GEOMORPHOLOGICAL FEATURES APPLIED TO SPATIAL DISTRIBUTION OF POPULATION

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ABSTRACT: This paper aims to hold up studies of spatial distribution of population and the environmental characteristics in the region of the junction of BR-163 and Transamazônica highway, PA, in Brazilian Amazonia. It describes the methodological procedure developed to build population density surfaces taking remote sensing imagery data as main information source to represent the spatial heterogeneity. PRODES image data (INPE, 2010) and SRTM (Shuttle Radar Topography Mission) data were the base of the methodological proposition. The digital image data of forest and water bodies areas indicate the places with restriction to human population presence, which corresponded to the nonpopulated cells in the final density surface. Slope, altimetry, vertical curvature and roughness obtained by SRTM products, in conjunction to percentage of forest area, distance to rivers, distance to roads and distance to urban centers, were used as variables to spatially distribute the population. Population density surfaces are a substantial data source to represent the population distribution in space, what is one of the main focuses of the debate between population and environment relationships.

Keywords: Demography, Geomorphology, Remote Sensing, Spatial Analysis, Brazilian Amazon.

RESUMO: Este trabalho tem como objetivo realizar estudos de distribuição espacial população e as características ambientais da região do entroncamento da BR-163 e da rodovia Transamazônica, PA, na Amazônia brasileira. É descrito o procedimento metodológico desenvolvido para construir superfícies de densidade populacional, tendo os dados de imagens de sensoriamento remoto como fonte principal de informação para representar a heterogeneidade espacial da área. Dados do PRODES (INPE, 2010) e dados SRTM (*Shuttle Radar Topography Mission*) foram a base da proposta metodológica. Os dados de áreas de floresta e corpos d'água indicaram os locais com restrição à presença de população humana, o que correspondeu a células não populadas na superfície de densidade final. Declividade, altimetria, curvatura vertical rugosidade obtida por produtos SRTM, em conjunto com a percentagem de área florestal, distância aos rios, distância a estradas e distância para os centros urbanos, foram utilizados como variáveis para a distribuição espacial da população. Superfícies de densidade populacional são uma fonte de dados importante para representar a distribuição da população no espaço, que é um dos principais focos do debate entre a população e as relações do ambiente.

Palavras-chave: Demografia, Geomorfologia, Sensoriamento Remoto, Análise Espacial, Amazônia Brasileira.

1 - INTRODUCTION

The Brazilian Amazon holds the largest area of tropical forests preserved and continuous in the world. General environmental issues became the object of study of the scientific community and focus of attention of preservationist organizations and international opinion. Parallel to the evolution of environmental concern, over three decades, the region has experienced the highest urban growth rates in Brazil. In 1970, the urban population of this region was 35.5% of the total population. This proportion has risen to 44.6% in 1980 to 58% in 1991, 61% in 1996 and 70% in 2000 (IBGE, 2010).

The mapping of population density characteristics obtained through the analysis of remote sensing images has been proposed as an alternative to conventional techniques of representation of the population (GREEN, 1957; IISAKA e HEGEDUS, 1982; LO, 1995, HARVEY, 2002; FAURE et al., 2003; AMARAL, 2003; GAVLAK, 2010). Remote sensing becomes effective in applications where you want to allocate the population density for a given area of known population, instead of estimating the population counts itself.

The population density can be represented by a structure more refined that only the polygons for which is obtained the original data, ie, regular surfaces that describe the density per unit area. There are several methods to represent census data across density surfaces. A summary of these methods is presented by Amaral et al. (2002) and Amaral (2003). However, the key to interpolate demographic data from one representation to another is to estimate an intermediate continuous surface that supports and is the basis for distributing the variable in question (AMARAL et al., 2005). Spatial data, such as those from remote sensing, describe the spatial heterogeneity and enable more appropriate redistribution of population density in combined methods, as described by Langford and Unwin (1994).

Thus, this work aims to apply and improve the methodology developed by Amaral (2003) and Gavlak (2010) to characterize the spatial distribution of population in the junction of BR-163 and Transamazônica highway (municipalities of Aveiro, Itaituba, Rurópolis and Trairão). It also seeks to assess the advantages and disadvantages of this method for studies of population distribution, whereas the insertion of the human dimension in studies on the Amazon region is increasingly important for the discussion of policies linked to regional and territorial planning. This time, it will be possible to provide subsidies to answer some fundamental questions, for example: "how this population is spatially distributed?", "how to represent spatially this population?" and "how this distribution is affected by geomorphologic features?".

2. MATERIALS AND METHODS

2.1 Study Area - The study area is located in the state of Pará (Fig. 1), where is the junction between the BR-163 and Transamazônica. The area is formed by parts of the cities of Aveiro, Itaituba, Trairão and Rurópolis, presenting a very important economic, social and environmental role (BECKER, 1995).

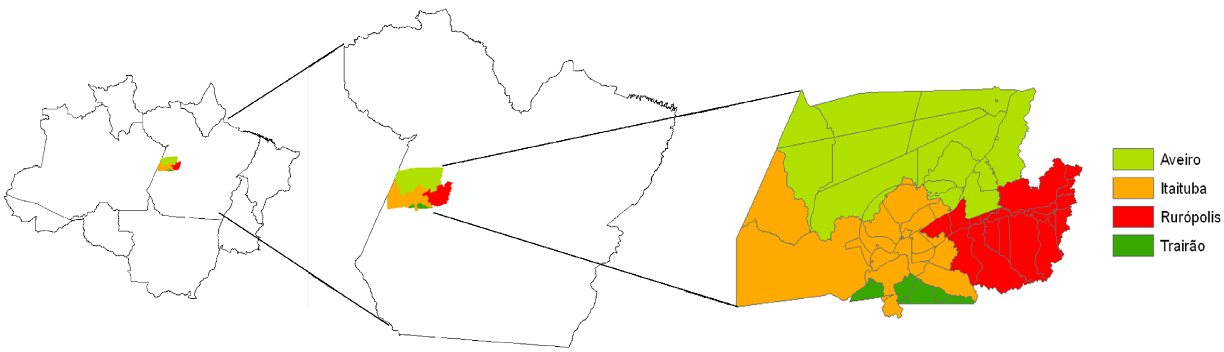

Figure 1 – Study Area

The population occupation in the Brazilian Amazon, where is inserted the study area of this paper is conditioned by historical, economic and environmental factors. Among the environmental factors, proximity to water bodies, the presence of the forest and geomorphological features are the main determinants of this occupation (PANDOLFO, 1994; AMARAL, 2003; FURTADO, 2004; BECKER and STENNER, 2008).

The occupation of this region occurred in the 70's through the colonization plans of the government and the creation of INCRA's settlement projects with lots of average size of 100 ha. Land use is predominantly livestock. In this region is possible to observe the existence of mixed cattle and milk production (ESCADA et al., 2009).

The high topographic variation is a factor that partly explains, for example, the fact that grain production had not advanced to that region. Figure 2 shows a map derived from

SRTM data for the location. These data show the occurrence of environments lowlands and plateaus in the region hindering mechanization and planting of grain, and consequently human occupation.

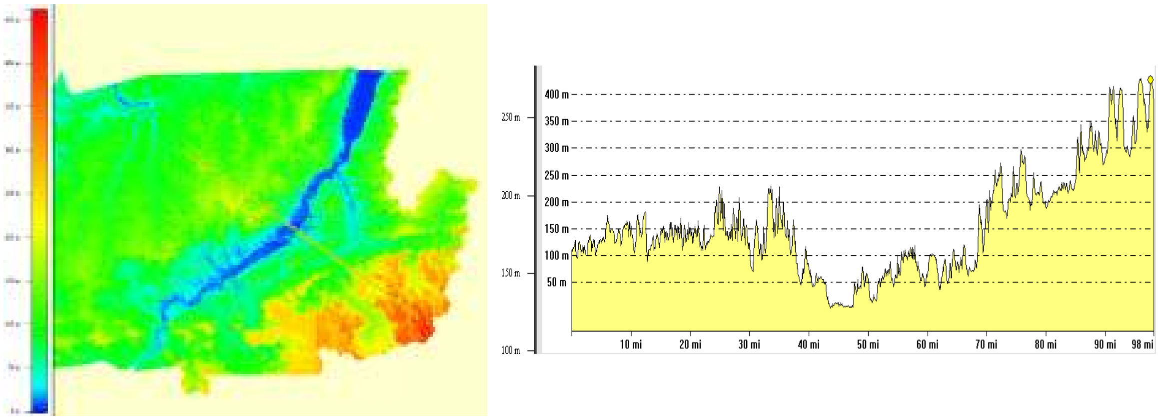

Figure 2: Map of altimetry and topographic profile of the study area

Data – All data used in this paper is described at the following table (Tab. 1).

Table 1 – Data Sources

Data	**Source**	**Year**
Deforestation	Prodes (TM/Landsat 5 and CCD/Cbers 2)/INPE	2009
Urban Centers	Brazilian Institute of Environment and Renewable Natural Resources	2009
Roads	Brazilian Institute of Geography and Statistics	2007
Rios	Brazilian National Agency of Water	2007
Geomorphological Data	NASA/SRTM	2000
População	Brazilian Institute of Geography and Statistics	2000

2.2 Methodology - To generate the population density surface by distributing the value of population count carefully within the census tracts, it was considered that (Fig. 3):

(1) There is no population associated to areas with a given quantity of water bodies and forest;

(2) There are variables that indicate the presence or absence of population in space and that can be used to suggest the occurrence and distribution of the population;

(3) The relationship between these variables generates a potential surface of occurrence of population which allows redistribution of census values[1].

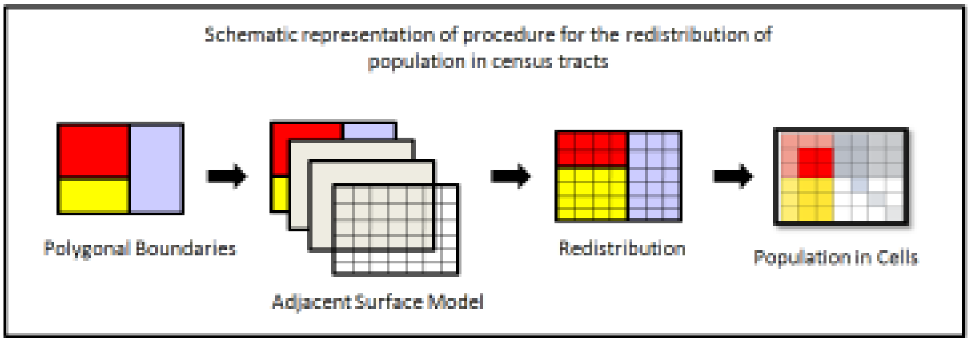

Figure 3: schematic Representation of the procedure for the redistribution of population within census sectors

The method consists of three basic steps: (i) by a dasymetric method (MENNIS, 2003, SLEETER, 2009) was eliminated the areas (cells) with more than 95% forest and water bodies for which there would be no inhabitants, (ii) indicative informations of human presence were used to generate a potential surface of occurrence of population, using Fuzzy Inference (ZADEH, 1988; MEIRELLES, 1997) and a multivariate interpolation method, (iii) redistribution of the values of the census population count in each cell proportionally to a potential occurrence of population defined by the indicator variables.

Thus, through a review of literature on the occupation of the region (PANDOLFO, 1994; AMARAL, 2003; BECKER, 2004; FURTADO, 2004), it was thought these variables in the diagram below (Fig. 4) as more representative as a starting point to generate a surface potential occurrence of population.

Because of its close association with gravitational transport processes (runoff, erosion, landslide) the terrain slope is a basic variable for targeting areas virtually all the procedures of territorial planning. We can say that all methods of assessment of land or conservation planning based on numerical modeling or logical decisions, deal with the variable slope (VALERIANO, 2008).

Given the strong relationship with the substrate and formation processes of relief, the studies of topography subdivision point the curvature as a variable with high power to identify homogeneous units for different mappings. This variable is related to processes of migration

[1] Any calculation to generate the surface density used cells as the unit of analysis, were made through TerraView software (TERRAVIEW FOR WINDOWS, 2004), developed by INPE.

and accumulation of matter through the surface (especially water), provided by gravity. By this mechanism, acts indirectly on the balance between the process of pedogenesis / morphogenesis, besides influencing the local distribution of water regime, the thermal regime and the spatial distribution of population (VALERIANO, 2008).

Unlike the other landsurface parameters such as slope or aspect, there is no clear agreement in the way roughness should be measured, and methods differ significantly in their underlying concepts. The concept of terrain roughness is, however, simple and easy to understand: it indicates how undulating the terrain is, i.e. how complex it is. High values of roughness indicate that the terrain is rather irregular around the cell being analysed, while low ones reflect a smooth terrain.

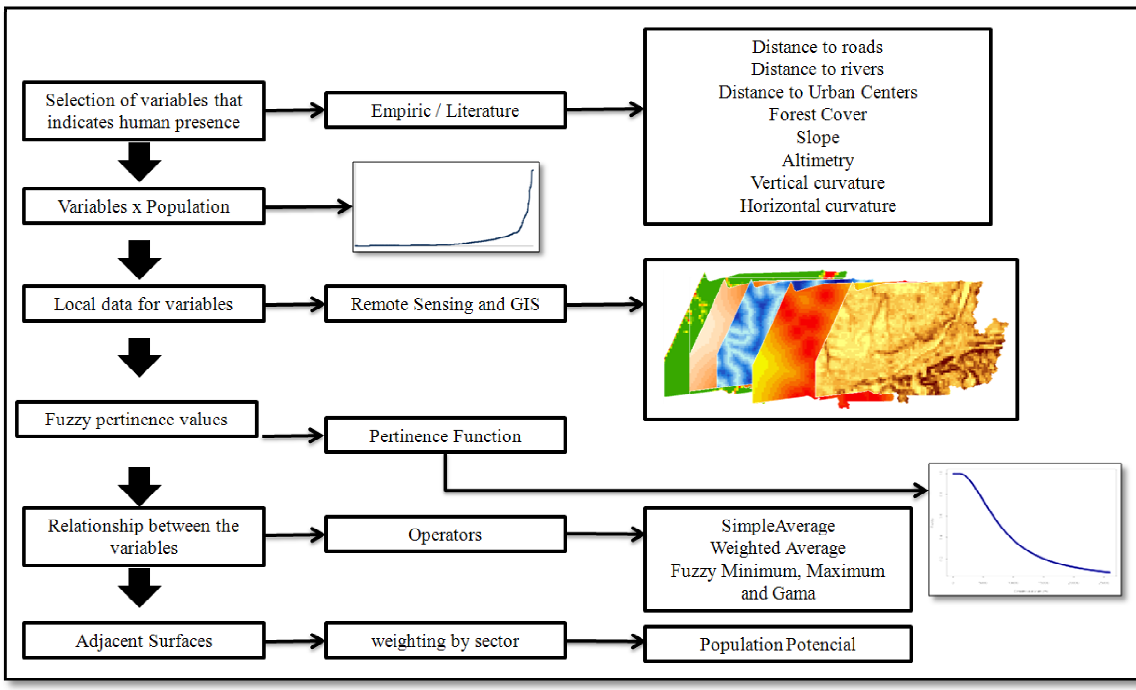

Figure 4: Steps for the multivariable method proposed

2.3 Multivariate method for a potential surface of population – For the Amazon region, the availability of access historically conditioned not only the human occupation, but the whole process of regional development. The presence of roads, even if subjected to poor maintenance and traffic committed during the rainy season, along with the river network, with the presence of nearby urban centers and with deforestation activities are factors that indicate human presence in the Amazon region.

Has been adopted criteria based on literature, as well as mathematical relationships between the variables. These variables were used to generate a potential surface of population occurrence based on the relative importance of each variable. Techniques based on Fuzzy logic as an alternative to the definition of smart interpolators have been proposed by Turner and Openshaw (2001), Amaral (2003) and Gavlak (2010) to evaluate different spatial interpolation methods to generate areas of population density. The relationship between indicator variables and population density can be translated into functions of relevance and Fuzzy inference (ZADEH, 1988; AN et al., 1991).

Shortly after the theory of fuzzy sets was introduced by Zadeh (1965), researchers began to argue that fuzzy sets theory could serve as an appropriate foundation for spatial analysis (GALE, 1972). It was argued early that fuzziness is a major factor contributing to the uncertainty of spatial behavior. The use of Fuzzy sets for characterization of classes should be indicated when dealing with ambiguity, abstraction, and ambivalence in mathematical or conceptual models of empirical phenomena (BURROUGH and MCDONNELL, 1998). Thus, to formally characterize a set, you can use the concept of pertinence function: given the value of an attribute "z", the function determines whether the element evaluated belongs to a given set of analysis or not.

Thus, it was necessary to quantify the relationship of predictor variables with the occurrence of population. Each variable was studied in particular, but taken as a general assumption that the occurrence of the districts (towns) would be evidence of human presence translated into population. Thus, we evaluated the relationship between each of the selected predictor variables: distance to roads, distance to rivers, distance to urban centers and slope for all districts in the region. These relationships will be used a second time to assign a potential occurrence of population within the census tracts.

In this work, to assign Fuzzy pertinence values was chosen applying of quadratic functions for all variables. The quadratic pertinence function was structured as follows, taking the distance to roads (z) as an example:

$$f(x) = \left\{ \begin{array}{c} 0 \; se \; z > 26000 \\ 1/(1 + \alpha\,(z - \beta)\,2) \\ 1 \; \mathrm{se} \; z \leq 900 \end{array} \right\}$$

The beta (β) value corresponds to the value of the variable when the possibility of have associated population is maximum, with a Fuzzy value equal to "1". The value of alpha (α) is obtained from the value of the variable where the occurrence or non-occurrence of the population would have the same chance of happening, in other words, when the value of function is equal to 0.5 and is given by the equation above:

$$\alpha = \frac{1}{(z - \beta)^2}$$

where z is the value of the variable for when f (z) = 0.5. A theoretical review on spatial inference techniques to relate variables can be found at Moreira (2001).

2.4 Relationship between the predictor variables - The relative importance of each indicator variables of the presence of population is essential to develop an adjacent surface which defines the possibility of occurrence of population. Through this surface the values of population will be redistributed into cells.

In the absence of a robust conceptual model or a pattern surface that could be used to obtain the relationship between variables, the following relationships were proposed: Simple Average, operators Minimum Fuzzy, Maximum Fuzzy, Gama Fuzzy and Weighted Average. The latter had their weighting from the pairwise comparison of evidence by the Analytic Hierarchy Process (SAATY, 1978). Figure 5 presents the selected relations and the pertinence function for four geomorphological variables used.

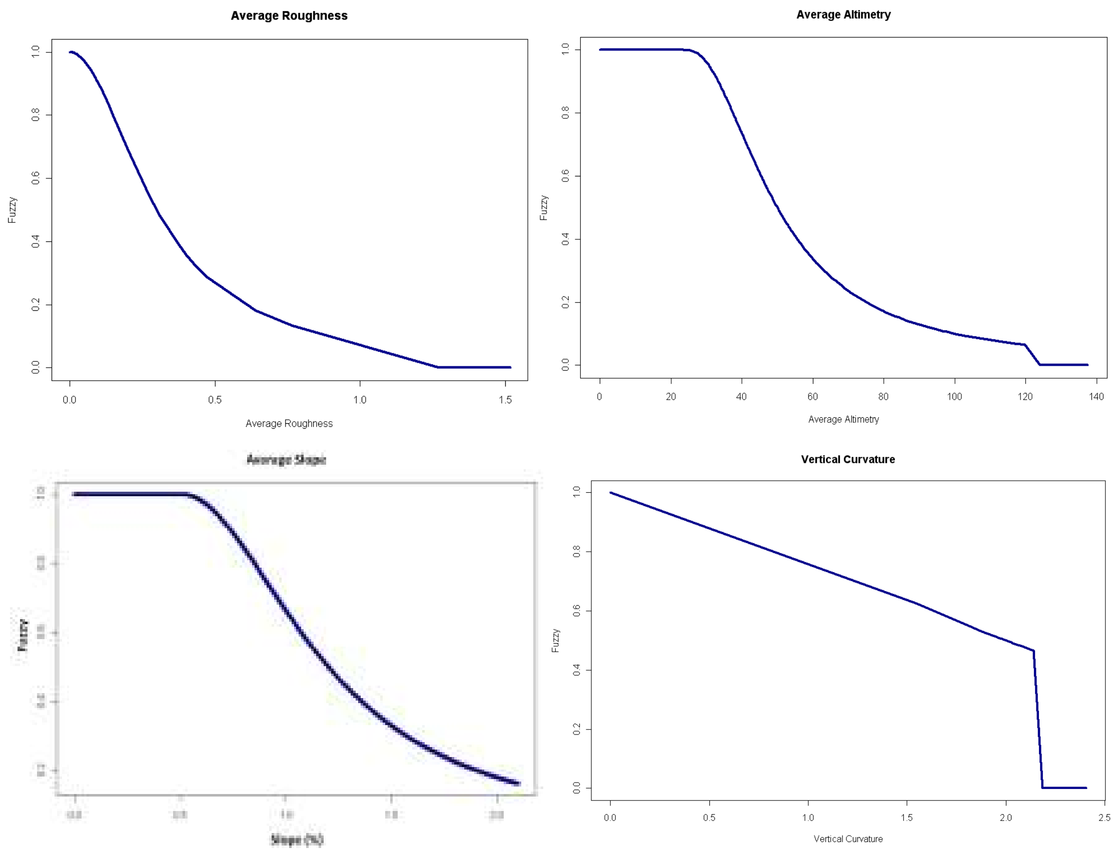

Figure 5 – Pertinence Function for Average Roughness, Average Altimetry, Average Slope and Vertical Curvature

The Table 3 shows the operators applied to relate the variables.

Table 3: Operators used to relate the variables		
Simple and Weighted Average	Minimum Fuzzy	Maximum Fuzzy
$\mu = \sum_{i=1}^{N} x_i P(X = x_i)$		
Gama Fuzzy		

2.5 Redistribution of population in cells - The count of total population, accounted for by census tract, was redistributed in cell grid considering the possibilities of the population suggested by the indicator variables as follows:

$$DP_{grid} = P_{CS} * \left(\frac{F_{grid}}{\sum_{i=0}^{j} F_{grid}} \right)$$

where DPgrid is the demographic density of the cell; Pcs is the censitary tract population; Fgrid is the fuzzy value of population possibility weighted by the summation of Fuzzy values obtained for each censitary tract.

Thus, the population density initially represented within the limits of census tracts (polygonal) was redistributed into cells according to defined relationships between indicators variables of population presence.

3 DISCUSSION

Above, is possible to see one potential surface of spatial distribution of population created by the proposed method (Fig. 6).

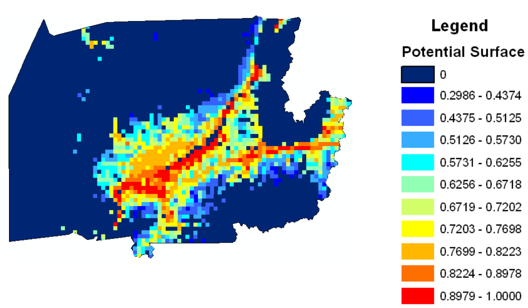

Figure 6 – Potential surface of spatial distribution of population

The generated maps can be viewed below (Fig. 7). The areas resulting from the Weighted Average surfaces showed areas with density values more homogeneous than the Simple Average. The surfaces resulting from the Fuzzy Minimum operator and Fuzzy Gama overestimated the density in some areas, because the presence of zeros invalidates the cell.

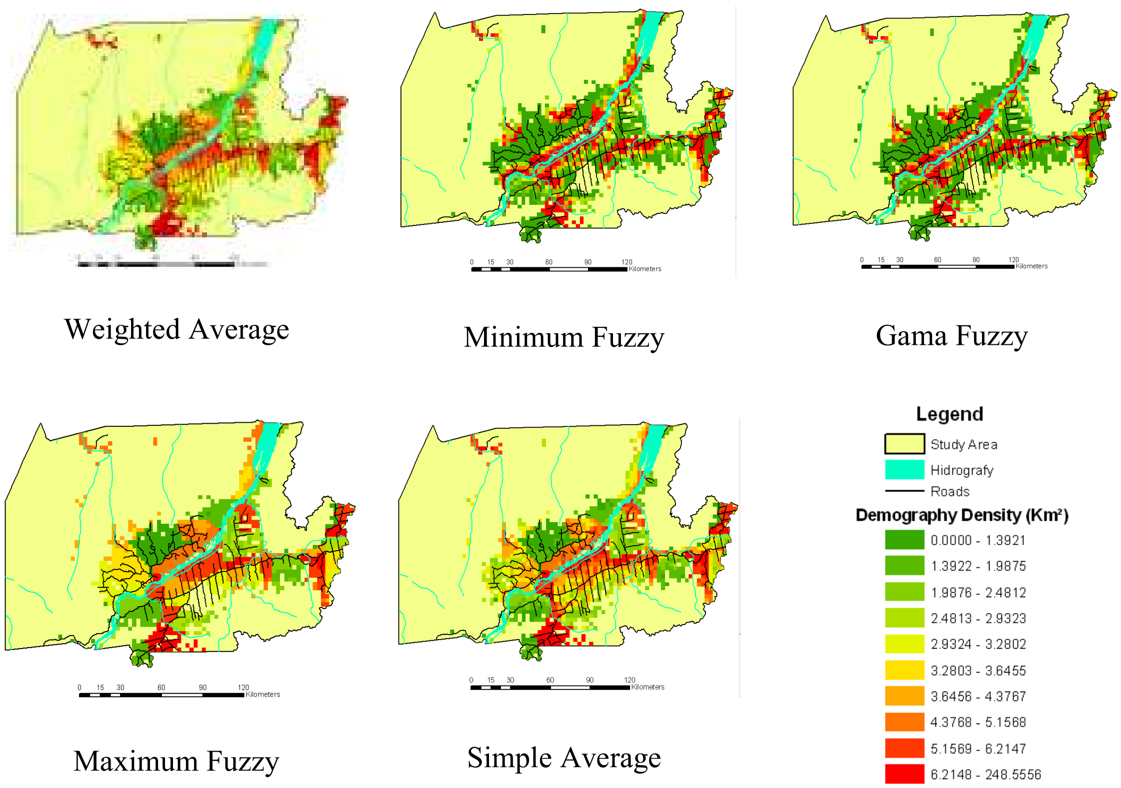

Figure 7 – Spatial distribution of population (inhabitants per square kilometer)

The map created by Fuzzy Maximum has a general appearance similar to the thematic map of population density of census tracts, creating a low heterogeneity in the distribution. The surfaces obtained by simple average were the ones that more properly incorporated spatial variation to distribute the population census sectors.

The proposed method proved satisfactory for measuring the population density in the area, given its characteristics. The Simple Average was the technique that showed the most consistent surface, being more sensitive to the heterogeneities in the locality. Attention should be paid for the procedure of deleting cells, avoiding the exclusion of population quotas. This shows that even the methodology returning very satisfactory results, some parameters still need adjustments.

Was presented a methodology and a first approximation of how to create adjacent surfaces using some geomorphological features and ancillary data to represent the spatial distribution of population density and the resulting surfaces. Improving the premises associated with the presence of the population, new rules can be established. This would make closer the areas of population to the reality of the distribution of population density in Amazonian territories.

One of the main advantages of the method is the fact that the population not be allocated in areas where there is no possibility of human presence such as in rivers, dense forests or any other location. Another positive point is the fundamental ability to disaggregate the data come from a census tract, for example, and store it in cells, which turns out to be an excellent solution when working with data over a period of time, and the spatial units of data indexing change over time.

4 CONCLUSION

This study showed the procedure developed for constructing surface density of population, highlighting the contribution of remote sensing data to capture the spatial heterogeneity of the region. From classified images PRODES was also obtained the percentage of forest in each cell, a variable that was used to weight the redistribution of population density values.

The possibility of representing the population distribution in density surfaces presented in this paper allows the temporal analysis of the evolution of allocation patterns in space, and indirectly about population mobility. Thus, they are provided additional data for analysis and diagnosis, to enrich the debate and integrated studies on population and environment in the Amazon region.

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