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Estimating Soil Loss by Water Erosion in the Microwatersheds of Brazzaville City

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Abstract: ***Micro watersheds of Brazzaville city are one of the main sources of drinking water supply in urban and neighboring areas. One of the factors that affect the hydrological functioning of these watersheds is the loss of soil by water erosion, which is accelerated by the intense deforestation due to illegal activities of housing construction in hazardous areas. The change in land use destroys vegetation cover and is the leading cause of water erosion intensification in the city. It is estimated that the annual rate average of current erosion is 7.86 ton/ha/year based on the Universal Soil Loss Equation (USLE). This is very noticeable in the middle and upper parts of slopes in the basins.***

Keywords: Universal soil loss equation, water erosion, Brazzaville, microwatersheds, urban area

1. Introduction

The great demand for housing accompanied by an illegal steep slopes occupation of the northern, northeast and northwest neighborhoods of Brazzaville city has changed the landscape of the environment and soil quality in areas affected by water erosion. The basins of the north, northeast and northwest districts of Brazzaville city show signs of deterioration in water, soil and vegetation, which are reflected in the high level of vulnerability experienced by the local population against water erosion and damage registered yearly after each episode of disasters. Problems of gullies growth have been reported and hazardous landslides that have caused human and material damage due to water erosion in populated watersheds. Determining degradation of a basin or subarea by water erosion, it is based on the assessment of soil quality, climate, topography, land use and land cover. The soil is a determining factor and is considered a basic resource that others are derived, such as vegetation. One methodology for quantifying soil degradation parameters is proposed by Wischmeier and Smith [1]. This methodology allows determine the annual rate average of soil loss by calculating soil loss, considering rainfall, vegetation cover and uniform type of soil. This universal soil loss equation (USLE) is based on the ability of raindrops to loosen soil particles [2].

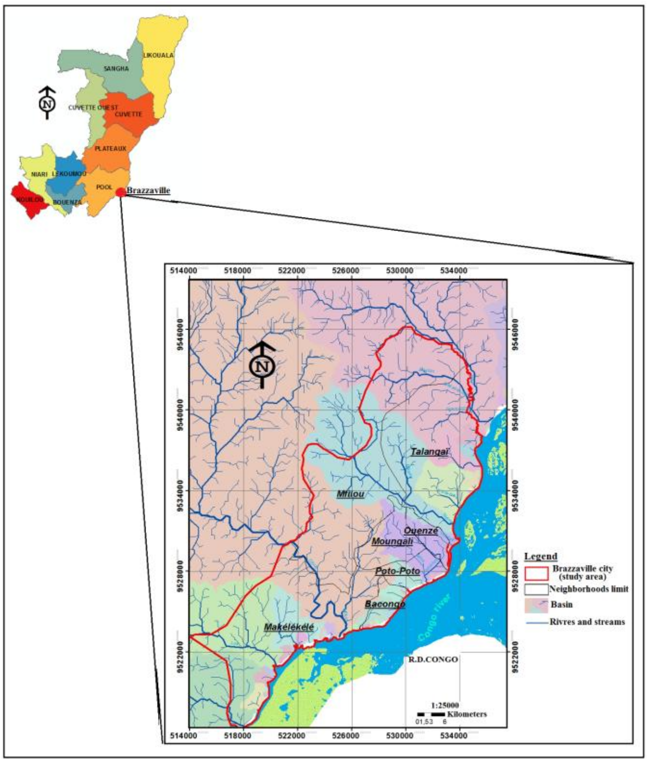

Figure 1: Study area location

This paper takes water erosion as one of the key steps to calculate and determine the soils degradation. It is based on the empirical method for calculating current and potential erosion, using databases to feed the model in the geographic information system (GIS). Geologically the groups of rocks from Precambrian to Paleozoic outcrop downstream of Brazzaville city, while the sedimentary cover from Mesozoic to Cenozoic outcrops upstream of Stanley Pool [3]. The study area is located in Brazzaville city, capital of the Republic of Congo, on the right bank of Congo River. It lies in the mapping area 33S between latitudes 4°10' and 4°17' South and between longitudes 15°16' and 15°45', being housing activities the main land use in Brazzaville city.

2. Materials and Methods

It was used data type of Digital Elevation Model derived from the treatment of Shuttle Radar Topography Mission (SRTM) image with input spatial resolution of 90 meters and output spatial resolution of 10 m. Landsat scene 185/62 from 2013, for mapping vegetation cover and land use. Geometric correction was made from 50 points. The images were rectified in the reference system called Universal Transverse Mercator with Datum World Geodetic System 1884 (WGS84) for Zone 33S. Polynomial of first degree linear fit was used, and the mean square error was calculated (RMS) with a value of 0.77 considered acceptable [4].

Estimating soil loss by water erosion in watersheds of Brazzaville city by assessment of current and potential erosion was based on the Universal Equation of Soil Loss, being an empirical model, in which soil loss is expressed as mass per unit area per unit time and is a function of the combined effect of six factors: rainfall erosivity (factor R); soil erodibility (factor K); length slope (factor L); degree of slope (factor S); vegetation management (factor C) and mechanical practices factor in the management of agricultural vegetation (P).

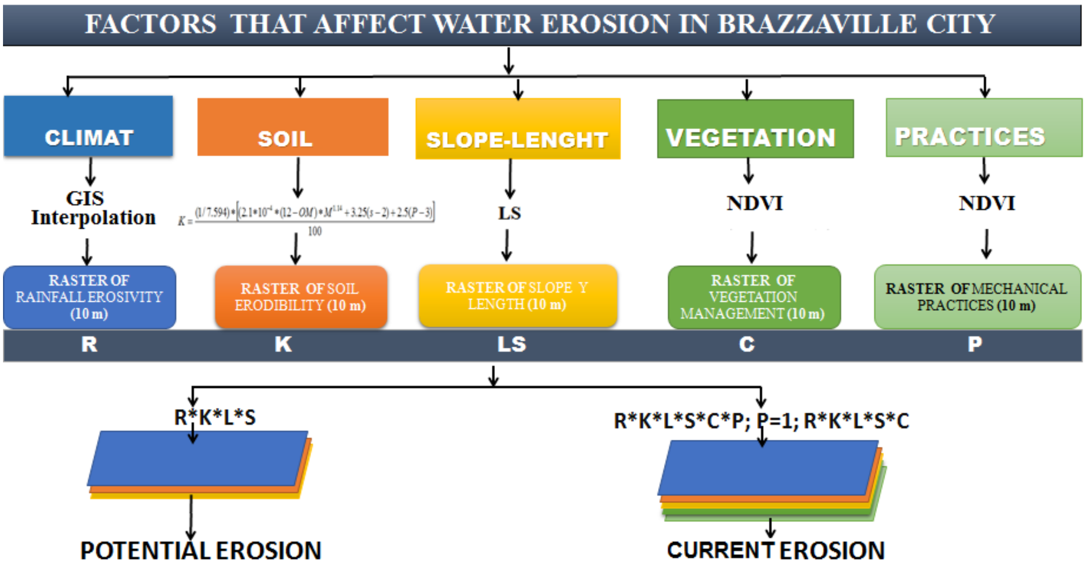

Figure 2: Methodological framework for calculating soil loss by water erosion in Brazzaville city, Republic of Congo

The function describing the process is expressed in equation (1).

$$A = R * K * L * S * C * P \qquad (1)$$

Where:
A = Average of annual soil loss per hectare expressed in tons/ha/year
Factor R = Rainfall erosivity factor in MJ.mm/ (ha.hr)
K =Soil erodibility factor in ton.ha.hr/ (MJ.mm.ha)
S = Slope degree factor, is dimensionless
L = Slope length factor, is dimensionless
C = Vegetation management factor, is dimensionless
P = Mechanical practices factor in the management of agricultural vegetation, is dimensionless

When considering all factors of USLE, it is said to have calculated the current water erosion, however when factors C and P are not included, it is calculated the potential water erosion, and estimate of how much land is lost if there were no vegetation cover and no conservation practices. Figure 2 presents the general methodology for determining each of the factors involved in the cartographic model to estimate the annual loss of soil by water erosion in Brazzaville city.

The factor R represents the erosivity as the potential ability of water drops of rain to cause erosion. It focuses on the detachment of soil particles by laminar erosion [5]. In this paper, through the analysis of 20 weather stations the erosivity map was obtained by interpolation in GIS and expressed in MJ.mm/ha.hr.
The factor K is the soil erodibility factor representing both the susceptibility of soil to water erosion and runoff rate, measured under the conditions of a unitary standard area. Soil structure affects both susceptibility to detachment as infiltration. The soil erodibility factor was calculated using the equation (2) taken from the Wischmeier nomogram [5].

$$K = \frac{(1/7.594) * \left[(2.1 * 10^{-4} * (12 - OM) * M^{1.14} + 3.25(s-2) + 2.5(P-3)\right]}{100} \qquad (2)$$

K = soil erodibility factor (t*acre*hr/100*tf *acre.pie in)
OM = organic matter [%]
S = soil structure code
P = permeability code

M = product of fractions of particles with primary grain size or (% silt +% very fine sand)* (100 -% clay)

The monogram was used to calculate the factor K where is multiplied by 0.1317 to remain in International System Units
(T*has*h*ha-1*MJ-1*mm-1).

The factor of slope degree (LS). From the Digital Elevation Model (DEM), the raster generated from terrain slope (θ). The slope length L (λ) is defined as the horizontal projection of the hypotenuse of the slope. This factor was obtained by the equation (3).

$$L=\left[\frac{\lambda}{22.1}\right]^{m};m=\frac{F}{1+F};F=\frac{\sin\beta/0.0896}{3(\sin\ \beta)^{0.8}+0.56} \qquad (3)$$

The factor L with drainage area

$$L_{(i,j)}=\frac{(A_{(i,j)}+D^{2})^{m+1}-A_{(i,j)}{}^{m+1}}{x^{m}\times D^{m+2}\times(22.13)^{m}} \qquad (4)$$

Where $A_{(i,j)}$[m] is the unitary contributing to the input area of a pixel; D is the pixel size and x is the factor of shape correction.

The factor S: the angle β was taken as the average angle for all subgrids in the direction of greatest slope.

$$S_{(i,j)}=\begin{cases}10.8\sin\beta+0.03 & ;\tan\beta<0.09_{(i,j)}\\ 16.8\sin\beta-0.5 & ;\tan\beta\geq 0.09_{(i,j)}\end{cases} \qquad (5)$$

Factor of vegetation cover (C)
As the study area has a low intensity of agricultural use, the factor C is determining based on the Landsat satellite image. Normalized Difference Vegetation Index (NDVI) was calculated according to equation (6).

$$NDVI=\frac{(Band\ 4-Band\ 3)}{(Band\ 4+Band\ 3)} \qquad (6)$$

Where:
Band 4 (0.76 to 0.90 microns)
Band 3 (0.63 to 0.69 microns)

The NDVI varies from -1 to +1, where the vegetation photosynthetic activity tends to +1, while areas like clouds or water tend to -1. Based on field trips of NDVI image, supervised classification was made and training polygons were defined and established four basic categories. Considered as bare soil all terrain without vegetation, which includes gullies and urban areas, as they have similar levels of reflectance.

The factor P is defined as the relationship between the soil loss corresponding to area with conservation practice and soil loss on land under cultivation in the slope direction, its value is dimensionless and is between 0 and 1. When P takes values close to zero indicates that the soil is not being eroded due to conservation practices and when P tends to 1 it indicates that there is the maximum erosion, such as the case of Brazzaville city for the lack of conservation practice.

Water potential and current erosion

The potential and current water erosion were calculated by map algebra of raster layers for all factors of the USLE (Equation 1). To calculate the potential water erosion, factors R, K, L and S were taken in account. Values were obtained as shown in Table 1 [5]. The classification considered the Table 1 and its distribution (Figure 5).

Unlike the potential erosion, the current erosion evaluates the effect of vegetation cover and conservation practices (factors C and P). The classification adopted is one proposed by FAO [5] and shown in Table 2.

3. Results

The rate of annual potential erosion average in the watersheds is 7.56 t/ha/year, if there would not lost completely the vegetation cover. May be increased up to 400 ton/ha/year as the range limit of high erosion. Unlike the potential erosion, classification rank is the proposal by FAO [5] and shown in Figure 5 and Table 2. As can be seen, the effect of factor C is significant because it reduces water erosion, their condition and annual average rate of 7.56 ton/ha/year are located in incipient water erosion.

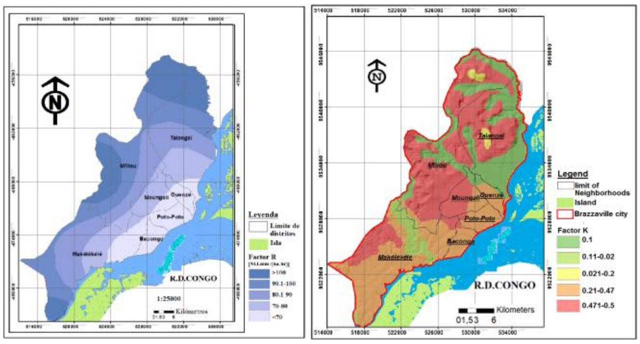

Figure 3: Factors R and K

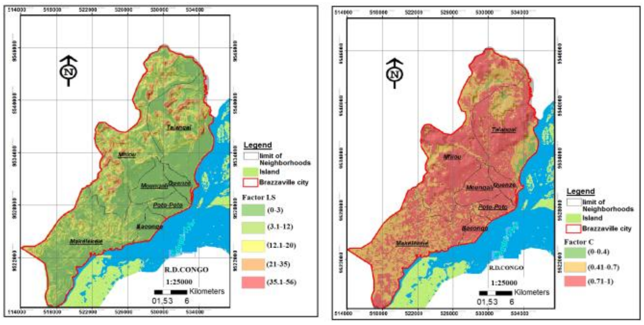

Figure 4: Factors LS and C

Table 1: Potential erosion for Brazzaville city

Erosión	ton/ha/year	Superficie (ha)
Incipient	0-10	16876.27
Low	10-50	4972.28
moderate	50-100	2264.23
High	100-400	1004.87
Very high	>400	357.72

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Table 2: Soil Loss for Brazzaville city

Erosión	ton/ha/year	Superficie (ha)
Incipient	0-10	20891.15
Low	10-50	2225.68
moderate	50-100	1282.97
High	100-400	637.66
Very high	>400	263.82

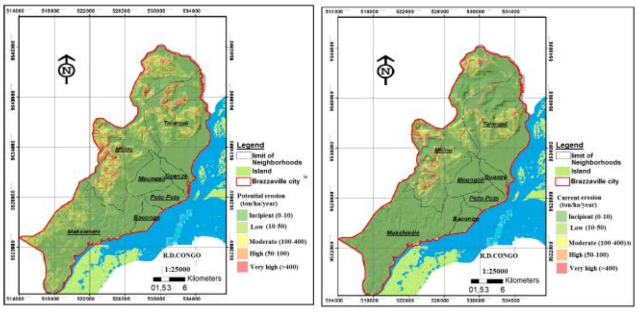

Figure 5: Pontential and current water erosion

4. Discussion

These results are consistent with those found in the Batéké Watershed [6] characterized by an abnormal increase of 0.2 to 0.3 for the factor C. These results are justified by the fact that despite the presence of vegetation, soil surface proportion found on steep slopes (> 35%) led to significant soils loss. Similar results were observed at the Djiri watershed with the presence of very high erosion on steep slops despite the presence of significant vegetation cover [7].

5. Conclusions

The current erosion in Brazzaville city is considered incipient and 7.56 t/ha/year can be increased to 400 ton/year, if not lost completely the vegetation cover in the watersheds. The distribution of potential erosion is determined by the LS and R factors. Areas considered as very high erosion are those with the highest values for both factors. However, areas of high and very high current erosion are determined by the factor C in consequence of deforestation. Based on the degree of erosion and distribution it is possible to implement conservation practices that reduce the effects of water erosion in the process of watersheds degradation. To determine the degradation of the watersheds of Brazzaville city, chemical analyzes of soil degradation and socio-economic studies are needed to draw comprehensive strategies for recovering areas affected by water erosion.

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