Identification of Areas with Potential for Flooding in South America

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***Abstract*— This paper presents the drainage network extraction of South American region using Shuttle Radar Topography Mission (SRTM) data set with 90 meters of horizontal resolution. Using different thresholds, the user can generate different drainage networks. The Height Above the Nearest Drainage (HAND) procedure was applied for each drainage. HAND determines the variation of relief in relation to the nearest drainage segments of each point, considering a regular grid structure representing the relief of the study geographic region. HAND is used to determine the areas with greatest potential for flooding. Results for South American region were shown illustrating the potential use of HAND process. The main benefit of this work is to show the viability of using this tool to study and simulation areas that can be flooded by natural processes or anthropic actions.**

Keywords-flooding; drainage network.

I. INTRODUCTION

The American continent has 39.6% of the world's fresh water, and of this total, 61.3% is in South America [1]. The existence of this huge amount of water is directly related to various situations of floods, both in cities and in rural areas, fast and slows flooding. Those floods, which can cause major social and economic damage, must be studied and whenever possible prevented.

This work employed a procedure, called Height Above the Nearest Drainage (HAND) [2], for determining the areas with greatest potential for flooding. The whole South American geographic region was used, considering drainage networks with different densities. These networks were defined by the TerraHidro system [3], which is a distributed hydrological model system that is being developed at Image Processing Division of the National Institute for Space Research, located in the city of Sao Jose dos Campos, Brazil.

HAND determines the variation of relief in relation to the nearest drainage segments of each point, considering a great regular structure representing the relief from their study geographic region. A comparison between the HAND flood results and the real flooded areas extracted from Landsat 8 image was done to show the accuracy of the HAND prediction in a real situation.

The objective of this work is to show the usefulness of HAND to determine areas with the greatest potential for flooding, from a drainage network extracted by TerraHidro system. We chose to apply the HAND throughout the region of South America, to get a sense of this potential across the continent. The paper is organized as follows: Section II briefly presents works related to the proposed in this article, Section III describes TerraHidro system, Section IV shows HAND procedure, Section V presents the results and some discussions, and Section VI contains the conclusions.

II. RELATED WORKS

The flood has been the subject of study for many years. The appearance of Digital Elevation Models (DEM) [4] and of medium and high resolution satellite images made possible the creation of methodologies and systems for identification, simulation and analysis of floods. Works have related to DEM quality and resolution with occurrence of floods [5]. Systems have also been developed in order to produce and analyze floods in local [6] and global level [7].

The study of flood forecasting involves specific models and different types of data, such as slope, land use and land cover, characteristics of rivers, soil types, among others. HAND constitutes a tool to aid the expert in the identification of areas with greater potential for flooding, based only on altimetry and drainage network.

The aim of this paper is not to propose a new methodology to say whether there is flood at a given geographical location. Its goal is to show places with greater or lesser potential for flooding only using the existing relief information. The quality of the result depends on the quality and appropriate resolution of employee DEM.

III. TERRAHIDRO DESCRIPTION

This work was carried out using TerraHidro system and HAND process, also a TerraHidro process [8]. TerraHidro is a distributed hydrological system created to develop water resource applications. It uses regular grid (DEM) as the surface and elevation structure for drainage extraction. TerraHidro uses HAND procedure to identify these areas.

TerraHidro is a plugin of the geographic viewer TerraView that loads and stores data in a geographical library called TerraLib [9], an open source geographical library implemented in C++ language that has also been developed at the Image Processing Division. This approach has allowed TerraHidro project team of designers and programmers to keep focused on the development of TerraHidro system functionality. It calculates, for every DEM cell, the altimetry difference between this cell and the nearest cell belonging to the drainage network, following the local drain directions.

TerraLib is an open-source Geographical Information System (GIS) software library. TerraLib supports coding of geographical applications using spatial databases, and stores data in different database management system (DBMS) including MySQL, PostgreSQL and other databases.

TerraHidro functionality used here are: first, the definition of local flow, called of Local Drain Directions (LDD) extraction [10]. For each DEM grid cell, the LDD was defined considering the steepest downstream regarding the 8 neighbors grid cell. At the end of the task, a new grid was created with the same number of columns and rows of DEM and same resolution. Each grid cell received a code indicating the water flow from this cell. Figure 1 shows LDD functionality.

The grid DEM contains the altimetry of the study area. The slope is calculated for each cell in the grid, considering its eight neighboring cells. The result of this can be seen in the second grid (SLOPE). The third grid (CODIFICATION) shows the encoding rule represented by numbers $2^{(0,1,\ldots,7)}$ defining the flow direction. The last grid (LDD) shows the flow direction for this example.

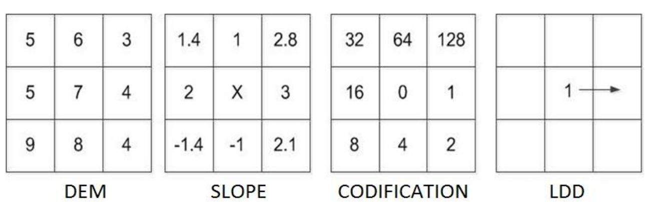

Figure 1. Local Drain Directions creation process.

Second, we consider the creation of the grid called contribution grid area. The user wants to work only with representative drainages regarding his application, not with drainages of all LDDs. Each cell of the contribution area grid receives a value that is the amount of the areas of all cells that participate in the path arriving at that cell. Figure 2 presents this concept.

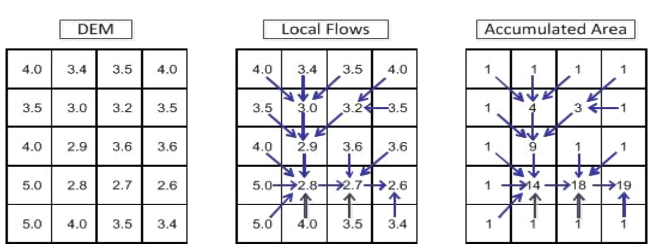

Figure 2. Contribution area.

Third, we consider the definition of a particular drainage network using a threshold value. The value of each cell of the contribution area grid is compared with the threshold value. If the value of contribution area grid is equal or greater than the threshold value the cell is selected as a drainage network cell. At the end of this process a new grid is created, defining the drainage network. Figure 3 presents a didactic example of drainage network and Figure 4 shows a South America drainage network extracted using threshold = 300000 and South America delimited by country and Brazil delimitates by States.

Threshold is an empirical value, defined by the user, in order to select a drainage containing the density necessary to their work. As a general rule, the threshold selects the most representative drainage because it contains the largest accumulated values.

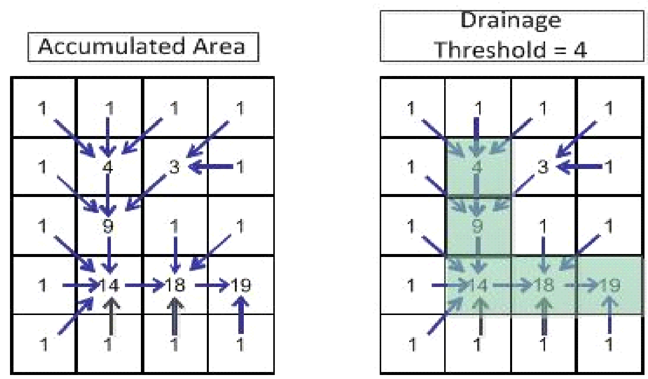

Figure 3. Drainage network (green), using threshold value = 4.

Another TerraHidro task is the watershed delimitation for drainage segments or for isolated points. A segment is a drainage path between water springs and junctions, between junctions, or between junctions and mouth of the drainage. A watershed point is a location defined by the user on a location containing drainage. Figure 5 presents an example of watersheds by segments.

Figure 4. America drainage network extracted using threshold = 300000.

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Figure 5. Basin created for each drainage segment represented in blue color.

HAND will be described in the next session.

IV. HAND DESCRIPTION

TerraHidro uses the HAND procedure to identify flood potential areas. It calculates, for every DEM cell, the altimetry difference between this cell and the nearest cell belonging to the drainage network, following the local drain directions. As the HAND terrain descriptor is sensitive to drainage changes in the regions of sudden terrain variations, it was used as an attempt to determine critical drainage areas. Figure 6 shows a numeric example of the HAND process. The top figure shows the flow directions for each altimetry grid cell. This is shown in Figure 6. In this grid, the cell with value equal to 72 was highlighted. The calculation done by HAND was the subtraction of this value from the value of the cell found, according to the shortest flow direction path. The value to be considered is the 53, which was found according to the path highlighted in red, in the Local Drain Directions grid. Thus, in the resulting grid, HAND grid, the value of altimetry is equal to 19.

HAND process can only identify the areas with potential for flooding. This result allows the water resources manager to focus his efforts on the most susceptible areas to the occurrence of extreme events involving water. For a more refined study, hydrological models must be developed.

The materials used to develop this work were SRTM (Shuttle Radar Topography Mission) of 90 meters of horizontal resolution as surface elevation data set. TerraHidro and HAND used this data set to extract their information. A Landsat 8 image acquired on July/05/2014, showing a flooded region was compared with HAND result of a test area.

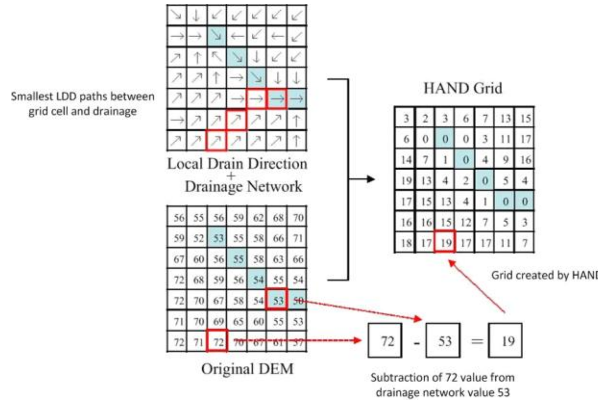

Figure 6. Hand process.

In the next session the results are shown.

V. RESULTS AND DISCUSSION

The HAND results extraction, based on TerraHidro drainage network definition, were shown as thematic maps containing altimetry tracks. Each altimetry track informs the greater or lesser proximity of its altimetry in relation to the nearest drainage altimetry. Different scenarios were created with the use of altimetry tracks with different relief intervals. Figure 7 shows HAND results for South America region from drainages extracted from threshold values of one and tree millions. The drainage networks were extracted from thresholds equal one and tree million. Only the differences between 0 and 15 meters divided into 5 slices were represented. Other areas have less potential for flooding.

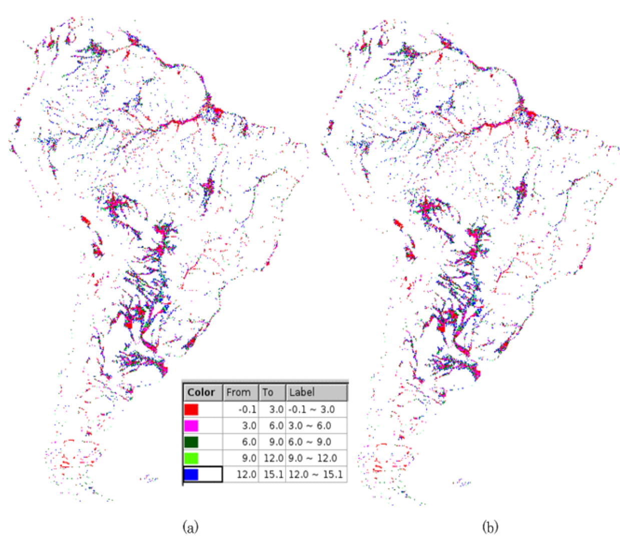

Figure 7. HAND results. (a) threshold = one million; (b) threshold = tree millions.

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Figure 8 presents the details of the north and south regions of South American region. It is possible to see areas in the red color, with less than 3 meters of difference between the altimetry and the closer drainage. These areas have most potential flood than the other areas.

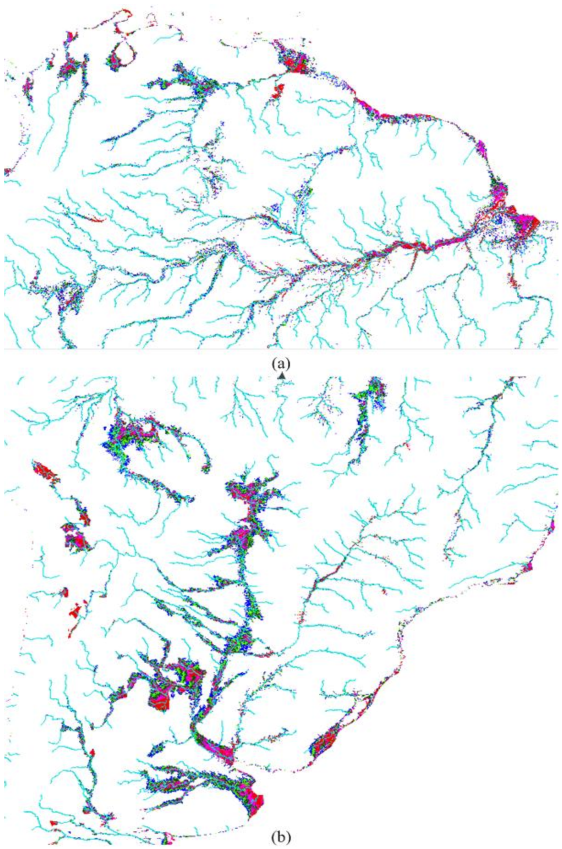

Figure 8. Zoom of (a) north and (b) south of South American region using threshold = one million.

This is the region Mariana, Minas Gerais state. The area reached by the rupture of a lake of mineral waste appears in red color. The result of the HAND appears in slices defined by lines of different colors, each color defines an altitude range. It may be noted that the blue line adequately represents the space occupied by waste. Figure 9 shows the area delimitated by HAND and the area extracted from image in a real flood situation.

The result discussion concerns the relationship between selected drainage and HAND results. Each drainage gives a particular potential flood region context. For quick floods, it is better to have dense drainages to grasp the water behavior in small regions. For slow floods the drainage can be less dense. HAND allows, in both situations, identifying the flood boundaries. Identifying how many meters the water will rise and how fast this will happen are parameters that are outside HAND scope.

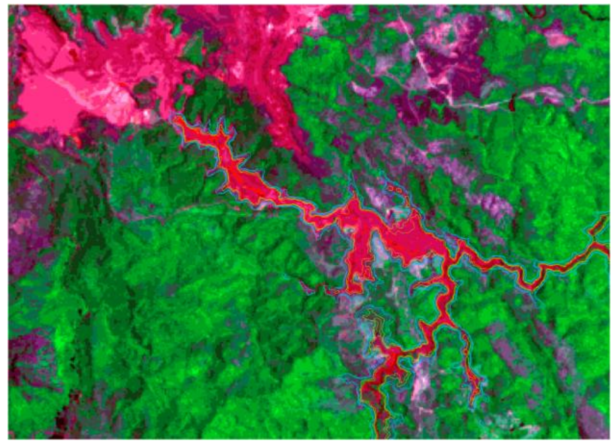

Figure 9. HAND real example. Brazil.

VI. CONCLUSION AND FUTURE WORK

TerraHidro and HAND are used to define respective drainage network and potential flooded areas for the South America region. These areas serve as priority areas for experts to carry out studies on flooding.

This work shows a simple solution for identification of locations with more potential for flooding. It only employs relief and drainage extracted from this relief. This methodology aims to help the expert to focus on areas with the greatest potential for flooding. It doesn't say that there will be flooding. To be sure, experts should use appropriate hydrological models, which are beyond the scope of this proposal. We will carry out a job applying this methodology. This work will consist in the simulation of the areas that were flooded by the disruption of mineral waste lakes.

A comparison between HAND result and a real flooded area shown by a satellite image revealed coincidence between both flood areas. This confirms that the methodology shown in this paper is useful to determine critical areas for flooding.

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