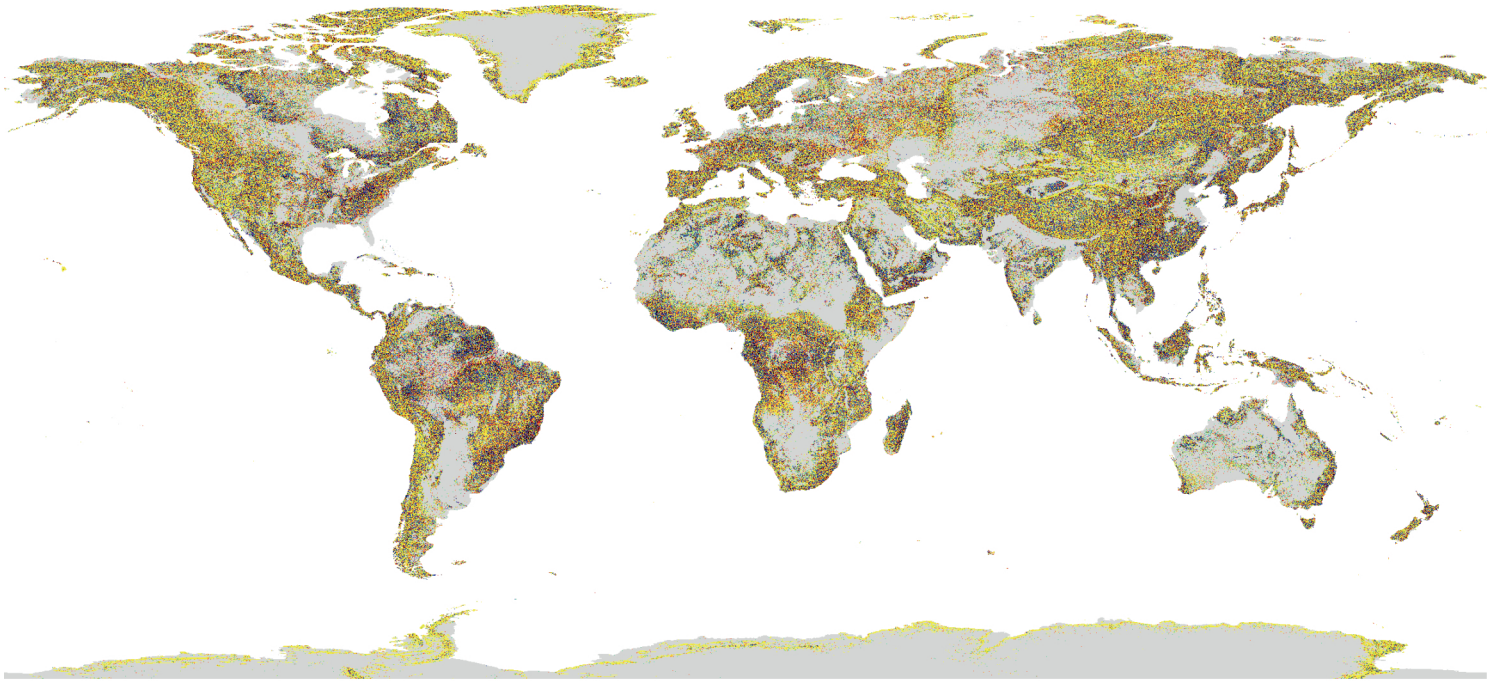
Geomorphometry for Geosciences



Editors:
Jarosław Jasiewicz, Zbigniew Zwoliński, Helena Mitasova, Tomislav Hengl

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Water resources assessment using GIS procedures: application in Ceará State (Brazil)

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Abstract—**A methodological approach and preliminary results on water resources assessment in large areas are described with the case study of Ceará State (Brazil). The methodology includes analysis and interpolation of climatic and hydrological data, Digital Elevation Model (DEM) production and interpretation, and GIS procedures. The present results include the distribution of historical rainfall and fluvial discharges and the definition of a 7-levels river and watershed hierarchy in the Ceará State. The highest rainfall and discharge average values are located in the northeastern sector of the state confirming the important role of climatic features in hydrological diversity. Water resources management must then consider technical tools for water resources assessment, in the line of other methods for quantitative assessment of natural features either biotic or abiotic..**

I. INTRODUCTION

Water must be understood as an environmental and social asset, an economical resource and a matter of extreme importance for all societies. Therefore water management must be handled as a technical subject but also as a political topic once water needs can lead to conflicts and ambitions by different factions evolving priority decisions [1]. Water resources quantitative assessment [2] [3] [4] has a special importance in the scope of the hydrological diversity approach [5]. In spite of being a rather new notion, geodiversity is defined [6] as the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landforms, topography, physical processes), soil and hydrological features. It includes their assemblages, structures, systems and contributions to landscape. Water features are then elements of geodiversity being a very important agent in geological and biological processes and evolution. To be accepted as a useful tool, that diversity must be assessed according to objective methodologies in order to be used for nature conservation and land-use planning, as biodiversity currently is [7]. Common geological, geomorphological, soil or hydrographical maps are important in qualitative, but not in quantitative diversity assessment. In addition, as technical documents, they are difficult to read for non-specialists, thus limiting their use in routine planning. In that scope, the first results on the assessment of water resources diversity in the Ceará State (Brazil) are presented. This work followed a methodology based on hydro and climatological data, spatial information and GIS procedures analysis.

II. METHODS

Relevant outcomes [8] [9] [10] [11] on water resources quantification using GIS based procedures were considered in the development of the method for the assessment of the hydrological diversity in the Ceará State. Ceará is one of the 27 states of Brazil, located in the northeastern part of the country, on the Atlantic coast, covering an area of 148,016 km2. With about 8.5 million inhabitants it is the eighth-largest Brazilian State by population. Ceará lies partly upon the northeast slope of the Brazilian Highlands, and partly upon the sandy coastal plain. The rivers of the state are small and, with one or two exceptions, become completely dry in the dry season. The largest is the Jaguaribe River, which flows entirely across the state in a northeast direction. Several data was acquired and a database was created for eventual analysis and processing. The database includes: DEM (Digital Elevation Model) of Ceará State based on the SRTM (Shuttle Radar Topography Mission) 90 metres per pixel resolution and enhanced to 30 metres resolution [12]; rainfall and discharge data (34 years series) in selected locations [13]; spatial information in vector format [14]. Methodological procedures included: statistical analysis of a 30 years sequence rainfall and discharge data and its distribution all over the territory; DEM treatment for automatic fluvial channels, networks and watersheds generation; hierarchy order of fluvial channels according to Strahler model [15]. Microsoft Excel© software was used to perform statistical operations. ESRI ArcGIS© 10.1 version, ESRI Arc Hydro© extension and Quantum GIS© 2.6.1 version software were used in DEM production, water resources analysis and GIS procedures.

A. Fluvial network, channel orders and watershed delimitation

The DEM is a computational representation of the altitude distribution in Ceará State, using a pixel grid with 30 metres of

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resolution. From it a set of information can be analysed and different maps can be produced: hypsometry (Fig. 1); slopes; aspect; morphological surfaces; hydrography; runoff flow directions. Besides, it is an important tool in erosional patterns, roughness textures and geomorphological analysis, allowing tridimensional visualization of different features [16].

In order to establish the fluvial network definition, the channel order classification and the watersheds delimitation the following tasks were performed using the ESRI Arc Hydro© tool:

1. Assemblage of the mosaic from the original DEM files;

2. Conversions in datum projection (from WGS 84 to SIRGAS 2000 - 24S Zone);

3. Cropping of the DEM mosaic, accordingly to the limits of the Ceará State area.

4. Specific in-software procedures to fluvial network and basins delimitation → Fill Sinks → Flow Direction → Flow Accumulation → Stream Definition → Stream Segmentation → Catchment Grid Delineation → Catchment Polygon Processing → Drainage Line Processing → Adjoin Catchment Processing → Drainage Point Processing → Batch Point Generation → Watershed Delineation → Export shapefile

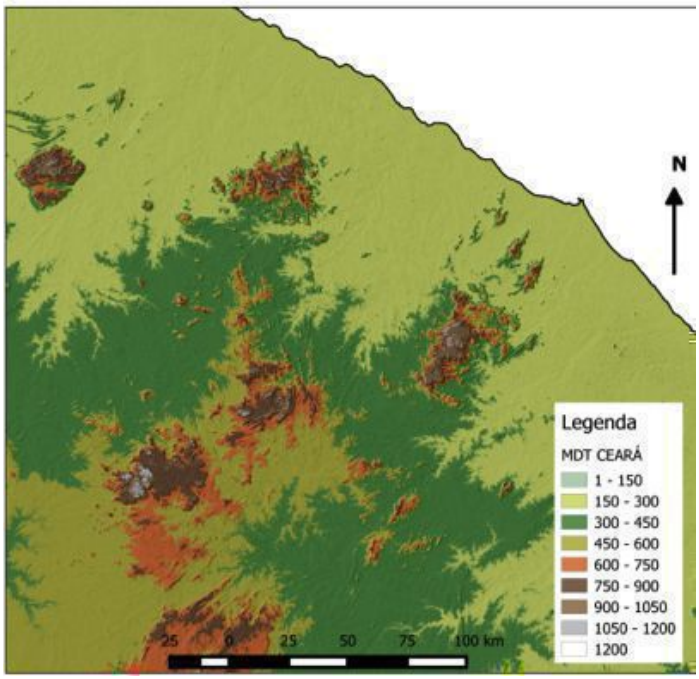

Figure 1. Digital Elevation Model (DEM) with 30 m resolution of the northeastern sector of Ceará State (Brazil).

B. Rainfall and discharge analysis

The climatological and hydrological features regarding the proposed method were handled by the following procedures:

1. Research and acquisition of official rainfall data from 1974 to 2014;

2. Average values for more than 700 precipitation stations, from automatic calculation using Microsoft Excel© software.

3. Exclusion of stations with absent or irregular values and inclusion of stations that have at least 85% of complete rainfall information for the 1974-2014 period;

4. Calculation of discharge historical average values for 69 stations, from the rainfall average values (34 years period and year 2014) and the discharge values of the year 2014;

5. Data exportation to ESRI ArcGIS© and Quantum GIS© software;

6. Interpolation of rainfall (Kriging method) and discharge (Inverse Distance Weighting) values.

III. RESULTS

The processing of values according to the described methodology provided maps with the distribution of historical rainfall (Fig. 2) and fluvial discharges (Fig. 3) in Ceará State.

Seven hierarchy orders (levels) were credited to rivers in result of the DEM analysis. Then, watersheds were classified according to the river hierarchy, and a polygon was produced for each river segment considered in the analysis [17]. Level 1 and level 2 watersheds were excluded to avoid a large number of polygons thus level 3 rivers express the 327 watersheds defined in Ceará State. These are included in 57 level 4, 13 level 5, 3 level 6 and 1 level 7 watersheds.

IV. DISCUSSION

The annual rainfall average values (Fig. 2) in Ceará State range from 284 e 1400 mm, constituting a large disparity (1116 mm) between some regions. The northeastern sector of the state has the highest rainfall values mostly due to the Atlantic influence and the variety of air fronts in different times of the year. The lowest values in the central-western sector (less than 300 mm per year) are related with the local inland atmospheric circulation [18]. These climatic features have an important role in a water resources overview. The river discharge values (Fig. 3) are even more wide-ranging, between 7 m3/s and 12069 m3/s because different types of river were included in the analysis and also regarding the station location, if more upwards or downwards the watershed.

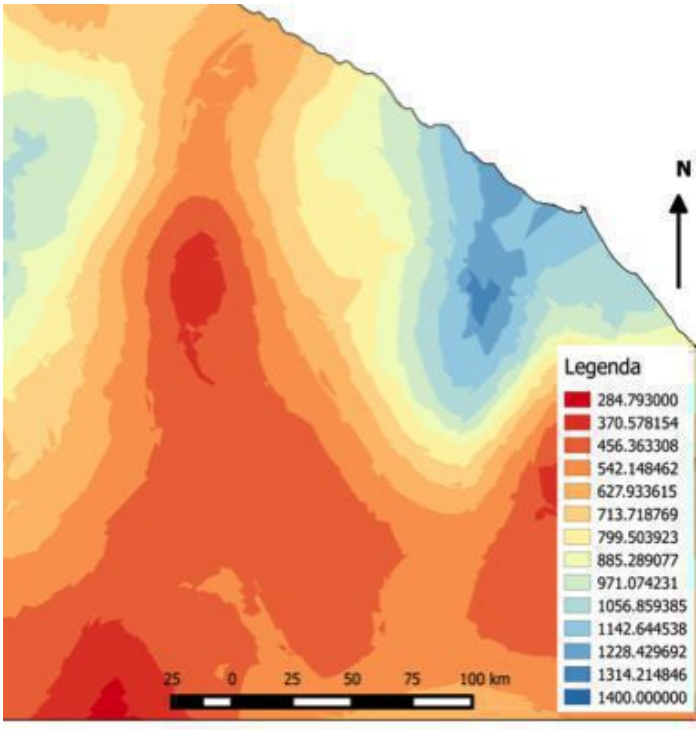

Figure 2. Average values (34 years series) of annual rainfall (in mm) in the northeastern sector of Ceará State (Brazil).

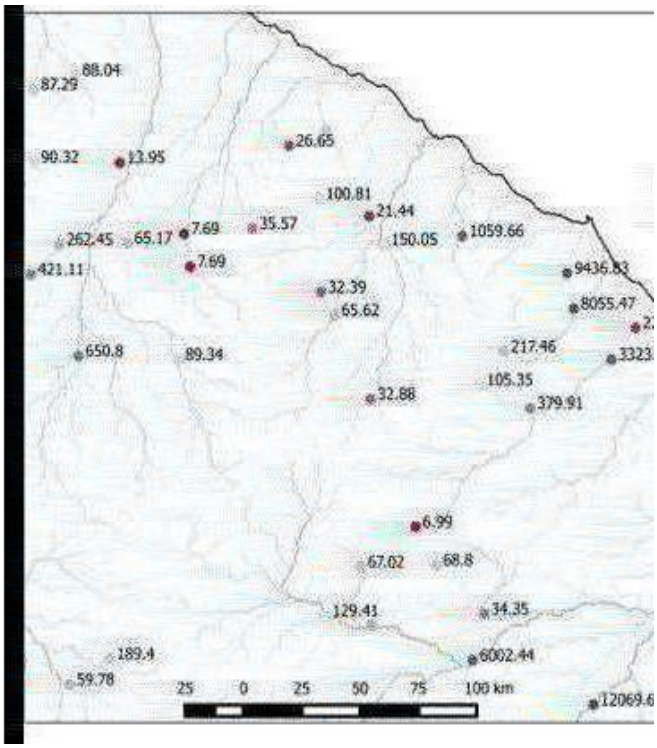

Figure 3. Average values (34 years series) of river discharge (in m3/s) in the northeastern sector of Ceará State (Brazil).

However, considering rivers and watersheds of the same level, the highest discharge values are present in the northeastern sector of the state, combining the influence of the highest rainfall and the specific fluvial dynamics in that region.

These are some preliminary results aiming to quantify the water resources and their distribution in a large region with important within climatic differences. They constitute a basis for the knowledge of regional issues concerning water needs, flood and droughts events and even engineering solutions for water resources management. Although at this point we look forward to discuss and define the best way to represent water resources diversity. The improvement of these preliminary results in a second stage of quantification is expected, using data interpolation techniques and eventually producing a hydrological diversity index and the map of the water resources diversity of the Ceará State.

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