



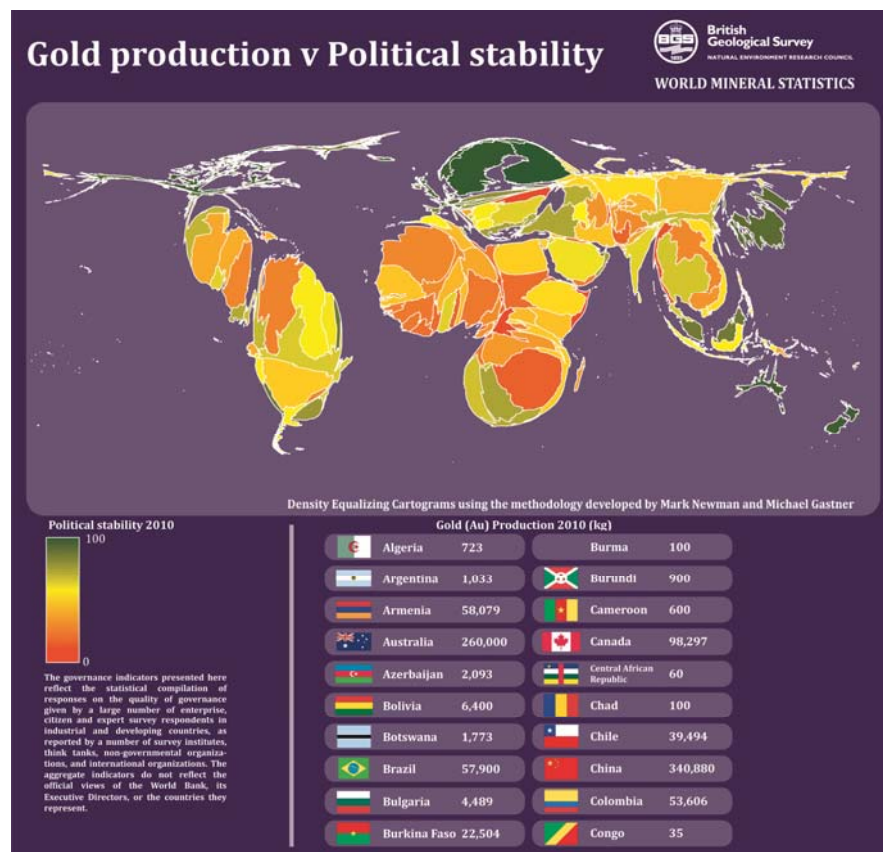
**British
Geological Survey**

NATURAL ENVIRONMENT RESEARCH COUNCIL

The use of cartograms for BGS data and information representation

GeoScience Products and Services Directorate

Internal Report IR/13/052



BRITISH GEOLOGICAL SURVEY

GEOSCIENCE PRODUCTS AND SERVICES DIRECTORATE

INTERNAL REPORT IR/13/052

The use of cartograms for BGS data and information representation

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Keyworth, Nottingham British Geological Survey 2013

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Foreword

This report is the published product of a study by the British Geological Survey (BGS) illustrating the potential for the use of area cartograms to present geological science information. The project involved establishing an overview of all the types of cartogram used; noting the types of data used in their creation and identifying similar sources of data that may prove appropriate for use in cartograms. Test examples were created and presented along with an evaluation as to their effectiveness and efficiency in communicating spatially orientated datasets.

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Contents

- Foreword i**
- Acknowledgements..... i**
- Contents..... ii**
- Summary iv**
- 1 Introduction 1**
- 2 Cartograms 2**
 - 2.1 Distance Cartograms..... 2
 - 2.2 Area Cartograms..... 2
 - 2.3 Discussion..... 5
 - 2.4 Cartogram Criteria 6
- 3 Investigations 7**
 - 3.1 World Mineral Production..... 7
 - 3.2 iGeology 10
- 4 Results 14**
 - 4.1 World Mineral Production Cartogram..... 15
 - 4.2 iGeology App Use Cartogram 16
 - 4.3 An Evaluation 17
- 5 Conclusions 19**
- Appendix 1 21**
- Glossary..... 22**
- References 23**

FIGURES

- Figure 1: The 2010 general election results. The choropleth map (left) illustrates a clear visual bias in favour of blue, but once the population density equalizing algorithm is applied to each region it becomes clear how the elections in 2010 resulted in a hung parliament. 1
- Figure 2: Choropleth map (left) showing the 2008 US election results compared to a contiguous cartogram (right) presenting the same data (Gastner, et al., 2005). 3
- Figure 3: Two examples of non-contiguous cartograms showing differential weightings for each polygon area (Keim, et al., 2005). 4
- Figure 4: Illustrating the linking method between the choropleth map and the circular cartogram. Reproduced with author's permission from 'Maps of the Census: a rough guide' (Dykes & Unwin, 1998). 5
- Figure 5: A rectangular cartogram (a) showing false topological relationships between Netherlands (NL) and Luxembourg (LU), when in reality these countries do not border each

other. An alternative would be to allow for abstract (non rectangular) shapes e.g. Hungary (HU) (based on Speckmann, 2006).	5
Figure 6: Effective readability – base map extremes in areal unit type and scale.	7
Figure 7: Choropleth map showing state gold production (2010).	9
Figure 8: Choropleth map showing state gold production and political stability (2010).....	10
Figure 9: Choropleth map showing iGeology app activation throughout Great Britain between September 2010 – November 2011.	13
Figure 10: Cartogram showing a clear reduction in visual bias towards large polygon areas (as seen on choropleth maps) by introducing population density.	14
Figure 11: Cartogram showing state gold production and political stability (2010).	15
Figure 12: Cartogram showing political stability and gold production (2010).....	16
Figure 13: Removing bias from hotspots of human activity through averaging app use over areal unit areas.....	17

TABLES

Table 1: Software and programme applications.....	21
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Summary

Cartograms are shown to be superior to both choropleth maps and bar charts, as they are designed to deliver geospatial statistics effectively and efficiently. This report presents the results of research in establishing the potential for the use of area cartograms for science information delivery. The research involved establishing an overview of all the types of cartogram used; noting the types of data used in their creation and identifying similar sources of data that may prove appropriate for use in cartograms. Test examples were created and presented along with an evaluation as to their effectiveness and efficiency in communicating spatially orientated datasets. The work was carried out as part of the Data Representation and Presentation project for the Geospatial Capture and Solutions team. This forms part of a wider research project investigating new ways in which BGS can display science and information more effectively to a broad range of audiences.

1 Introduction

During the mid 1980's the arrival of the desktop PC gave the researcher direct access to word processing and spreadsheet packages for the first time. Statistical data packages such as: Cricket Graph, Lotus 1-2-3, and Microsoft Excel facilitated quick and easy production of graphs and pie charts and they soon became the standard tools for communicating statistical data. Thirty years on this now familiar method of statistical communication continues to deliver, even though it is somewhat lacking in visual impact. Graphs and charts may fulfil the functional role they are created for but they often fall short of capturing the attention of the reader, especially in the transient media context of conference posters or the internet (Miller, 2007). Statistical data of a spatial nature isn't always appropriate for use in charts and graphs when the data can be visualised spatially. Innovative moves away from charts and graphs can be found in broadsheet newspapers through the use of information graphics or infographics (Infographics.com, 2012). Infographics are highly designed statistical graphical representations of data. A successful infographic communicates purely on a visual level often transcending language barriers by reducing text to the absolute minimum, avoiding visual fatigue and improving efficiency.

Another type of visualisation that can often form part of an infographic image are cartograms. Quantitative data of a spatial nature can be presented in the form of an area cartogram, which is a distorted map-like illustration of statistical data providing a powerful visual impression that is capable of delivering multiple attributes at a single glance (Inoue & Shimizu, 2010). During general elections cartograms are used in preference to the traditional choropleth map in order to alleviate the spatial bias of large and small polygon areas (Lekien & Leonard, 2009). Figure 1 shows UK general election results for 2010 and how a choropleth map doesn't always communicate as efficiently as a cartogram can. They are most notable when political victories are won largely due to voters in densely populated constituencies inside metropolitan areas such as London and Manchester (Openshaw, 1984; Dorling, 1996).

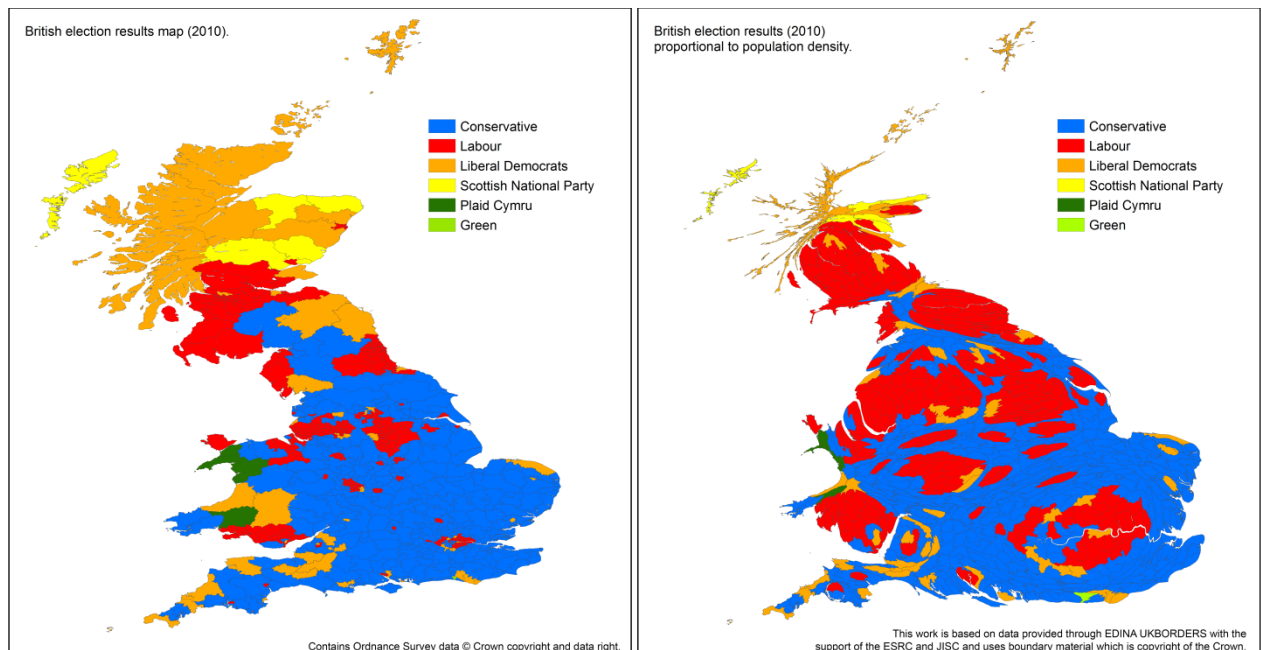


Figure 1: The 2010 general election results. The choropleth map (left) illustrates a clear visual bias in favour of blue, but once the population density equalizing algorithm is applied to each region it becomes clear how the elections in 2010 resulted in a hung parliament.

The concept of an area cartogram has been around for well over a century (Tobler, 2004; Krygier, 2008) but it is only in recent years that the technology has become accessible, enabling the researcher to apply this useful method of statistical presentation (Gastner, et al., 2005). It is interesting to note that only subjects within the social sciences have so far been known to adopt the use of cartograms (Keim, et al., 2005). Considering the frequency with which graphs and charts appear in papers and displays throughout science information delivery it could be a missed opportunity in not using cartograms to represent this data more effectively.

The aim of this report is to establish if the cartogram is an appropriate method of data representation for the geological sciences and statistical data. A brief description of the various types of cartogram will be explored and illustrated, with a view to establishing any potential for information representation. From this list, an appropriate cartogram will be created by using existing BGS data and visually assessed on its effective communicative qualities. Finally a compendium of existing software's available for the creation of cartograms will be sourced and listed in the appendix.

2 Cartograms

The current school of thought identifies two main categories of cartogram: the distance cartogram and the area cartogram (Shimizu & Inoue, 2009; Sun & Li, 2010). The area cartogram can be further categorized into two subtypes: the contiguous cartogram or the non-contiguous cartogram, although a third category is frequently advocated, the circular cartogram (Kreveld & Speckmann, 2007; Bortins & Demers, 2002).

2.1 DISTANCE CARTOGRAMS

Distance cartograms are value over distance diagrams, displayed in the form of points and vertices. Unlike the isochronic map, used to show time over distance from a common starting point (Galton, 1881), the distance cartogram applies the value over distance rule to all inter-connected features, simultaneously. One example of the distance cartogram has recently been employed to show overall time taken to travel between Japanese cities via the national rail network (Shimizu & Inoue, 2009). A series of cartograms using data collected over a period of years demonstrates a quantitative impression of travel time between each city; revealing an obvious improvement in travel speed over the years. This technique can be used to animate a sequence of data groups over time, thus adding an extra dimension to the presentation (see example

http://www.plan.civil.tohoku.ac.jp/inoue/english/research/cartogram/distance_cartogram.html).

2.2 AREA CARTOGRAMS

An area cartogram is a map that distorts its regions according to a chosen attribute, generally described as a 'value by area' diagram displaying statistically aggregated data in a loosely based geospatial context. In other words, it is a statistical representation of data that might look like a map, but is no longer a map (Bortins & Demers, 2002). The map projection and the map topology are secondary to the quantitative attribute assigned to each areal unit (polygon area). The draw between retaining original spatial shape (Kreveld & Speckmann, 2007; Keserica, et al., 2009) and allowing absolute attribute dominance over topology, does vary depending on the

subject matter (Kocmoud, 1997). One significant advantage over the standard choropleth map is that cartograms help reduce the effects of the modifiable areal unit problem (Openshaw, 1984; Openshaw & Alvanides, 1996; Kardos, et al., 2005). The Modifiable Areal Unit Problem (MAUP) is a well understood issue with choropleth maps resulting in the delivery of misleading information as a result of scale and inconsistently sized artificial (fiat) boundaries. Cartograms can reduce visual bias towards large regions over smaller ones (Nöllenburg, 2007). The overall visual effect of the cartogram makes it a very efficient method of communicating quantitative information (Inoue, 2011a). Area cartograms generally come in three types: contiguous, non-contiguous and the circular cartogram.

2.2.1 Contiguous Cartograms

Contiguous area cartograms (sometimes known as continuous cartograms) use algorithms that allow each areal unit or region to be distorted by a chosen attribute without breaking up the map topology (Figure 1). The advantage of using a contiguous cartogram is that there is a good chance the areal regions will be recognisable to a point, as topological relationships are maintained, albeit sometimes heavily distorted (Figure 2). Should the attribute chosen for weighting each areal region contain a large range, or the areal regions shown display extreme differences in area size, the distortion might prove too much for a meaningful representation; To remedy this, adjustments in either the scale of attribute or the choice of areal unit coverage (normalise units making them more uniform in area and size) might help solve the problem (Kocmoud, 1997).

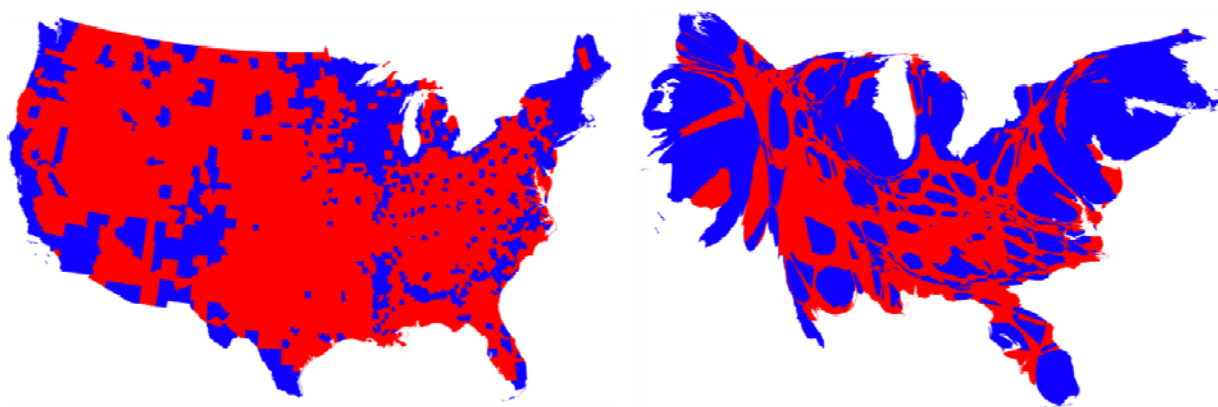


Figure 2: Choropleth map (left) showing the 2008 US election results compared to a contiguous cartogram (right) presenting the same data (Gastner, et al., 2005).

2.2.2 Non-Contiguous Cartograms

Non-contiguous cartograms apply the same rule for weighting a chosen attribute to each areal unit, but the topology is discarded. One of the easiest methods of creating a non-contiguous cartogram is to allocate the largest attribute at 1:1 scale and shrink the remaining proportionately, centred on the region centroid (Figure 3).

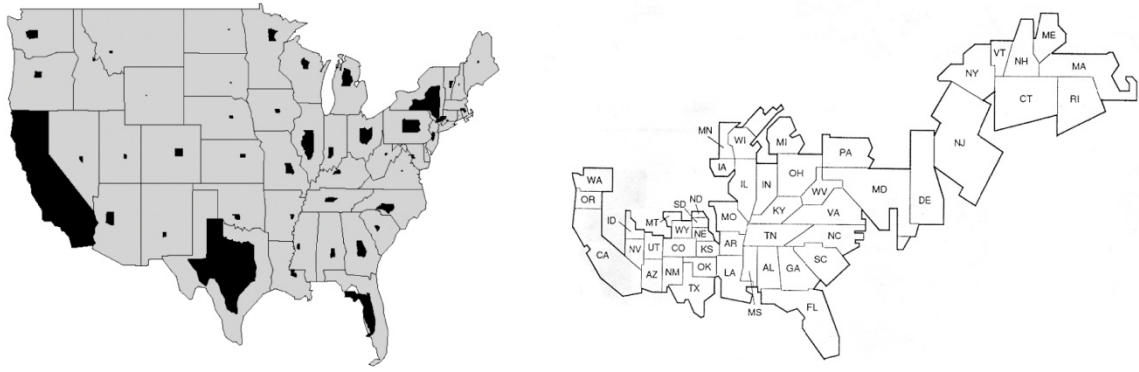


Figure 3: Two examples of non-contiguous cartograms showing differential weightings for each polygon area (Keim, et al., 2005).

One of the main drawbacks of this method of representation is that it works best if all the regional areas are of a similar size and shape. Any extremes will lose meaningful communication. However, the main advantage to this type of cartogram is that the regions they are made to represent are more likely to be recognisable to the user (Sun & Li, 2010).

2.2.3 Dorling Circular Cartograms

It has been proposed that the term ‘simple-shaped cartogram’ might be a more appropriate name for this category (Inoue, 2011b), but most publications refer to this type as the Dorling Circular Cartogram. Circular cartograms were developed during the early 1990’s by Professor Dorling (1996) and have proved to be a very popular method of presenting population data (Dykes & Unwin, 1998) albeit not without some criticism (Sun & Li, 2010). The abstract nature of the circular cartogram can result in a total loss of shape and studies have shown that people generally find them difficult to interpret (Sun & Li, 2010).

Circular cartograms work by replacing areal unit boundaries (e.g. districts, counties or countries) with a circle, which is centred on a centroid based on the original areal unit area. Each circle is then scaled proportionately according to its weighted attribute value. These circles are then moved, one by one, into a collective position of ‘best fit’ based on two opposing parameters: a process that repels overlapping circles and simultaneously attracts each circle to a point of least displacement from its original position (Dorling, 1996; Inoue, 2011a). Should the resulting cartogram look too abstract, a visual technique called ‘linking’ may be necessary, where a choropleth version of the original map is placed adjacent to the circular cartogram in order to provide a visual cue for spatial comparison (Figure 4)(Dykes & Unwin, 1998). Another method called the ‘brushing’ technique borrowed from statistical graphs can also be employed. This is where a map of normal projection is presented alongside a cartogram and a point of location can be simultaneously highlighted on both maps through cursor interaction by the user (Tobler, 2004).

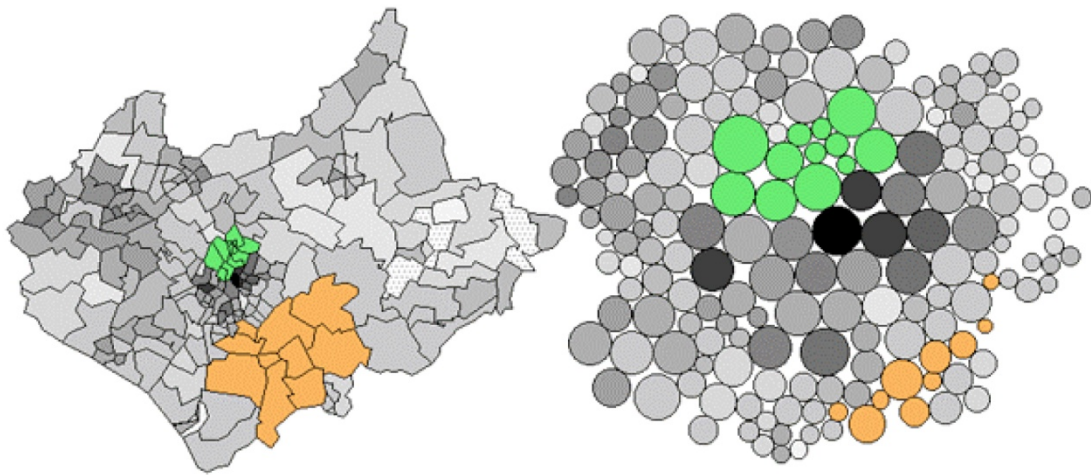


Figure 4: Illustrating the linking method between the choropleth map and the circular cartogram. Reproduced with author's permission from 'Maps of the Census: a rough guide' (Dykes & Unwin, 1998).

It could be argued that the term 'circular cartogram' is a misnomer, as any shape or symbol can be used as an areal unit such as the rectangle (Figure 5a) (Raisz, 1934) or the hexagon (Kardos, et al., 2005). It can be argued that the rectangle is much better for estimating area, but serious topological problems can occur for example, Luxembourg surrounded by Belgium, France and Germany. One method to overcome this problem is to drop strict rectangle use and allow the introduction of 'L' shaped units (Speckmann, 2006).

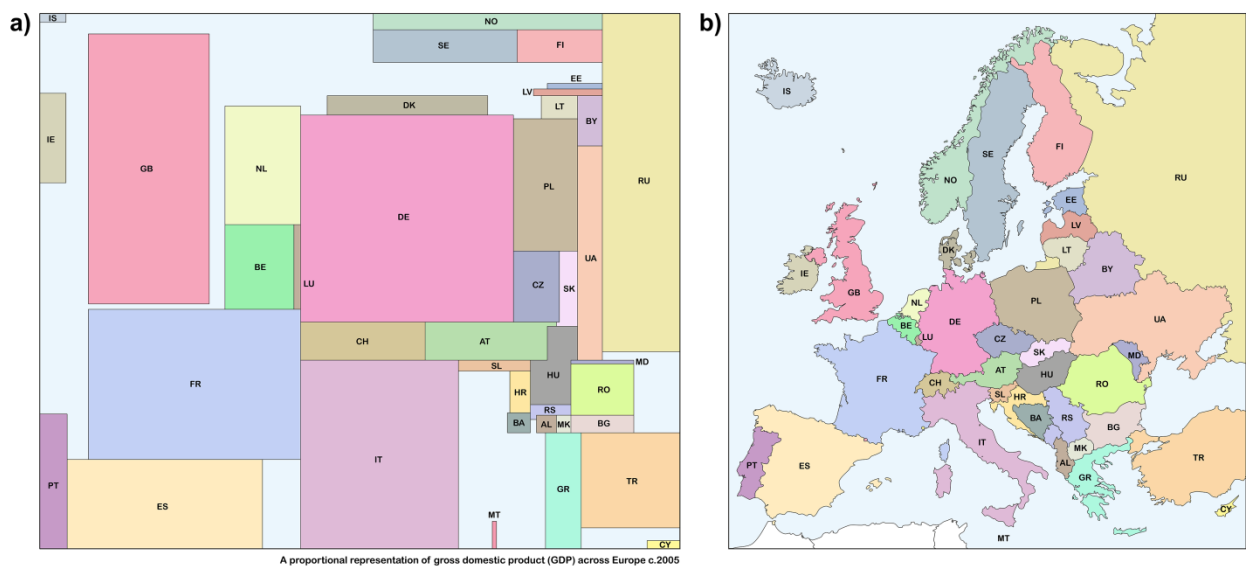


Figure 5: A rectangular cartogram (a) showing false topological relationships between Netherlands (NL) and Luxembourg (LU), when in reality these countries do not border each other. An alternative would be to allow for abstract (non rectangular) shapes e.g. Hungary (HU) (based on Speckmann, 2006).

2.3 DISCUSSION

The following discussion will establish why cartograms should be considered for use within science information representation. Based on the main types of cartogram listed in the previous

section, an overview of the benefits and potential issues with regards to their use will be addressed.

2.3.1 Benefits

- 1) Cartograms hold a clear visual advantage over the standard graph, table or chart. This is not based on purely visual impact; cartograms are more efficient communicators of quantitative data than graphs and charts (Dorling, 1996; Miller, 2007).
- 2) Cartograms, particularly area cartograms, have a clear advantage over both graphs and the choropleth map by their ability to simultaneously representing more levels of data. The choropleth map is limited to visually displaying one or two attributes at a time (texture and colour fills for the regions) if added symbols or labels are not taken into account (Dykes & Unwin, 1998). The area cartogram, however, can simultaneously show three sets of attributes; one for the area unit size and the others being the texture and colour of each region (Nöllenburg, 2007).
- 3) Area cartograms have the useful ability to reduce the effects of the modifiable areal unit problem (MAUP) that is inherent on choropleth maps. MAUP is a well understood issue with choropleth maps resulting in the delivery of misleading information as a result of scale and inconsistently sized artificial (fiat) boundaries. Equalizing the polygon areas to their attribute density helps to balance out the static bias towards large and very small areas that would remain on a standard choropleth map (Openshaw & Albanides, 1996; Jelinski & Jianguo, 1996).

2.3.2 Issues

- 1) Cartograms rely on the user recognising the regions (Dent, 1975). If the regions are beyond recognition the diagram becomes meaningless (Keserica, et al., 2009; Tobler, 2004). If the original map is of an area not familiar to the potential audience, a technique called 'linking' or the 'brushing technique' might be necessary (Nöllenburg, 2007; Anselin, et al., 2006). The 'linking' approach involves showing a choropleth version of the cartogram side by side (Figure 4) whereas 'brushing' is interactively showing the same point on the choropleth map and cartogram at the same time. Failure to do this may result in confusion (Sun & Li, 2010). This process is more likely for contiguous cartograms, particularly Dorling circular cartograms, due to the abstract nature of the output.
- 2) Original base maps used as templates for distortion will be more successful in communicating distorted polygon areas if all polygon (areal unit) areas are within a visually discernible size range. If areal units are initially invisible to the naked eye, any meaningful change in size due to proportional attribution distortion will be lost, especially if nested next to large neighbouring areas.

2.4 CARTOGRAM CRITERIA

To successfully create an area cartogram it is important to have quantitative spatially related data. There are two important factors required for producing an effective cartogram:

- 1) Each areal unit (polygon) should ideally be of a similar size or at least within a useful visual size range (the smallest polygon is easily observable in its natural projection).
- 2) The base map should be easily recognisable to the viewer/reader.

For a cartogram to be an effective successful communicator of statistical information, both factors must operate. Any bias or absolute weighting towards one or the other factor will render the cartogram ineffective.

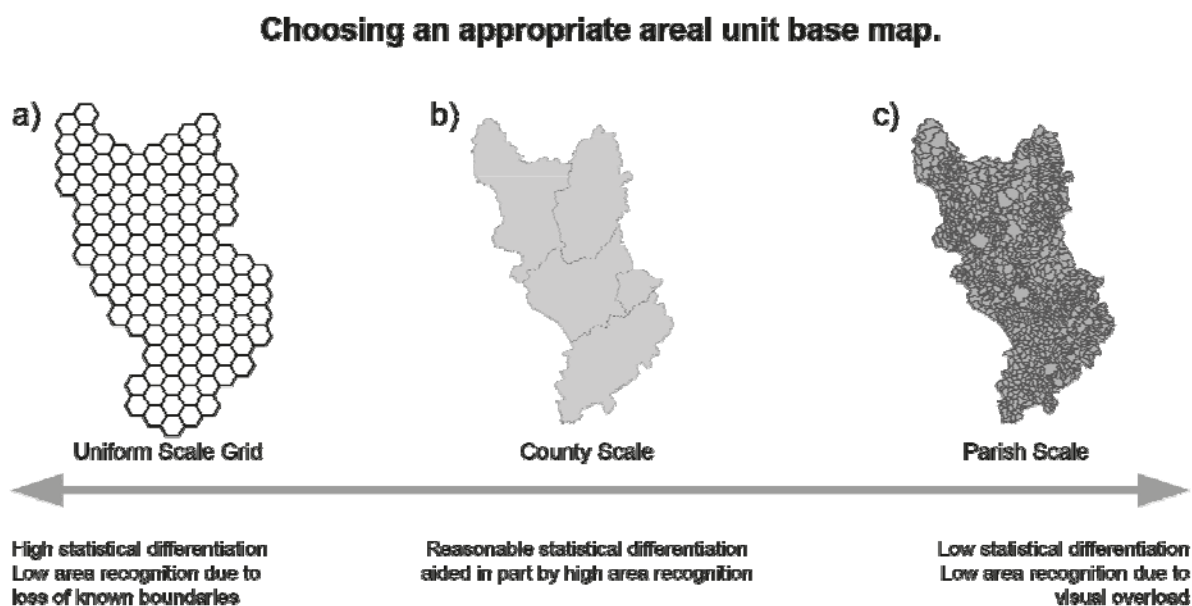


Figure 6: Effective readability – base map extremes in areal unit type and scale.

Establishing an effective compromise between areal unit uniformity and area recognition is an intrinsic element to cartogram production (Figure 6). In practice, authors may encounter limitations with the base map or appropriate spatial data provided in the attribute table, ruling out the possibility to create an effective cartogram. However, as long as one of the data inputs are constant (equal area sized base map, or a standard value applied to all areas) the results should prove both effective and readable.

3 Investigations

If projects within BGS produce spatially related quantifiable data that can be aggregated within a base map that is both spatially uniform and easily recognisable, there is no reason why cartograms cannot be utilised. For the purpose of this study, two datasets were identified as appropriate for testing: World Mineral and Metals Production data and the returned results from the usage of the iGeology app, launched in 2010.

The following tests were achieved using available software and BGS sourced data identified as appropriate for cartogram production based on the criteria stated in 2.4.

3.1 WORLD MINERAL PRODUCTION

Since 1913, the British Geological Survey has maintained a database of statistics that reveal global outputs of minerals and metals compiled through the cooperation of numerous national and international organisations. These statistics help to fulfil the global need for maintaining and managing the security of mineral and metals supply worldwide (British Geological Survey, 2012). BGS collates and publishes one of the largest databases on the production and trade of

minerals throughout the world, and these statistics are traditionally presented in table form (Brown, et al., 2012).

These statistics are released annually in tables contained within an online brochure downloadable from the BGS website. The British Geological Survey's unique position on collecting and presenting statistics on world exports and imports of minerals is an ideal candidate for testing data in cartogram form.

3.1.1 Methodology

The World Mineral Output statistics were used as the values that determined the proportional distortion for each areal region - in this case, the countries. The colour ornament (fill) of each country was reserved for an appropriate complimentary statistic based on the basic rules for allocation data within cartograms in 3.1.4. To help test the effective nature of the cartogram it was decided the colour fill attribute would be best served by using a social or economic indicator appropriate to the mineral attribute such as GDP for example. This social or economic attribute of the cartogram would then fulfil the conventional choropleth role of displaying qualitative categories for each country, indicated by colour, with the quantitative element (in this case: mineral statistics) used to generate the spatial area distortion aspect of the cartogram.

3.1.2 Data Sources

Two dataset types were utilised to help present a meaningful visual expression of global aggregate production in a social context.

1) World Minerals and Metals

Statistics based on geological aggregate production was sourced from the World Minerals and Metals statistics, which are available in listed table format within an online portable document file (pdf) openly available from the BGS website. A spreadsheet of the data used to create the pdf was sourced.

2) Worldwide Governance Indicators

Social statistics based on countries of the world was obtained from the Worldwide Governance Indicators (WGI) project that annually report on six broad dimensions of governance for over 200 countries, in this case over the period 1996-2011. Full interactive access to the aggregate indicators, and their underlying source data, is available at www.govindicators.org.

3.1.3 Cartogram

From the data sources, one category was chosen for the creation of the cartogram, the other for the colour attribution. The '*Mine production of gold*' statistics sourced from the World Mineral Production list, annually published by the BGS; and the '*Political Stability and Absence of Violence*' statistics (Kaufmann, et al., 2010) as sourced from one of six potential choice of indicator from the Worldwide Governance Indicator website.

The choice of cartogram category depends on the nature of the data you wish to communicate. In the case of world mineral production, the contiguous area cartogram proved to be most appropriate, on the basis that the context of the data (a map of the World) will have a high potential for area recognition and deliver an effective visual impact on the viewer. However,

limits set by the level of aggregation by both the gold production statistics and the qualitative classifications of political stability restricted base map choice to the political world map, as both sets of data are only available by country (Figure 7).

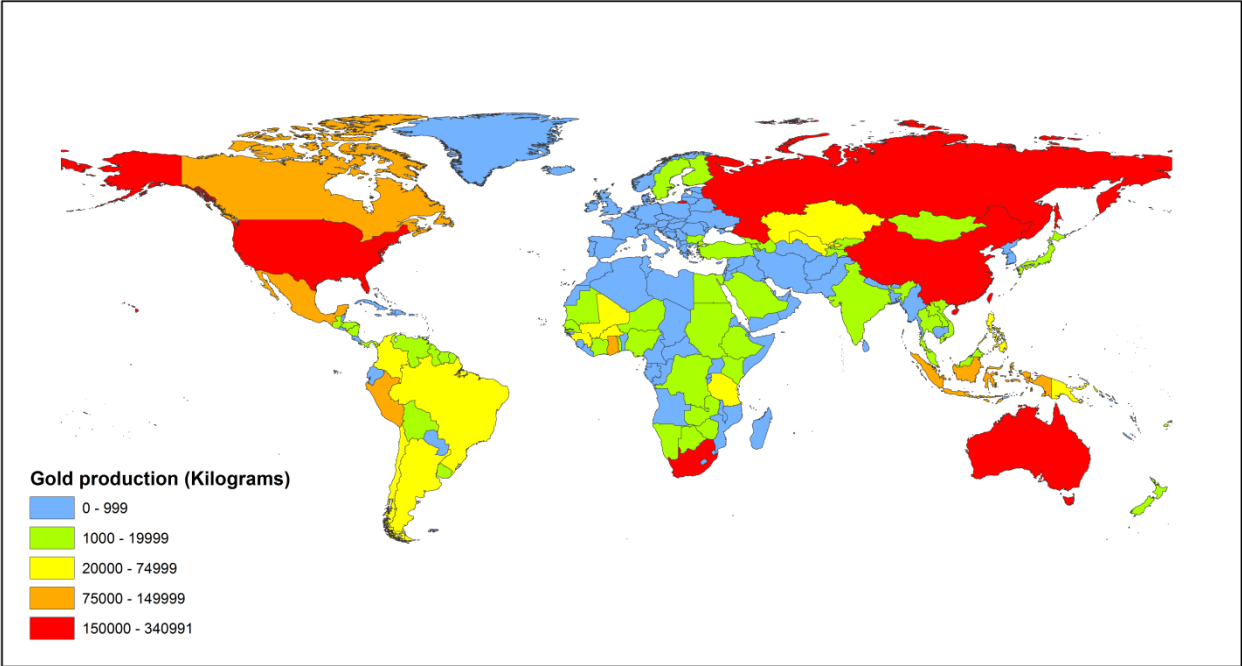


Figure 7: Choropleth map showing state gold production (2010).

3.1.4 Data for Cartograms

Careful consideration is required when choosing how to display datasets in cartograms. Even if both sets of data are appropriately aggregated to fit the areal units (polygons) of the base map, the datasets used for areal unit distortion must follow two basic rules:

- 1) Data should not be an abstract qualitative ranking.
- 2) Data should be quantitative, ideally with linear scale increments.

It is often not appropriate to use the primary subject theme as the parameter for polygon ratio distortion, as it may fail due to these points above.

3.1.5 Building a Gold Production Cartogram

Figure 7 illustrates world gold production in kilograms, aggregated into five basic colour classes as would be common in a standard choropleth map. The traditional method of adding context to choropleth maps is either to add symbols or supplement an extra polygon pattern ornament to the existing colour fill range (Figure 8).

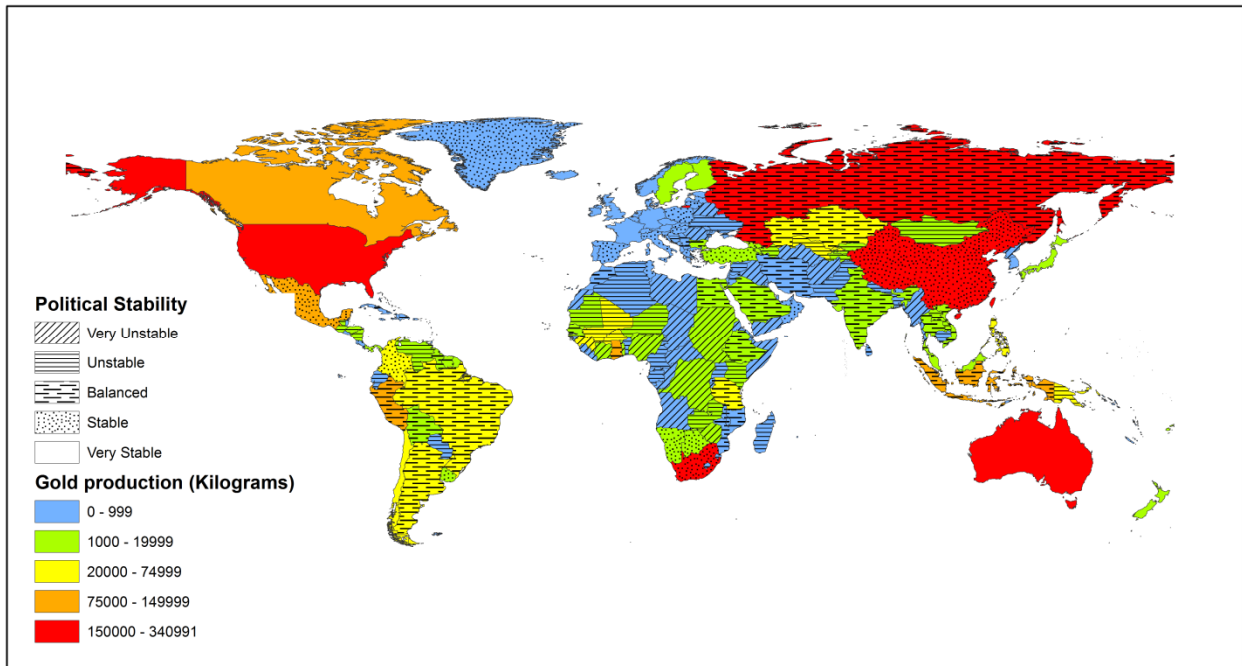


Figure 8: Choropleth map showing state gold production and political stability (2010).

Choosing the most appropriate dataset for display as the distorting value on a cartogram is important. Consideration as to what you wish to communicate can dictate what value is used for the distortion side of the cartogram. However, as a general rule, quantitative statistics are best used as the distorting (ratio) element of the cartogram 3.1.4.

3.2 IGEOLOGY

In recent years, the British Geological Survey has strived to deliver its data in new and innovative ways, as part of its ongoing commitment to improve accessibility to data owned and maintained by the organization. One of the latest methods facilitating public access to its data is via the ‘iGeology’ app; an application designed for both iPhone (iOS) and Android platforms. iGeology allows free access to the entire BGS 1:50,000 scale 2D geological dataset. Within the first year of its launch iGeology achieved nearly 100,000 downloads from 56 countries around the world (Westhead, et al., 2012). Since its launch towards the end of September 2010 a server side log file has recorded some limited aspects of user activity each time the iGeology app is launched, e.g. date, time and what map tile has been viewed. The data retrieval system used by the app works by downloading tiles of maps appropriate to the viewing area of the screen. These tiles are graded according to their spatial scale in categories called Zoom levels. These zoom levels range from a global view of ‘0’ to a maximum zoom level of ‘19’, at roughly 1:1,130 in scale. It proved necessary to restrict viewing beyond zoom 16, as the DigMapGB-50 data used by iGeology was never intended to be scrutinized at scales too far beyond 1:50,000 due to cartographic generalizations. The optimal viewing scale in iGeology is zoom 14; which roughly translates to 1:36,000 in scale. Based on this, zoom 14 is chosen as the activation scale of choice for this study, as viewing at such a scale is more likely to indicate serious use by the user.

The server side log file records all tile downloads as Lat/Long coordinates (WGS-84 projection). This coordinate is derived from a centroid representing the centre of the tile which covers a ground catchment of 2.447km². Collating all ‘zoom 14’ tile downloads allows for potential analysis on where the iGeology app is used and may possibly help to identify areas of most interest. These data can then be aggregated into regional units and saved as point data to present

popular areas of use. For this to work successfully, demographic statistics for each region will need to be established along with the cumulative total of all app use in each region.

3.2.1 Methodology

A visual inspection of the point based dataset in ArcGIS presented a high number of spatial anomalies in the form of app use offshore, perhaps as the result of idle app activity while the user on boats or aeroplanes. As a cleanup measure, clipping away offshore data points help to simplify statistic analysis and increase processing speed. Clipping the required data using a terrestrial polygon dataset outline of England, Scotland, Wales and their associated islands left a total of 110360 land based data points, recorded between September 2010 and November 2011. These data points are then aggregated and presented by their grid catchment area, representing a sum total of app use in each grid area.

3.2.2 Cartogram

The choice of cartogram category depends on the nature of the data you wish to communicate. In the case of iGeology app usage over area, the contiguous area cartogram proved to be most appropriate, on the basis that the context of the data (map of Great Britain) will have a high potential for area recognition and deliver an effective visual impact on the viewer.

3.2.3 Selecting appropriate areal units

Choosing an appropriate areal unit involves making a judgement between two opposing factors: spatial uniformity and user recognition. One extreme involves converting the map of Britain into a uniform grid (e.g. squares, hexagons, etc.). This is acknowledged to be one of the most efficient ways of communicating quantitative spatial data as the proportional distortion of the grid acts as a powerful visual cue for instant quantitative evaluation (Speckmann, 2006). However, the use of an abstract grid for areal units would result in a significant loss of spatial recognisability, especially for inland areas beyond the visual aid of a coastline. An alternative to this method is to use pre-existing political boundaries. Political boundaries are more likely to be recognised by the viewer and continue to afford the possibility of recognition after a significant level of spatial distortion, albeit at the expense of quantitative evaluation, especially if areal base units display an extreme range in shape and size, see section 2.4 above.

For the purpose of this test, UK political boundary data was chosen based on two criteria: user recognition and their ability to successfully join with annually published census statistics. Two sources of dataset were identified as appropriate for use with census statistics: the OS OpenData 'OSBoundaryLine' political boundary datasets (supplied by Ordnance Survey) and datasets from the EDINA UKBORDERS online service. On close inspection, it soon became apparent that no one dataset would display anything near what would be considered a visually homogeneous areal unit base map. Datasets supplied by both sources contained cases of disparate areal unit size (e.g. Scotland and London would contain both extremes in polygon area size – large and small). The 'Local Authority' level borders layer data supplied by EDINA proved to be the most appropriate dataset scale, with most polygons showing general parity in area, albeit with a 25,718km² area size difference between the largest and smallest areal units. Local Authority areas ranged in size from 2.9km² for the 'City of London' local authority boundary to 25,721km² for the Highlands local authority boundary in Scotland; 8875 times larger in area than the 'City of London'.

3.2.4 Joining point data

Once the appropriate level of areal unit was chosen, a spatial join of the point data was applied and displayed as a choropleth map (Figure 9). It is at this stage that we can observe evidence of bias towards large polygon areas. In this case, the Highlands in Scotland show up as one of the greatest areas of app use. Examination of the data shows the Highlands to contain 13955 data points within its boundary, implying an average 18 app activations for each point in the time recorded. This result is an ecological fallacy, as no more than 2.5% of all data points within this boundary show this value. Comparing this average to densely populated areas reveals a significant flaw in the choropleth presentation. In the densely populated areas, app activation averages can reach as high as 2118 (i.e. Kensington and Chelsea). The visual domination of the Highlands with an average of 18 app activations per data point, compared to the visually diminutive densely populated London boroughs is a serious flaw. This bias is known as the modifiable areal unit problem (MAUP) and one of the best ways to help reduce the effect of MAUP is to add a second attribute to the map that effectively normalizes the imbalance inherent to choropleth maps; in this case, by converting the map into a cartogram, by adding population density to the mix.

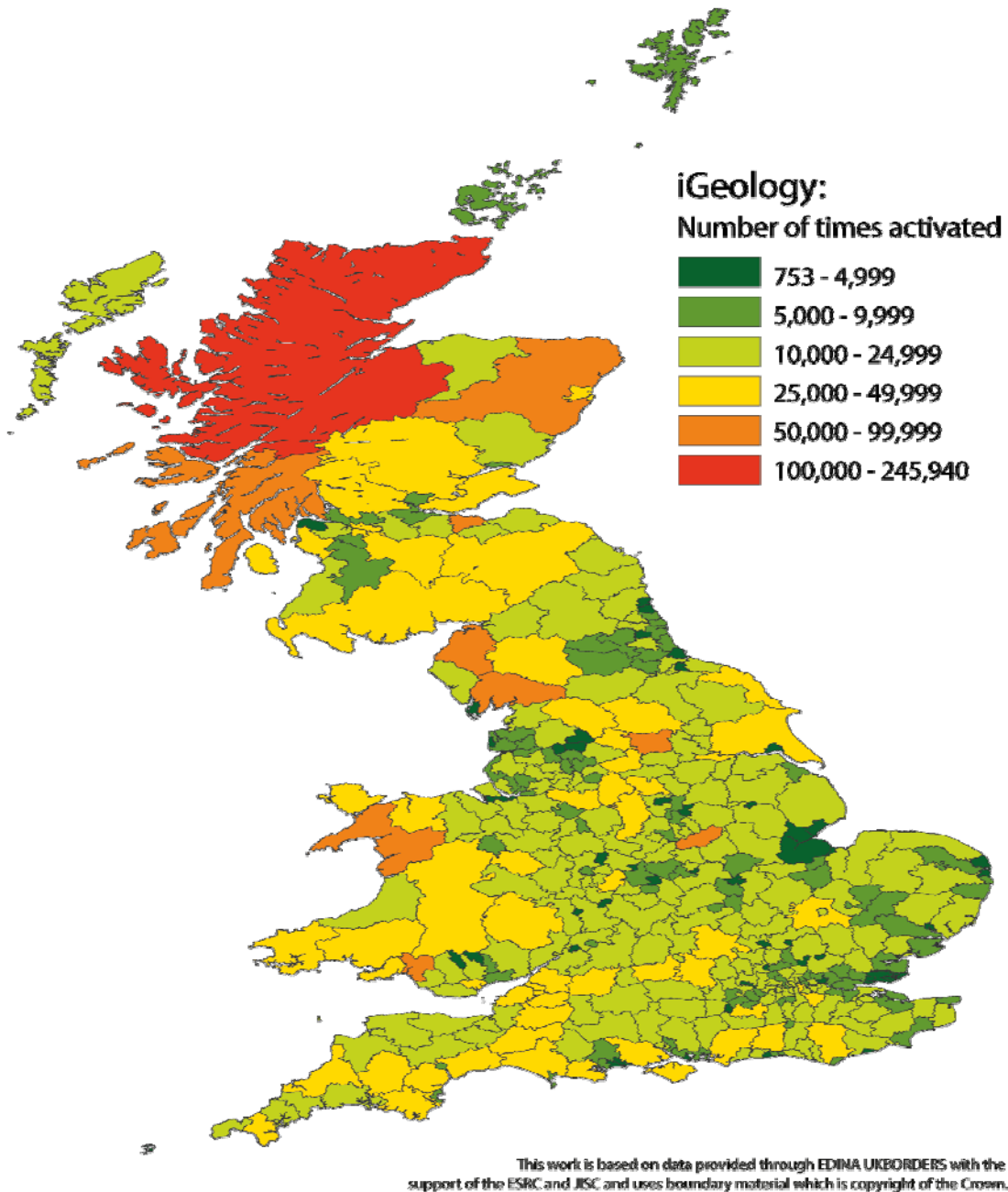


Figure 9: Choropleth map showing iGeology app activation throughout Great Britain between September 2010 – November 2011.

3.2.5 Population Density

The choropleth map is limited to displaying a maximum of two attributes at once, using texture for one and colour fill for another (Dent, 1990). The area cartogram however can show up to three sets of attributes simultaneously, the third being the unit area size statistically adjusted proportionally with its neighbouring polygons. When designing a cartogram it is important to identify which attribute is most appropriate for display as either an areal unit size variable, or an ornament variable (shade or texture). This was the purpose of testing different attributes for different purposes in the World Mineral Production cartogram explained later in 4.1.1

Choropleth maps are bound by spatial projection. This, coupled with the application of *fiat* boundaries (i.e. modifiable manmade district boundaries), create situations of strong visual bias in favour of the larger polygon areas (Figure 9). Removing commitment to spatial projection by

applying ‘population density’ as a quantitative weighting factor to all polygons (effectively resizing each polygon proportionally), help reduce the effects of this visual bias. The advantage to this method is not only the reduction in size of the largest polygon areas that visually dominate but there is also a proportional increase in the size of the smallest polygon areas, often hidden from view by maps maintaining a standard projections (Figure 10) e.g. inner London Boroughs.

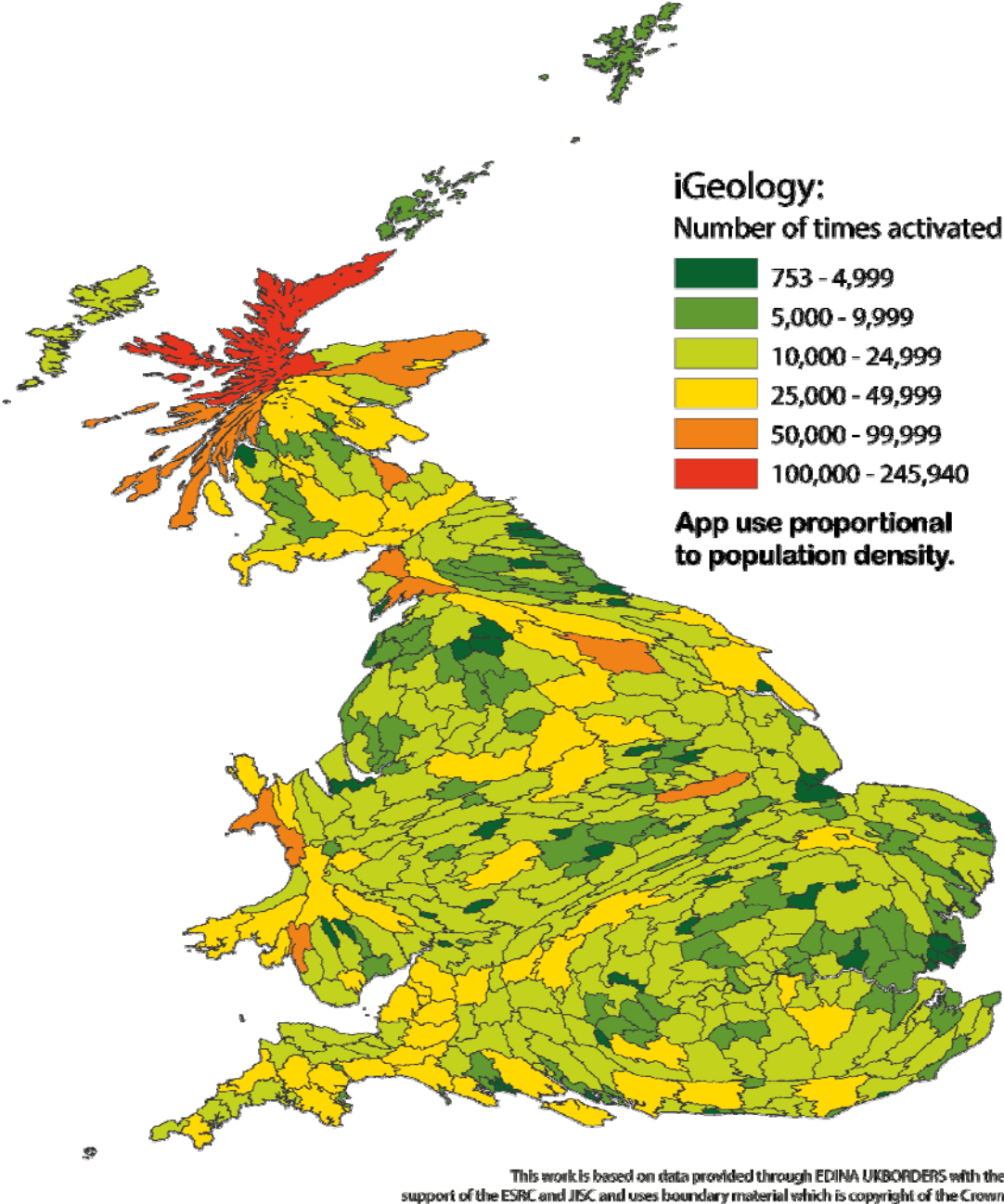


Figure 10: Cartogram showing a clear reduction in visual bias towards large polygon areas (as seen on choropleth maps) by introducing population density.

4 Results

An overall assessment for both the World Mineral Production cartogram and the iGeology app use cartogram is detailed below.

4.1 WORLD MINERAL PRODUCTION CARTOGRAM

No examples of state gold production in the context of political stability have been sourced, but tabulation tends to be the dominant method of displaying these types of data when published. Representing these data in the form of a cartogram (where gold production is the value weighting for the proportional distortion of the base map and the perceived qualitative ranking of state political stability represents the polygon fill), creates an effective result, see Figure 11. The political stability was ranked into five categories to create a more meaningful attribution rather than using the published data range between 1 – 100; 100 representing the highest level of political stability.

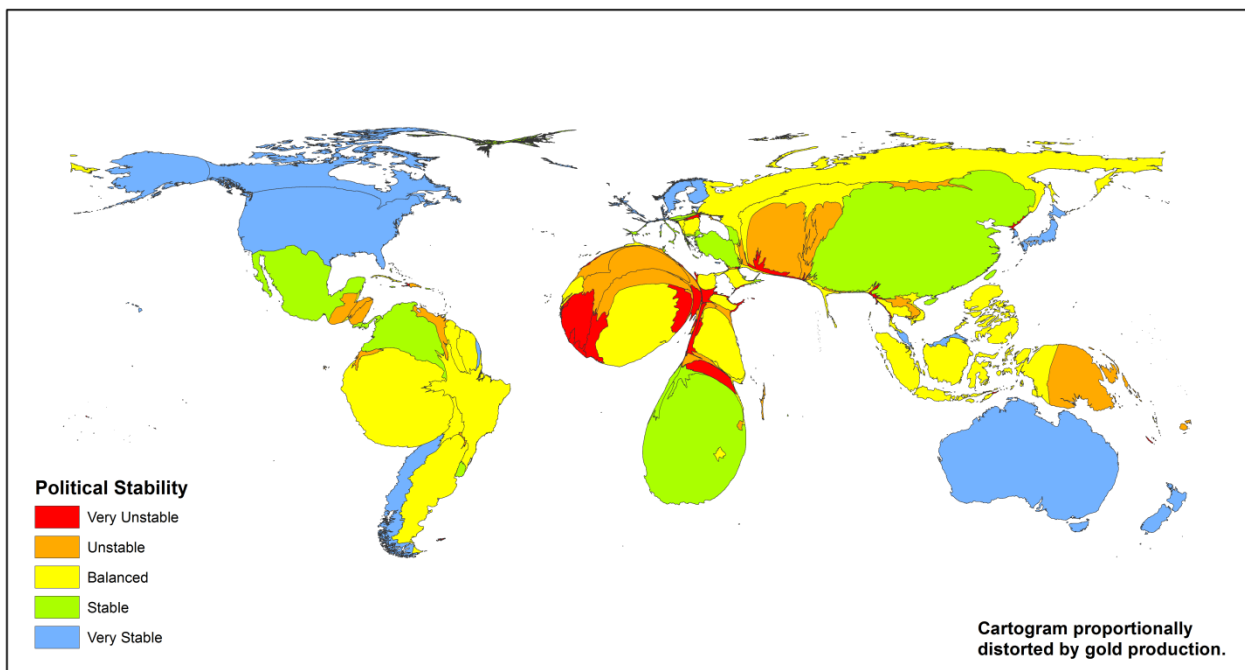


Figure 11: Cartogram showing state gold production and political stability (2010).

On first impression, there appears to be a strong correlation between gold production and state political stability. Compare this to the alternative method of delivering these data using the traditional choropleth map (see Figure 8) it soon becomes apparent that more effort is required by the viewer to ascertain the general picture, albeit with less bias towards Africa.

The danger of using a cartogram such as this can result in information overload. It may not be immediately apparent what the cartogram has been based on or the relationship between the colour and distortion and its relevance. It's only when all the information is understood by the user that the cartogram becomes effective. The information shown may not be immediately as apparent as it is shown in the choropleth map resulting in the cartogram needing more interpretation by the end user.

4.1.1 Using qualitative data

In order to fully test the concept of different data for cartogram creation a cartogram was created based on the 'qualitative' *Political Stability and Absence of Violence* statistics for spatial distortion and the 'quantitative' mineral statistic (gold production) aggregated into five categories and displayed as a colour fill (ornament) for each country. The result produced a level of distortion which obliterated any meaningful representation of these data (Figure 12) as a

standalone static image. Attempting to quantify any attribute of a socio-cultural nature usually fails meaningful representation. Cartograms generally require data that is quantifiable, either tangible in quantity or measurable (i.e. space, time, etc.). All qualitative datasets should be reserved for the ornament.

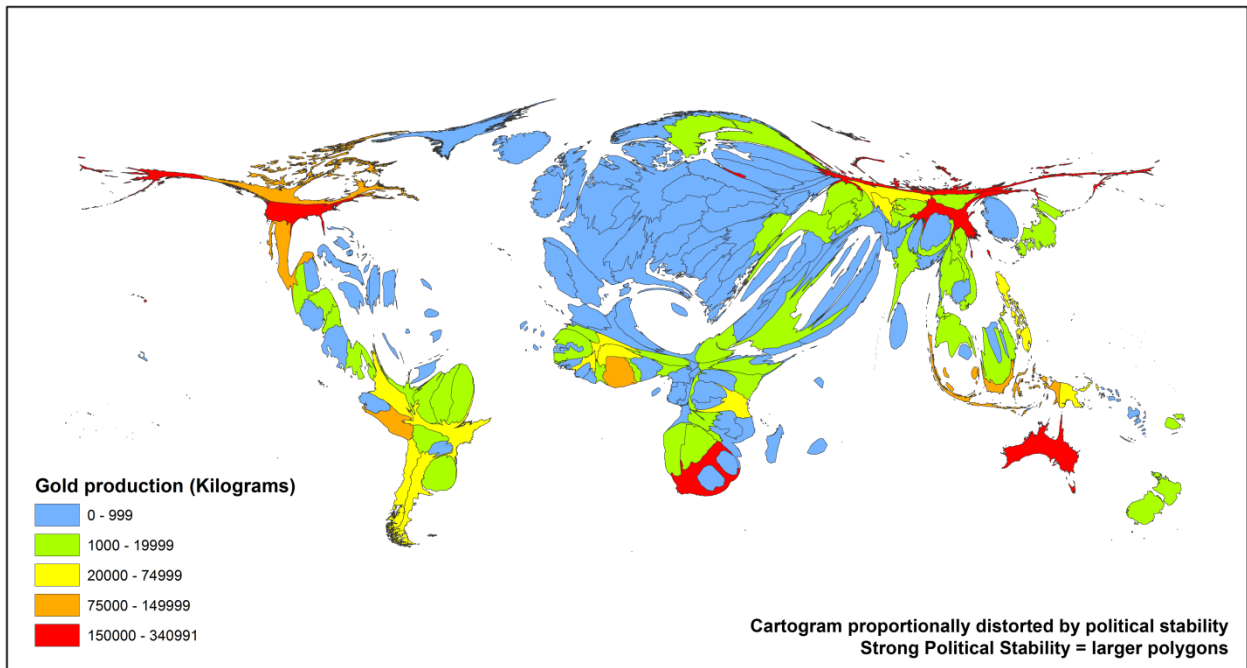


Figure 12: Cartogram showing political stability and gold production (2010).

4.2 IGEOLGY APP USE CARTOGRAM

Previous published versions of the iGeology app activation statistics have tended to use an inverse distance weighting algorithm on the recorded aggregated point values placed on a map of Great Britain. Displaying these statistics on a map comes with significant problems. The dataset reveals a spatially exponential scale of app use between 0 – 4432 activations per square kilometre. The only way to show any meaningful display of these statistics is to limit the range of aggregated app activity to between 1 and >93 activations per km². The result displays a narrow bandwidth of app activation with a predictable spatial distribution (e.g. densely populated urban areas and popular recreational rural zones) implying app use is proportional to population activity (Figure 13a). However, when population density is applied through the use of an area cartogram the results change significantly (see Figure 13b).

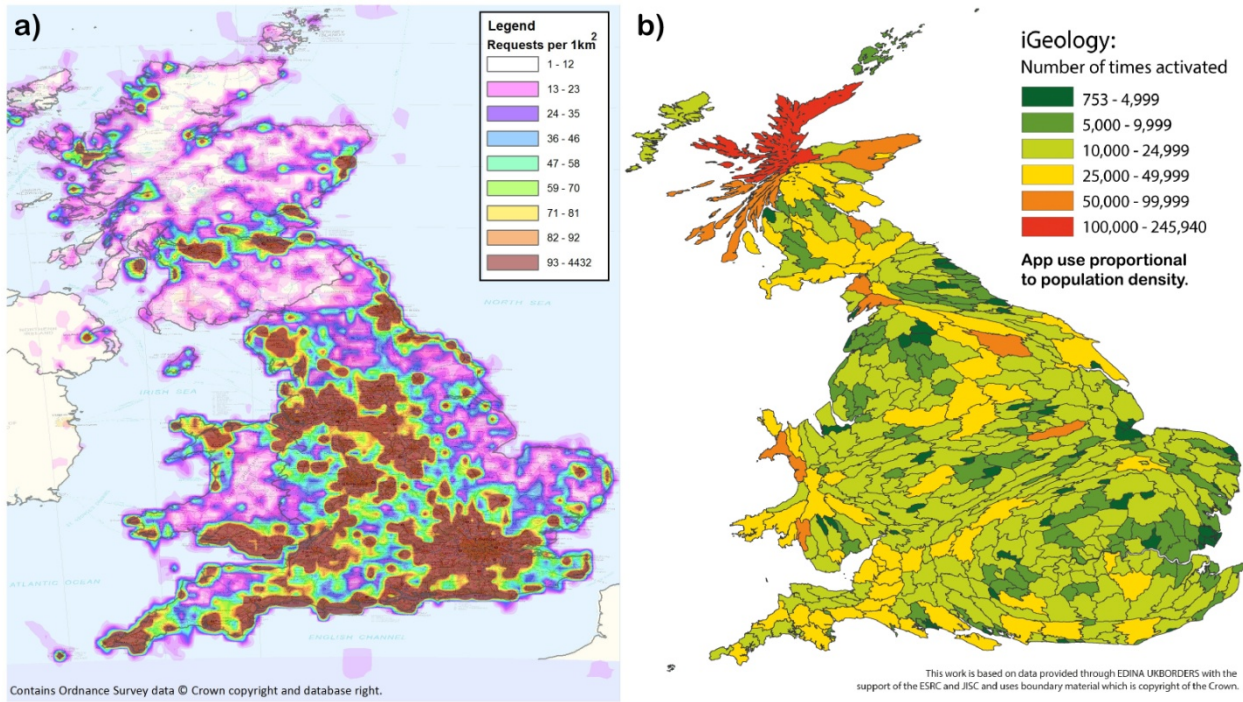


Figure 13: Removing bias from hotspots of human activity through averaging app use over areal unit areas.

Aggregating all recorded app use within an areal unit effectively smoothes out all spikes in app use, removing the necessity for utilising data range thresholds; as was the case for the inverse distance weighted map in Figure 13a. Weighting the size of each polygon area proportionally to its density of population provides a useful context for displaying app use in that polygon area, providing a more informative picture of app activity over area – albeit spatially distorted.

4.3 AN EVALUATION

Based on these tests an evaluation as to any observable benefits or disadvantages are recorded.

4.3.1 Dataset Range

Traditional methods of data representation such as the choropleth map and to some extent projected point-based maps require an element of data manipulation in order to convey the desired message across to the viewer.

Choropleth maps require data to be processed into manageable numbers of discrete groups, a process known as classification (Kraak & Ormeling, 2003). This process is necessary, as a dataset range of more than ten discrete units will become indistinguishable to the general observer. Splitting large dataset ranges into defined blocks allows for better visual differentiation between each class. However, this irreversible process significantly reduces dataset detail resulting in stepped incremental blocks of data.

Data classification is not confined to choropleth maps. As observed in section 4.2, it proved necessary to effectively filter 98% of the dataset range into one class in order to show any meaningful representation of app activity for the original iGeology inverse distance weighted map (Figure 13a). Alternatively, applying data as the sum value for proportionally distorting areal units removes the necessity for data classification and therefore allows at least one opportunity to display data in its pure state.

The problem with this aspect of the cartogram is that the gain from using absolute values is not transferred to the observer. Identifying the metrics of areal unit change in area can only be vaguely understood in a relative manner. In other words, the viewer can only gain a relative assessment of the polygon change in area; even though the extent of distortion is governed by an absolute value. One way to address this would be to try and apply a spatially homogeneous base map which would help the observer distinguish changes in shape and size. However, this is not always appropriate or even possible as any compromise to areal unit recognition will render the cartogram meaningless (Figure 6). In some instances it might not be appropriate to redefine areal unit boundaries, as in the case of a data collated in the context of the world map. Data created in this context would be subject to aggregation processes in the context of world states; subdivision of these areal units along with their datasets would be impossible. Data collected and aggregated in a specific unit area can only be presented in the bounds of that areal unit area. However, this may not apply to all spatial data, as observed when analysing the iGeology source data. It can sometimes be possible to redefine *fiat* boundaries to suit the message you wish to convey if the scale the dataset captured is large enough. For example, the iGeology app use cartogram was fortunate in having a range of political boundary base map scales to choose from. The resolution of data collation for population density was such that almost any scale could be utilised above 'Parish' level. This choice allowed for a degree of mix and match between the different scales (e.g. Parish, District, County, etc.) enabling the areal units to be homogenized to some extent, yet retain a level of continued user recognition. In the case of the Mineral Production data, these statistics are confined to country level, which limits the opportunity to homogenize area polygons prior to cartogram production.

4.3.2 Reducing Bias

It is generally acknowledged that area cartograms reduce the effects of the modifiable areal unit problem (Openshaw & Alvanides, 1996) and this effect appears to work well with the iGeology app use cartogram. A notable reduction in visual bias towards the Highlands of Scotland is clearly evident with the iGeology app data cartogram (Figure 10) when viewed with the choropleth map (Figure 9). However, reducing the effects of the modifiable areal unit problem by presenting statistics in a cartogram can create an undesired effect as witnessed with the world gold production datasets. The cartogram showing gold production and political stability (Figure 11) shows a strong visual bias towards the developing countries (i.e. Africa, South America and South East Asia); the choropleth map, however, (Figure 8) presents a 'more balanced' effect. Once the five qualitative classes of 'political stability' are added to the polygon ornament (colour fills), a clear visual bias towards the red zones occurs. Although the qualitative classes of political stability communicate effectively, the value by area message of gold production is significantly diminished. The main reason for the failure to communicate gold production effectively (as a cartogram) is down to the imbalanced areal unit sizes of the original base map. In other words, the diverse range in country size makes it almost impossible for the viewer to discern any informative changes in proportional polygon growth or shrinkage. The iGeology app use cartogram, on the other hand, is far more successful due to its initial high level of areal unit conformity. This is the problem faced with creating a cartogram with countries as the areal unit and using a contiguous cartogram.

4.3.3 Communicative ability

Cartograms appear to capture viewer attention more successfully than conventional choropleth maps. There appears to be an instinctive attraction towards familiar objects and patterns that have been subject to a degree of distortion that compel people to investigate. On the basis that

the image is familiar to the viewer, the ability for the mind to process and evaluate spatial distortions appears to be strong and efficient (Logothetis & Sheinberg, 1996). However, the quality of communicating the spatial metrics via cartograms appears to be limited. Only a generalized overview of proportional distortion can be conveyed, especially between non-uniform areal unit shapes. Performance in spatial comparison can only be improved if the original base map is more homogeneous in nature, albeit at the risk of losing recognisability. There is no “best” cartogram or method of creating cartograms just as there is no “best” map (Monmonier and Schnell, 1988). However, many things can be achieved with cartograms which cannot be shown successfully on ordinary maps. (Dorling, 1996)

5 Conclusions

Based on these tests, cartograms are both effective and efficient in communicating a general overview, but poor communicators of absolute values. Used in an appropriate context where delivering a message in limited time is important (e.g. a poster), cartograms can perform well. This is why they are used widely within the media. However, the limitations involved with creating a successful cartogram are significant.

The primary issue for all cartograms are (Hennig, Pritchard, Ramsden, & Dorling, 2010) that they require at least one quantitative dataset, ideally spatially aggregated to the regions of the base map. Once an appropriate dataset is identified, careful attention to the type of base map is then required; addressing both opposing needs of a homogenized polygon base map and the essential necessity for viewer recognition (see Figure 6).

These tests have revealed that the production of a cartogram using datasets published by the BGS is far from simple. Even with what would appear to be an ideal candidate for use as a potential cartogram, an imbalance towards areal unit recognition and unit standardization in size may result in confusion for the viewer. However, the range of political maps available for the United Kingdom allows for much greater potential for areal unit standardization; this proved invaluable when creating the cartogram of Britain’s use of the iGeology app.

If there is a geologically orientated dataset (especially based on the British Isles) that is either quantitative or is at least associated with another dataset that is, there is no reason why these data cannot be utilised in a cartogram successfully.

A suitable areal unit (polygons) could be created for the UK that could be used for a wide range of cartograms. This could be based on a combination of sources (such as topographic data), however there wouldn’t be a suitable ‘long term’ solution (administrative boundaries change every few years which would mean that a new areal unit base would have to be recreated to reflect any changes).

Alternatively the areal unit could be replaced by a grid. An example of this cartogram by Hennig et al. is where a population cartogram, has been taken from www.worldmapper.org and the terrestrial borders removed and replaced by The Gridded Population of the World (GPW) database. Therefore the artificial territorial borders relied on for cartograms are replaced by an actual unit of population density. The grid has an extra advantage in that it can be displayed so

that it becomes obvious where the distortion of the cartogram is taking place. This method also has problems – scale of grid, how the units it represents are amalgamated as well as the visual interference that a grid can have. However it could be an alternative method to evaluate.

Although heavily distorted cartograms don't work as a static image, they can work if another level of usability is applied. An interactive cartogram would ensure that the data displayed in the cartogram could be displayed (such as clicking on an area to reveal information about it). This would also help resolve the problems associated with familiarity of the areal unit and its spatial relationships.

Contiguous cartograms which result in distortion that limits its effectiveness may well be more suited to a non-contiguous cartogram. Data which needs to be presented at country level would be an ideal candidate especially as country boundaries are one of the most recognisable areal units.

The effectiveness of cartograms needs to be further explored when used as part of an infographic. An infographic is a heavily graphically styled portrayal of data and information which lends itself to be included as part of how cartograms are displayed. The image included on the front of this report was an example of how the cartogram could be styled and this could be further developed to produce an effective infographic. The use of graphical images reduces the need for text and makes the information apparent at a visual level without the need for lengthy interpretation.

Appendix 1

Results of an online search for software and programme add-ons that generate various types of area cartogram:

Name	URL	Type	Description	Release date	Cost
dorling.py	http://indiemaps.com/blog/2008/01/dorlingpy/	Python code	Program to create Dorling circular cartograms. Program to create Dorling circular cartograms written by Zachary Forest Johnson.	4th Jan 2008	Free
MAPresso (v.1.2.)	http://www.mapresso.com/	Java applet	A free Java applet by Adrian Herzog for unclassed choropleth maps and cartograms, based on the 'rubber sheet method' algorithm proposed by Dougenik, Chrisman and Niemeyer (1985).	c. 2009	Free
Cart (v.1.2.2.)	http://www-personal.umich.edu/~mejn/cart/	C++, Java, ArcGIS and MapInfo	Cartograms based on the Diffusion-based method for producing density equalizing maps proposed by Gastner, Shalizi and Newman (2005).	9th Nov 2006	Free
MapViewer 7	http://208.84.116.202/products/mapviewer/mapviewer-maptypes.shtml	Software	Claims to create cartograms including Dorling Circular cartograms.	c. 2012	\$249.00
Protovis	http://mbostock.github.com/protovis/ex/cartogram.html	Javascript	Online javascript capable of generating Dorling Circular cartograms.	c. 2012	Free
Worldmapper	http://www.worldmapper.org/	Online	An online facility based on the Diffusion-based method for producing density equalizing maps proposed by Gastner, Shalizi and Newman (2005). Website set up by Sheffield University, Department of Geography.	2009	Free
OpenGeoDa (v.1.2.)	https://geodacenter.asu.edu/	Software	Capable of creating cartograms and 'Dynamically Linked' graphics termed 'Linking and Brushing'.	21st Aug 2012	Free
Cartogram Geoprocessing Tool (v.2.)	http://arcscripsts.esri.com/details.asp?d_bid=15638	ArcGIS 10.0	Cartogram Geoprocessing Tool by Tom Gross based on the Diffusion-based method for producing density equalizing maps proposed by Gastner, Shalizi and Newman (2005).	14th May 2009	Free
Cartogram creator for QGIS	http://www.ftools.ca/cfarmerQgisRepo.xml	QGIS Python plugin	Create continuous rubber-sheet cartogram based on an input point shapefile.	c. 2009	Free

Table 1: Software and programme applications.

Glossary

<i>Cartogram</i>	Distorted map like illustration of statistical data.
<i>Choropleth</i>	A map that displays discrete areal units (regions) that are shaded or coloured to represent a chosen value.
<i>Ecological Fallacy</i>	An overall statistically derived value that does not exist in practice. For example: Two people live on an island and work from home. One earns an annual salary of £25,000, the other earns £75,000. Statistically, the average annual salary for people living on this island is £50,000. This is an ecological fallacy.
<i>Fiat</i>	A fiat boundary is an abstract concept, a human demarcation; e.g. political borders or postal regions. <i>opp.</i> 'bona fide' boundaries which are solid, tangible features such as rivers, walls and object surfaces.
<i>Infographic</i>	Highly designed statistical information graphic or illustration.
<i>Isochronic Maps</i>	A map spatially distorted to equal units of time, i.e. a map or chart constructed to show distances that can be traversed in 'equal times' from a common point.
<i>MAUP</i>	The Modifiable Areal Unit Problem.
<i>Percentile</i>	One of 99 actual or notional values of a variable dividing its distribution into 100 groups with equal frequencies.

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