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REFEREED PAPER

# Creating a Dot Density Map: Resident Population in Mainland Portugal

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*Dot maps are one of the best ways to visualize absolute values in thematic cartography. Dots represent quantitative data on a map. Population is often used in this type of representation. This paper presents a population dot density map for the year 2011 on two scales: (1) for mainland Portugal, and (2) for the Lisbon and Oporto regions. We have used dots with constant values and sizes at the most detailed statistical level (i.e. statistical subsection) for localities with less than 5000 inhabitants, and proportional circles for localities with more than 5000 inhabitants. These two scales of analysis coupled with two cartographic representation techniques used on a single map allow for a clear reading of the distribution of population.*

Keywords: dot map; geographic information systems (GIS); population; mainland Portugal

## INTRODUCTION

Population is one of the most critical variables used in planning. One of the forms to represent it is using cartographic point symbols. In this study, two types of symbols are used according to the size of the population of each locality: dots and proportional circles.

When dealing with the distribution of the population, dot representation supplants graduated colours, which is a method that conceals the correct geographical location of the inhabitants, especially when the spatial basis corresponds to large areas (Dias, 1991a). Dot maps provide a simple visual representation by associating the spatial location of each dot or circle with the value at that location (Hey and Bill, 2014).

The first dot map was created in the nineteenth century in France by Frère de Montizon (1830) to represent population distribution (Thrower, 1999). Dot maps representing different phenomena started to be published some decades later. The first published scientific paper on dot mapping was written by De Geer in 1922. In the past decades, some authors have argued that dot maps are one of the best options in terms of cartographic representations (e.g. Robinson *et al.*, 1995; Slocum *et al.*, 2009).

The first dot maps used in Portugal were created in the early 20th century between the 1920s and 1950s. The first dot map of the distribution of population in Portugal was created by A. Girão in 1922 specifically for the Bacia do Vouga region. The first dot map of the distribution of population in the entire territory was developed by H. Lautensach

in 1932 (Dias, 1991a). In 1951, based on statistical data on localities gathered from a population census of 1940, Ribeiro created a dot map at a 1:500,000 scale. Decades later, Dias drew up a new dot map of the distribution of population in Portugal using the 1981 population census data (at parish level) (Dias, 1991b). These maps were all hand-drawn.

In the past few years, with the new resources and software currently available in the geographic information systems (GIS) context, we have some examples of dot maps for Spain (Zuniga *et al.*, 2012) and the United States of America (Martin-Anderson, 2012).

For the present study, we have created a dot density map of the residential population. This paper represents the first attempt to apply similar GIS techniques in the Portuguese context. We selected mainland Portugal as our case study due to the very uneven pattern of population distribution, including some very sparsely populated areas. The data used were based on the subsection statistical data of the 2011 Census (Instituto Nacional de Estatística (INE), 2011). This spatial unit corresponds to blocks in urban areas and localities or parts of localities in rural areas (Instituto Nacional de Estatística (INE), 2013).

## MATERIALS AND METHODS

The dot is the main cartographic element in this type of density map. Therefore, much care was taken to specify some of its characteristics. The value and size of this element is based on three parameters: (1) spatial units; (2)

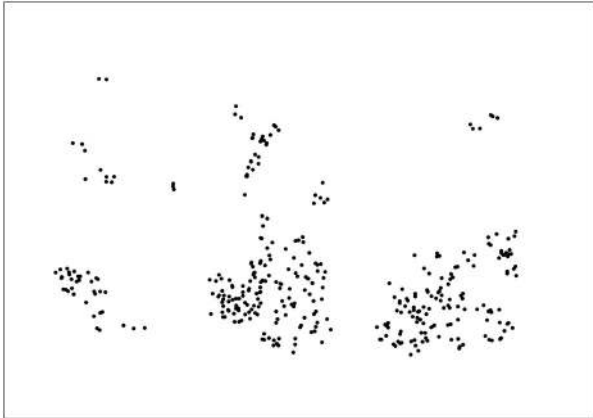


Figure 1. Dot value = 100 – low value

spatial variation; and (3) map scale. For these three parameters, assigning to a dot a value that is too low creates excess density in some places, preventing correct interpretations of the phenomena (Figure 1). On the other hand, if we choose a dot value that is too high, an impression might be given that an area is devoid of population (Figure 2). The number of dots must be as balanced as possible: too many or too few can lead to a loss of information (Robinson *et al.*, 1995).

Dot size assignment is linked to unit value. A graphic scale that is too small leads to a lighter distribution (Figure 3), while one that is too large causes dot coalescence. In both situations, the overall map becomes difficult to read (Figure 4) (Dias, 1991a; Robinson *et al.*, 1995).

To aid in the choice of dot size for this study, we used the Mackay monograph (Mackay, 1949), which was developed in the 1940s and has been used ever since as a guide for cartographers (Kimerling, 2013). This monograph enables the visualization and quantification of the relation between dot size and density (namely, smaller or larger overlapping area dots) according to the size representation on the map. This follows Anson and Ormeling (1991) recommendation that dot diameters should be between 0.5 mm and 3 mm in size.

Each dot is randomly placed within each statistical subsection. This does not constitute a limitation because the map has a small scale and the statistical limits are greatly



Figure 2. Dot value = 1000 – high value



Figure 3. Dot value = 500 – small dot size

reduced, thus minimizing the effects of random distribution. Furthermore, the proportional circles are located in the centroid of each locality. These circles are placed on the map from largest to smallest in order to ensure visibility.

The dataset used was the 2011 Census of the resident population by statistical subsection. In 2011, there were 10,042,021 inhabitants in Portugal (Instituto Nacional de Estatística (INE), 2011). The data were grouped by statistical subsection, and there were 255,876 spatial units. There are 266 localities with over 5000 inhabitants.

Setting dot size and value – Portugal (1:1,000,000 scale map)

For the 1:1,000,000 scale map, the dot diameter was set at 1.5 mm based on several tests according to the previously mentioned criteria. Furthermore, each dot was chosen to represent 500 inhabitants.

The number of dots (NumDot) is calculated using the total resident population in each subsection (totalpop), divided by the value assigned to each dot (dot value) computed as follows:

$$\text{NumDot} = \left( \frac{\text{totalpop}}{\text{dotvalue}} \right) \tag{1}$$

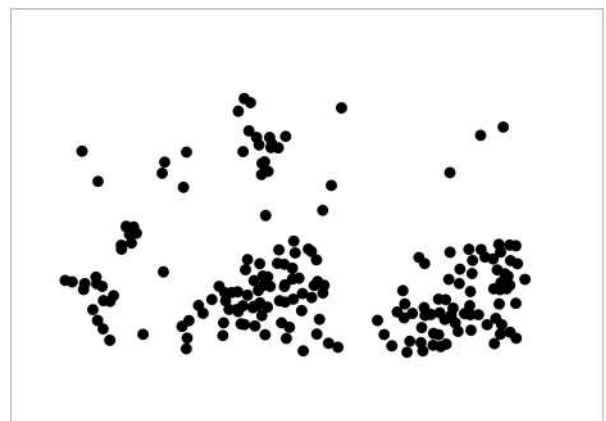


Figure 4. Dot value = 500 – large dot size



Figure 5. (a) Subsections with more than 250 = 1 dot; (b) subsections with more than 250 = 1 dot plus subsections that resulted from the addition of remaining dots

In the subsections with under 250 inhabitants, the number of dots is less than 0.5. Therefore, an alternative method was used to aggregate the residuals from these cases, consisting in:

- (i) identifying to what parish (a higher level of statistical aggregation) each subsection belongs to;
- (ii) summing the inhabitants belonging to subsections with under 250 inhabitants for each parish;
- (iii) using (1) the number of dots was calculated based on the sum of inhabitants of all subsections with under 250 inhabitants in the parish;

- (iv) sorting decreasingly the subsections under 250 inhabitants of each parish and distribute the dots from the highest ranked subsection to the lowest (Figure 5a and b).

In the unlikely situation that after giving one dot for each subsection some dots still remain unrepresented, the process returns to the beginning of (iv) and the loop continues until none persist.

Because of the observed dot overlapping in some areas and since some dots were quantifiably unreadable, proportional circles were used for localities with population size higher than or equal to 5000 inhabitants (this value was achieved after several tests to find a balance so that we could have the maximum dots possible without coalescence). The statistical

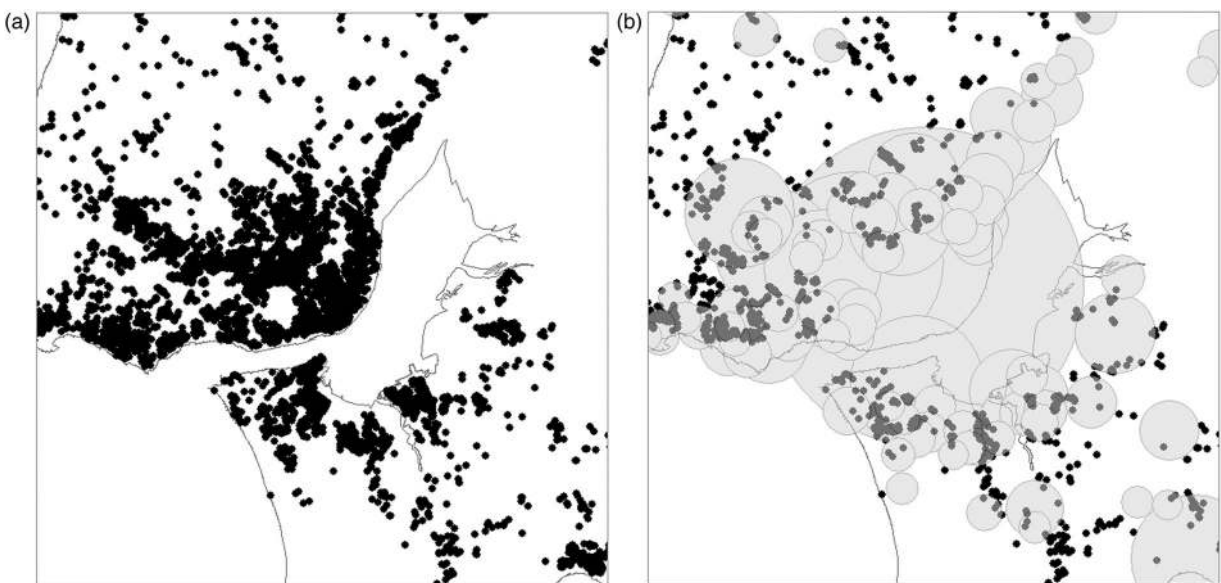


Figure 6. (a) Dot coalescence – data at statistical subsection; (b) dot and proportional symbol combination

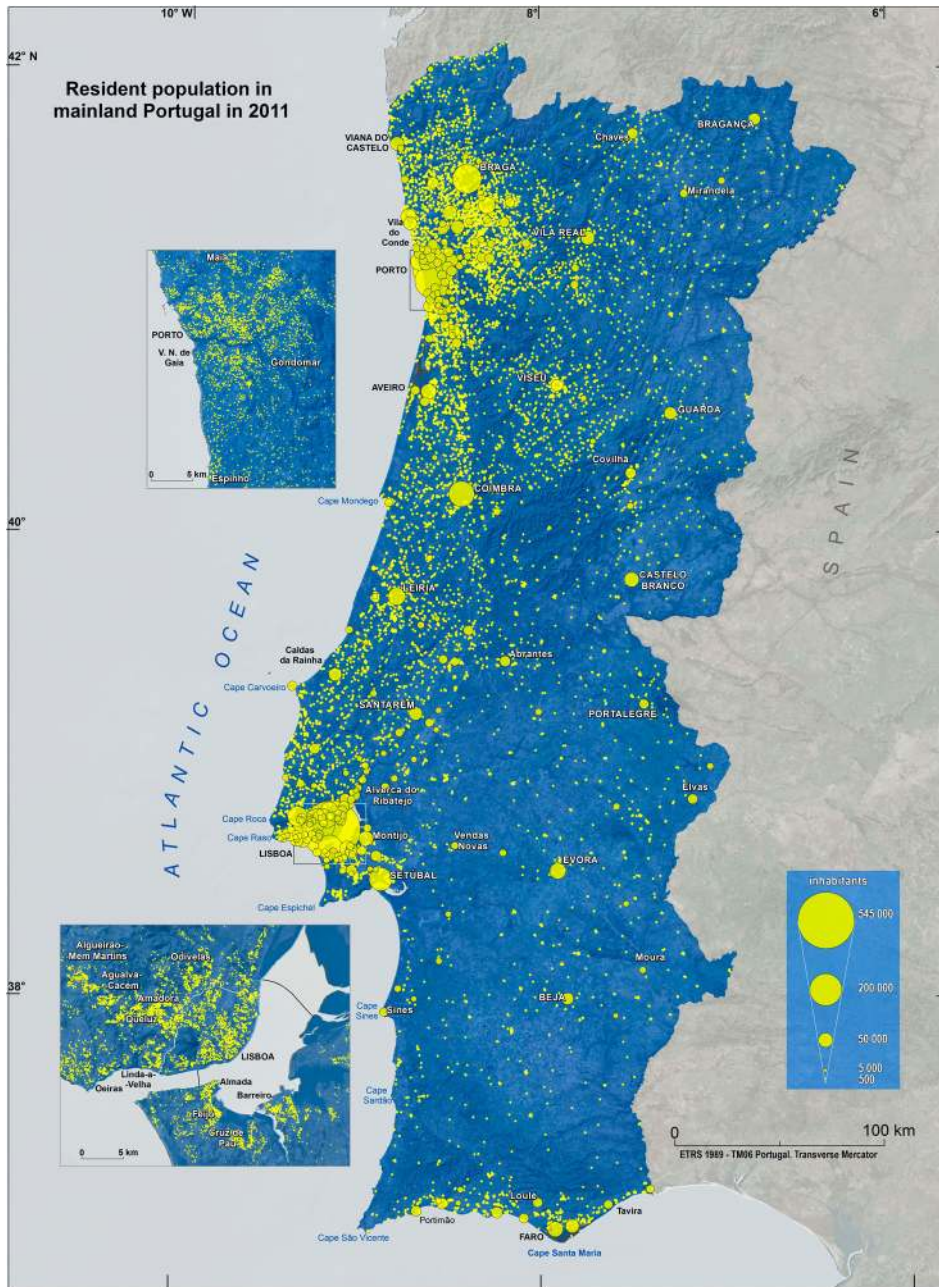


Figure 7. Resident population in mainland Portugal in 2011

subsections in these areas are aggregated at locality level and only represented by proportional circles (Figure 6a and b).

The proportional circle method used was the Flannery Appearance Compensation (Flannery, 1971). This method is experimentally derived from a power function exponent of 0.5716. It is calculated by Eq. (2):

$$r_i = \left( \frac{v_i}{v_{max}} \right)^{0.57} \times r_{max} \quad (2)$$

where  $r_i$  is the radius of the circle to be drawn;  $v_i$  is the value of the variable for which the circle will be drawn;  $v_{max}$  is the

maximum value of the variable;  $r_{max}$  is the radius of the largest circle on the map.

**Setting dot size and value - Lisbon and Oporto (1:250,000 scale map)**

The regions of Lisbon and Oporto are densely populated. Thus, we had to highlight these two areas on a larger scale (1:250,000). The two highlighted regions are mapped using only dots (without proportional circles). The values were the same (1 dot = 500 inhabitants), but dot diameter was reduced (1 mm) to circumvent overlapping. Thus, dot coalescence was avoided, allowing for a better understanding

of population distribution in these more densely populated areas.

#### Colour variables in the map

The visual variables are directly linked to the perception of spatial distribution, namely symbol colours and the map layout background colour (Sadahiro, 2000). Colours in Cartography allow readers to distinguish between phenomena (Dias, 1991a). As the most important information on the map, dots and proportional circles were shown in yellow with an RGB (red, green, and blue) colour model with the values: 255, 255, 0. Yellow emphasizes the phenomena represented. The proportional symbols are 20% transparent, so that every dot represented underneath is visible.

#### Map design

The map includes additional secondary information: the administrative boundaries of Portugal, a digital terrain model (DTM), and a satellite image on the background. The administrative boundaries of Portugal are blue (RGB 0, 92, 230) with 50% transparency to ensure that DTM and satellite image are visible. This type of secondary information on a map with such characteristics allows us to emphasize the most important variable in the map: the resident population (Figure 7).

## RESULTS AND CONCLUSIONS

Point symbols on maps emphasize clarity and readability as their main visual qualities. They allow for quantitative analyses by showing each dot and proportional circle, and for qualitative ones by indicating variation in population density.

The densest areas in Portugal are the metropolitan regions of Lisbon, Oporto and the Algarve Coast, the least densely populated areas are located in eastern Portugal, including parts of the Alentejo region whereas the least densely populated areas are located in east Portugal namely in the Alentejo region. This region is a specific example of a sparsely populated area.

The distribution of the population will help to identify the strengths and weaknesses in different areas and subsequently to suggest feasible recommendations for improvements regarding spatial planning. Future work should include monitoring the distribution of residents using census population of future decades.

This paper has demonstrated the use of a dot map to represent wide variations in population density such as those found in Portugal. Moreover, the humble dot map can still play a useful role in promoting wider public awareness of regional inequalities and spatial planning issues, thanks to its inherent simplicity and immediate visual impact.

#### SOFTWARE

Two software programs were used in this study:

- (1) Microsoft Access: for database structuring;
- (2) ArcGIS. ESRI 10.3: for map building.

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