The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLII-3/W12-2020, 2020
2020 IEEE Latin American GRSS & ISPRS Remote Sensing Conference (LAGIRS 2020), 22–26 March 2020, Santiago, Chile

ANALYSIS OF POSSIBLE AREAS FOR RAIN GARDENS IMPLEMENTATION IN PLANO PILOTO, BRASÍLIA - DF

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KEY WORDS: Rain gardens, LS Factor, SIG, USLE, Erosion, Flooding

ABSTRACT:

The rainwater is a crucial element in the hydrologic cycle, however, due to human impacts in the environment, this cycle does not work as it should. Roads, highways, buildings, and other kinds of constructions are necessary in a community. These paved areas rely on build drainage systems to function properly, otherwise, the areas impact the waterway and consequently cause serious flooding, such as the ones near to Banco do Brasil, that is a recurring case of flooding' over the last few years. In large cities, the lack of sustainable and green stormwater infrastructure is marked; That is why this study applies to the area of Plano Piloto - Brasília DF. The identification of these possible flooding areas was performed by analyzing the density and drainage order of the region, along with the calculation of the topographic factor (LS), belonging to the Universal Soil Loss Equation (USLE). Thus, this research aimed to locate the ideal areas for the implantation of rain gardens; A shallow depression to capture, temporarily pond, and absorb run-off water from impervious surfaces, for instance roofs and pavement, as Cityofames has shown (2016).

1. INTRODUCTION

When the expansion of urban center occurs in a disorderly manner, it does not take into account many infrastructure factors, such as water supply, sewage services, urban drainage, solid waste, among others. Furthermore, one of the most impaired services is urban drainage, as shown by Melo (2011). One of the methods that can be applied to improve pluvial drainage is the rain garden. The rain garden consists of a depressed area in the landscape that collects rain water from a roof, driveway or street and allows it to soak into the ground. According to Epa (2014) planted with grasses and flowering perennials, rain gardens can be a cost effective and beautiful way to reduce runoff from your property (EPA, 2014). This technique can be implemented in virtually any outdoor location and assists in the infiltration, retention and treatment of water from impermeable areas, avoiding events like erosion caused by water. It is very common in many countries such as the United States and Australia.

One of the most commonly used models for annual soil loss is the Universal Soil Loss Equation (USLE), developed by Wishmeier and Smith (1978) whose expression is:

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

Where
A = Annual soil loss in $Mg \cdot ha^{-1} \cdot year^{-1}$;
R = Precipitation erosivity factor in $MJ \cdot mm \cdot ha^{-1} \cdot h^{-1} \cdot year^{-1}$;
K = Soil erodibility factor in $Mg \cdot h \cdot MJ^{-1} \cdot mm^{-1}$;
L = Ramp length factor;
S = Slope Factor (dimensionless);
C = Coverage and crop management factor (dimensionless);
P = Management practice factor (dimensionless).

In accordance to Galdino (2011), the intensity of water erosion is influenced by both the ramp length, which influences the runoff path, and the slope of the terrain, which are respectively the factors L and S of the equation 1. The Plano Piloto region, located in the Distrito Federal, has been an area with recurrent flooding events, causing big damage to the city. The objective of this work was to identify areas with prominent risk for flooding, and assist those areas in planning a local drainage system, with possible implementations of rain gardens, based on topographic factor combination (LS factor) with strahler order, both directly related to erosive processes.

2. METHODOLOGY

The research was conducted in the Plano Piloto region, located in Brasília - DF, Brazil; between latitudes 15º42'40 "S and 15º51'45" S and between longitudes 47º48'10 "W and 47º56'52" W (Figure 1).

The geographic reference system adopted was the SIRGAS 2000 UTM (Universal Transverse Mercator) Zone 23 S. The study used as input the contour lines - 5 meters intervals provided by SEDUH (2009), which was refined by removing contour lines that included buildings as topographic features, to generate the digital elevation system (DEM) by using the Topo to Raster tool on ArcGIS. Figure 2 presents this process and the succeeding in a flowchart.

This research sought to analyze the relationship between the topographic factor (LS factor) and the drainage in order to determine the most susceptible flooding areas. In the calculation process, it was necessary to generate intermediate data from the initial data, such as slope, flow direction, accumulated flow and drainage order.

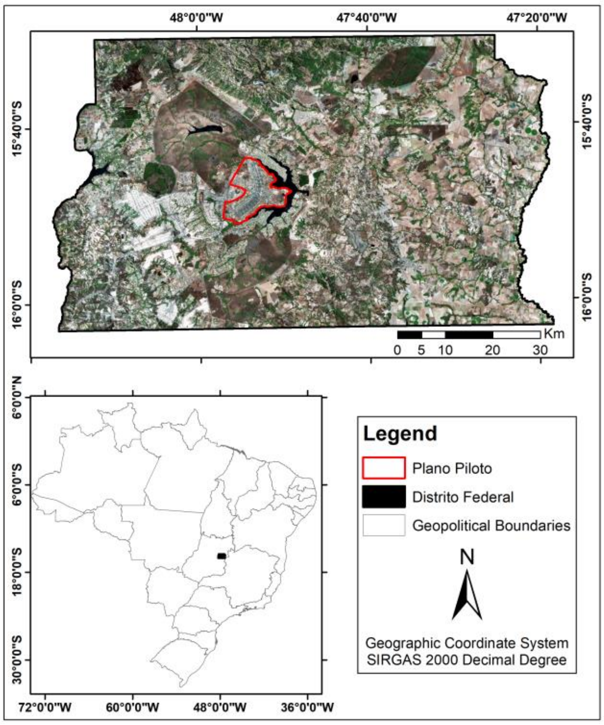

Figure 1 - Location map of the study area.

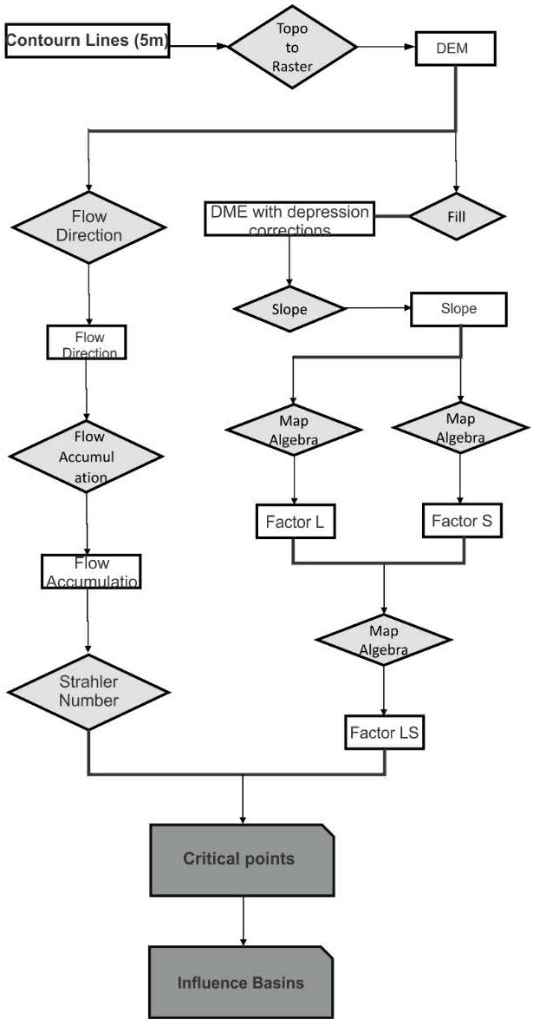

Figure 2 - Workflow, from the input data the rectangles represent the generated products and the diamonds are the tools used in the software.

To generate the water's flow direction, the method D8 proposed by O'Callaghan and Mark (1984) was used, which consists of the restriction of the water flow into 8 directions; This method identifies the steepest path through which water will flow, gravity-driven into one of the 8 surrounding cells. This model is a simplification of the path that the water could flow, symbolized as North, South, East, West, and their diagonal combinations.

Each direction has a representative code that is outlined in figure 3.

32	**64**	**128**
16		**1**
8	**4**	**2**

Figure 3 – D8 method.

Using the result of the flow direction, it was possible to generate the accumulated flow, which indicates the degree of flow convergence and is associated with the topographic factor (LS). Therefore, it was possible to observe the formation of preferential flow paths that also originated the hydrographic network. This hydrography results in the separation of basins, which enables the use of Strahler's (1952) methodology of the hierarchy of watercourses.

To obtain the factors L and S, it was necessary to work with map algebra, present in ArcGIS software. The slope length factor (L), according to Desmet & Govers equation 2 (1996) is:

$$L_{i,j} = \frac{\left[(A_{i,j-in} + D^2)^{m+1} - (A_{i,j-in})^{m+1}\right]}{\left[D^{m+2} \cdot x_{i,j}^{m} \cdot (22{,}13)^{m}\right]} \qquad (2)$$

$L_{i,j}$ = Slope length factor of a cell with coordinates (i, j);
$A_{i,j-in}$ = Contribution area of a cell with coordinates (i, j) (m^2);
D = Cell grid size (m);
xi, j = Flow direction value; and
m = Coefficient depending on slope of hill.

$$m = \frac{\beta}{1+\beta} \qquad (3)$$

β = ratio of groove erosion (caused by flow) to groove erosion (mainly caused by the impact between raindrops).

$$\beta = \frac{\sin\theta / 0{,}0896}{3 \cdot (\sin\theta)^{0{,}8} + 0{,}56} \qquad (4)$$

θ = Slope (%).

The slope factor (S) was obtained according to Wischmeier & Smith methodology (1978) (Equation 5) in which the slope (s) was determined using the Slope tool of ArcGIS software. Thus, the topographic factor (LS) was determined by the product of factors L and S (Equation 6), using the map algebra method present in ArcGIS.

$$S = 0{,}00654s^2 + 0{,}0456s + 0{,}065 \qquad (5)$$

This contribution has been peer-reviewed.
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Primary publication at IEEE Xplore: https://doi.org/10.1109/LAGIRS48042.2020.9165627

S = Slope factor (dimensionless); and
s = Avarage slope of the strand (%).

$$LS = L \times S \quad (6)$$

Visual analysis of the LS factor with the Strahler hierarchization allowed the determination of critical points, which enabled to identify the influence basins– influence basins are the upstream area, from there, all the water flows to the same point - and, consequently, the main risk areas (higher values of LS factor and drainage hierarchies).

3. RESULTS

The study area of the Plano Piloto was quantified at 99,012 km^2. Observing the maps generated in Figures 4 and 5, it is possible to notice three critical points with imminent risk of flooding. Those points have a 17,158 km^2 total influence area (influence basin), associated with the highest order drainage, which are the orders 5 and 6, accounting for only 2.57% of total drainage. These basins demonstrate the regions of influence for possible excessive accumulation of water and may be associated with the inefficiency of drainage system infrastructure logistics, as well as waterproofed regions.

By analyzing the map generated in figure 4, it is possible to observe that the influence basins of exutory 1, which is the head office of Banco do Brasil, as the main factor influencing the flooding processes. It is inserted in the basin of exutory 2, where the intersection of two of the main roads of the region called *L2 / L3 North* is, suggesting a high potential site; enough to affect two identified critical points. And can also be seen a basin related to exutory 3, where it coincides with a viaduct (called *tesourinha*).

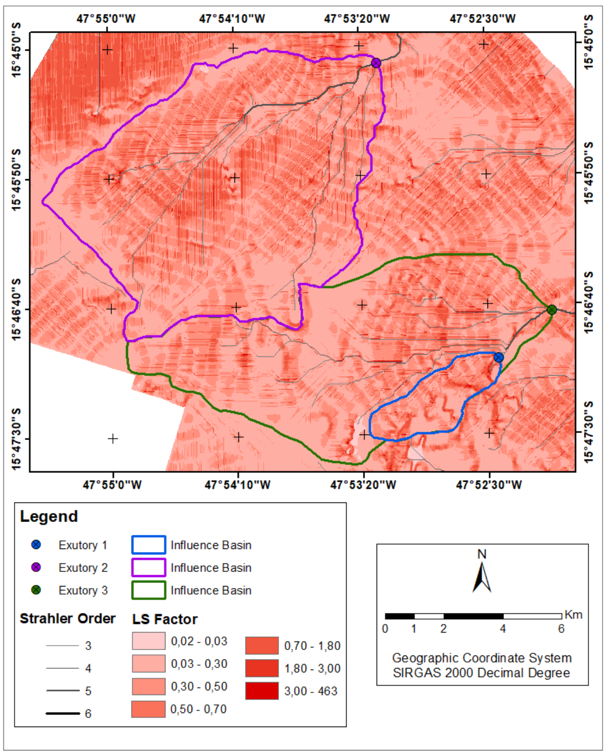

Figure 4 - Map of the basin of useful influence to the critical points.

The distribution of the LS factor classes is shown in Figure 5, where most of them are between 0.03 and 0.70. Therefore, the ramp length is homogeneous throughout the study area, however, the highlighted regions differ due to the variation of the LS factor, justified as a consequence of the anthropic actions of the region.

Comparing the LS factor of the territories identified with the others in the maps, it can be seen that they do not greatly differ in the topographic factor, and are naturally drained, mostly, to the Paranoá Lake strip.

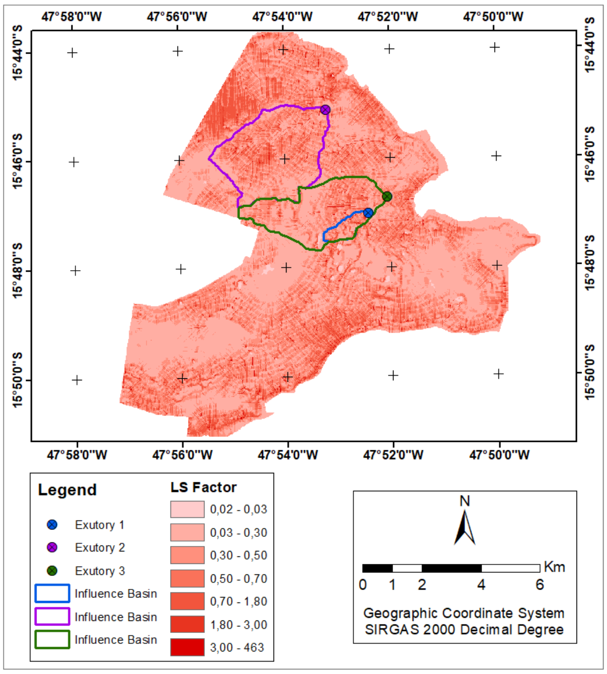

Figure 5 – Map with the LS factor classes.

4. CONCLUSION

The critical areas identified in this study converge to three points: exutories 1,2 and 3 in Figure 4. Their respective influence basins represent 0.84%, 7.19% and 9.3% of the territory of the Plano Piloto; 1.59%, 13.58% and 17.56% of *Asa Norte* (District of Brasilia), a significant area, where all rainwater from the basin regions converge to the critical points; basins were highlighted because they have large drainage order values combined with a relatively high LS factor. Effect of a region with an insufficient drainage system for large impermeable areas, such as the Mané Garrincha Stadium (Western zone of exutories 1 and 2), which is topographically just upstream the highlighted basins. This study is of great value to society, as the studied area has been suffering from flood events. The identification of these poor regions in the drainage system facilitates the efficiency in the implementation of a new rainwater policy, such as construction of rain gardens, also called the Bioretention System, this measure uses the biological activity of plants and microorganisms to remove pollutants from rainwater, and contributes to the infiltration and retention of precipitated water volumes, a method already quite efficient in others countries, allowing great design flexibility and reducing part of the runoff volume. This system is beneficial in reducing the size and cost of the downstream drainage system, in addition to reducing flooding in the basin and improving the water quality, according to ABCP and FCTH (2013). Some suggestions after observing the results of this study: The implementation of a rain garden in the parking lot of the stadium since its total area is more than 100,000 m^2 of

impermeable soil; The area below the *Noroeste* region (Northern zone of exutory 3), had an ineffective drainage method implemented along with saturated soil and it is unable to absorb all runoff water from there. Together with the SGAN 908 racetrack and parking area, it is a total of approximately 400,000 m^2.
Some floods that historically occurred in the analyzed places were broadcasted by websites, newspapers, and TV stations.
On April 21, 2019, the road access of northern 209/210 blocks was completely flooded. On the same day, University of Brasilia was also flooded, causing a huge loss of books, documents and equipment; the main flood was on the underground of the Central Institute of Northern Sciences, and at the College of Technology (FT) (TV Globo and G1 DF, 21/04/2019).
The disaster could also be observed in the underground garages of some buildings, such as Block G of the North 402 which was seized by mud, where, according to one resident, water even hit the ceiling (Rios, A. and Machado, M. - Correio Braziliense, 23/04/2019).
Thus, in view of the increase of flooding events occurring in Plano Piloto, the implementation of rain gardens to assist the drainage system is essential for a better quality of life for the population, and to improve the effectiveness of the drainage system, the GIS tool proved to be very efficient for decision making during the location of the possible implementation points.

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