtained at the Observatory of Central African Forests (OSFAC). The integration of alphanumeric data and maps has been made possible through the Arcgis 9.3.1 softweare.

Methodology: The methodology consists of a logical integration of different available data knowing the study area in terms of physical and environmental aspects. All information obtained is stored as a spatial database for analysis and subsequent processing with arcgis 9.3.1 where data of natural and environmental vulnerability maps were crossed (figure-2).

The basic maps used to prepare a natural vulnerability map are: soil map, slope map and vegetation map. The maps overlay is made in order to produce a new map that reflects sensitivity of each environment elements toward erosion process (table-1). The data processing was done by adapting some pre-existent norms according to the environmental context of our study area. These norms propose vulnerability values ranging from 1 to 3 (table-2) with a class interval of 0.5 [24, 25].

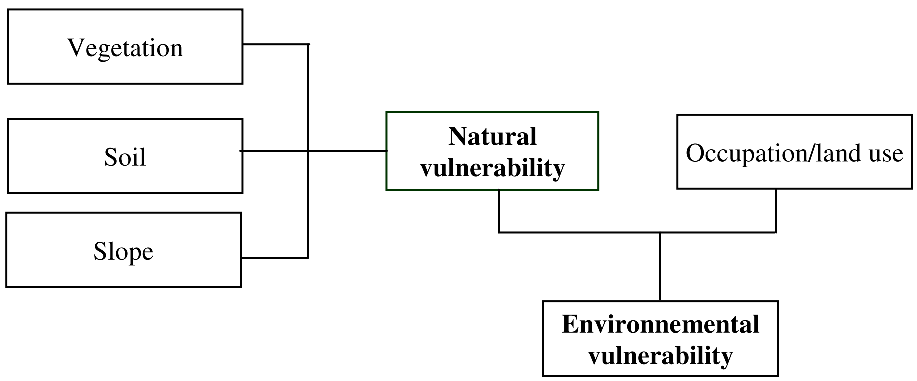

Figure-2
Procedure for the natural and environmental vulnerability cartography

Table-1
Degree of vulnerability of geological map

Class	Type of material	Degree of vulnerability
1	Unaltered compact rocks, conglomerates strongly cemented, crusts, ferruginous sandstone outcrops (limestone massifs, soils heavily rocky, igneous or eruptive rocks, local encrusted soil)	1.0
2	Cohesive soils or fractured rocks or moderately weathered	1.5
3	Rocks or sedimentary soils weakly or moderately compacted (slate, shale, marl, etc.)	2.0
4	Rocks and / or profoundly weathered (marl, gypsum, clay slate, etc.)	2.5
5	sediment or soft ground, cohesive and non detrital material	3.0

Table-2
Degree of vulnerability of slope map

Class	Slope (%)	Degree of vulnerability
1	0 - 3%	1.0
2	3% -12%	1.5
3	12% - 20%	2.0
4	20% - 35%	2.5
5	>35%	3.0

In our case we just worked with class 5 that represents soils. According to the geological context of our study area the one geological material that outcrops is different types of soils as this justifies the significant degree of vulnerability for these materials attributed to a single class 5. The intervals of the slopes are grouped into five classes according to their impact on the risk of erosion as shown in table-2. These intervals have been taken from the study "priority areas for soil conservation in the city of Brazzaville led by the Ministry of Forestry and Environmental Economics and implemented in 2010.

It has been considered that the higher the slope the greater percentage of soil erosion. An increase in the slope angle causes an increase in the speed of streaming and thereby the kinetic energy of the water that causes increased movement of soil particles. There is variability between erosion potential for each type of land use, that is to say not all types of vegetation, land use and occupation are in the same degradation state. Erosion that occurs in a forest is not the same as that produced in a savannah, or one that occurs in a well conserved area or on bare ground, or that which occurs in areas with or without built conservation practices. In this study, the categories defined in the occupation and land use are shown in table-3.

Table-3
Degree of vulnerability of occupation and land use

Class	Vegetation and occupation/land use	Degree of vulnerability
1	Lake	1.0
2	Forest	1.5
3	Savannah	2.0
4	Built	2.5
5	Bare ground	3.0

The maps algebra was performed using the spatial analysis tool of Arcgis 9.3.1 software which allows a crossing between two maps. First, we crossed soil map and a slope map, then the maps of slope, vegetation and land use (figure-2). Subsequently, the two maps were crossed to produce a vulnerability map and then determine the vulnerability intervals by Arcgis 9.3.1. In order to obtain more detailed results, the vulnerability was divided into five classes as shown in table-4.

Table-4
Average rating for Natural vulnerability classes

Classification	Arithmetic mean
Very low	0 - 1.3
Low	1.4 - 1.7
Medium	1.8 - 1.22
High	1.23 - 2.5
Very high	2.6 - 3.0

Source: adapted from[25]

The environmental vulnerability means the level of susceptibility that presents the environment against the human intervention. Thus, the classification of different occupation and land use is based on the kind of action led by a man on the environment. This was obtained by crossing maps of different kinds of susceptibility[26]. In order to obtain an environmental vulnerability map that represent most accurately the characteristics of the study area, we respected the environmental classification units proposed in some studies[27]. These values have been taken considering the importance given to the capacity of each environmental unit to be exposed or not to erosion risk (table-5).

Table-5
Importance of factors in the analysis of environmental vulnerability

Factors			
Slope	**Soil**	**Vegetation**	**Occupation/land use**
0.2	0.1	0.1	0.5

Source: adapted from[25]

Results and Discussion

The natural and environmental vulnerability maps serve for decision making by the government or private agencies. The objective of vulnerability maps is to represent the knowledge of the soil erosion behavior in relation to the irrational occupation and land use. The natural vulnerability map aims to show the intensity and distribution of the environment susceptibility over the city taking into account the stability of factors as relief, vegetation and soil. The map of environmental vulnerability refers to the environmental susceptibility to human action. The natural vulnerability map (figure-3) shows the distribution of the categories or classes of vulnerability on the study area and its related areas in hectares and percentages. This map shows the behavior of physical features in the face of natural process of erosion without human interference.

The table-6 shows that the category corresponding to the average surface more vulnerable represents 55.42%, followed by the very high vulnerability (16.60%), low vulnerability (13.48%), very low vulnerability (31.94%) and lastly high vulnerability 26.64%).

Table-6
A natural vulnerability in hectare% of the study area (Brazzaville city)

Natural vulnerability		
Category of vulnerability	**Area (ha)**	**%**
Very low	8070.78	31.94
Low	3406.2	13.48
Medium	2857.88	11.31
High	6731.55	26.64
Very high	4202.16	16.60
TOTAL	**25268.58**	**100.00**

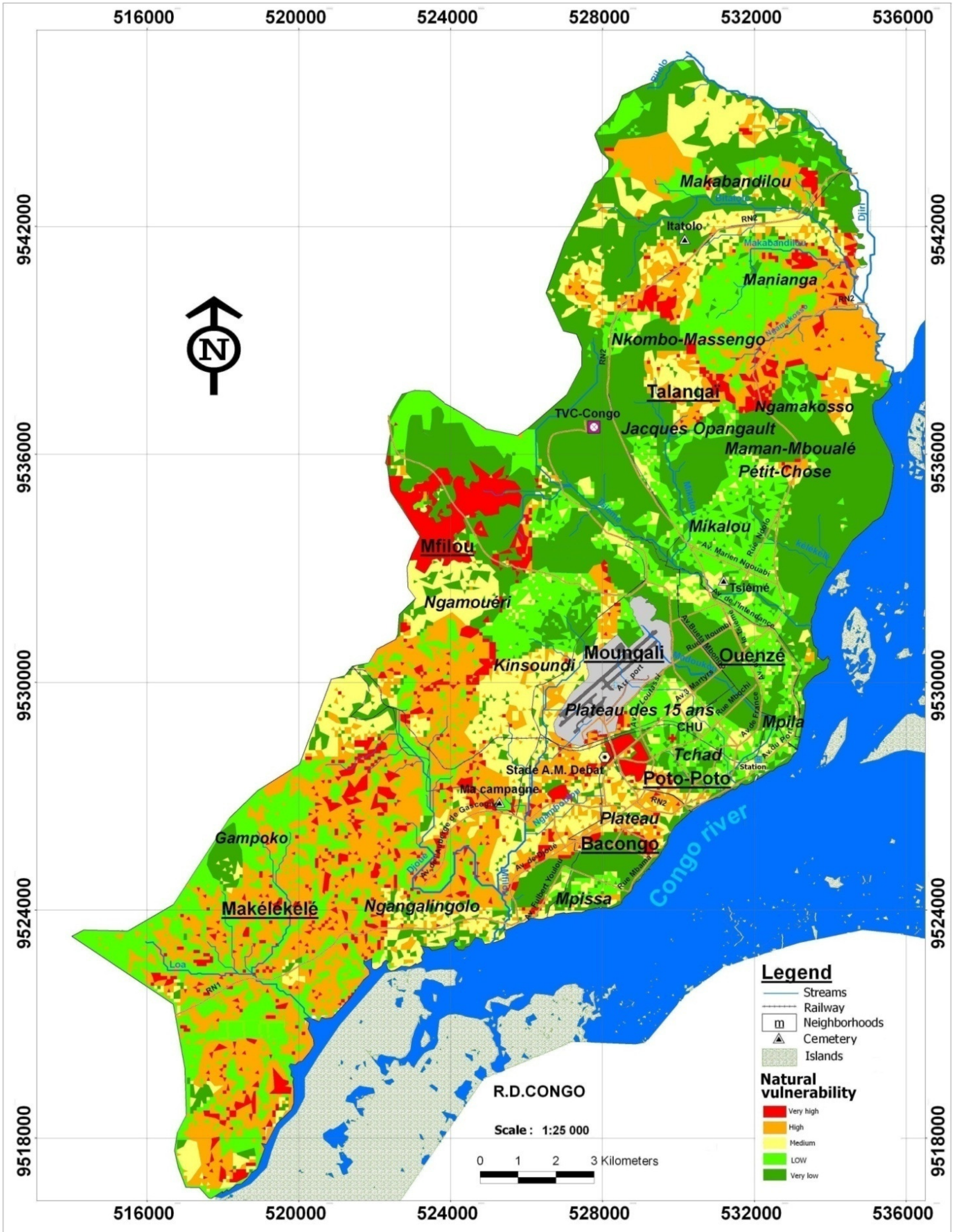

Figure-3
Natural vulnerability map

The environmental vulnerability is any set of environmental factors of the same nature in the face of activities that are occurring or likely to occur and may suffer adversity or affects in whole or in part the ecological stability of the region in which occurs[28].

The environmental vulnerability has been determined by maps algebra using the Raster calculator tool in Arcgis 9.3.1. The maps of different factors involved in natural vulnerability are considered with value attributed to each factor importance as shown in table-5 and applying the following formula:

0.2 x slope + 0.1 x soil + 0.1 x vegetation + 0.5 x land use (1)

In this formula, the slope factor has weight more than soil factor because it has a strong influence in shaping the land forms as a result of the constant action of physical processes and climatic variations or activities of supplying sediments carried by surface water[29].

The occupation and land use factor has gained a higher weight than the others with a value of 0.5 because human factors are considered relevant as landscape modeling agent. In this sense, it is very important in any type of environmental analysis, especially in a place where the confluence of economic activities of potential environmental risk, for example industrial activities and implementation of private and public infrastructures. Therefore, the occupation and land use serve to demonstrate how the environmental units studied suffer from anthropogenic pressure. The environmental vulnerability map with a combination aforementioned is shown in figure-4. Areas and its equivalent percentages are shown in table-7. The environmental vulnerability is distributed as follows: very low vulnerability (37.05%), low vulnerability (18.45%), medium vulnerability (15.31%), high vulnerability (10.44%) and very high vulnerability (18.72%). In adding the very low, low and medium vulnerability, one obtains 70.81%. This explains that most of the study area is affected by soil erosion.

The implementation of the occupation and land use in a region requires knowing how the environment reacts to anthropogenic pressures imposed and how the environment resists to these pressures. The generation of map aims to show the intensity and spatial distribution of the natural vulnerability. While the environmental vulnerability, implies the importance of the man in the transformation of environment and its possible consequences for the population. The aim of this map is to make us aware of environmental behavior of soils regarding an improper land use or occupation of the environment. From the two maps, it is possible to know areas that are subject to a high risk of erosion and those which are potentially stable for a better environmental management.

The areas of very low vulnerability, naturally found in Brazzaville are areas covered by undisturbed forest. The natural vulnerability category low or medium is mainly distributed in areas with savannah vegetation. Areas of high and very high vulnerability represent mountainous areas with increased pressure on environmental units. In these areas, human activities are considered as dangerous situation for local people.

Table-7
Environmental vulnerability in hectare and percentage (%) of the study area

Environnemental vulnerability		
Degree of risk	**Area (ha)**	**%**
Very low	9364.38	37.05
Low	4663.03	18.45
Medium	3869.29	15.31
High	2640.28	10.44
Very high	4731.58	18.72
TOTAL	**25268.58**	**100.00**

In Cuba, it has been proven that the use of different methods in environmental studies has highlighted some problems in the comparison of results, so sometimes in the same geological situation one can get different results according to the method and technique used. In this context, the methodological approach applied to a region of lateritic soils of Havana, considering the soil morphology method and the dynamic of the biological environment, has shown that according to the scale of representation used for different geo systems, it would not be possible to study the erodibility of soils with similar methods[30].

Moreover, the thematic maps used to assess factors of soil erosion have proved the benefits of GIS. Recently, a methodological approach for the design and GIS implementation for soil of hillside regions of Cuba have shown the efficiency in the decision-making process on the use and soil conservation[31].

Conclusion

The protection of our natural and economic resources means we are preparing to respond decisively and effectively in an emergency in case that is occurring erosion processes. Environmental studies are not sufficient to ensure proper and efficient management of the environment.

The methodology associated with the software tool for analysis is flexible and allows the inclusion of additional information or a review of the thematic information and criterion used which can reach a decision. The interpretative map can be prescriptive indicating also the most sensitive areas and the most suitable for the development of specific projects.

The potential relationship between environmental vulnerability map and additional information provide spatial and georeferencing results, one important and useful tool for decision-making and to prevent environmental disasters. The results regarding the vulnerability caused by erosion are products of a limited database. So, additional information is required as well as field studies and more accurate mapping scale for further analysis. However, this analysis serves as a first approach for future studies. From the environmental vulnerability map is worth noting neighborhoods Mfilou-Djiri and Talangai presenting high dangerous areas for housing deserve special attention to avoid the worst.

The activities developed by the irrational land occupation are of great risk to the environment and people living around. Apparently, the local population is not aware of the risks and is not ready to face them. The government has to take important measures to prevent and reduce accidents which may damage the space that everyone needs to live. Therefore, the creation of a contingency plan becomes extremely important like reforestation systems, information and alert, physical planning and environmental protection.

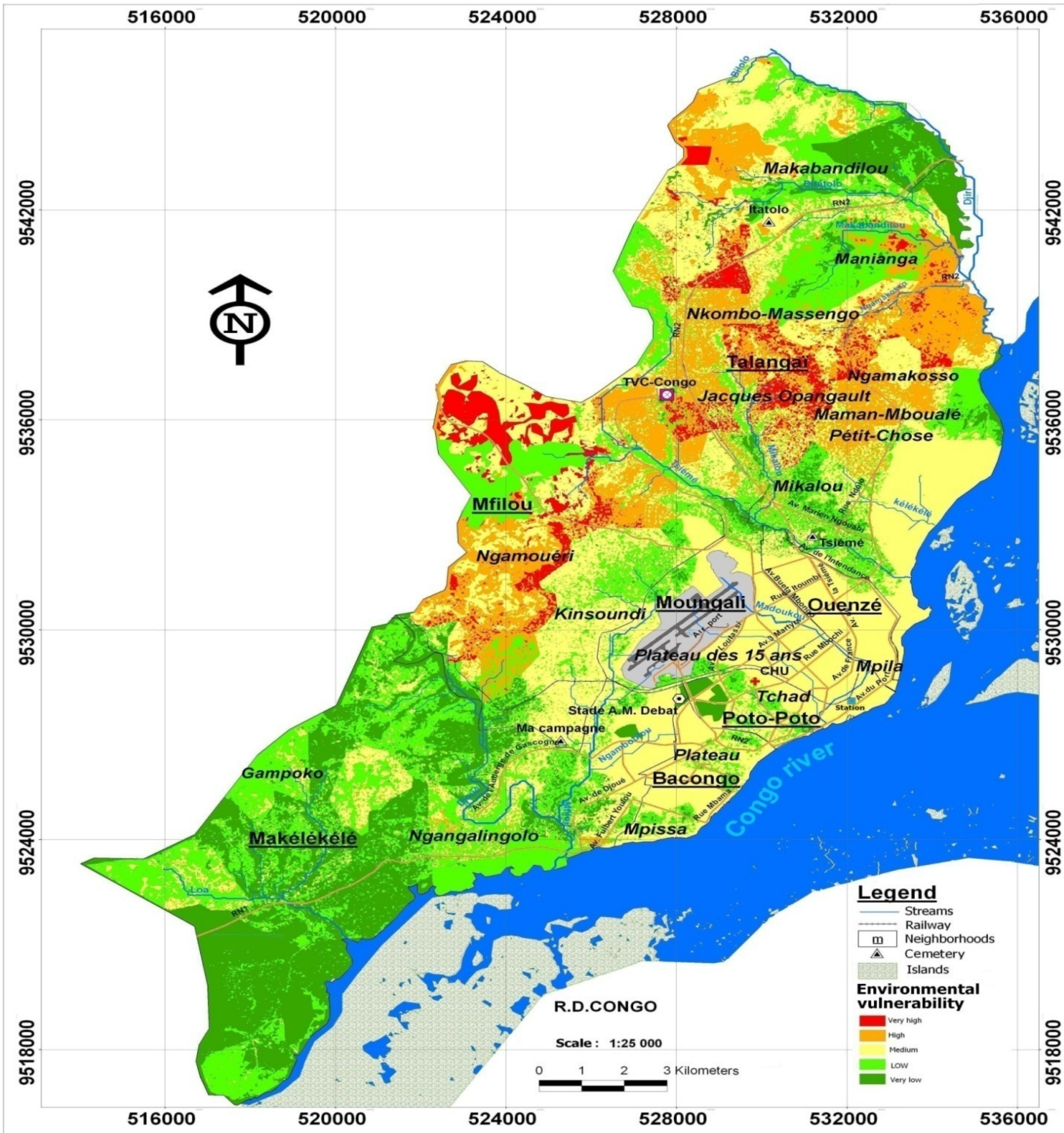

Figure-4
Environmental vulnerability map

References

1. Sharma M., Mishra S.K. and Tyagi S., The Impact of Torrential Rainfall in Kedarnath, Uttarakhand, India during June, 2013**,** *International Research Journal of Environment Sciences,* **2(9),** 34-37 **(2013)**
2. Louiza R., Artificial and Natural Regeneration of the Forests of Bombay Presidency: 1838 to 1860, *Research Journal of Recent Sciences,* **1(2),** 113-118 **(2012)**
3. Costa M.I.P., Os Sistemas de Dunas Litorâneas da Região de Natal: Granulometria e Morfoscopia dos Grãos de Quartzo. Natal. UFRN/CCET, Departamento de Geologia, Boletim **1**, 1-5 **(1999)**
4. Ladwani K.D., Ladwani K., Manik V.S. and Ramteke D.S., Impact of Industrial Effluent Discharge on Physico-Chemical Characteristics of Agricultural Soil, *International Research Journal of Environment Sciences,* **1(3),** 32-36 **(2012)**
5. Nirmala B., Suresh K.B.V., Suchetan P.A., Shet P.M., Seasonal Variations of Physico Chemical Characteristics of Ground Water Samples of Mysore City, Karanataka, India, *International Research Journal of Environment Sciences*, **1(4),** 43-49 **(2012)**
6. Sangamner N.A., Malpani C.D.J., Impact of Human Activities on the Quality of Groundwater from Sangamner Area, Ahmednagar District, Maharashtra, India*, International Research Journal of Environment Sciences,* **2(8),** 66-74 **(2013)**
7. Matini L., Ossebi J.G., MBedi R. and Moutou J.M., Rare Earth Elements in Soil on Spoil Heap of an Abandoned Lead Ore Treatment Plant in the District of Mfouati, Congo-Brazzaville, *International Research Journal of Environment Sciences,* **1(2),** 33-40 **(2012)**
8. Abbai S.S.and Sunkad B.N., Effect of Anthropogenic Activities on Zooplankton Population of Sogal Pond, Belgaum District, Karnataka, India, *Research Journal of Recent Sciences,* **2(7),** 81-83 **(2013)**
9. Patil S.G., Chonde S.G., Jadhav A.S., Raut P.D., Impact of Physico-Chemical Characteristics of Shivaji University lakes on Phytoplankton Communities, Kolhapur, India, *Research Journal of Recent Sciences,* **1(2),** 56-60 **(2012)**
10. Gohil B., Kundu R., Ecological Status of *Cellanaradiata* at Dwarka Coast, Gujarat, India**,** *Research Journal of Recent Sciences,* **2(5),** 1-5 **(2013)**
11. Seyed A.R.H., Gholamreza E., Hoshang A., Biomass of Fish Species in the Shadegan Wetland, IRAN, *Research Journal of Recent Sciences,* **1(1),** 66-68 **(2012)**
12. CNSEE., Répartition de la Population du Congo Brazzaville par Département et par Commune et Projetée 2000 à 2015 **(2008)**
13. Codou A., Géographie : la République Populaire du Congo, Hatier, collection André-Journaux, **79**, 7-11 **(1976)**
14. Nanitelamio B.G., Qualité des eaux des sources et puits dans les quartiers périphériques de l'arrondissement 1 de la ville de Brazzaville, Mémoire de CAPES, E.N.S., Université Marien Ngouabi, Brazzaville, **76**, 2-3 **(2006)**
15. Vennetier P., Atlas de la République du Congo, Edition J.A., **67**, 45-50 **(1977)**
16. Moukolo N., Etats des connaissances actuelles sur l'hydrogéologie du Congo Brazzaville, ORSTOM, Brazzaville, **120**, 47-58 **(1992)**
17. Makany L., Végétation des Plateaux Tékés (Congo), collection des travaux de l'Université M. Ngouabi, Brazzaville, **301,** 2-7 **(1976)**
18. Mayima A., Etude de l'érosion dans les quartiers Kingouari, Kinsoundi, Météo, Ngangouoni Moukoundzi Ngouaka dans le versant du Djoué au Sud de Brazzaville, Mémoire de Maîtrise, Faculté des Lettres et des Sciences Humaines, Université Marien Ngouabi, **118**, 5-8 **(2007)**
19. Samba K.M.J. Le climat du Bas Congo, Thèse de doctorat 3ème cycle, Université de Bourgogne, C.R.C. de Dijon, **280**, 120-133 **(1978)**
20. Schwartz D., Les sols des environs de Brazzaville et leur utilisation, ORSTOM, Pointe Noire, **21**, 15-17 **(1987)**
21. Nzila J.D., Les sols du Congo et les problèmes d'aménagement des sols, E.N.S., Université Marien Ngouabi, **68**, 3-5 **(2001)**
22. O.R.S.T.O.M., Carte pédologique de la région de Brazzaville au 1/200 000, Service Central de Documentation **(1974)**
23. Ray H., Etats érosifs dans les quartiers Nord de Brazzaville, Mémoire de DEA, Faculté des Sciences, Université Marien Ngouabi, **48,** 30-31 **(2009)**
24. Barbosa C.C.F., Álgebra de mapas e suas aplicações em Sensoriamento Remoto e Geoprocessamento. Programa de Pós-graduação em Sensoriamento Remoto. Instituto Nacional de Pesquisas Espaciais, São Paulo, Dissertação de Mestrado, **126**, 101-120 **(1997)**
25. Grigio A. M., Aplicação do Sensoriamento Remoto e Sistemas de Informação Geográfica na Determinação da Vulnerabilidade Natural e Ambiental do Município de Guamaré (RN), Simulação de Risco ás Atividades da Industria Petrolífera, CCET. PPGGG. UFRN, Dissertação de Mestrado, **222**, 161-180 **(2003)**
26. Tagliani C.R., Técnica para Avaliação da Vulnerabilidade Ambiental de Ambientes Costeiros utilizando um Sistema Geográfico de Informações, In: XI SBRS, Belo Horizonte, MG, Anais, **2567**, 1657-1664 **(2003)**
27. Chuvieco E., Aguado I., Yebra M., Nieto H., Salas J., Martín M.P., Vilar L., Martínez J., Martín S., Ibarra P., Riva J., Baeza J, Rodriguez F., Molina J.R., Herrera M.A.

and Zamora R., Development of a framework for fire risk assessment using remote sensing and geographic information system technologies. Ecological Modelling, **221**, 46-58 **(2010)**

28. Bertani R.T., Neto A.F.A., Matos R.M.D., O habitat do petróleo da Bacia Potiguar Emersa. Boletim de Geociências da Petrobrás. **1(1),** 41-49 **(1987)**

29. Silveira I.M., Estudo evolutivo das condições ambientais da região costeira do Município de Guamaré-RN. Programa de Pós-graduação em Geodinâmica e Geofísica da Universidade Federal do Rio Grande do Norte, Natal, Dissertação de Mestrado, **177**, 102-107 **(2002)**

30. Febles J.M., and al., Limitaciones objetivas del “perfil patrón” como índice diagnóstico para evaluar la intensidad de la erosión en Cuba, En: Memorias, 3ra Jornada Científica del Instituto de Suelos. Academia de Ciencias de Cuba, La Habana, **255**, 227-232 **(1985)**

31. Garea E., Métodos para el manejo de la información de suelos en las regiones montañosas de Cuba mediante técnicas digitalesInstituto Técnico Militar José Martí, La Habana. Thèse de doctorat, **114**, 95-105 **(2003)**