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Geodetic method to obtain a digital elevation model associated to the Brazilian Geodetic System

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***Abstract*— The present paper presents a geodetic methodological proposal used to link limnimetric ruler to the Brazilian Geodetic System (SGB) and obtain a Digital Elevation Model (MDE) applied to flood areas also linked to the GBS. The bond of the rules to the GBS was given by the geometric levelling using as a starting point a Reference of Level (RN) of the Basic Altimetric Network of Brazil (RAFB) and finalizing in one of the limnimetric rules implanted by the Geological Service of Brazil (CPRM) the margins of the Uruguay River. The coordinates within the study area were determined by the relative static positioning of the GNSS, using as reference a forced centering frame whose coordinates were obtained by Positioning by Precision Point (PPP) made available by the Brazilian Institute of Geography and Statistics (IBGE). The orthometric altitudes were determined by relative mode GNSS altimetry, using an RN together with the IBGE gravimetric geoid, and the MDE was generated in ArcGis environment using the top to raster interpolator. The resulting MDE allowed the delimitation of the areas constantly affected by the floods based on the data provided by the CPRM and monitoring of the level of the river and the areas affected during the flood of the year 2017.**

index Terms— orthometric height, floods, modeling

I. INTRODUCTION

The city of Itaqui is located to the edges of the Rio Uruguay and not rarely it is flooded during the flood season, as well as several other cities of this region. Itaqui survives the same reality of most of the Brazilian small cities, the lack of resources and of specialized professionals in order that they act in the projection and in the orderly urbane development. This fact reflects in the lack of studies and information that aid the urban management aim to minimize the negative impacts to the society.

A peculiarity of the city is that, having the river in this region a width of about six hundred meters, its Permanent Preservation Area (APP) along the marginal strip of the waterway would be five hundred meters as it is explained in the new forest code. This rule does not apply in the municipality, since part of the urban network containing several houses occupy the area that should be destined to APP.

The undue occupation causes various problems that have a direct impact on society, including floods and floods within the urban area. One of the reasons is the disorderly urban sprawl, without the adequate infrastructure along with the non-observance of the natural characteristics of the occupied environment that shows as consequence impossibility of the areas near rivers and creeks absorb floods [13].

It is important to highlight that, in addition to the lack of financial resources to be invested in the municipality, there is an almost frequent expense with the damages caused by the increase in river level. Most riverside families live in so-called flying houses, these are wooden houses and can be transported from one place to another. But in some extreme events such as the one occurred in the year 2014, some families lost all their belongings and in some cases, even their homes, leaving to the public power to help with the expenses of these families..

The possible measures for flood control are of the structural type that alter the fluvial system and tend to avoid the damages caused by the flood, with the use of hydraulic works, channeling of the runoff and dikes, and those of the non-structural type in which it is tried to minimize flood damage through strategic planning, mapping and modeling. The way in which the control of the flood can be reached more efficiently would be through a set of structural and non-structural measures combined, allowing the harmonious coexistence between the rivers and the river minimizing their losses [2].

In this context, a study to determine an MDE that represents the areas near the Uruguay River in the city of Itaqui, can subsidize and encourage the elaboration of an MDE encompassing the cities of the western border that are also affected by the constant variations of the level of the River.

The development of such work will be possible due to the recent technological advances that have led to an evolution in topographic and geodetic survey techniques, directly influencing the cost and quality of the work developed. For example, the Global Positioning System (GNSS) has shown that its use enables fast, accurate, and low cost surveys, including altimetric surveys with significant improvements in the quality of its final product.

The application of geodetic concepts and the use of new geodetic data collection resources are powerful tools for the development of new methodologies for describing and monitoring physical space. In the case of the municipality of Itaqui, the different data sources combined will serve as a basis for the elaboration of a precise and georeferenced MDE, which can be used as a basis for the main engineering works and assistance to the population that is constantly reached by the river waters.

II. GEODESIC SURVEY

In 1958 began the development of satellite positioning systems with the well-known TRANSIT system that had as principle the Doppler effect. This effect was observed by the terrestrial receivers in the signals transmitted from satellites,

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which is a function of the distance of the satellites and their direction in relation to the receivers. Knowing the frequency that the signals were transmitted, together with the data of the position of the orbit and the time of the observations, the position of the receiving stations was determined [4].

The positioning consists of determining the position of objects in relation to a frame. They can be classified in absolute positioning (or positioning per point) method, when the coordinates are determined relative to the geocenter, and relative, when the coordinates are determined in relation to one or more materialized reference points of known coordinates [10].

In positioning by the relative method, the coordinates of the point of interest are determined in relation to one or more known coordinate points (base station). In this case it is necessary for the receivers to collect the data simultaneously on the points, and according to the state of the receiver to be positioned, it can be classified in relative static when the receiver is stopped and kinematic relative when in movement [14].

III. Leveling

The altimetric topographic survey or leveling is the procedure that aims to determine the heights relative to a reference surface, points of support and / or details, where it is assumed that its planimetric coordinates are known, in order to represent the altimetry of the raised region. Geometric leveling determines the level difference between points on the ground through horizontal views made with a level on vertically positioned sights on the points to determine the height difference. It is considered the most accurate method of leveling being simple or composed [16].

In this work to link the linimetric ruler to the SGB was used the compound geometric leveling method that consists of installing the level more than once to obtain the unevenness of the section to be leveled.

IV. Modeling

In different countries, different concepts and nomenclatures are used to represent the surface of the GROUND, such as digital elevation model (MDE), digital height model (MDA), digital terrain and surface model (MDTS) and numeric digital terrain model. These terms are commonly used synonymously, but in some cases they may mean different products.

Reference [9] explains that digital terrain model (MDT) is a set of selected points, with known coordinates X, Y and Z representing a continuous surface of the terrain, [6] assert that MDT is an ordered set of sampled data points representing a spatial distribution of several types of landless information that can be used in the following mathematical formula:

$$K_P = f\,(X_P, Y_P)$$

where:

KP is an attribute value of the k^{th} type of terrain feature at position P, ranging from 1,2,3, ..., m total number of terrain information;

(XP, YP) is the two-dimensional coordinate pair of the point P, where P varies from 1,2,3, ..., n total number of points sampled on the surface.

Adopting here the denomination given by [6], MDT tends to have a broader meaning and will incorporate specific terrain features into the model. In the case where the value of m is equal to one, the only information of the relief to be represented will be its elevation being called MDE.

V. Interpolation

Currently the mapped attributes require an increasingly accurate assessment of their quality. An example of this is the study of data interpolators used in determining spatial representation models [12].

Modeling a surface is a process in which value estimates are performed for a variable having a single value, z (x, y), as x and y (spatial position) vary by study area [15].

The value estimation process is performed through interpolators that will depend on a number of factors, such as the type of surface to be modeled and the purpose of the modeling. Interpolators are used in applications to estimate conditions that exist in places where there are no observations or data recorded [7].

The various interpolators can be divided into deterministic ones, which through mathematical equations adjust the surface to the point values taking into account that closer points resemble more than distant points, and in probabilistic ones, where the mathematical formulation is applied together with the statistic analyzing the spatial autocorrelation of values with the use of Geostatistics [8].

VI. Study of Area

The study area, as shown in fig. 2, is located in the city of Itaqui, situated in region of the western frontier in the state of Rio Grande do Sul, Brazil. It has the Cambaí stream, the Sanga das Olarias and the Uruguay river as the main water bodies. It has a territorial area of 3,406,606 Km^2 and an estimated population of 39,049 in habitants according to the Census conducted by IBGE in 2016.

The city of Itaqui had his settlement initiated into the edges of the river Uruguay. Currently, this portion is occupied by those who depend on Rio to withdraw their livelihoods and also those of low economic class. These dwellers are often displaced to higher regions so as to move away from the constant flood.

CPRM is working on the recognition of areas of high and very high risk to mass and flood movements, and in 2013 estimated that in the city of Itaqui there were 800 residences in a high risk area totaling 3.200 people living in these areas of flood risk areas in the urban area of Itaqui.

The low risk area occupies a space of 1.30 Km^2, equivalent to 12.85% of the urban area and is characterized by areas limited by the maximum flood of 1983, with a fluviometric dimension of 14.52m (measured on the linimetric rulers).

The medium risk area occupies a space of 0.05 km^2, equivalent to 0.50% of the urban area. However, the area with a high degree of risk occupies a space of 0.03 km^2, equivalent to 0.30% of the urban area.

Finally, the very high risk area occupies a space of 1.20 km^2, equivalent to 11.87% of the urban area.

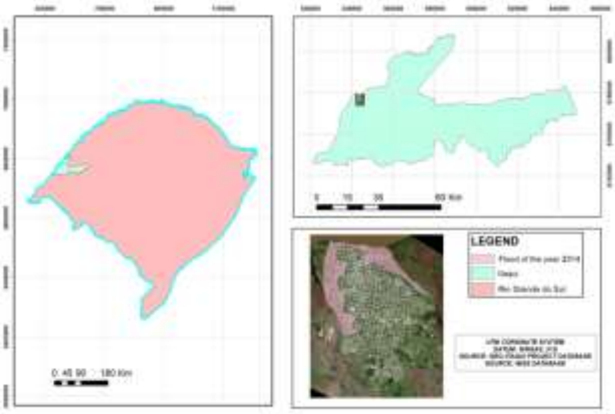

Fig. 1: Location of study area

VII. EXPERIMENT AND ANALYZE

A. Point survey

The MDE generation points were obtained by means of GNSS positioning using 5 Frequency GNSS receivers (L1 / L2) of the brand ASTEK, model Promark 500, by the static method. The techniques and methodologies for the geodetic survey presented in this paper follow the recommendations for GPS surveys of IBGE. At the end of the field campaigns, a total of 836 points were distributed throughout the study region. It should be noted that the survey was conducted only in the urbanized area.

Fig. 2: Points collected on the study area

The processing of the data collected in the field was done with the GNSS software Ash tech Solutions 3.70.5.

At the end of the data processing, the X, Y and Z coordinates were obtained for each point, the first two being the planimetric coordinates, and the last the altimetric coordinate (geometric altitude), there were only used the points which results of the processing presented fixed solution.

B. Determination of the orthometric height of points

With the set of coordinates already processed, set out to obtain the geoid undulation of each point. To do so, it was necessary to create a coordinate file in TXT format, identifying points and their latitude and longitude coordinates in degrees, minutes and seconds. The file was loaded into the MapGeo 2015 software which returned the value of the geoid ripple for each point in the file.

With the values of geometric altitude and geoid undulation for each tracked point the orthometric altitude was calculated by the relative method as expressed by [5] by the following equations:

$$H_i = H_A + \Delta H_i = H_A + (\Delta h_i - \Delta N_i) \tag{1}$$

$$\Delta h_i = h_A - h_i \tag{2}$$

$$\Delta N_i = N_A - N_i \tag{3}$$

Where H_A is the orthopedic altitude of RN1931A, linked to the Imbituba Datum, Δh_i is the difference between the geometric altitude of RN1931A and the point of interest and ΔN_i is the difference between the geoid undulation between the RN1931A and the point of interest. In Microsoft Excel software the above formulas have been implemented, obtaining the orthometric altitude for all points. It is worth mentioning that the determination of the geometric altitude of the RN1931A was also due to the other points, by the GNSS positioning, however opting for a longer tracking time of thirty minutes because it is located near trees.

C. Modeling

The TIN represents a surface through a face composed of interconnected triangles based on the Delaunay triangulation that avoids the redundancy of information present in the regular grid and is more efficient for the most diverse types of calculations [3].

According to [17] the TIN is able to adequately represent the variable data density and roughness of the terrain, requiring few points to obtain a DEM of a certain accuracy.

Reference [11] shows that in the use of TIN, the estimation used in the regular grid is not necessary since the triangular irregular grids use the sample points themselves to model the surface, eliminating the factor of decreasing the reliability of the model, since for better which is the procedure, some characteristic of the procedure is incorporated into the model.

Reference [6] explains that in the TIN it is possible to insert lines representing relief discontinuities, whether natural (water dividers, channels, lakes) or artificial (reservoirs, constructions, slopes), in the inclination of the terrain. It also explains that these lines should not be crossed by triangulation edges and their non-use allows undue smoothing of the terrain.

Some of the difficulties of using TIN are its handling complexity and its inadequacy to generate 3D visualization as they present [1].

With the MDE resulting it was possible to accompany the river rise up to its maximum value of 13.20m achieved on the day 12/06/17 as shown in fig. 3.The places affected by the flood that have an orthometric height up to 53,3885m are shown in blue.

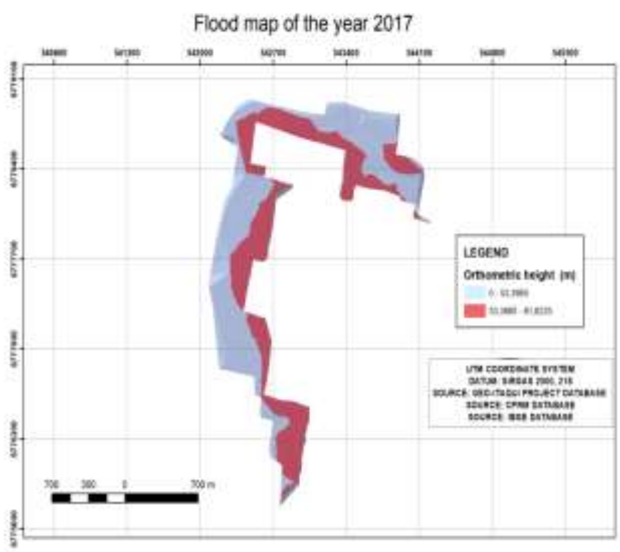

Fig. 3: Flood of the year 2017

VIII. CONCLUSION

This paper presented a geodetic methodology for surveying and generating MDE for flood area, for study and monitoring of the variation of the river 's dimensions.

The methodology allowed to obtain a valuable tool to be used continuously and in conjunction with other data sources that provides the user with a forecast of the areas that will be affected by the waters of the river, thus minimizing the damage of the in habitants of the riverine areas.

From the MDE it was possible to size the areas affected by the major floods that occurred in the study site in previous years and allowed the monitoring of the recent flood between May and June of the current year (2017).

The expansion of the study area will allow a representation of all the surface that composes the urban area of the municipality to be realized, being able to be in the future associated to other projects, mainly to urban drainage projects.

This paper also demonstrates that geotechnologies accompanying the technological advance, when well applied, return tools that can be used in urban management and development with a low investment cost, being able to meet the unique characteristics of a given locality.

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