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Rediscovering the World

Gridded Cartograms of Human and Physical Space

PhD Thesis
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to my parents
Ingrid and Wolfgang Hennig

in memory of
Benedikt Frese
† 2010

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Abbreviations

ASCII	American Standard Code for Information Interchange
BIL	Band Interleaved by Line
CPU	Central Processing Unit
CSS	Cascading Style Sheets
CSV	Comma-Separated Values
DBF	Database File
DPI	dots per inch
ESRI	Environmental Systems Research Institute
FAO	United Nations Food and Agriculture Organisation
GB	Gigabyte
GDP	Gross Domestic Product
GIS	Geographical Information System
GIScience	Geographic Information Science
GPS	Global Positioning System
GPW	Gridded Population of the World (also: GPWv3: Gridded Population of the World, version 3)
HDI	Human Development Index
HDR	Human Development Report
HPI	Happy Planet Index
IGU	International Geographical Union
ISO	International Organisation for Standardisation
LSOA	Lower Super Output Area
MB	Megabyte
MDG	Millennium Development Goals
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
ONS	Office for National Statistics of the United Kingdom
PC	Personal Computer
PDF	Portable Document Format
RAM	Random Access Memory
Sasi	Social and Spatial Inequalities
SEDAC	Socio-Economic Data and Applications Center
SVG	Scalable Vector Graphics
TIF	Tagged Image File
UN	United Nations
UNDP	United Nations Development Programme
UNICEF	United Nations Children's Fund
UNPD	United Nations Population Division

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Abstract

‘*We need new maps*’ is the central claim made in this thesis. In a world increasingly influenced by human action and interaction, we still rely heavily on mapping techniques that were invented to discover unknown places and explore our physical environment. Although the traditional concept of a map is currently being revived in digital environments, the underlying mapping approaches are not capable of making the complexity of human-environment relationships fully comprehensible.

Starting from how people can be put on the map in new ways, this thesis outlines the development of a novel technique that stretches a map according to quantitative data, such as population. The new maps are called *gridded cartograms* as the method is based on a grid onto which a density-equalising cartogram technique is applied. The underlying grid ensures the preservation of an accurate geographic reference to the *real* world. It allows the gridded cartograms to be used as basemaps onto which other information can be mapped. This applies to any geographic information from the human and physical environment. As demonstrated through the examples presented in this thesis, the new maps are not limited to showing population as a defining element for the transformation, but can show any quantitative geospatial data, such as wealth, rainfall, or even the environmental conditions of the oceans. The new maps also work at various scales, from a global perspective down to the scale of urban environments.

The gridded cartogram technique is proposed as a new global and local map projection that is a viable and versatile alternative to other conventional map projections. The maps based on this technique open up a wide range of potential new applications to rediscover the diverse geographies of the world. They have the potential to allow us to gain new perspectives through detailed cartographic depictions.

Chapter 1 **Introduction**

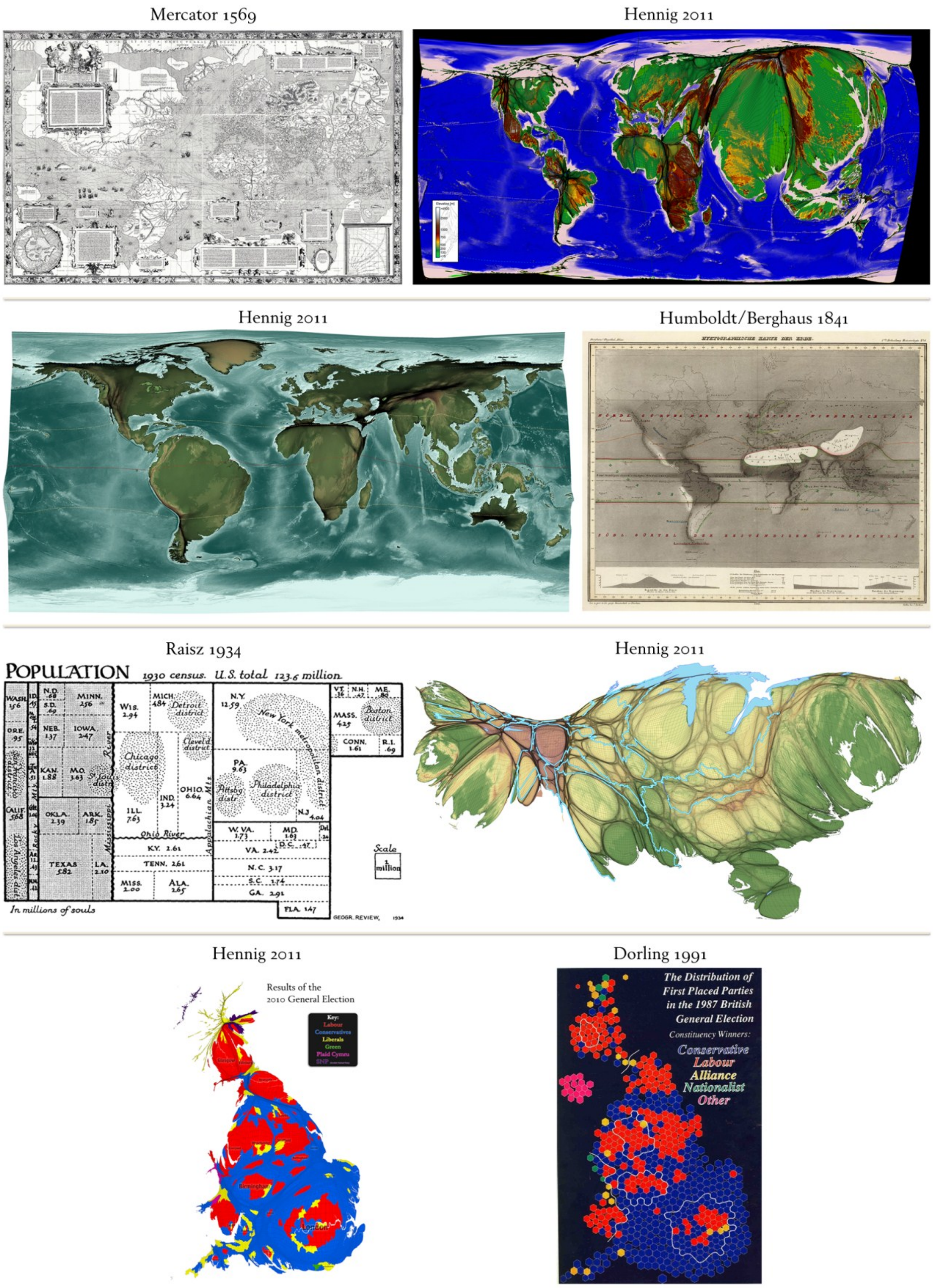

FIGURE 1.1: MILESTONES IN MAPPING COMPARED TO MAP RESULTS OF THIS PHD RESEARCH
Selected examples for important mapping achievements in cartographic history compared to maps created in this PhD research (own depictions, included in this thesis): Mercator's 1569 map of the world (obtained from WC 2006a), Humboldt/Berghaus' 1841 global precipitation map (obtained from Ette & Lubrich 2004: 20-21), Raisz' 1934 US population cartogram (Raisz 1934: 293) and Dorling's 1991 UK election cartogram (Dorling 1991: Print LXXXIII)

1.1 Background

In a reflection on cartographic practice in British geography published at the time the research presented in this thesis started, Dodge & Perkins (2008: 1272) stated that "*[t]here are few PhDs that explicitly focus on mapping in the UK*".

This is a PhD thesis about maps (Figure 1.1).

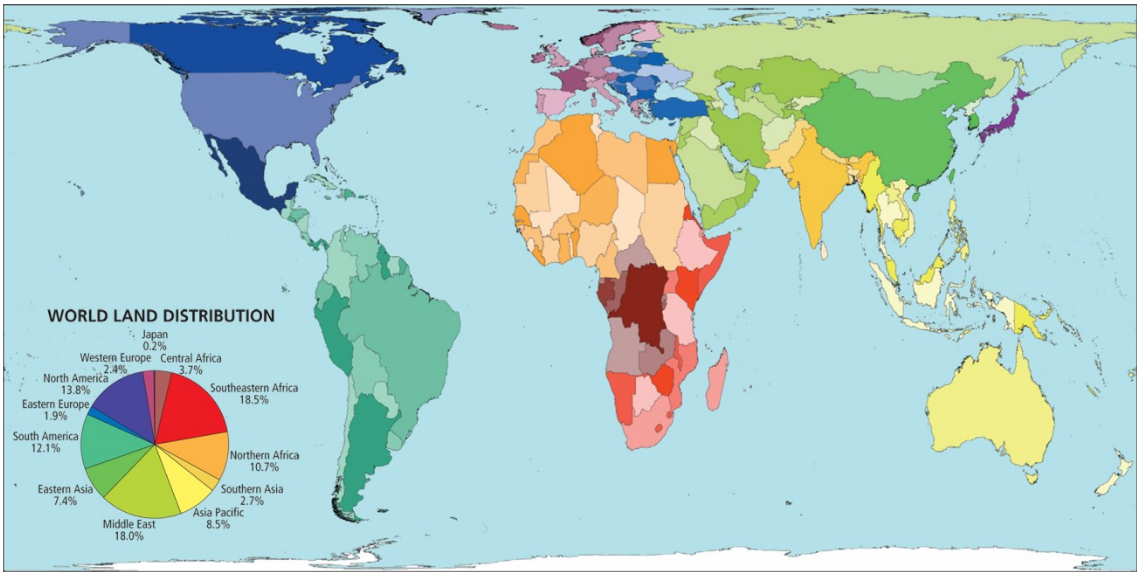

FIGURE 1.2: WORLDMAPPER LAND AREA MAP COMPARED TO A LAND AREA PIE CHART
Reference map of the Worldmapper project depicting the countries in the Worldmapper colour scheme, compared to a pie chart showing the same data of land area distribution split by the main regions used in Worldmapper
(modified from Sasi Research Group & Newman 2006b)

Maps and other forms of geographical data visualisation are not only an enlightening way of making geographical phenomena understandable by stimulating our visual imagination, but also a way to explore the underlying data, to gain new knowledge, and to raise new questions about the emerging pictures (Börner 2010). Visualising geospatial data began to become increasingly important with industrialisation in Europe, which resulted in the collection of a growing amount of data about the people and their living environments.

The development of new statistical methods and ways to visualise them influenced cartographic practice considerably, and coincided with the emergence of thematic maps. Cartographic practice has never been limited only to the mere production of maps, but has always been closely linked to the analysis of data and their visualisation in, around and outside of maps (Figure 1.2). The art and the science of cartography[1] in its deepest origins lends itself to showing the complexity of our world that we

[1] As Endey remarks, the art/science dichotomy that started to be made in modern cartography is a false distinction "*promoted by Modernity's pervasive scientism*" (Edney 1999: 165).

otherwise would not fully apprehend, and to using the language of imagery to translate geographical knowledge into understanding.

Digital technology has changed cartography and data visualisation. From a discipline that aims to describe and understand the means of conveying geographic information via traditional mapping methods it has turned into a complex field of analysing and visualising data. The initial limitations of computers that could hardly compete with the hand-drawn display of a statistical graphic or a map are long gone. Computer systems now allow not only complex analysis and calculations, but provide sophisticated means of making the results visible in not only meaningful but sometimes also very beautiful ways (Unwin, Chen & Härdle 2008).

We are now living in a time where we see a new data revolution, with digital technology making yet again unprecedented levels of data available and accessible that needs to be adequately processed and analysed (Figure 1.3). At the same time, what we refer to as globalisation has turned the world into an extremely complex environment that science finds hard to even illustrate in its complexity. The different dimensions of the natural and the human environment become increasingly interrelated and interdependent, and conventional ways of showing these interrelations and interdependencies fail to explain the processes that determine our everyday life.

"After closer investigation, it's become clear that we need to enter more than one value."

FIGURE 1.3: DATA VISUALISATION FAILURE
Growing amounts of data require meaningful ways of analysing and visualising them (cartoon reproduced with permission by Mark Anderson)

In earlier research several years ago, undertaken at the Alfred Wegener Institute for Polar- and Marine Research in Bremerhaven (Germany), I was working with hyperspectral remote sensing data of the coastal areas in the German North Sea (Hennig 2005, Hennig, Cogan & Bartsch 2007). Back then I stated, that "*the growing amount of remotely sensed data and the ongoing developments in the improvement of spatial and spectral resolution lead to high expectations for current research*" (Hennig, Cogan & Bartsch 2007: 63). Revisiting these thoughts now, I see a striking parallel in these notions in relation to the broader area of geospatial data in general (which metaphorically can often also be regarded as remotely sensed, although the sensors are not always an airborne or satellite piece of technical equipment). In some areas we believe that we have all the data that could help us explain the processes that shape our globalised world. The expectations in science are high to make sense of these mountains of data, but these expectations are often not fulfilled because geographical research either fails to understand the complexity of the interrelations and interdependencies, or fails to make sense of its findings and communicate this adequately.

And as I did back in my remote sensing study, I similarly claim now that, although many scientific disciplines benefit from geospatial data, it is still the strength of geographical research to widen and optimise the use of geospatial analysis and their appropriate visualisation. The role of geography is the wider and integrated perspective of the discipline, which can help to understand the wider implications of the complex interrelations between human and natural environments. Cartographic methods (understood in the wider sense of statistical data analysis and visualisation) are an important element in achieving these aims. Cartographic practice integrates the different fields of geography, and communicates geographic work in a visual form.

The research follows the thoughts of Crampton (2010) who describes cartography as a critical way of spatial knowledge production. He sees the role of cartography being to understand how geographic science (and other spatial-related fields of science) can be visualised, comprising technical and aesthetic but also ethnical and philosophic issues that need to be addressed and brought together.

Although strongly relying on the use of geographical information systems (GIS) in my work, the mere technical focus of the methods does not express the emphasis that I wish to concentrate on. I position my research in the tradition of cartographic works and thus understand cartography in a very wide sense as the discipline that investigates the methods and understanding of visualising spatial knowledge. My thesis can be seen as an attempt to abandon the barriers between the technical side of cartography (which some see as the science of geographical information and geovisualisation, or *GIScience*), and the aesthetic as well as more conceptual side that many '*traditional*' cartographers defend (Buchroithner & Fernández 2011, Board 2011, Fisher 1998).

Contemporary cartography is both a technical and an aesthetic domain within the field of geographic science. And with '*cartography being dead*', as Wood (2003, 2010) put it referring to the end of traditional academic cartography, contemporary cartography needs to be redefined according to today's challenges. This is a chance to revive cartography. And for geographers who neglected and abandoned the mapping in recent years, it is a chance to '*reclaim the map*' (Dodge & Perkins 2008) and become again a contributor to a new understanding of our world. As early cartographers explained the world centuries ago by discovering previously unknown physical spaces, it is now a necessity to tell the stories of the spaces of humanity in a time of globalisation. One new role of cartography is to contribute to an understanding of those spaces that we still do not fully understand, and to analyse how these can be visualised.

1.2 Aims and objectives

The research project links to the work of the Worldmapper project which has made a collection of several hundred cartograms on a broad range of socio-economic conditions of our world available in an online mapping platform. Worldmapper can be seen as a contribution to provide new understanding of the large quantities of information that describe today's complexity of the world. This connects Worldmapper to the wider background of changing challenges for geography and cartography as outlined above. The scope of Worldmapper[2] defined the initial considerations so set the main aims for the research.

The overall aim of this research is

(a) *To improve capabilities of the cartogram techniques used in the Worldmapper project*.

This is complemented by the following specific aims:

(b) *To present a method for the creation of cartograms that meets the requirements of an alternative map projection;*

(c) *To demonstrate the suitability of the new technique at different scales, and using different geospatial data for the transformation;*

(d) *To show the potential of the new cartograms to serve as an alternative basemaps for additional types of data at changing levels of resolution;*

(e) *To establish a range of potential applications using the new cartogram approach;*

(f) *To show the implications of the new maps for geographic theory and practice.*

Based on these aims, the following objectives were identified:

(1) *To investigate how globalisation processes changed the interrelation between the human and physical environment and how this relates to our understanding of space;*

(2) *To illustrate how the changing understanding of the world outlined in objective 1 is reflected in the theory and practice of modern cartography;*

(3) *To investigate the special role of digital technology in cartography;*

(4) *To develop a method for the computer-based creation of density-equalising gridded cartograms;*

[2] Worldmapper will be introduced in more detail in section 2.5.

(5) *To provide ways of generating higher-resolution population data that is suitable for a gridded cartogram transformation;*

(6) *To outline design principles for a suitable presentation of gridded cartograms;*

(7) *To present a new gridded world population cartogram as an alternative basemap for human space and investigate its value compared to other map projections;*

(8) *To assess the effects of different resolutions on gridded cartograms using population data;*

(9) *To apply different types of data as overlays on gridded population cartograms and investigate their appearance in comparison to other map projections;*

(10) *To transform other quantitative data using the gridded cartogram approach to review its flexibility beyond a population projection;*

(11) *To provide examples for further applications of gridded cartograms that demonstrate the potential and limitations;*

(12) *To discuss the role of new methods such as the gridded cartograms within the debate about the relevance of space in geography;*

(13) *To review the value of the results for the Worldmapper project;*

(14) *To identity future directions of research which could facilitate and establish the use of gridded cartograms in a future wider range of cartographic visualisation and geographic practice.*

The research will be presented in seven main chapters (Table 1.1) that relate to the objectives outlined above:

Chapter	Focus	Objectives
1	*Introduction*	*(n/a)*
2	*Literature review and background*: Globalisation and the role of space Cartographic visualisation over time	 *1* *2, 3*
3	*Methods*: Creating and visualising gridded cartograms Generating gridded population data	 *4, 5* *6*
 4 5 6	*Results:* A gridded world population cartogram Gridded population cartograms at changing scales Mapping data onto gridded population cartograms Gridded cartogram transformations of quantitative data Applications for gridded cartograms	 *7* *8* *9* *10* *11*
7	*Discussion*: Gridded cartograms as a map projection for the globalised world	 *12, 13, 14*
8	*Conclusion and outlook*	

TABLE 1.1: OVERVIEW OF THE THESIS CHAPTERS

Following this introduction, the literature review in chapter 2 outlines the background of a globalised world and the changing meaning of space in geography. This is then put into the context of changing practices in cartographic data visualisation, which is reviewed as part of the development of modern cartography until the most recent changes of digital mapping practices. Map projections and cartograms will be given special consideration, as these do not only reflect the theoretical background of cartography and globalisation, but also relate directly to the Worldmapper project in which this research has been conducted. With the general background outlined, chapter 3 presents the data and methods that are needed to create gridded cartograms as the core methodology developed in the context of this work. This includes the development of techniques to generate gridded population data and considerations of an adequate design of the new map form.

Chapter 4 introduces the first results by evaluating the gridded world population cartogram that has been created with the new technique. Furthermore, the effects of different data resolutions and changing map scales at national-, regional- and urban-level are presented and reviewed. Chapter 5 extends the evaluation of the results towards the versatility of the gridded cartogram technique in comparison to other map projections. The further capabilities are tested for (a) the suitability of gridded population cartograms as a base projection for different types of data, and (b) the use of a gridded cartogram *transformation* for other quantitative information. Chapter 6 tests the wider applicability of the new technique by presenting a range of case studies that redraw different geographic themes as gridded cartograms. The discussion in chapter 7 critically revisits the broader implications of the research from a methodological and a theoretical perspective and identifies future needs that result from the research. The final synthesis in chapter 8 concludes and reviews the main findings.

1.3 Implications

The implications of this research are to be seen wider than the limited scope of the Worldmapper project. As highlighted above and further outlined in the state of the research in chapter 2, Worldmapper stands for some significant changes in cartographic theory and practice. The demand to find alternative ways of visualising geographic information to explore the complex human-environmental interrelations is high, and should therefore be an essential element of geographic research. There is not only a need to reclaim the map, but also to reclaim geography.

Space is a defining element of geographic research. This applies to empirical, theoretical work as much as to methodological studies as this one. The research presented in this thesis focuses on the human dimension of geographic space by using demographic and socioeconomic data as the main source of data in the development and evaluation of the methodology. However, the domain of human geography is at no point been seen as a restricting boundary to the methodological scope. While most traditional maps have an element of the physical geography in themselves by showing the continent as the basis for human action, the attempt to put the space of humanity in the centre does not reduce the importance of the physical environment. A more universal understanding of the complex interrelations not only of the different spheres of humanity (such as the social, the economic, or the political environments), but also the interdependencies of the natural and the social environments have therefore also been taken into account.

It is essential to focus on particular areas of research. To prevent a distraction from the main review of the technique developed in this research, the presentation of examples from the physical world remains limited to a small number, but is included very consciously and stands for this integrated view of geography. It should always remain a part of geographic practice to consider these links between physical and human geography, and to support the aspiration to preserve the role of geography as an integrated and interdisciplinary subject. If we do not do that, we help to contribute to the abolition of geography as an academic discipline.

I see the technique presented in this thesis as a contribution to redraw the geography of the world by changing our perspectives on the most prevalent features that shape the modern world we are living in. Only by questioning the views that we are used to – be it even the most trivial thing that we take for granted – can enlighten our interpretations of the world and our understanding of issues that we did not understand as much as we thought before. That is why this thesis is neither a piece of research in cartography nor human geography, but a research in geography. I want to contribute a tiny little piece to understanding our planet differently. It is an attempt to rediscover the world of the 21st century by drawing new maps.

Chapter 2 **Cartography and globalisation**

2.1 Introduction

This chapter introduces the research context of the thesis within the fields of cartography and geography with a special consideration of the role of globalisation and their interrelation. Globalisation has not only changed the way the world works, but also the way we, as those affecting and being affected by globalisation processes, see and perceive the planet. Graphic displays have a long history in translating the complexity of our environment into understandable visual representation, with maps being the most fundamental image that we have in our minds when we reflect on the spaces that we are living in. Maps and visualisations shape our view of the world, and how they do so in the context of a globalised world will be outlined and discussed in this chapter.

Section 2.2 explains the diversification and the changing role of space in geographic practice and theory related to globalisation processes and shows, how this is reflected in the underlying principles of cartographic techniques to construct the base projections of maps. Section 2.3 outlines, how these changes are reflected in the history of modern cartography since the 16th century and presents some key examples. The shifting concepts and roles of maps caused by the increasing integration of demographic and socioeconomic data mark the beginning of including the human space(s) in maps. These are therefore given special consideration. Section 2.4 builds on these theoretical and conceptual foundations to outline the contemporary state of cartography by assessing the impact of digital technology on geographic data visualisation. The changing nature of cartographic practice will be demonstrated not only by introducing the Worldmapper project, but also by looking at the general identity of the cartographic discipline.

2.2 Changing geographies in a globalising world

"*The role of geography is to analyse and explain the phenomena of the landscapes that surround us, as well as to monitor the nature of human society and the economic, social, political and cultural lives that we live*" (Dorling & Fairbairn 1997: 1).

Globalisation in a very simplified way describes an increasing economic, social, political and cultural interconnection. It includes the exchange of goods, money, services, of people and ideas. Hence the beginnings of these processes date back much further than the recent 200 years since the industrial revolution started in Europe. The early roots can be found in the 15th century, in an age of discovery that also established the first lasting commercial trading links beyond the pure interest of conquering new territories (Tempel 2005). It is also the age of a changed world perception that we now take for granted, which is why it is such a crucial moment in cartographic history.

The industrial revolution marks the beginning of the most recent changes in which technological inventions accelerated these global links exponentially, with commercial air traffic and information technology having led to a perception of the world as a *global village* (McLuhan & Powers 1992) in which distances count increasingly less (Smith & Timberlake 2001, Zook & Brunn 2006). The technological innovations resulted in a complex web of global links[3] that transformed almost every aspect of our existence regardless of our own degree of integration into these processes (Bekaerta, Harvey & Lumsdainec 2002, Edwards 2000). As a result, globalisation processes affect our social and physical living conditions in multiple ways that can hardly be comprehended in their full extent (Altbach 2004, Chortareas & Pelagidis 2004, Hoekstra & Hung 2005, Lo & Marcotullio 2000, Stulz 2005).

2.2.1 Geography in the anthropocene

The role of geography to analyse and explain the physical and human environments has changed with the increased understanding of the complex correlation between these two environments. While scientists in the 18th century were often regarded as polymaths who looked at all facets of science, science became increasingly diversified and specialised in the 19th and especially the 20th century (Ross 1962, Thurs 2007). The image of the geographer as the universal genius is certainly outdated. But interdisciplinary approaches have gained new attention during the past two decades in the light of understanding the human impact to global environmental change. This resulted in a renaissance of a more universal approach to geographic research (Johnston, Taylor & Watts 2002).

The term *anthropocene* stands exemplarily for a return to traditional virtues of geography as an interdisciplinary discipline. The term is attributed to Paul Crutzen, who used it to describe the human impact on the physics of the atmosphere and on climate change. Crutzen sees the effects of humans on the global environment as being so significant that he claims that with the beginnings of industrialisation they have become a major driving force in environmental change, standing on par with the forces of nature (Crutzen 2002, Crutzen & Stoermer 2000).

[3] However, some parts almost disconnected from these links to the globalised world (Chortareas & Pelagidis 2004, Dodge & Kitchin 2004).

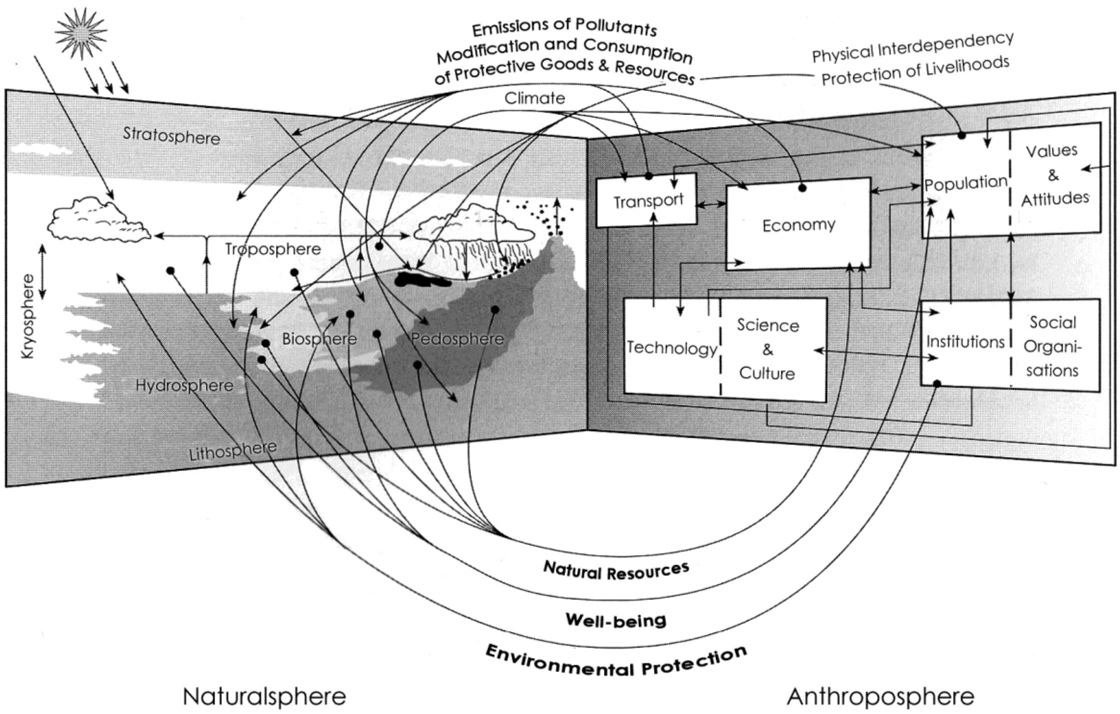

FIGURE 2.1: DIAGRAM OF THE NATURAL- AND ANTHROPOSPHERE
showing the key components and their interrelations
(translated and modified from Ehlers 2008: 239)

The anthropocene is proclaimed to be a new geologic era, in which the effects of human population and economic development that are also part of the processes of globalisation influence the natural environment as much as the natural environment previously determined the existence of human life across the globe. The anthropocene has become a '*vivid yet informal metaphor*' of global environmental change (Zalasiewicz, Williams & Ellis 2011, Zalasiewicz et al. 2008). In a broader context, global change research goes further than the focus on climate-related effects and processes, but contains the full range of human-environment relationships (Figure 2.1). This includes the various human and physical dimensions and the processes that also take place within these spheres, as they do not exist as independent entities (Ehlers 2008).

The debate about the complex relations and the diverse natures of the different spheres in which globalisation and global environmental change take place had an impact on how space is perceived in geography. There are theoretical and practical elements to this debate, which become relevant in this research while it addresses the problem of finding new representations for these diverse natures of space in cartographic form.

2.2.2 Relevance of space

For the past decades space has been at the forefront of a discussion not just in geography but in social sciences and beyond. Recent discussions have emphasised the significance of space and in particular have suggested that space plays an active role in the shape and formation of society. As part of some very basic theory in GIS, Tobler's so called first law states that "*everything is related to everything else but nearby things more so*" (Tobler 1970: 234). Just thinking of the fractal hierarchy of places in which the richest and the poorest people live, and how they are not all geographically adjacent to each other, helps to dispel that theory. But there is little interaction between the schools of thought in geography that the first law perhaps has never even been addressed by those who care more about theory than using GIS and geospatial analysis.

Contemporary discussions on the significance of space began with early *spatial battles*, and a debate about the relevance of space. The thrust of the argument put forward is that greater social understanding of the complex realities in a globalised world requires us to recognise the dynamic or active character of space. This is in contrast to past thought where social science viewed space, or geography, as a mere reflection or outcome of other underlying factors that were determined through time or history. From this standpoint, time is the dynamic factor which shapes the world, while space is relegated to the receptacle that retains the outcomes of the changes once they have occurred. This passive, or static, view of space is argued to preclude political agency or at least the way in which space can be used politically (Massey 1992, Massey 1995). By the traditional view it is the temporal that is the agent of change and thus contains the seeds of the political.

Through an understanding of the active role of space Massey (2005) and Amin & Thrift (2005) (amongst others), hope to re-kindle political discourse within geographical sciences, giving greater relevance and urgency to geographical matters and broadening its appeal beyond academia. More recent theoretical work in geography often tries to avoid overemphasising either space at the expense of time, or vice-versa. More emphasis is now given to discussing a unity between space and time, with a dialectical understanding of the relationship between the two (see e.g. Jones 2009a). Nevertheless, the outcome of these theoretical developments has been an upgrading of the importance and diversity of space. And space, it is claimed, is no longer the territory of geographers but others such as sociologists, political scientists and economists.

The effort to bring space to the front, to see space as of equal significance to time, reflects the growing emphasis put on multiplicity or difference. The study of space gives a broad scope to consider different experiences according to different areas and cultures. Therefore, there is no single history, say the history of Britain or of the *West*, but a multitude of different histories and experiences. These experiences differ according to the geographical context: both within and outside Britain and the *West*.

This includes not just the experience of peoples but of individuals, hence under this view there can be no universal history or grand narrative (Eagleton 2003). Alternatively, it is possible to bring space to the fore and still have some narratives that are quite grand (Taylor 2004b).

Trying to understand the patterns and implications of globalisation processes and their relation to the human being are crucial to human geography. In a remarkably timeless synopsis of the state of human geography in a shrinking world from 1975 (Abler et al. 1975a), Abler and colleagues already noted that "*instead of viewing our world as shrinking, it is perhaps more accurate to view man as expanding*"(Abler et al. 1975b: 4). In part, these processes have been described as a result of the tyranny of space (Abler et al. 1975b, Warntz 1968), which is a rather negative interpretation of the formation of the global population distribution. These works are an expression of studies about gaining a better understanding of population patterns and the reasons for their emergence. First ideas of a dwindling ('*lifting*') perception of space (Philbrick 1975: 30) begin to enter the theoretical debate about the role of space in a globalised world, although this already indicates that it may not be the loss of the relevance of space but a newly defined space in which a globalised world continues functioning. Some scenarios included a vanishing significance of space as a result of these space-adjusting technologies (transportation and telecommunication), and what continues in contemporary debates is the notion of a growing importance of people's imagination of space and distance rather than "*the "*real*" nature of space and distance*" (Abler 1975: 53).

Often a greater focus on space is claimed to be one of the elements responsible for the history's dissolving into the study of multiple histories. Space appears to suggest multiplicity. Space is a place where the experiences of different people or places have been elevated over objective measures or universal narratives. Particular experience now is thus often given preference over supposedly over-generalisation. A multiplicity of experience and values gives space wider relevance. A consequence of the unravelling of universalism has been a tendency to reject science and rationality, and the search for objectivity in general (Eagleton 2003). All these propositions have serious implications for those who want to use empirical evidence to further their arguments.

Researchers in social science are often divided between two sides: into those who are said to be quantitative and those who are labelled qualitative. Clearly, the main narrative in this thesis followed the quantitative path and avoided the theoretical implications whenever space came into the main focus. This is a quiet route, where the quantitative researcher makes use of surveys, generating or collecting numbers to measure social (and of course physical) phenomena, numbers that claim to be representative. In contrast, the qualitative social science researcher typically draws on '*rich*', in-depth, interviews "*as an analytical lens through which to examine*" phenomena (Lewis, Larner & Le Heron 2008: 42). In practice there is, or at least should be, a huge overlap between the two categories. An appreciation that a single method contains both quantitative and qualitative dimensions is inevitable to reconcile these different worlds (Schwanen & Kwan 2009) and to bring the mutual wars of criticism to an end (see Amin & Thrift 2000, Fotheringham 2006, Lawson 2003). A greater integration between qualitative and quantitative approaches should be welcomed.

With a rejection of universalism, emphasis is now often placed on local power relations. From this perspective, observation almost always merely reflects the power relations between different subjectivities (Foucault 1982). Therefore presenting evidence as objective will always be problematic as critics can always argue that this evidence is open to subjective treatment and interpretation. *Official* information has been particularly criticised for being the product of the subjective will of powerful and oppressive states and other interests. This connects well to Radcliffe's thoughts that mapping is part of the process whereby states legitimise their power and territory: "*Maps have retained the power to silence/make visible*" (Radcliffe 2009: 428).

Running in parallel to these theoretical developments is the rejection of borders and categorisation (Painter 2008). Related to arguments for multiplicity, the drawing of borders and devising of schemes of categorisation has also been criticised. Conventional cartography has been criticised for an inability to show the complexity of connections and interrelations. The legitimacy of the mapping of borders and the categorisation of people e.g. by ethnicity, has been undermined by its association with a western-centric worldview. It is argued that categorisation and border drawing is one way that particular interests have been asserted and how the *Other* has been defined and excluded. Critics have even named a condition '*cartographic anxiety*' (discussed in, but not claimed by Painter 2008).

Jones (2009b) challenges these arguments by making a distinction between the instinctive and cognitive need for humans to categorise and a recognition that borders and categories are not fixed but are what he terms inchoate (blurry or fuzzy). Cartographies of complexity do exist, but they rarely become part of a vivid academic debate. Discussing how great it would be if you could visualise the multiplicity of lives lived is far easier to express than actually visualising these great thoughts.

Recent work in geographical theory tends to reject the idea that places should be seen as bounded wholes. Instead it emphasises the connections and flows between places, organisations, people and structures (e.g. Marston, Jones III & Woodward 2005, Massey 2005), which is known as the relational approach (Ettlinger 2003, Yeung 2005). Space from the perspective of the relational approach tends to be imagined as a product of networks and relations rather than as a defined topology (Amin, Massey & Thrift 2003). It is argued that to visualise the relationships between flows, networks and connections and their relationship to territorial boundedness is what it means to carry out human geography today (see Dicken et al. 2001, Jones & Macleod 2004, Painter 2008, Swyngedouw 2004). However, almost all of this visualisation takes place in the minds of those doing the describing. Cartographers of the unconventional are continuously criticised if they produce images others find hard to understand, what Tobler (2004) addressed in his notion that for example cartograms are simply approached in the wrong way and should simply be accepted as yet another map projection rather than as being unusual.

Jones (2009a: 496) points out a limitation in what he calls the ideal relational approach of the relational approach that is currently so popular in theoretical geography. He points out the lack of a widely applicable and observable material basis. It is mostly through tackling theoretical issues in relation to observable concrete forms that we can increase our understanding of issues he claims. As Amin & Thrift (2005: 223) suggest, "*theory-making is an assemblage of testable propositions and probable explanations derived from sensings of the world*", which means that theory must be put to the test. A solution might be to look at a few of the problems and phenomena occurring in the world for instance in the form of mapping (Ballas & Dorling 2011).

The methodology presented in this thesis, and its implementation in geographic research, is also a contribution to bridge the described growing divide between recent theoretical developments in human geography and work in human geography with a more empirical focus. By introducing alternative mapping techniques to an audience that has in some ways eschewed visual and especially cartographic imagery (Perkins 2004), a revitalisation of maps as part of the identity of geography may succeed.

A more productive relationship (rather than an unlikely reconciliation, see Turnbull 2000) between some of these disparate schools of thought in contemporary geographical scholarship for a better communication of geographic knowledge is something that lies in the self-interest of geographic practice. By communicating too abstractly, too many members of the potential audience may be left behind. The potential audience in contemporary (not only human) geography is huge. In spite of this potential audience, Johnston (2009) points to a gap and lack of interaction, between what he calls the academic discipline of Geography and geography presented through popular media. The discipline has also been criticised in recent years and decades for a failure to build an appropriate popular understanding of the subject (Harvey 1984, Johnston 2004). Some of this gap is the result of a set of academic studies which have been too frequently divided between theorists and empiricists.

It lies in the nature of the subject that the academic arguments of geographers relate to issues of great importance to the mainstream news media, from capitalism in crisis to the divisions within a society, there is everyday geography that overlaps considerably with theoretic and empirical academic geography (everything else would be a disgrace and question the relevance of the discipline). However, academic talk in the abstract about systemic failings in spatial systems, about the complexity of processes that shape the globalised world, falls short of the purpose of science to explain its research, and possibly provide solutions to critical questions.

By suggesting new techniques in response to contemporary scholarly debates, empiricists might benefit from insight into new theories in human geography which otherwise they miss, but possibly theorists may benefit from new perspectives on the works of empirists. There is little point in presenting a new method that allows an alternative mapping of the world with gorgeous detail and advanced statistical techniques if one has very little idea what it is that is being mapped, and why and how and for what purpose one might be mapping it.

2.2.3 Map projections as manifestations of space

Maps are the visual manifestation of space. They have become a crucial element in the description of the different spheres of human and physical geography, and helped to illustrate the phenomena that explain the environments we are living in. The physical space has always remained the main centre of the map depiction onto which these phenomena are mapped. But even this physical space adopts very different appearances in map form, as the two-dimensional representation of a three dimensional space requires certain compromises. Depending on the purpose of a cartographic depiction, the question of the appropriate map projection is crucial in the process of map making and has contributed to the changes that cartographic practice underwent in the course of its history.

Map projections did not only solve specific questions of navigation, but also changed people's perception of the planet. Our idea of a map is not inherent, but are developed by most of us in our childhood, and what we learn then becomes our understanding of space (Bluestein & Acredolo 1979, Presson 1979). Therefore, map projections are of pivotal interest to cartographic research from a conceptual as much as from a methodological perspective. The right map projection can solve a technical problem in the same way as it can provide a thought-provoking new perspective on an already known topic – or completely distort the view they give. Maps are never neutral, and "*there is no innocent way to see them*" (Wood 2010: 44). Map projections are part of that problem and of the solution at the same time. The field of map projections would be highly undervalued if it were only discussed from a technical-methodological point of view – is connects very immediate to the above outlined changes in geographical thought. Changes in map projections also reflect the diversification of space, and maps always accompanied the globalisation processes (if they not even supported them by providing solutions to discover the planet).

2.2.3.1 *From Mercator to Peters*

Projections are a key element of mapping techniques. And map projections have some considerable impacts on our understanding of the world, especially (but not only) in a global perspective where different map transformations can result in considerably different appearances of the land areas. Due to the compromises that are necessary to display a three-dimensional space on a flat surface, maps will always remain imperfect cartographic depictions, as stated in a Nature editorial about the virtues of visualisation (Nature 2008). The power of maps also lies in the imperfect nature of a map projection. Maps create images of a space that we cannot oversee with the human eye (not even an astronaut can see all continents at one time in the enviable views from space), and maps shape our imagination of space, our mental maps of the planet.

Before a map serving a specific purpose can be created, the right choice for an appropriate map projection has to be made. The *best* cartographic visualisation can convey misleading information if an inappropriate map projection is chosen. An infamous example (amongst uncountable others) is a map showing the range of North Korean missiles (Figure 2.2) published in the Economist magazine (ESRI 2009). The map shows the potential missile threat drawn in circles of different ranges on a Mercator projection world

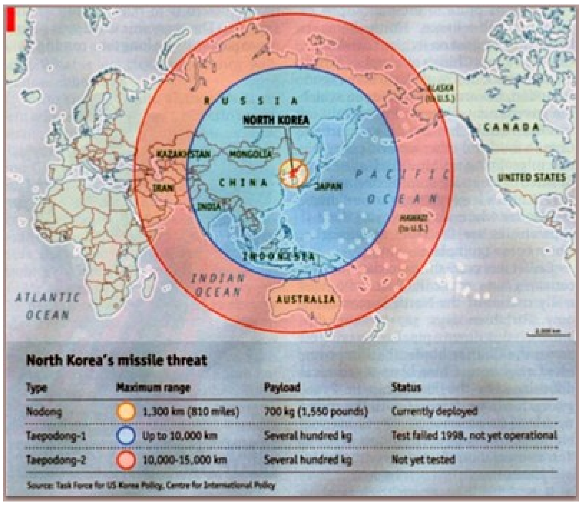

FIGURE 2.2: NORTH KOREA MISSILE THREAT MAP showing the missile range in circles drawn on a Mercator projection (printed in The Economist on May 3, 2003, obtained from ESRI 2009)

map, which simply is a false depiction as a result of the underlying projection[4].

The missile threat map demonstrates not only the importance of map projections and of basic skills that are needed to create a map; it also highlights the lasting legacy that a single map projection can have. Mercator's map (see section 2.3.2) was a significant contribution to cartography, and particularly useful for navigational purposes which made a new dimension of global links possible in the 16th century. It may not have been the main cause for the early days of globalisation (and other cartographers had been working on similar approaches before), but his map can be highlighted as one important element in the innovations that were needed to create the globalised world as we know it.

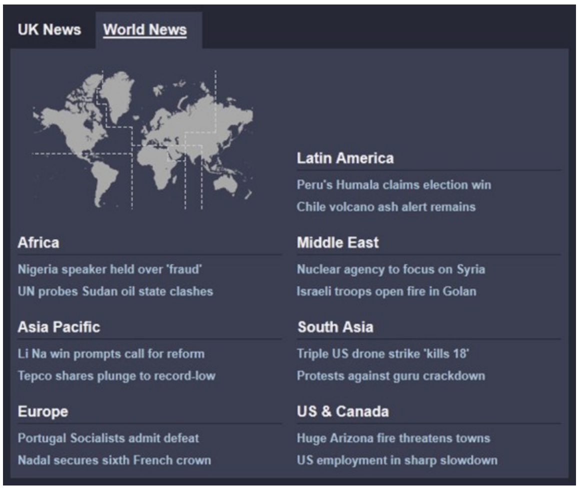

FIGURE 2.3: MERCATOR MAP ON BBC NEWS
Clipping from the BBC news website on June 6, 2011 (BBC 2011)

The cylindrical map projection used in the Mercator map is less suitable for showing distances or correct land area sizes, due to the specific mathematic transformation that defines the basic character of the map. Nevertheless, we see Mercator projections in many parts of our everyday life. The screens in airplanes showing the flight route often show a Mercator map (which may please the navigational experts on board, but may sometimes trigger confusion among the less cartophile passengers who wonder why the plane does not fly in a direct straight line towards the destination), many news media include a Mercator map as a graphical design element (Figure 2.3), to only mention two common uses. These are not particularly false uses, but proofs of the lasting impact of Mercator and of the picture that many people see as the correct depiction of the world.

As the map projection is so central to the cartographic display, the different techniques for mathematical transformations of the Earth's spherical surface into a plane representation are well investigated. Centuries of cartographic work in this field have led to a wider range of projections, of which Mercator is only a fraction of the different concepts, to create the presumably *best* map projection. Every map projection follows a certain mathematical procedure that aims to preserve some geometric qualities of the

[4] An incorrect use of Mercator's projection has a long tradition in cartographer's moaning about improper cartographic practice (see e.g. Miller 1942, Robinson et al. 1995), but the criticism of incorrect uses of map projections shall not be further discussed here.

physical space, or – like the Mercator projection – to reconstruct this space to provide better solutions for a specific purpose.

Four areas are of particular interest in map transformation approaches that have been developed over the centuries: (1) the transformation of angles, (2) the transformation of areas, (3) the transformation of distances, and (4) the transformation of directions. A look at different map projections[5] highlights the effects of the different transformations on the map appearance (Qihe, Snyder & Tobler 1999, Robinson et al. 1995, Snyder 1987, Snyder 1993).

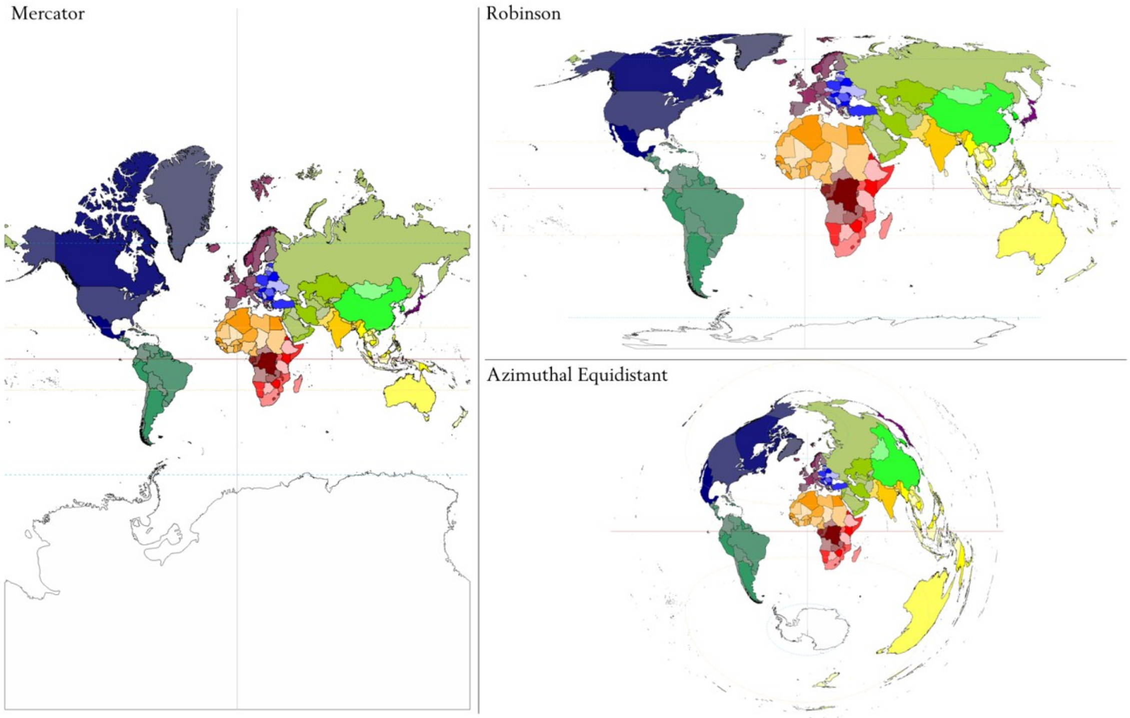

FIGURE 2.4: MAP PROJECTIONS: MERCATOR, ROBINSON & AZIMUTHAL EQUIDISTANT
Included in the maps are key geographic reference lines, i.e. the Equator, the Prime Meridian and the polar circles (own depiction by the author)

There is, of course, no *best* or optimal map projection that gives the most accurate picture of the world or that is capable of serving all purposes of a map. On larger scales, these issues also become less crucial (although not irrelevant!), as different transformations of a smaller area result in less distortion of area, distance, or direction (Figure 2.4). But different map projections can tell different stories, and, especially on smaller scales, also change our image of the world considerably. Map projections can therefore be used very consciously to convey a specific message. The above-mentioned examples for the use of the Mercator projection may just represent non-reflective uses of a projection that became common, while the same projection in other circumstances

[5] The visual style of most world maps and conventional cartograms in this thesis is adapted from the Worldmapper project, which will be introduced in section 2.5. Figure 1.2 serves as a reference map for this colour scheme.

can also make a political statement to create the image of influential power spheres (with e.g. Russia and the USA appearing extensively large on the Mercator map).

Apart from the aim to evaluate new mathematical concepts to create better or other map projections, the power of visualisation itself was recognised by many cartographers, and resulted in the creation of specialised projections with different backgrounds and impact. The *Dymaxion* map by Fuller is eye catching because it does not rely on the basic concept of a coherent reference to the general compass directions. It therefore challenges the map reader with an unusual geometric shape of the surface of the planet. The concept is based on an icosahedron, a regular geometric shape, onto which the land surface is projected and which is then unfolded for the plane display. A projection showing the whole land area in an almost contiguous map can be created by using the North pole as the central unfolding point, which Fuller used as a key depiction in one of his later works on an analysis of the state of humanity (Fuller 1981).

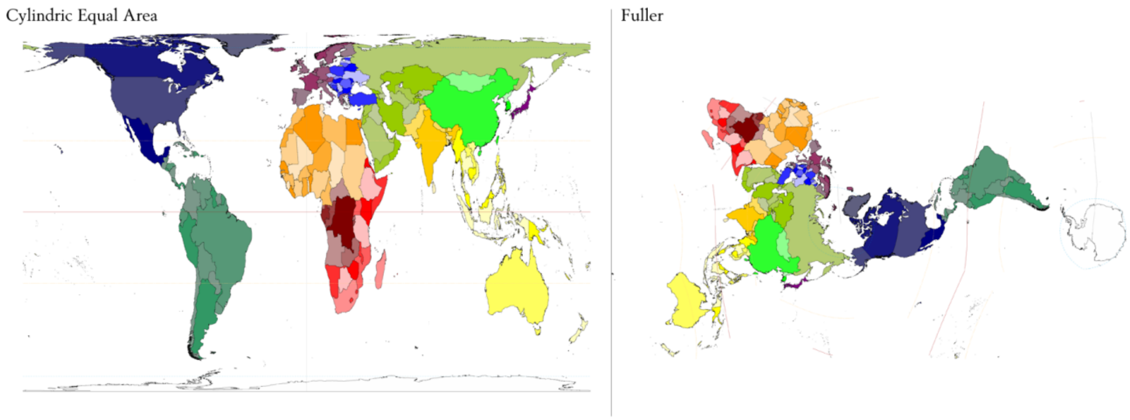

FIGURE 2.5: MAP PROJECTIONS: CYLINDRIC EQUAL AREA & FULLER
The cylindric equal area projection shown here is similar to the map depiction used in Peters' map of the world. The Fuller projection is based on an icosahedron onto which the world's surface is unfolded. In this depiction the central unfolding point is the North pole. Included in the maps are key geographic reference lines, i.e. the Equator, the Prime Meridian and the polar circles (own depiction by the author)

The Fuller projection (Figure 2.5, right) is a visually striking representation because of the unusual arrangement of the continents in any of the resulting maps. Compared to his projection, another controversial projection appears rather conventional at first sight. The projection introduced by Arno Peters in 1974 as the Peters projection is based on the concept of a cylindrical equal-area projection (Figure 2.5, left), and as such not a new idea at the time. One of the controversies actually questioned the novelty of Peters' specific transformation approach. It is originally contributed to James Gall who described the concept already in the 19th century (Gall 1885). Apart from an argument about the correct credits, further controversy was caused by the political statement that

Peters deliberately linked to his newly published world map[6] (Porter & Voxland 1986), which was later also complemented by a full atlas using this projection (Peters 1989).

Generally, the Peters projection is an equal area map, in which every continent and every country is shown in its true physical size, but appears deformed in horizontal dimensions towards the higher latitudes (and in vertical dimensions towards the equator[7]). The innovative element of the map projection itself therefore is rather little. Peters also emphasised that his world map is fairer to the world's population, as is does not overrepresent the political North and suppress the appearance of the developing countries that are largely located closer to the equator. His map was thus acclaimed as a fairer view to tackle the imbalance between the wealthier North and poorer South of the world (Monmonier 1995).

Peters faced criticism for a politicisation of cartography, which certainly neglects the fact that cartography has always been a political instrument, but often in the more subtle form of the topics that were drawn onto the maps, rather than the shape of the map itself. Beyond the controversies around the map, it can perhaps be fairly summarised that the release of the Peters map of the world was a masterpiece of cartographic communication, that did not only contain a slightly provocative and unusual perspective[8], but was complemented by some trenchant claims and statements that questioned the distribution of power and the western-centric views of the world (Crampton & Krygier 2006, Monmonier 1995, Porter & Voxland 1986).

The Gall-Peters projection is an example for how map projections were used to challenge the notion of power and question culturally biased or bigoted world views, which demonstrates how map projections have a tradition in going beyond merely solving mathematical problems of putting the globe on paper, so that not only the topics that are put on the map can constitute an instrumentalisation of maps as political instruments, but also the mistakenly mathematical concept of the specific use of a map projection. As a result, the debate about the power of maps is now complemented by some substantial theoretical accounts related to a critical investigation of maps, map projections and their influences (Harley 1988, Harley 1989, Harley 2001, Wood 1992, Wood 2010, Wood & Fels 2008). This is continued in more recent accounts related to the use of geographical information systems in the creation of maps (Crampton 2010, Schuurman 2000).

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[6] Peters was not the only one to have presented a new approach to mapping over the years that tries to overcome the Western or Eurocentric view that cartography has been criticised for (see e.g. Mogel & Bhagat 2007).

[7] The standard parallel used in the Peters map is the 45th parallel. The distortion is therefore lowest at the 45° latitudes.

[8] Peters made further adjustments that added to the unusual appearance. Most remarkable is the relocation of the map centre eastwards, so that he was able to show Russia as a contiguous land area that is not cut at the 180th meridian.

2.2.3.2 Cartograms

Arno Peters challenged the political imbalance of the world by claiming to have drawn a map that is fairer to people living in the world. Technically, his world map is a fairer view of the continents, rather than the people living on them. A fairer picture of the people living in these countries is given in a rather more unusual cartographic display which is commonly known as a cartogram. There are many different ways to draw a cartogram. Basically a cartogram also applies certain mathematical principles to transform a map or a map-like representation into the cartographic result, just like a conventional map projection.

There is an extensive range of cartogram transformations, such as works related to Lynch's concept of mental maps as distorted personal representations of space (Gould & White 1974, Lynch 1960), the creation of tube-map style diagrams like Beck's underground map of London (Garland 1994, Ovenden 2005) and other transport network concepts and map transformations based on (travel and other aspects of) time (Jenny et al. 2006, Street 2006). Although the term was originally very broadly used for maps showing statistical symbols or statistical information[9], it now is mainly used in reference to maps that are transformed on a '*scale other than a true scale*' (Mayhew 2004, Tikunov 1988).

2.2.3.2.1 Cartogram types

Cartograms themselves were not a completely new development in cartography in the 1970s. Tobler (2004) and Fris (1974) refer to Minard for the first series of published cartograms in the mid-19th century. A first more systematic approach towards the development of value-area cartograms has been described by Raisz[10] who mentions the idea of a '*statistical cartogram*' (Raisz 1934). In his paper he outlines a method to create rectangular representations of geographical census divisions resized according to their population size (Figure 2.6). The rectangular shapes that represent the US states are easy to create and simplify the arithmetic operation (Raisz 1934). Raisz elaborated further examples using other data such as wealth, manufacturing, mining and farming, and suggests a wider application of such depictions for

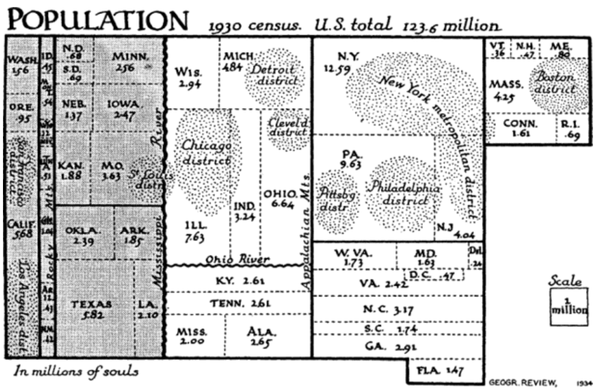

FIGURE 2.6: RAISZ' US POPULATION CARTOGRAM (Raisz 1934: 293)

[9] The German word *Kartogramm* for instance refers to a choropleth map depiction, although it becomes increasingly used in the same way as in the English language (Wilhelmy 1996). See Tobler (2004: 2ff) for historic notions of the term cartogram and its developments.

[10] Earlier depictions of cartograms date back to works from Minard and Tissot in the 19th century (Tobler 2004).

other topics and other countries. He also suggests the suitability of such maps as basemaps for certain topics that are difficult to display on a normal map, such as the nationwide depiction of business branch locations in one map.

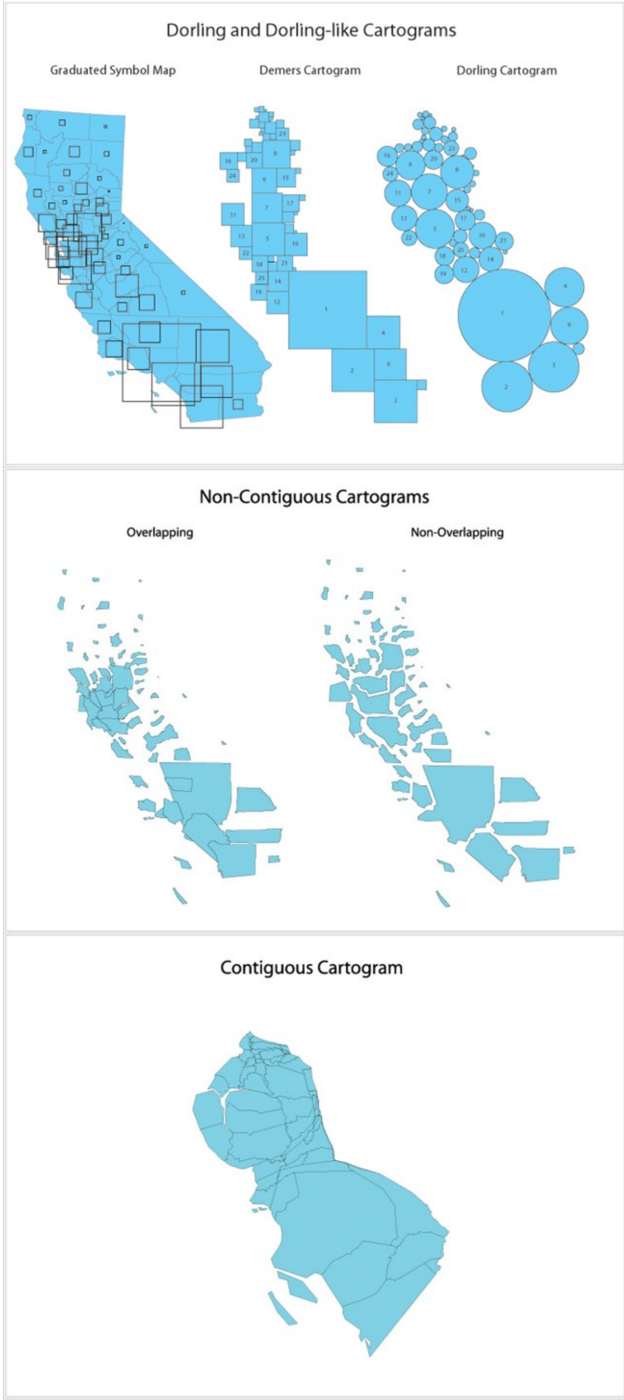

FIGURE 2.7: CARTOGRAM TYPES
Population cartograms of the US state of California created using different cartogram techniques (image obtained from Demers & Bortins 2002)

Raisz' work is an example for a hand-drawn predecessor of a rectangular population cartogram. Similar depictions are still popular and often used in school books and atlases because of their easy construction (Dent 1999). In rectangular cartograms, the area of interest is displayed as a rectangular shape. In the usual approaches this generalises the physical map considerably and leads to the more diagram-style depiction in which the arrangement of the rectangles indicates the geographic location. While this approach is generally useful for a manual cartogram creation, it has also been translated into a computer-based algorithm. The algorithm describes the creation of rectangular cartograms in a mathematical form based on a specific set of transformation rules that aim to preserve the recognisability (Kreveld & Speckmann 2006). The time span between Raisz' and Kreveld & Speckmann's works on rectangular cartograms covers a dynamic period of developments and innovations in the techniques to create different types of cartograms that are now common. The implementation of algorithms that facilitate the digital creation of computer-generated contiguous cartograms has been demonstrated by a number of approaches since the first concepts were created at the GIS-pioneering institution of Harvard[11] (Dougenik, Chrisman & Niemeyer 1985, Edelsbrunner & Waupotitsch 1997, Gastner & Newman 2004, Gusein-Zade & Tikunov 1993, Kocmoud & House 1998, Tobler 1986, Wolf 2005). Many of these concepts realised in the digital domain are based on earlier theoretical considerations and mathematical concepts. The capabilities of computing helped to turn these conceptualisations into practicable approaches.

Apart from rectangular cartograms, three other types can be distinguished (Figure 2.7) (Cuff, Pawling & Blair 1984, Kreveld & Speckmann 2006, Tobler 2004). Dorling cartograms are based on the use of circles to represent a geographical unit (Dorling 1996, Dorling 1991), and thus follow a similar pattern of using geometric shapes for the transformation, but with the additional aim to preserve the relative geographic proximity to the neighbouring areas. Non-contiguous cartograms preserve the shape of the geographical unit, but with the rescaling they lose their connection and become detached from their geographical neighbours (Olsen 2005). The last type, contiguous-area cartograms, is often regarded as the standard type, and is based on the concept of resizing the geographical areas while preserving the continuity of the overall area (Wolf 2005, Gastner & Newman 2004, Gusein-Zade & Tikunov 1993).

All cartogram approaches have in common that they try to solve the problem of an overall readability of the resulting cartogram, while at the same time being an adequate representation of the underlying quantitative information. The range of methodological concepts to construct the different types of cartograms is widespread, similar to the range of map projections that have been developed over time. As argued before, in principle cartograms are a special form of a map transformation (Canters 2002), and some approaches even aim to combine the principles of value-area and other geographical map transformations (Carroll & Moore 2008, Kadman & Shlomi 1978, Panse et al. 2006).

Concepts for contiguous area cartograms are particularly close to the wider field of other geographical map projections, because the transformation of the *real* geographical shape of an area stands in the centre of interest, and the relative geographical location remains preserved in some form. Contiguous value-by-area cartograms, where a specific value of interest defines the scale of the actual areal units of the map are also the base concept that is used in the further research for this thesis.

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[11] See Tobler (2004) for a description of the early works on computer cartograms at Harvard. Tobler's further works and assessments of the mathematical construction of cartograms are perhaps the most significant contributions to the computer-assisted generation of cartograms (Tobler 1979, Tobler 1981, Tobler 1986). The major advances in computer cartograms can be seen as part of the digital turn in cartographic methods (see section 2.3.3).

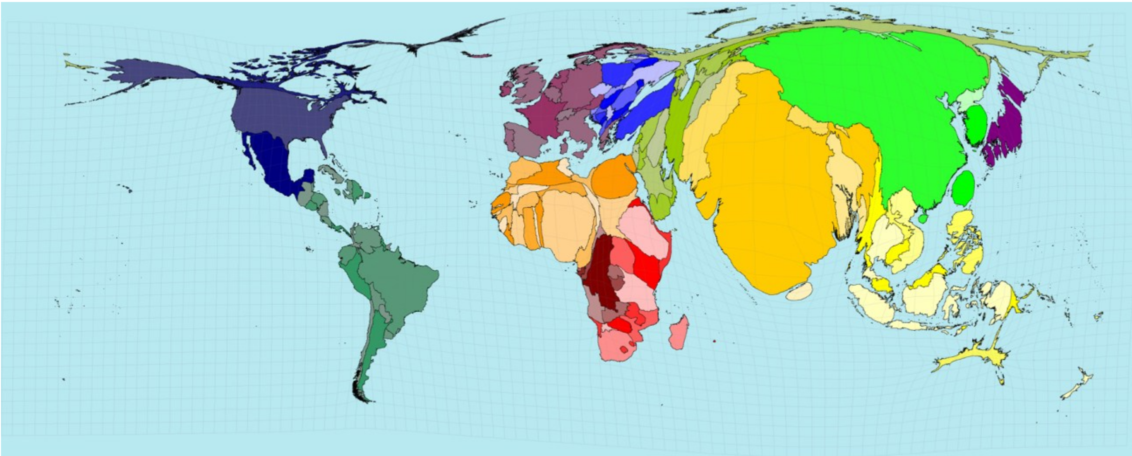

FIGURE 2.8: WORLD POPULATION CARTOGRAM
Showing 2010 national-level population estimates in the Worldmapper visual map style, see Figure 1.2 for a reference map (own depiction by the author using data from UNPD 2008)

The Worldmapper world population cartogram (Figure 2.8, see also section 2.5) is the materialisation of Abler et al.'s (1975b) theoretical notion of *'shrinking spaces and expanding people*'. The map provides the base for the development of a new methodological approach in chapter 2. The algorithm deployed for this map uses a diffusion-based method to create a density equalising map which preserves the unique administrative shapes. This allows an easy identification of countries, and additional visual elements, namely the simplicity of the map depiction and a unique coherent colour scheme of all Worldmapper maps, make this map a paramount example of contemporary advances in the use of cartograms (Dorling 2007, Newman & Girvan 2004, Webb 2006).

The simplicity and the advantage of an easy readability are reached at the cost of a vanishing level of detail. The cartogram depiction shows one population figure per country, which allows the global comparison, but does not reach the level of detail that is shown such as in more conventional map projections (see examples of population maps presented in section 2.3). Despite the lack of detail, this map can be regarded as an example of a significant advance because it has helped to gain wider acceptance of cartograms as being alternative forms of maps.

2.2.3.2.2 A diffusion-based method for density equalising cartograms

The diffusion-based method for producing density equalising maps has been published by Gastner & Newman (2004). It is one of the most substantial recent advances in the computer-generation of contiguous cartograms. Dubbed as "*one small step for two men, one giant leap for mapping*" by Dorling (2006: 35), their approach is based on principles of diffusion modelling in elementary physics which results in "*useful, elegant, and easily readable maps*" (Gastner & Newman 2004: 7499). Their so-called diffusion cartogram transfers the physics of a linear diffusion process into the process of a map transformation.

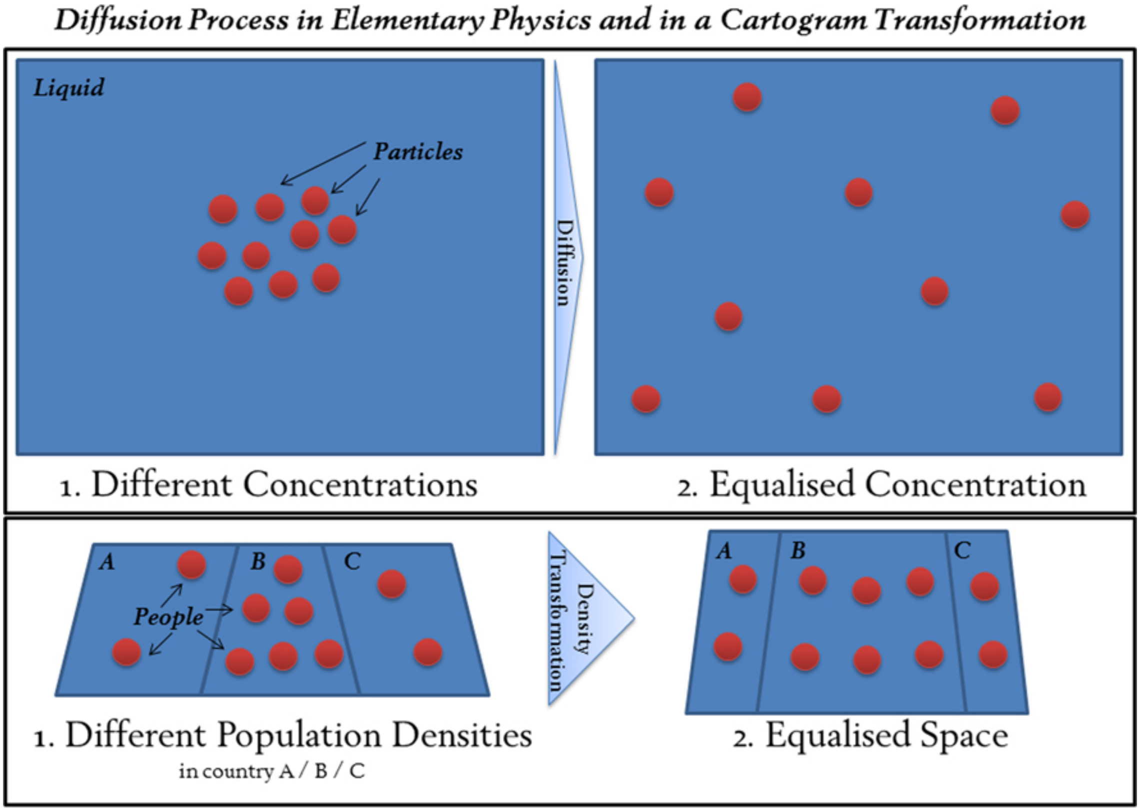

FIGURE 2.9: BASIC PRINCIPLES OF A DIFFUSION PROCESS
The diffusion process describes the redistribution of particles in a liquid with the resolute of an equalised concentration. Transferred to a cartogram transformation, this results in a resizing of areal map units (e.g. country shapes) in order to read an equalised spatial distribution of the value of interest (e.g. population) (own depiction by the author)

The diffusion equation used in Gastner/Newman's approach emulates what happens when a liquid flows from higher to lower densities to smooth out the differences (Figure 2.9). The density therefore is allowed to diffuse to create a uniform transition. In the map transformation, the same principle changes the shape of the geographical areas. As a cartogram that uses one number per country, such as the total population, this figure shows the total population throughout the geographical extent of the particular country, hence represents an equal population density within that geographical area. For the different countries within a world map, therefore different densities exist side by side, and the map transformation applies the diffusion process to equalise the differences in a way which is conformal[12] over each geographical unit. The resulting map therefore retains the contiguity of the countries and preserves their relative geographical location, while it also conserves the original geographical shape.

[12] *Conformal* means that the true shape of an area is preserved.

The same principle also works with any other geographical unit, and on any other geographical scale, as long as a consistent set of data is available.

Gastner & Newman (2004) refer to earlier similar approaches and highlight especially the cellular automation method of Dorling (1996), which demonstrates the consequent progression of these approaches and the continuing progress of the techniques. In terms of readability and geographical accuracy, the diffusion-based method remains unrivalled and the most elegant cartogram transformation available to date. It provides a reasonably efficient (and fast) way of constructing density-equalising cartograms. The preservation of the topological relations is an important feature of the algorithm, as it has practicable implications for the use of additional geographical features in the resulting cartogram. The algorithm also allows a high flexibility in the extent of the distortion, which can be adjusted by the user to balance between the density equalisation and a lower degree of distortion.

Not least thanks to Gastner/Newman's approach, cartograms have become a popular (yet unusual) way of mapping, where popular and unusual are not meant as a contradiction, but where the unusual appearance often aims to be an eye-catching element of the map depiction (Breding 1998, Burgdorf 2008, Butler 2008, Cuff, Pawling & Blair 1984, Gillard 1979, Rittschof et al. 1996, Tikunov 1988). Other works put more emphasis on the benefits of the additional analytical value of the technique (Colizza et al. 2005, Monmonier 2006, Wieland et al. 2007). The most extensive compilation of cartograms based on Gastner/Newman's algorithm has been realised within the Worldmapper project (see section 2.5), which helped to promote the use of cartogram-style maps in science, education, and also for the broader public. Nevertheless, cartograms are still a niche product in the range of cartographic depictions, because their realisation is still not always a straightforward procedure, and the acceptance of cartograms as a more conventional alternative to other map projections is not yet fully existent. Partly this problem of acceptance lies in the unusual shapes that emerge. It also lies in the limited versatility of cartogram transformations.

2.2.3.2.3 Cartograms as a map projection

Map projections generally result in a geographical representation that is used for other purposes than the mono-dimensional display of the country shapes. As such, map projections define how the underlying concept of space is translated into its visual manifestation. Every map projection serves certain purposes and provides a basemap for other cartographic applications. Contiguous cartograms aim to preserve the shape of an areal unit in the map, hence a world cartogram of a certain topic is based on differently sized geographical areas (which often are the country shapes). The map transformation is based on a very limited number of values.

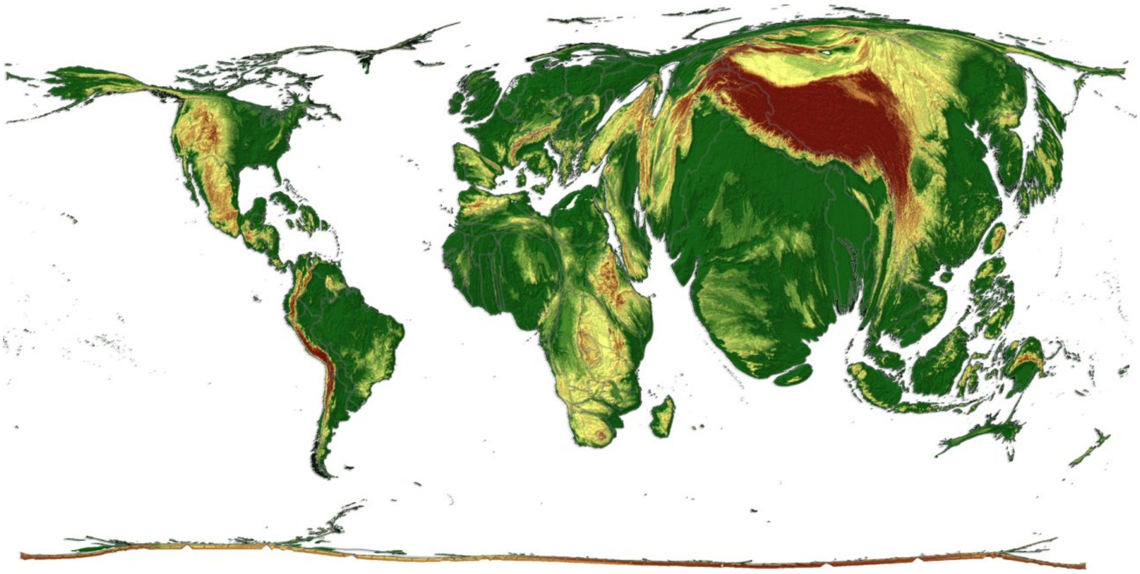

FIGURE 2.10: NATIONAL-LEVEL WORLD POPULATION CARTOGRAM WITH TOPOGRAPHIC LAYER
The topographic information is transformed together with the country shapes according to their total population. The depiction does not allow an interpretation of where people really are in relation to the topographic display
(own depiction by the author using data from UNPD 2008, USGS 2009)

Using a cartogram created from national-level data as a basemap is only feasible for the same level of data, and becomes problematic when used with other geographic features that represent a different level of detail. Drawing e.g. physical features such as mountains onto a world population cartogram based on national level data (Figure 2.10) does not allow these features to be understood in their specific context of the underlying space that is represented in the cartogram.

A cartogram can be used as a basemap to show any other geographical feature, but drawing roads, rivers, or railways onto a cartogram will in most cases make a similarly invalid statement about these features as drawing circles of supposed distances onto a Mercator map projection (as shown in section 2.2.3.1). The capability of cartograms to be used as a basemap for other information therefore is highly dependent on the level of detail that the geographical units on which the map transformation is based depict. Dorling (1991) demonstrated a range of uses at smaller geographical scales, but these early works remain exceptions in the use of cartograms to date. Generally the use of cartograms as a basemap is predominantly limited to a mono-thematic depiction (or sometimes to showing a second level of quantitative data on top, such as the display of national-level per-capita carbon emissions on a world population cartogram or comparable depiction).

Tobler (2004) dismisses suggestions of a difficulty in reading cartograms (see e.g. Roth, Woodruff & Johnson 2002) with the general manner that many people approach cartograms. He emphasises that some of these difficulties vanish when cartograms are seen as a map projection, rather than a graphic representation of data. He also refers to techniques to augment additional information onto different types of cartograms to enhance readability, but also to increase the analytical value, and calls for additional efforts in advancing the visual and analytical capabilities of cartograms.

The range of algorithms and methodological concepts for the creation of cartograms has been extensively investigated[13]. In contrast, the practical use and the wider applicability of cartograms as an alternative map projection for a detailed geography of the world remains less considered in the works that have been undertaken to date. Much of the technical advances originate from computer science, where the solution to a specific technical-mathematic problem defined the scope for the development of a new algorithm. The geographical scope remained outside the main interest of these works. The underlying concept of a transformation based on a specific value of interest, however, contains a huge potential to be used for more extensively visualising the ever-growing amount of geographical data that is generated to reach an understanding of the complex (human and physical) processes that determine the shape of the modern world.

2.3 A brief history of maps

Changing map projections are one part of the changing nature of maps. They provide the base for the stories they are supposed to tell (Wood 2010). The following overview outlines major developments in modern cartography. The overview is by no means meant to be an exhaustive portrayal of advances cartography – this has been done by many others before and requires no repetition in the same extent (see e.g. Barber & Harper 2010, Clark 2005, Harley 1988, Harley 2001, Wood 2010). The focus here is a concise depiction of the major milestones that are relevant in the context of this research to understand the links between globalisation processes and their graphical representations. This is not only important in explaining how the world itself and our image of the world have changed in the last 500 years and what crucial role cartography has played in this context. It is also relevant in understanding the most recent trends in cartography. Furthermore has the amount of information and the way how we can analyse this information with digital technology changed significantly.

[13] Improving cartogram-generating algorithms is certainly not a finished field. As Tobler (2004) notes, the computational complexity is similar to that of any other map projection and improvements in the efficiency of existing concepts and to minimise false distortions are still problems that need to be evaluated further in this field.

New attempts to include these changes in cartographic practice will also be outlined and investigated to set the framework of the methodology deployed in this research.

2.3.1 Prologue

Beginning with the very early roots of globalisation occurring in the 15th century when seamen, tradesmen and colonists started the considerable increase in global links. These times can be seen as the early days of modern cartography – Wood even makes the hyperbolic remark that "*[t]here were no maps before 1500*" (Wood 2010: 22)[14]. Part of the first cartographic efforts in that time were advances of mapping land area and creating suitable maps to conquer the globe were part of the first cartographic efforts.

The name Mercator remains an iconic name in these mapping efforts, although his projection is not the only significant cartographic invention of the early heyday of maps[15]. His map projection remains a lasting legacy even 500 years after Mercator's birth in 1512[16], being one of the most commonly used ways of depicting the world.

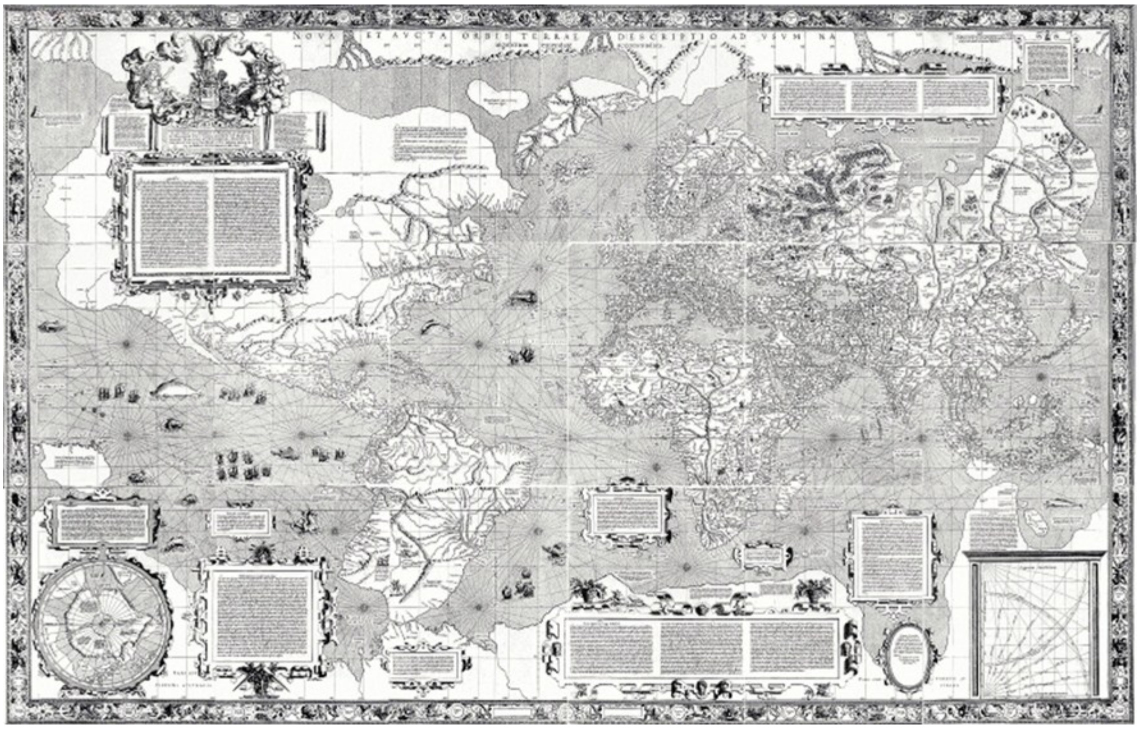

FIGURE 2.11: MERCATOR'S MAP OF THE WORLD
(original publication in 1569, obtained from WC 2006a)

[14] Tufte (2001) mentions slightly less hyperbolic that the first maps were drawn about 5000 years earlier.

[15] It has also to be mentioned that the depiction is very Euro-centric, and that crucial developments took place in many other cultural regions around the world that deserve similar merits (Thrower 1999). The narrow focus taken here can be justified with the main aim to outline the major changes in cartography and mapping in direct relation to the emergence of data visualisation in the industrial age that undisputedly started in Europe.

[16] On a slightly biased notion it should not remain unmentioned that Mercator's creation and publication of his new world map took place during his appointment in the Duchy of Cleves (Crane 2003), which happened to be the place where the author of this thesis spent most of his childhood.

Like many scholars of these centuries of discovery, Mercator understood his work as part of a universal science that aimed at comprehending the world as a whole. Mercator developed the first full world map that was capable of showing loxodromes (or rhumb lines) as straight lines on the plane map surface. This principle was highly valuable for navigational purposes, as the compass bearing was shown in straight lines. Mercator created the first real world navigational map (Figure 2.11), which was published in 1569 and is seen as a breakthrough in sea navigation and has thus played a crucial part in the European exploration of the world (Crane 2003, Monmonier 2004, Taylor 2004a, Thrower 1999).

More and more accurate depictions of formerly unknown places on the world led to the compilation of the first modern atlases in the 16th century. The first modern atlases – like Abraham Ortelius' *Theatrum Orbis Terrarum*, which is widely acknowledged as the first of the wave of atlas and map publications following thereafter – created for the first time a clearer picture of the land surface and the real look of the world (Goffart 2003, Jacob 1996, Thrower 1999). These developments laid the foundations for the subsequently ever-improving capabilities of maps to show the world in increasing detail, and were at the outset of these early days of globalisation.

The diffuse meaning of cartography is reflected in the different words of the subject and the meanings that relate to them. *Carta*, the Latin word for a paper (*papyrus*) document, and *mappa*, Latin for cloth, have their origins in materials on which first cartographic depictions were drawn, rather than the subject of the graphic display. And although the depiction of the land area has always been a key element of a map itself, it was often complemented by additional information. This is the case in illustrations and observations of the natural environment like in the maps of explorers such as Humboldt, whose maps are also considerable contributions to thematic cartography.

Humboldt (Figure 2.12, *see below*) and many others started placing additional elements and information outside the actual map, which became increasingly a common feature and important component in depictions of social and economic statistics (Robinson 1982, Robinson & Wallis 1967). Statistical charts became integral parts of maps, but also individual graphical displays of often geographically related data to which cartographic work contributed considerably[17].

[17] The modern use of the word *chart* does not only describe statistical graphs, but is also applied to hydrographic maps (Thrower 1999).

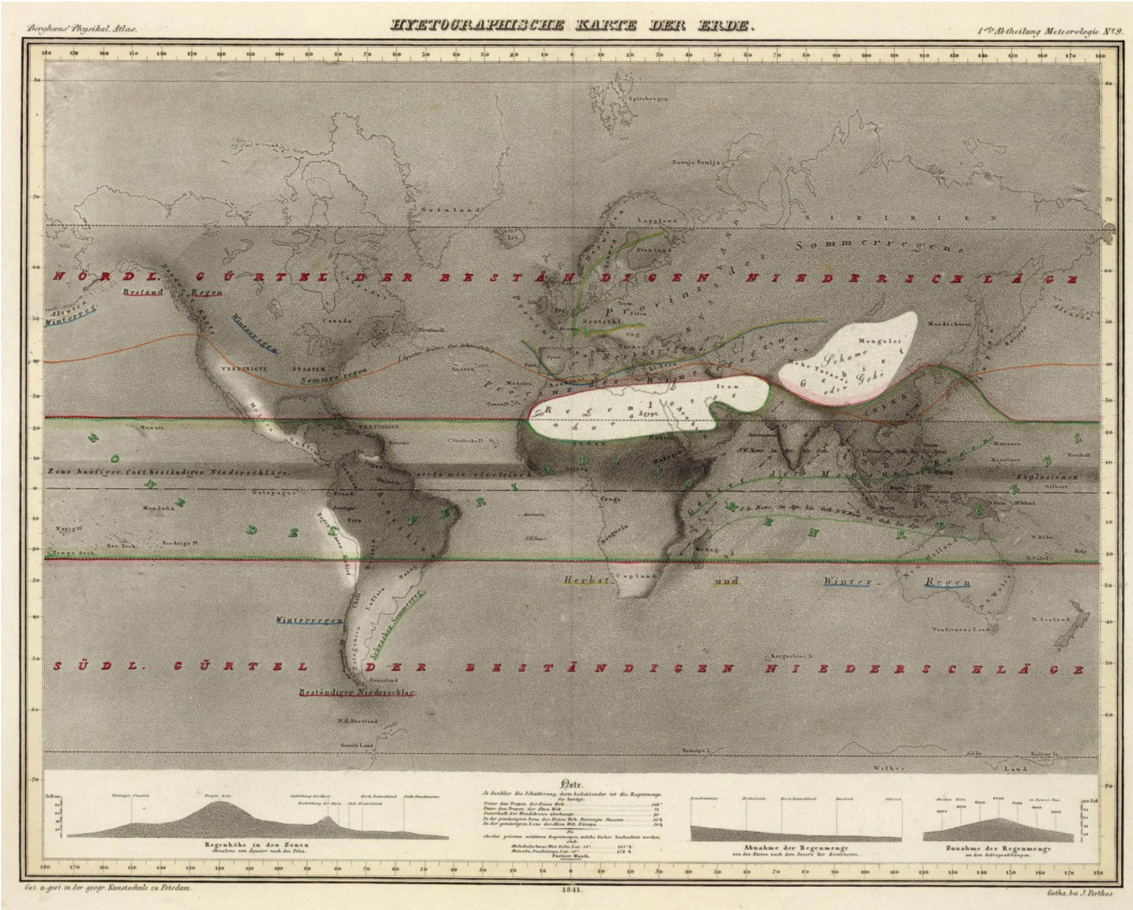

FIGURE 2.12: HUMBOLDT/BERGHAUS' GLOBAL PRECIPITATION MAP
The map is one of the early examples of additional statistical information that complements the actual map depiction. Below the map information about the distribution of rainfall in relation to latitude, coastal distance and elevation is shown
(original publication in 1849, obtained from Ette & Lubrich 2004: 20-21)

2.3.2 Beginnings of modern cartography

The combination of cartographic and statistical skills in maps started in the 17th century,. But statistical visualisation of demographic and economic data only started to become important in the dawn of industrialisation in Europe. The changing demographic structures and the ongoing diversification of European societies made an understanding of these processes inevitable for the manifestation of political power. With the first regular modern censuses held in Sweden (1749), the United States of America (1790) and Great Britain (1801), geographical information was no longer limited to physical features (Thrower 1999). The newly collected data needed to be analysed and visualised, leading to a time of prosperity for statistics in the 19th century that complemented the huge innovations in thematic mapping of that time (Robinson 1982).

People and population-related topics became increasingly part of new mapping approaches. Harness' maps of Northern Ireland stand out as examples for the new dimension in mapping, such as the creation of a traffic-flow map of Ireland (Figure 2.13A, *see below*) that included quantitative flow lines and graduated circles to visualise the traffic density and the populations of a place in the map (Harness 1838, Robinson 1955, Thrower 1999). Other iconic maps in that field include John Snow's cholera map (Figure 2.13B, *see below*), in which the location of deaths from cholera in central London was displayed as dots and provided a picture of their relation to the water pumps in the area (Gilbert 1958, Snow 1855). Thematic and statistical maps of the human and physical geography are perhaps the last major achievement that has been made in cartographic practice, before digital technology started to transform the field and transformed cartography into the wider area of geovisualisation.

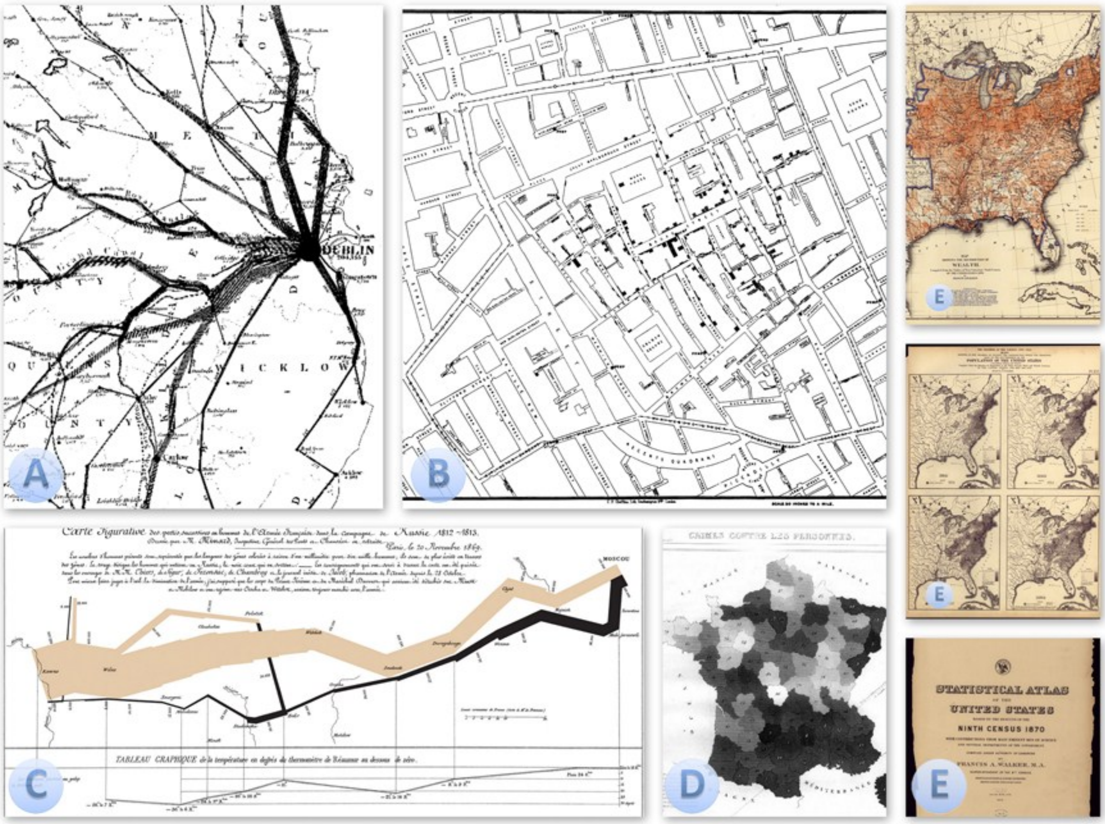

FIGURE 2.13: SELECTION OF 19TH CENTURY MAPS AND VISUALISATIONS
The examples demonstrate the visual appearance of geographic data visualisation in the 19th century: A: Passenger transportation flows in Ireland (Harness 1838, obtained from Friendly & Denis 2001a), B: Cholera cases in London (Snow 1855, obtained from WC 2006b), C: Losses in men during Napoleon's 1812 Russia campaign (published by Minard in 1869, obtained from WC 2008), D: Crimes against persons in France (Guerry 1833, obtained from WC 2007), E: Cover page (bottom) and two sample pages (above) of the *Statistical Atlas of the Ninth Census 1870* of the United States (Walker 1874, obtained from Library of Congress 2011)

Along with thematic and statistical maps came the visualisation of data outside the actual map display in the 19th century. The field of data visualisation began to develop in close relationship to cartographic works. Charles Joseph Minard's graphical display of Napoleon's devastating 1812 army campaign trying to conquer Russia has become the classic example of data visualisation (Figure 2.13C). The *Carte Figurative* (Figurative Map) labelled image integrates the complex dimensions of space, time and quantitative information about the army's size during the campaign in one diagram, making it a connecting link between a statistical diagram and a map display (Marey 1878, Robinson 1967). Edward Tufte[18] goes as far as calling it the "*best statistical graphic ever drawn*" (Tufte 2001: 40), and it certainly is an unrivalled graphical display of statistical information in space and time on a plane surface, which successfully communicates a complex idea in a precise and efficient way. This combination of displaying substantial statistical information in clear, precise and efficient ways is the core of what is described by Tufte as "*telling the truth about data*" (Tufte 2001: 51).

The first half of the 19th century marks the beginnings of modern statistical graphics. The growing amounts of data and the advances in statistical methods resulted in new forms of data display. Almost all modern forms of data display date back to this time, with extensive conceptual works about these new graphical elements such as pie charts, histograms, line graphs, or scatterplots (Friendly 2008, Friendly & Denis 2001b). The key works in this field, such as Guerry's crime analysis of France (Figure 2.13D) (Friendly 2007, Guerry 1833), are at the beginnings of social science. A substantial statistical theory began to be established by the works of Gauss, Laplace and others. The establishment of statistical methods and new forms of data visualisation set the foundation for the '*Golden Age of Statistical Graphics*'[19], in which works such as these of Minard and also the cholera map of Snow were created (Friendly 2008). Statistical Atlases such as the *Statistical Atlas of the Ninth Census of the United States* (Figure 2.13E) (Walker 1874) are the manifestation of the prospering achievements in statistical graphics and thematic maps in the 19th century.

With the rise of statistics the first population maps were created based on more accurate population counts. An early example of the use of population data in maps is Montizon's dot map of population from 1830 (Figure 2.14B) and Angeville's 1836 choropleth population map of France (Figure 2.14A). The maps show population data based on regional administrative units (*Départements*) and follow the early modern statistical maps of Dupin, whose choropleth map about illiteracy in France from 1819 is believed to be the first of its kind (Friendly 2008, Friendly & Denis 2001a).

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[18] The works of Edward Tufte in the field of statistics and their visualisation have become classical contributions to data visualisation. They do not only provide a comprehensive overview of the major developments in statistical and their visualisation, but also help to understand the theory of data graphics and how statistical data and visual thinking correlate. His own contributions to the field include the use of sparklines as minimalist representations of data trends over time (Tufte 1997, Tufte 2001, Tufte 2006).

[19] An extensive illustrated overview of the graphical innovations including many displays of the original works is given in the online *Milestones* project (Friendly & Denis 2001a).

The main obstacle for creating global depictions in a similar way was the lack of data, which mainly existed for the industrialising countries, but much less for most other parts of the world. Scrope's first dasymetric map of global population density from 1833 used only three broad classes and was gradually enhanced over the following decades. A more accurate picture of the global population distribution applying the statistical methods and the newly developed cartographic principles began to evolve at the beginning of the 20th century.

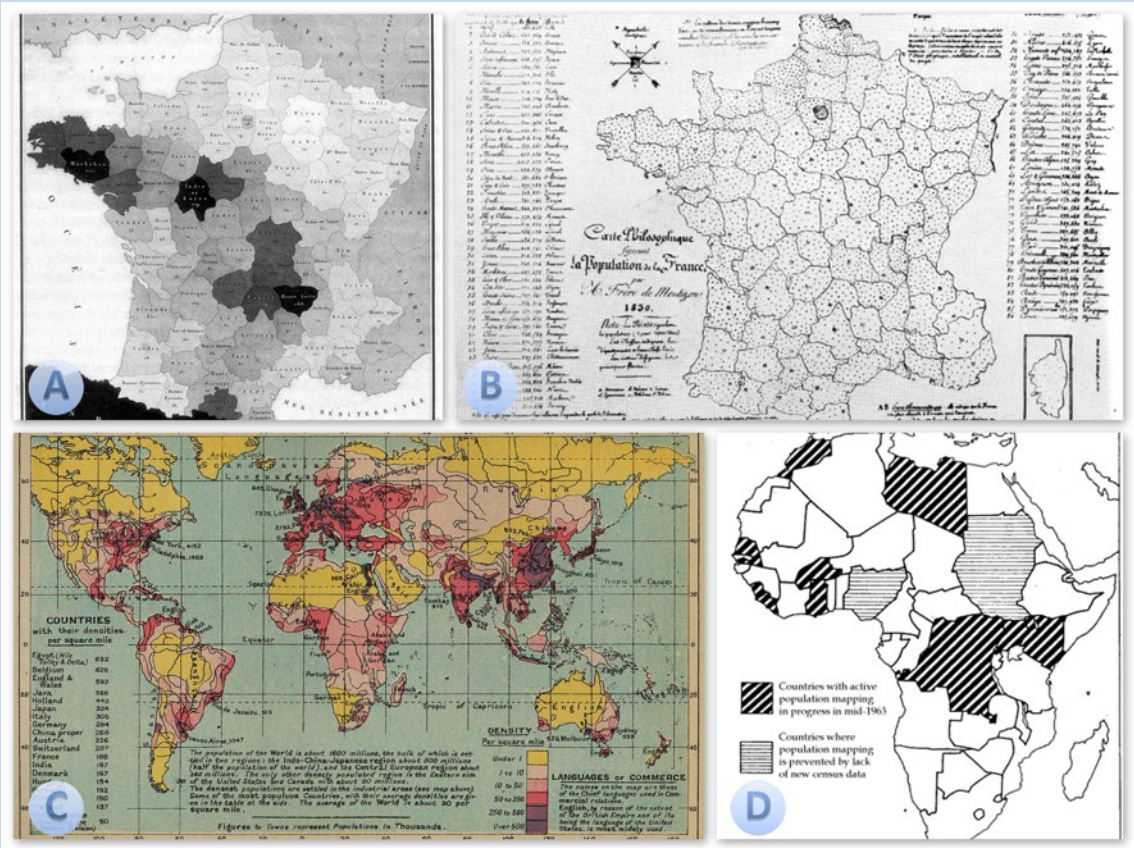

FIGURE 2.14: MAPPING POPULATION IN THE 19TH AND EARLY 20TH CENTURY
The examples demonstrate the visual appearance of population visualisation in the 19th and early 20th century: A: Choropleth population map of France (published by Angeville in 1836, obtained from Friendly & Denis 2001a), B: Dot density population map of France (published by Montizon in 1830, obtained from Friendly & Denis 2001a), C: Dasymetric map of global population densities (published in the British Dominions Year Book 1918, obtained from Kent 2011), D: Documentation of population mapping in Africa in the 1960s (published by Prothero in 1963, obtained from Stamp 1964: 226)

The world map *Density of Population* printed in the *British Dominions Year Book 1918* is a classic example of the first advanced world population map (Figure 2.14C). It shows a dasymetric population depiction using six classes with higher levels of detail beyond national boundaries.

The rising political tensions and two world wars brought these advances to a halt and took cartography and data visualisation into the '*Modern Dark Ages*' (Friendly & Denis

2001a) with little innovation in the first half of the 20th century. Among the almost forgotten efforts of that time are the discussions of the Vienna Circle about the urgent need to visualise social science, and to systematise the way of representing scientific work in a more comprehensible way (Hartmann & Bauer 2006, Uebel 1991). This resulted in a '*popularisation*' of statistical graphics (Friendly 2008), which found their way into textbooks and now became standard use in scientific, political and commercial publications, and are now common elements and used in all aspects of life.

In the 1950s the relevance of trying to understand spaces of humanity in the increasingly interconnected world led to new efforts to tackle the lack of reliable population data on a global scale (William-Olsson 1963). This is a quite delayed development, given the increasingly advanced mapping efforts for population and population-related quantitative data on regional and national levels in many European countries data visualisation in the 19th century. But in many parts of the world there was still very little similarly detailed information available, which first needed to be assessed before further strategies for solutions could be discussed. Prothero's map showing the advances in African censuses (Figure 2.14D) illustrates these pioneering works (Prothero 1962). The efforts undertaken in this time revealed the struggles in finding international consent about common methods in the increasingly independent discipline of cartography (Horstmann 1963, Prothero 1962, Stamp 1964, William-Olsson 1963).

The changes that took place from the 17th to the 20th century with industrialisation and increasing degrees of globalisation promoted the fields of cartography and data visualisation. Some of the major advances are directly linked or interrelated to these processes that transformed the global societies considerably. Our understanding of the world advanced with the new visual representations of physical and human layers that we began to understand were shaping the modern world.

The growing importance of commercialisation and global business began to play an increasing role in the second half of the 20th century. Stamp notes the "*much more down-to-earth practical uses*" (Stamp 1964: 225) of maps and refers to British practices of market research studies benefiting from cartographic research. A growing commercial demand for a better understanding of global market opportunities may thus also have supported an intrinsic scientific interest to spend more resources on further advances.

2.3.3 The digital turn

The second half of the 20th century contributed considerably to understanding the declining importance of physical distances in our perception of the world, as these were shrinking to some extent with cheaper and faster ways of travelling and communicating (Tempel 2005). The most recent trends in cartography are closely related to the developments of a new dimension of globalisation that is characterised by the complex network of economic, political and cultural links.

An identity of a cartographic discipline is accompanied by an increasing amount of conceptual and theoretical considerations. The debate about the meaning and relevance of space (see section 2.2.3) as a crucial element of maps finds its manifestation in the research on humanistic mapping. Cartograms such as the world population cartogram as introduced before (see section 2.2.3.2) are some examples for these changes, but must be seen much broader than only being restricted to mapping merely population or people. They reflect the effort to address the changing realities in cartographic concepts and practice (further reflections on humanistic mapping and a human cartography are outlined e.g. by Ballas & Dorling 2011, Ballas et al. 2005, Dorling & Barabási 2006, Dorling & Fairbairn 1997, Monmonier 2007, Szegö 1987, Szegö 2003, Thomas & Dorling 2005).

Further more recent cartographic works demonstrate that despite the outlined long history of advancing mapping techniques, the conceptualisation of maps is still an ongoing effort (Bertin 2011, Board 1972, Dodge, Kitchin & Perkins 2011, Morrison 1976, Robinson & Petchenik 1976, Tobler 1976, Wilkinson 1963). This complements the historic efforts that have been presented in the previous sections. Progress in cartography is not only a matter of innovation, but also about understanding how maps work (and fail). Understanding but also contesting their theory (as investigated in section 2.2.2), history (as outlined above) and principles (as described in this and the forthcoming section) has become increasingly important (Kitchin, Dodge & Perkins 2011), not only to retain the relevance of cartography, but also to be able to evaluate alternative ways for a better communication of geographic knowledge.

The implications of globalisation also have a very immediate effect of the principles and practice of cartography and the way, maps are now produced. The growing importance of computer processing in many aspects of life should not be underestimated in their relevance to cartography in various ways. Digital cartography and computational statistics began to enter all areas of cartographic practice and brought new possibilities of data analysis and visualisation (Figure 2.15, *see below*).

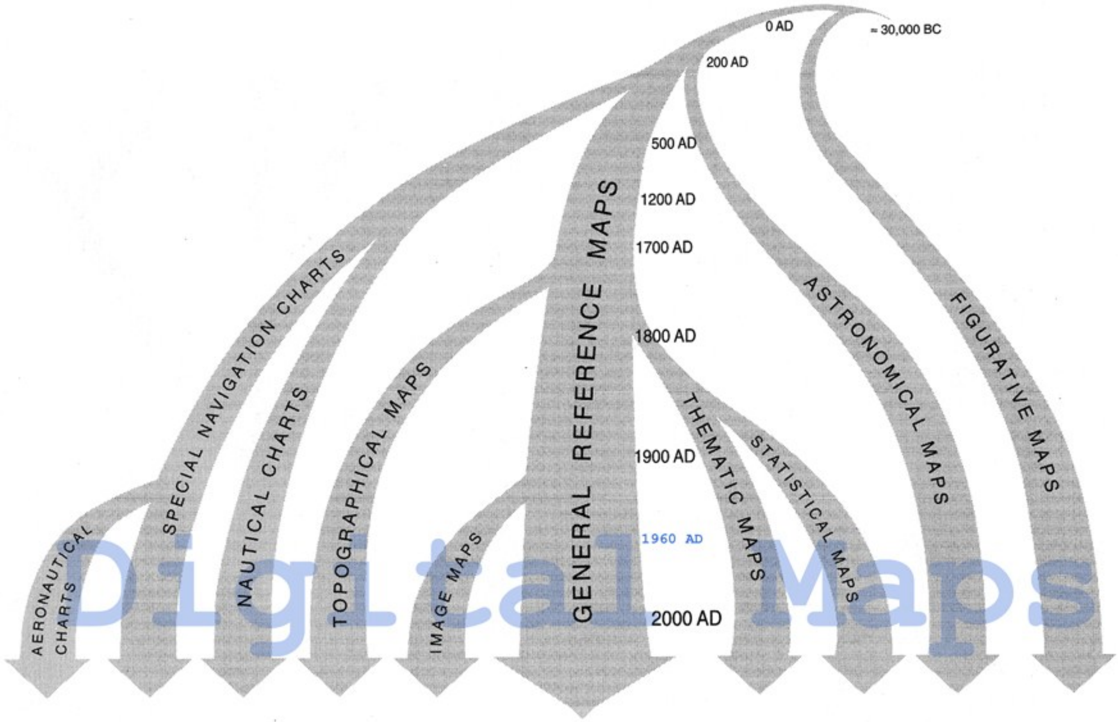

FIGURE 2.15: EVOLUTION OF MAPS
Scheme showing the development of major map types throughout cartographic history. All map types are now under the influence of digital mapping practices
(modified from Robinson et al. 1995: 22)

After the first working programmable computers emerged, statistical data began to be processed digitally in the late 1950s using early programming languages for computing (Friendly 2008). The first steps in digital cartography were made in the 1960s, in which the concept of Geographical Information Systems (GIS) found its roots. However, the weak performance of the first affordable personal computers in the early 1980s was hardly an alternative for mapping tasks and could only be seen as an additional new way to make maps, even if there was little benefit from going digital in the beginning (Dickmann & Zehner 2001). But the early pioneers in this field triggered the invention (and sometimes reinvention) of graphical techniques for digital data that gradually enabled new dimensions of multidimensional quantitative data analysis, and later also their visualisation (Friendly 2008).

The technological capabilities of computers advanced rapidly, and as computers found their way into offices as well as private households in the second half of the 1980s, they also started to become the most important tool of a cartographer. GIS techniques became a standard utility in geographical sciences in the 1990s. This has hugely been supported by the introduction of graphical user interfaces of the personal computer that simplified the use of computers, and by the increasing affordability of computer systems (Dickmann & Zehner 2001).

The changes that took place between the 1950s and the end of the 20^{th} century can be described as the digital turn in cartography that has changed the cartographic practice in a similarly radical way as the innovations that took place in the first half of the 18^{th} century. Computer cartography and cartography can nowadays be seen as almost synonymous entities[20]. The major commercial software and internet companies all provide some sort of product related to cartography or design (which is an important part in the process of map-making). Digital methods of creating maps are not only extremely diverse, but have almost replaced manual cartographic techniques. In addition, automated processes and enhanced ways of data processing and data analysis have become integral parts of map-making, so that the emergence of GIS software and GIS methods can be seen as the most important single development in cartographic methods that led to the digital turn in the 20^{th} century. GIS enabled the combination of geospatial data analysis and data visualisation on one platform, bridging the gap between geographical research and its visualisation.

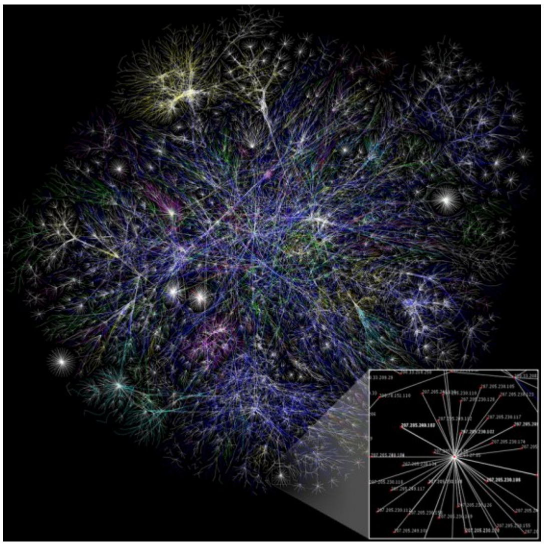

FIGURE 2.16: PARTIAL MAP OF THE INTERNET
The lines represent connected web servers, the length stands for the connection speed (image obtained from Britt & WC 2006)

The growing importance and accessibility of the internet has become another key factor in these developments (Figure 2.16). A wide variety of data sources are now made available online – a process that has started not more than one and a half decades ago and which has triggered a new *golden age* of data visualisation. The term *neogeography* was coined in response to the new technical potential that became possible with digital mapping environments and new data repositories in the internet. This little '*revolution*' started to take cartographic practice out of the domain of professional cartographers and led to the emergence of '*new geographies*' (Turner 2006). Web cartography with digital globes, crowd sourced maps and other innovations are the latest phenomena in this development. The debate about a new

[20] With this claim I do not deny that handcrafted cartographic practice is still existent and often produces remarkable pieces of cartographic work. Innovation and new practices rarely replace, but add to existing practices, just like new cartographic projections have never made old projections disappear. Mercator's work may be the best proof of that.

cartography[21] shows that the developments triggered by the digital turn are an ongoing process that continues to transform cartography (Faby & Koch 2010).

2.4 Cartography in a digital world

The recent developments of digital cartography root in the changes that computers and the development of geographic information systems have started. As a consequence, map-making is not a profession limited to trained cartographers anymore (if it has ever been), but to everyone who is interested in it. Easy-to-use tools are now becoming available to everyone, and the web enables everyone to present their results to a wider audience (at least an audience with access to the internet). And once again, the technological changes that are part of the processes that shaped the globalised world also changed the field of cartography (Korduan & Zehner 2008, Kraak 2003, Turner 2006).

2.4.1 A new golden age of data

The past decade has seen an unprecedented release of comprehensive quantities of socio-economic data on a global scale. In addition to that, there is also a more recent trend to release national datasets as part of open government initiatives. The amount of other data from the physical environment is growing likewise, with increasing sensors constantly monitoring a wide range of indicators, and airborne and satellite remote sensing platforms capturing almost every spot of the planet in various forms of data. Not only the generation of new data, but also the *public* and *instant* data availability over the internet has a significant impact on the way this data is used and analysed. The constantly progressing computational capabilities and the development of new methods and techniques add to the trend, which started a new age of data. At the same time, the internet provides a platform for the public presentation of the results that originate from the use of this data. This is also a form of democratisation of data where context and objectives under which these datasets are investigated are not predetermined, but free and open. The following part looks at these trends and how they affect the practice of cartography. The example of the Worldmapper project demonstrates how science can utilise these trends by turning cartographic theory and related principles of humanistic mapping into practice.

The changed conditions of data availability in the digital age remind of the changes that took place in the 19th century after the establishment of national censuses in many

[21] Neocartography is a new term that emerged only recently (Faby & Koch 2010) and started to replace the use of the word neogeography, indicating the strong cartographic link of the processes that these terms try to describe.

countries, in the '*Golden Age of Statistical Graphics*' (Friendly 2008). The process of opening data resources over the internet started in the domain of science in the 1990s (Kouzes, Myers & Wulf 1996), and widened into the public sphere in the last decade. A new dimension of data availability started with the first release of global data made accessible through international organisations such as the United Nations in the first half of the last decade. It continues with more recent developments of national and local open data initiatives, in which the political administrations make raw data available to the public[22] (Chilton 2011, Lilley 2011).

For geographic practices, the new age of digital data has several implications. While the new accessibility can reduce the effort that is needed to collect data, the existing datasets need to be approached with a high caution for their origins and assessed with great care. Public data cannot always replace additional data collection to ensure the quality of scientific work (Goldston 2008). Growing amounts of data also contain challenges for the correct data management and data interoperability to ensure the lasting conservation of digital datasets that exist in uncountable digital formats (Lynch 2008).

"*Visualisations are not a panacea. The adage 'rubbish in rubbish out' still applies. But when used well […] visualisation can provide different views of data that force us to ask new questions, and generate fresh hypotheses*" (Nature 2008: 264). This quote from a Nature editorial highlights the importance of visualisation for scientists with the new and expanding stream of data that we face today.

The availability of all this data is a great opportunity to develop and investigate new cartographic approaches. Turning data into meaning is an important part of data analysis, not only in cartography or geography, but in many fields of science (Börner 2010, Fry 2008). New methods cannot only provide new views on the topics that they visualise, but also have the power to convey new perceptions and lead to new findings that result from that data (Spiegelhalter, Pearson & Short 2011). Understanding is a crucial element to benefit from the growing amounts of data, and finding valid ways to make sense of the data therefore has once again become highly relevant (Frankel & Reid 2008).

2.4.2 Mapping from the experts

In the early stages digital cartography, digital mapping was generally more focused on experimenting with the multimedia capabilities of the first multitasking operating

[22] The US initiative Data.gov is one example for these trends (US Government 2011) that started with open data access being urgently demanded by many scientists (for more details about the open access initiative see Klump et al. 2006).

systems. The mapping process was shifting towards digital platforms, but the methods and principles behind cartography did not change immediately (Dent 1999, Dickmann & Zehner 2001, Robinson et al. 1995). These conditions changed with the development of advanced GIS technology that enables a new dimension of handling geographic data(Korduan & Zehner 2008).

Advances and new concepts in cartographic visualisation require approaches different from easy to use mapping tools. Here, the investigation of new ways of data analysis and new ways of visualisation are essential, and can only be carried out in specialised computer environments. GIS software is one main part of these tools, and GIS is the main platform that was used in this research, but other applications with different capabilities can be used for digital mapping and data visualisation (Dickmann & Zehner 2001).

Digital technology has made the process of map making and geographic visualisation easier and more complex at the same time. It has also extended our capabilities to visualise large amounts of data by digital processing methods. Diffusion-based cartograms would be impossible to be worked out on paper and drawn by hand, but can only be created with the support of digital technology that processes these large amounts of data. The underlying steps of geospatial analysis and the methodological background need to be carefully elaborated to receive valid results. For doing that, a number of new tools and applications have emerged in the last years. They specialise in the different tasks of statistical analysis and visualisation, which allows more and more advanced geovisualisation concepts and new forms of working with data outside the domain of informatics and pure computer sciences.

Geospatial analysis was introduced to the spectrum of (geo)scientific methods (Longley et al. 2011), resulting in the creation of GIScience as a discipline between geosciences, cartography and informatics. Many of the innovations in cartographic practice can be attributed to this field. Although research is of a very technical nature – the methodology elaborated in this thesis can be seen as part of this – the core ideas root in the developments of cartography. The idea of digital mapping goes further than the mere digital design, but includes these elements of analysis and data processing before it comes to the actual visualisation (Kraak 2008).

Research in mapping on digital platforms is wide-ranging. It includes the work on navigational applications and mobile maps (Ishikawa et al. 2008, Jahnke, Krisp & Kumke 2011, Leshed et al. 2008), digital mapping platforms (Baaser 2010, Ramm, Topf & Chilton 2010, Zipf 2010), location based services (Bridwell 2008, Jiang & Yao 2006, Kraak & Ormeling 2010), and augmented reality (Kraak & Ormeling 2010, Longley et al. 2011). Mobile GIS tools can improve the efficiency and accuracy of geographical and scientific data collection (Hennig 2005, Hennig, Cogan & Bartsch 2007). Research in this field currently focuses on advancing database structures and queries, and analytical algorithms that better connect the increasing amount of geospatial information (Bernard, Fitzke & Wagner 2004). Another focus is put on a harmonisation of the data standards that are used in the digital world (Krechmer 2005). Further research aims to improve the visualisations towards a more realistic appearance (rather than alternative concepts of visualising complex data). In these fields of GIScience, the map itself as a cartographic element plays a subordinate role, while major efforts are put into the technical and analytical capabilities (Kim & Jeong 2009, Kraak & Ormeling 2010, Longley et al. 2011). GoogleEarth has also become a popular choice for the presentation of scientific geodata. It is the digital equivalent to an analogue globe that is capable of displaying a vast amount of geographical data while reducing the effort that needs to go into the consideration of appropriate cartographic presentation (Google Inc. 2011a). GoogleEarth and other online mapping platforms allow the integration of external GIS data and geodata servers as a visualisation platform (see e.g. Asche & Herrmann 2003, Korduan & Zehner 2008, Kraak & Ormeling 2010).

Many of the fields of GIScience described above indicate a detachment of these methods from cartographic theory and principles. However, digital map design principles are extensively discussed in cartographic literature (see e.g. Asche & Herrmann 2003, Jenny 2006, Jenny, Jenny & Räber 2008, Jenny, Patterson & Hurni 2008, Jenny et al. 2010, Turner 2006). Research topics focus on specific design guidelines for digital technology and the investigation of cartographic principles in relation to the specific technological configurations. Issues such as screen typography, colour rendition, and map navigation tools to simplify the user interaction are among the well discussed issues that solve some of the key problems in transferring existing cartographic practice to the (not so) new digital environments (Jenny, Jenny & Räber 2008, Jenny et al. 2010, Swienty 2008).

Geospatial analysis has become a standard operation in data processing. It is not only a necessity given the huge amount of data which many geospatial sciences are working with, but also a result of growing data availability and increasing computing power. The pivotal element in this process often is the geographic information system (GIS), which brings data together. It also allows performing a large number of geospatial analyses, which is not least the reason for GIS software having been developed in the first place. Many new techniques find their way in GIS applications. Programming interfaces allow a highly specialised customisation of these applications and the integration of particular algorithms and techniques in the process of geospatial analysis. The cartogram creation is one example for how GIS software provides a platform that enables linking various data sources and applying new algorithms to them.

The main purpose of using GIS software is the execution of spatial analysis and the integration of various geospatial-related data. Mapping and cartography are subordinate elements in these applications. Although maps can be designed using a set of design options, these capabilities are rudimentary. This is a weak point of using GIS for geospatial analysis while at the same time aiming for good cartographic practice or looking for innovative visual mapping approaches. Map results derived from GIS software often lack that design component that is essential to convey a message or tell a story with a map beyond the sole purpose of putting data on a map display.

Drawing visually appealing maps starts with the way in which data is analysed and how results from this spatial analysis come out of that process. This process of spatial and statistical data processing is essential for the mapping results, but the outcome of the techniques is only a first step that results in a rough draft that needs particular cartographic treatment before it can be seen as a more understandable and as such also more meaningful cartographic representation of the processed data. Visualisation concepts and cartographic theory are thus as essential as the underlying methodologies themselves, which makes cartographic concepts so valuable and their outcome a key component of geographic visualisation.

This changing practice of cartography towards GIScience is also reflected in the changes of textbooks published in this field. Traditional textbooks on cartography (such as Robinson et al. 1995) have increasingly started to include sections on digital cartography (see e.g. Dent 1999) and GIS (Kraak & Ormeling 2010), and are now often replaced by dedicated GIS textbooks that in turn include sections on cartography (Krygier & Wood 2005, Longley et al. 2011).

GIScience is the result of the digital changes in cartography has therefore to be seen as integral part of it, despite the ambivalent relationship between technological innovation and a sometimes detached theoretical background (Cartwright 2011, Slocum et al. 2008). However, visualising geospatial data has also left the domain of cartography, and maps or map-related visuals have become only one option to show geographical information. The line between digital cartography and data visualisation has vanished. Visual designers as well as geographical information science researchers see maps as one of many ways to make sense of data and information.

Arguing with Turner (2006: 2), "*Cartography enabled and recorded exploration and discovery for ages*", which in a time after adventurers have discovered almost every place on the planet turns into a different purpose. Although we believe to know about the remotest places, we still do not fully understand the complexity neither of the nature nor of our societies and our interrelations with our environment. Cartography and geovisualisation thus have taken over the role – to use Turner's original phrase – to '*enable and record exploration and discovery*' for the (post)modern ages. Finding patterns in large amounts of data, developing new concepts of displaying things that we believe we already know, these are the characteristics of the new exploration of the world. Results of these works start to turn into important elements of new cartographic theory and cartographic practice. This makes the field of cartography remain highly relevant in the digital world.

The Worldmapper project is an example of a pioneering cartographic online project that contains all the elements described in relation to the digital turn in cartography. The mapping technique embraces the possibilities of unprecedented data availability (while ensuring a scientific standard in using and validating the data), computer-assisted data analysis and processing, and an online presentation of the data, while at the same time contributing to advances in cartographic theory (in new ways of humanistic cartography) and cartographic principles.

This section outlined the academic efforts in relation to this digital and '*data revolution*' (Friedman 2001). Digital technology started to transform the ways in which various disciplines approach the analysis and representation of scientific data. It is a challenge for cartography to redefine its role within this field and follow the advances that the digital turn brought over the last 50 years. Advanced cartographic works remain part of the work for trained experts, but the degree of technical expertise that is needed to create maps is slowly declining and opening cartographic practice to a new audience.

2.4.3 Mapping from everyone

With the advancing geospatial technologies outlined before, and not least heavily supported by the increasing possibilities of the internet, a revived interest in maps can be observed in recent years (Couldry & McCarthy 2004, Dodge & Perkins 2008, Poster 2004). The changing technologies and the revival of public interest in mapping led to the emergence of a large number of untrained cartographers producing maps and geographic data visualisations in the online world[23], who have become part of the above described process of a new understanding of data. These developments have led to a renaissance of maps, with an increasing number of people becoming interested in maps yet again, and maps entering our everyday life in new forms.

The digital age led to easier ways of using cartographic practice. There are a growing number of tools for digital mapping and geovisualisation outside GIS environments that do not require the corresponding specialist knowledge about the use of geodata and GIS techniques. The tools aim to translate cartographic principles into practice, without the user of them having the need to acquire the underling expert knowledge.

The range of tools is widespread, and the following examples stand for the different degrees of complexity and specialisation of currently available visualisation environments. Many other resources exist, and the developments and advances in this field are very dynamic.

FIGURE 2.17: DIGITAL CARTOGRAPHY IN THE INTERNET
A: *Natural Earth* geodata repository, B: *Colorbrewer* map colour guide, C: *Typebrewer* map typography guide, D: *Indiemapper* online cartography application (screenshots taken from Kelso & Patterson 2011, Brewer & Harrower 2011, Sheesley 2006, Axis Maps LLC. 2010)

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[23] An appraisal of specific people in this field is hardly justifiable, because it is the diversity of the people in the field that this crowd of visualisers is constituted of, many of whom are not particularly working on geographic data visualisation, but in the domain of creative visualisation of anything of their interest. The development is very dynamic, and new resources are constantly emerging. At the time of writing in 2011, the following websites were some widely acknowledged representative redistributors of visualisation works that also cover geographically relevant visualisations: http://www.visualizing.org/ (Bly 2011), http://www.floatingsheep.org/ (Zook et al. 2011), http://flowingdata.com/ (Yau 2011) (all websites last accessed 2011-06-01).

Natural Earth (http://www.naturalearthdata.com/, Figure 2.17A) is a repository of datasets containing basic geographic features of the world at different scales. The archive includes raster data for topographic and bathymetric information and vector data from a wide range of key elements of land and sea, such as borders, cities, rivers, roads, and geographic lines (Kelso & Patterson 2011). These datasets can be used to quickly create basemaps without the struggle of searching through complex geodata repositories and having to deal with different projections, resolutions and similar problems that are barriers for many inexperienced users. Natural Earth gives user the time to focus on the actual data visualisation and mapping process. The mapping process can be supported by platforms like *Colorbrewer* (http://colorbrewer2.org/, Figure 2.17B), a web application[24] that helps to create colour schemes for mapping different types of data (Brewer & Harrower 2011), or *Typebrewer* (http://www.typebrewer.org/, Figure 2.17C), a web application that helps to decide on appropriate typographic choices for map labels (Sheesley 2006).

The *Indiemapper* application (http://www.indiemapper.com, Figure 2.17D) brings data and concepts as the ones mentioned above together and makes the user completely independent from the necessity to use (or even understand) specialised GIS and design software (Axis Maps LLC. 2010). Kessler & Slocum (2011) refer to this platform as a good example of the future directions for encouraging better mapping practices using digital technology. Key principles of cartographic practice, such as different map projections (including cartogram transformations), styles of map labels, symbols, colour schemes, are all integrated in the application, so that an inexperienced user can create maps based on principles of good cartographic practice from own scientific data.

In addition to dedicated cartographic tools, so called *map mashups* have become popular amongst amateur cartographers (but are also used by cartographic professionals). Map mashups are online maps that use GoogleMaps[25] and other mapping platforms such as OpenStreetMap[26] as a template to build other information and additional functionalities on top of the geodata contained in these online platforms (Brown 2006, Turner 2006, Wernecke 2009).

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[24] Web applications are software applications that need no installation on a computer but can be fully used over an internet browser. The actual software is running on remote webservers, and the browser provides the interface through which the user works in the application.

[25] GoogleMaps (http://maps.google.com/) is a web mapping service by the US internet company Google Inc. (Google Inc. 2011c). GoogleMaps has become a universal map service with a currently providing advanced routing and transport functionality and serves as a database for a large variety of geographically relevant information (shops, tourist attractions, doctors, online dictionary entries about places, etc.).

[26] OpenStreetMap (http://www.openstreetmap.org/) is a web mapping service similar to GoogleMaps but with a crucial difference (OSM 2011). It is a free and open source project, which means that all data contained in the platform has been gathered by voluntary contributors, and the technical development is realised in an open process in which every user and developer can contribute to the further improvements and progress (Bennett 2010, Ramm, Topf & Chilton 2010).

Tools and applications that enable anyone who have an interest in creating maps to not only do so, but to make the results available to a wider public relates to the changing nature of the cartographic discipline. The emerging field of neocartography (see section 2.3.3) explicitly refers to these developments and does not exclude these amateurs from the reflection on the changes in cartography. The revived interest in maps is not only a result of innovation developed by experts, but partly contributed to this new dimension of new map-makers.

Some may associate a risk with such trends of enabling non-experts to get easy access to cartographic practices[27]. Dodge & Perkins note that easy-to-produce '*Mc-Maps*' can "*leave a nasty taste in the mouth*" (Dodge & Perkins 2008: 1273), but they also argue, that "*[m]apping becomes both easier, and […] potentially better*" (Dodge & Perkins 2008: 1274). Professional cartographers may feel threatened in their existence by the emergence of this huge number of self-made cartographer, but the importance of the development of such mapping applications with digital technology should not be underestimated in its value for cartographic practice. Not only can better mapping practices be promoted with these tools, but they can also help to encourage academics to use of cartographic visualisations to make scientific work and results from academic research visible and understandable. The growing demand for maps and the rising interest in geographical issues in a globalised and interconnected world can be a chance to revive the importance of maps in a world of which all maps have seemingly been drawn already. In this context, digital technology enables experts and amateurs alike to contribute their particular strengths to the future of cartography.

2.5 The Worldmapper project

The publication of Gastner/Newman's diffusion-based method for creating value-area cartograms led to the creation of an online repository of cartograms visualising a wide range of socio-economic data. The Worldmapper project is an attempt to communicate some of the most challenging and pressing issues that help to understand the complexity of the human dimension of the world. It contributes to research on global social change, and due to the wide range of topics it also covers some of the basic living conditions that explain the relationship between humanity and the environment.

The aim of the Worldmapper project is to "*communicate to the widest possible audience, but particularly to school and university students, how parts of the world relate to each other*

[27] Before everyone had access to digital cartographic tools, not all experts using GIS were equally unaware of the fact that the technology is not a *magic black box* that produces meaningful results of geospatial analysis and creates stunning images (Guerin 2004, Poore 2003, Schuurman 2003). Good cartographic practice is not a question of the ease of access to the tools to produce maps.

and the implications of these relationships for society. This is achieved by mapping quantitative geographic data using an unusual cartographic projection, with the resulting maps being made freely available on the internet" (Dorling, Barford & Newman 2006: 757).

The key idea of Worldmapper follows the principle that the visual perception of a topic can support an immediate understanding of the underlying data, and that visualisation can turn complex data into simple representations. These allow a much easier interpretation of the information that is shown. For data with a geospatial background, a cartographic depiction thus remains a very obvious choice to visualise quantitative data. A cartogram transformation is a valuable alternative to make quantitative dimensions better understandable, but also to challenge the map-reader and provoke a response (Barford & Dorling 2008, Dorling 2006, Dorling 2007, Dorling 2009, Dorling & Barford 2006, Dorling, Barford & Newman 2006).

Worldmapper was created in 2006 and benefited considerably from the three developments that have been outlined earlier in this chapter in relation to the proposed digital turn in cartography: The digital publication and increasing availability and accessibility of global geographical data on the human and physical environment build the base frame for the range of topics that are mapped. The improvements in digital mapping techniques and their efficient application are the background for the specific Gastner/Newman mapping approach that has been deployed. The increasing influence of the internet not only in scientific, but also in public media use was essential for the enduring use by a broader audience.

The main component of the Worldmapper project is the project website (Figure 2.18, http://www.worldmapper.org), which contains approximately 700 maps and supplementary material on numerous mainly socio-economic topics, ranging from demographic factors, goods, trade and services to pollution, resources, wealth and poverty (Sasi Research Group & Newman 2006a). The selection of the topics was very much oriented on the data sets that became available at the time of the initial phase of the project. This reflects the data availability in the early days of the increasing

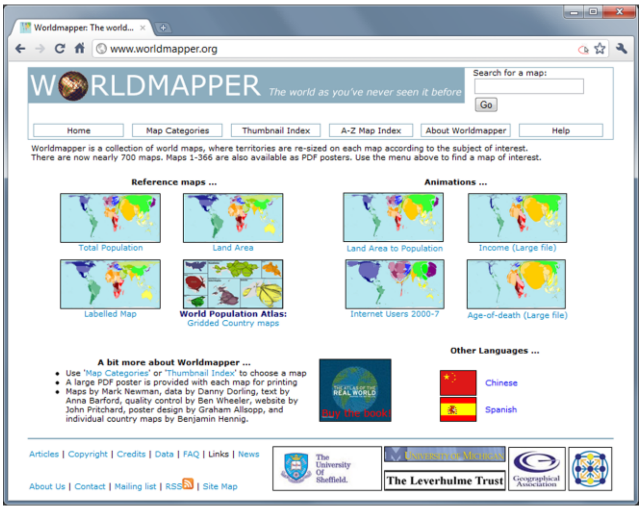

FIGURE 2.18: WORLDMAPPER WEBSITE (screenshot taken from Sasi Research Group & Newman 2006a)

online release of public data that is now, only about five years later, almost taken for granted. Worldmapper itself follows a similarly open approach, meaning that all data and material used in the project is made publicly available through Worldmapper, and all sources and adjustments are documented. An important task in the creation of these maps was the compilation of a coherent set of statistics for each topic and the estimation of missing data. It demonstrates the need for the careful assessment of publicly available data (Dorling, Barford & Newman 2006).

The style and design of the Worldmapper maps (see Figure 1.2 for a reference map) is an important cartographic element, which has proven to be an essential signature element of these maps. A consistent colour scheme was created, oriented on twelve major geographical regions (which all contain at least a population of more than one hundred million), and with a unique colour for each country that can be identified throughout the maps and enhances the readability of some of the most extremely distorted maps. The colours follow a rainbow scheme following the wealth of the regions, ranging from violet for the best-off country (represented by Japan) to dark red for the poorest countries on the African continent. Further technical and organisational requirements were carefully evaluated for the launch of the project platform (Dorling, Barford & Newman 2006: 760ff), which in its conception is a pioneer in the emergence of online data visualisation resources (the full list of territories and the related basic data used in Worldmapper and within this research is documented in appendix A).

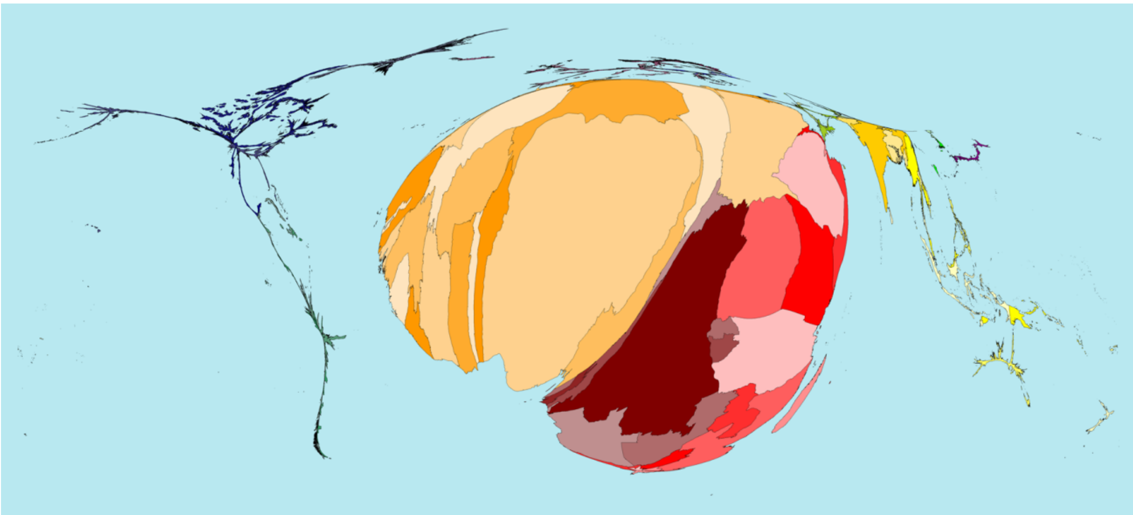

FIGURE 2.19: CARTOGRAM OF MALARIA DEATHS IN 2010
See Figure 1.2 for a reference map (own depiction by the author using data from WHO 2010)

The Worldmapper project also resulted in the release of the first printed world atlas based solely on cartograms (Dorling, Newman & Barford 2008). Many of the maps were featured in a wide range of scientific, educational and popular publications, and are increasingly used in academic talks and exhibitions to visualise the various dimensions of the world's geography (see e.g. Baleela & de Castro Martin 2010, Barford et al. 2006, Bogardi 2007, Burgdorf 2008, Butler 2008, Haworth 2010, Jainski et al. 2009, Khalifa, Sharaf & Aziz 2010, Koesling 2010, Scott 2008, Shrivastava 2011).

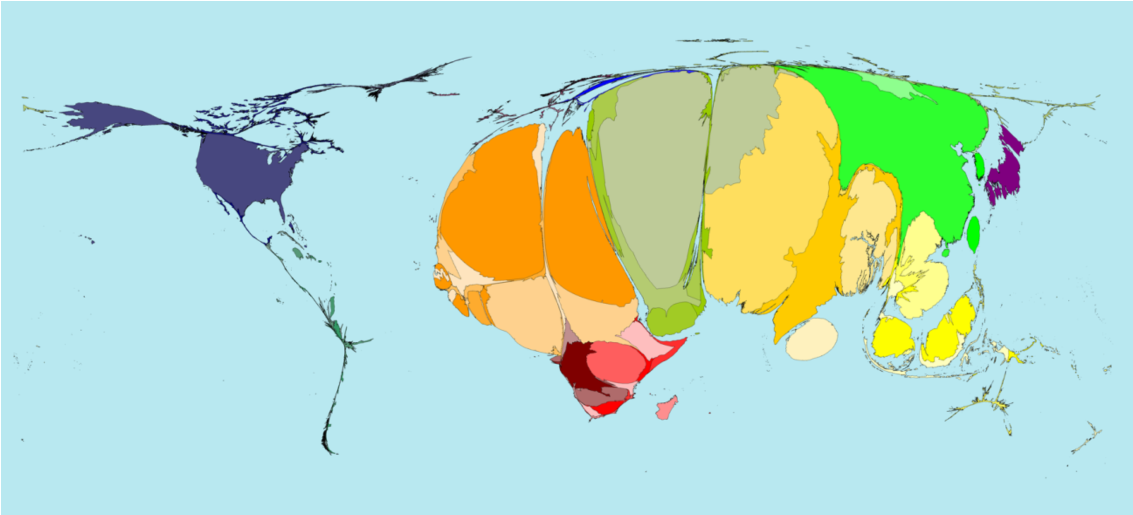

FIGURE 2.20: CARTOGRAM OF DEATH PENALTY PROSECUTIONS 2007-2010
Data for China is uncertain and estimated to be in the thousands. China has been set to 1000 in the calculation of the map (own depiction by the author using data from AI 2011)

The interest in the Worldmapper project continues with many requests for customised Worldmapper maps from all types of inquiries (academic, political, commercial, etc.). In the course of this PhD research, a range of new maps of Worldmapper maps have been created and published online to ensure the continuation of the original project framework (mainly based on inquiries or newly released data of public organisations such as malaria death cases for UNICEF[28] – Figure 2.19 – and death penalty prosecutions using data released by Amnesty International – Figure 2.20). It can certainly be stated that the Worldmapper project contributed a broader acceptance of cartograms in common cartographic practices.

Potential criticism on the cartographic approach of the Worldmapper project can be made regarding the mono-dimensional nature of the maps as it was mentioned before in in relation to cartograms (see section 2.2.3.2.3). Despite their novel cartogram technique they remain limited in their capability of showing the various dimensions of humanity within one image. From a methodological point of view, the Worldmapper concept can be seen as the first step towards new ways of showing the human geography of the world, and to eventually provide alternative visualisations for the social space in its full detail. Limitations of the Worldmapper approach include a restriction to country-level data, where internal variation within countries remains uncovered (but often matters). Worldmapper therefore provides a solid base from

[28] UNICEF stands for United Nations Children's Fund.

which a new direction can be taken in mapping humanity in novel ways. It needs, however, further exploratory research into more detailed depictions of the complex human geography (and eventually its links and interrelations to the physical environment for a full understanding of the world).

2.6 Conclusion: Rethinking maps

Cartography has always been connecting the worlds of art and science. McLuhan & Powers (1992) underline the importance of cartography by claiming that without the map "*the world of modern science and technologies would hardly exist*" (McLuhan & Powers 1992, quoted from Thrower 1999: 1). One may not fully agree with this notion, but the importance of cartographic contributions to our understanding of the physical and social environments is hardly questionable. With the digital technology this power of making the complexity of the world more understandable has reached yet another dimension (Buchroithner & Fernández 2011, Cartwright, Gartner & Lehn 2009, Thrower 1999).

This chapter introduced the theoretical, conceptual and practical context used in this research by looking at the implications that globalisation processes have within the theoretical debate about the relevance of space in geography. As it was shown, these debates found their expression in changing cartographic practices over the last centuries, with changing map projections and the increasing relevance of demographic and socioeconomic aspects in maps.

The currently occurring changes in the domain of data (data analysis, data visualisation) appear to be similarly vigorous as the changes that altered cartographic practice so considerably in the 19th century. The living conditions of societies in Europe started to diversify and differentiate with the changes that the industrial revolution triggered, prompting the (often political) need for the collection of unprecedented amounts of socio-economic and demographic data. This resulted in the development of new statistical methods and new forms of geographic data visualisation that are now a solid base for today's practices of geographical data analysis and visualisation. The influence of digital technology today started to transform the modern society likewise, and again a new age of data has emerged that accompanies and documents the changes that are now taking place. Old methods of understanding these data do not always exploit the full potential that the new dimensions of available data provides, so that the digital age did not only change the way we live and work, but also provides new means of understanding the complexity of our world.

The digital turn in cartography that took place in the second half of the 20th century resulted in significant changes within the discipline. The different dimensions of the new digital cartography in the light of new technical capabilities and new forms of communication and data accessibility were outlined, including an assessment of the direct implications on today's cartographic practice by professionals and amateurs. The changes continue to modify the nature cartography and the emerging field of GIScience, which within this thesis is seen as an integral part of cartography.

Currently it can only be speculated where the described changes will lead cartography in the future. The digital turn has given cartographers new means and tools to work with, and it is now up to cartographers to redefine their role in map making. This comprises the transfer of traditional skills of map-making to the new host of untrained cartographers, thus ensuring that maps are created to a certain cartographic standard. And while more and more traditional map-making is done by non-cartographers, cartographic advance can concentrate on defining the new role of cartography as an integral part of geographic science.

It should be the role of cartographic research to delve into new technical approaches and extend the geographic relevance in order to find ways of picturing the different dimensions that shape our planet. Geography and cartography have helped to picture the world, and now have to move on to explain the complex reality that we have turned our world into since we got the first full pictures of it in the 16th century. Mercator helped us to see the world, and to start the processes of globalisation. Now we need to find new ways to revise our antiquated Mercator-biased view of the world and to understand the implications that the globalisation processes have on humanity, and the impact that humanity has on the planet.

Cartography was able to change the way people understood the world in 1569, and cartography is certainly able to change the way we understand the complexity of the modern world. This is clearly not a pure limitation to questions of visualisation, because the development of new methods has to take the theoretical and conceptual aspects that have been outlined into account to find alternative and potentially better cartographic methods. This research is an attempt to connect to these developments and build on them to develop a new methodology that can help to find new questions, findings and understandings of the globalised world. The Worldmapper project provides a promising start for changing some of the principles by embracing the digital. Cartograms are a new way of depicting the human space and to apply existing mapping concepts to make new sense of the world, which we can now deploy because of digital mapping techniques.

Chapter 3 **Creating gridded cartograms**

3.1 Introduction

This chapter outlines the methods for a new approach to create cartograms. The methodology aims to address the limitations that cartograms previously faced, and also considers the changing relevance of different spaces in geography.

Mapping and geography have always been closely interconnected. Geography diversified into its main sub-disciplines of human and physical geography. Cartography, in contrast, remained predominantly a universal field that did not follow this dedicated specialisation. In the history of cartography, mapping the environment and mapping humanity largely build upon the same set of techniques, even if the cartographic suggestions for techniques were adjusted to the specific topics that they aim to show. While there has been progress in data availability and the methodology of data visualisation for the core subject of research in human geography on a global scale, the radical technological advances in recent years predominantly rely on the representation of physical space in maps and fail to address theoretical debates about different perceptions and a diversification of the concept of space.

From the early 1970s, human geography had turned into a discipline that increasingly started to look at new dimensions of space. This goes beyond the physical space, which usually is the underlying base for maps created in cartographic work. As a result, the conceptual gap between new ideas of space and their visualisation in maps is growing. Geographic space cannot only be seen as the representation of the physical surface of the Earth, but acquires new dimensions with the human action and interaction on it.

Processes as they are described by globalisation have changed our perception of the world. Globalisation puts people into the spotlight and describes the changes that relate to people’s action and interaction on the planet. These processes take place in a different space, which does not always relate to the physical space, resulting in new perceptions of physical space itself. In addition to the physical space, the globalised world is increasingly also functioning in a social space created by people. This is a human space that looks different than the physical space. Conventional maps often fail to adequately visualise this dimension because of differences between the physical reality and the social sphere. The globalised world is seen as a shrinking world, but the social world as a populated world is not well reflected in a map which gives land area the most space.

Cartogram techniques have addressed this problem to some extent (see section 2.2.3.2) and by using a diffusion-based method for density equalising cartograms, the Worldmapper project provided an alternative mapping of the diverse geography of the world (see section 2.5). The world population cartogram from the project (Figure 2.8) could be seen as a technical solution that puts population on the map in its true proportions. The result, however, remains limited in its further cartographic use, as it does not provide a solution that can serve as a basemap for other geographic dimensions – and eventually could therefore be even seen symptomatic for the struggle to adequately understand the relationship between the different understandings of space (and almost confirms the gap between human and physical geography).

The research strategy for an improvement of the Worldmapper cartogram technique uses the population cartogram as the starting point. The essential limitation of this cartogram lies in its inaccuracy which is not a general weakness of the density-equalising cartogram. It is caused by the limited amount of population data that is contained in the transformation (one population value per country), and by the highly variable physical extent of the geometries (i.e. the countries) that constitute the base of the map transformation. Finding a method to improve on these inaccuracies is addressed in two main steps: (1) an increase of the data values that are used for the transformation and (2) a standardisation of the base geometry that is transformed. Before these improvements can be realised, the relevance of appropriate data has to be taken into account, as this provides the essential base for a cartogram and needs to be as reliable as the information about the physical space that is the fundamental element of conventional maps.

The premise for the exploratory realisation of an alternative cartogram technique builds on these limitations. The basic hypothesis for the research strategy is that a diffusion-based algorithm can be adjusted for a more accurate visual representation of geospatial information in cartogram form. The exploratory and open approach that stood in the beginning of the investigation can be explained with the experimental character of the methodology, which required testing different types of data and different ways of editing and processing them before the final technique could be applied to the actual cartogram transformation. It therefore did not follow existing methods to produce cartograms, but required a new approach to be developed and then applied to the cartogram algorithm.

The methodology consists of three major parts (a description of the technical requirements for the realisation of the methods is provided in section 3.2):

Part 1: Data considerations (section 3.3)

Before a new method can be outlined, the issue of data needs to be understood. An essential part of the new technique relies on appropriate data sets, which have become available only recently as part of the recent developments in cartography that were outlined in chapter 2. The nature of the data needs to be understood in order to deploy it in a valid manner. Population data is investigated in detail to understand its limitations. Further data used within this research is also introduced and described.

Part 2: Data processing (section 3.4)

This part presents the methods that are needed to prepare the input data for the cartogram transformation. The data preparation includes the creation of a gridded dataset. This step realises the goal of a modification of the basedata used in the cartogram transformation. It includes an increase in the number of data values, and a standardisation of the base geometry that is transformed. Alternative solutions for the generation of gridded data sets are presented for those cases, where no adequate data is available or a higher data is resolution is desired.

The final step in the development of the new approach is the actual cartogram transformation, which due to the character of the input data is hereafter described as a gridded cartogram transformation.

Part 3: Data visualisation (section 3.5)

The consideration of the map display is an essential part of cartographic practice. Therefore an adaption of key design principles for the appropriate visualisation of gridded cartograms stands at the end of the methodology.

The presentation of the methods in this chapter is guided by the development of a new population cartogram. This is reasoned by the relevance of population in the previously outlined debates about the spaces of humanity and their adequate cartographic representation. Population data is therefore given priority. However, it needs to be mentioned that the outlined technical procedures in section 3.4 do not only apply to the population data that they refer to, but can also be performed with any other quantitative data (as those datasets described in 3.3.2).

The gridded cartogram approach is the result of a novel combination of existing methods and algorithms. The proposed technique aims to provide a way of visualising the world's population and other quantitative geographical data that solves the problem of losing an accurate spatial reference in the cartogram display while putting other spaces than the physical space in the centre of the map projection.

3.2 Technical notes

Computing methods and technical capabilities change constantly. Therefore I describe some basic aspects that need to be understood and reflect the current state-of-the art related to the methodological works at the time this research has been conducted. The specifications are outlined to ensure a transparency in the methods applied to the datasets and allow a reproduction of the methods.

3.2.1 Hardware and software

The research builds on the described advances in GIScience (see section 2.4.2). To achieve the improvements on computer-generated cartograms that were made, a certain technical configuration was essential to perform the tasks outlined in the methods in a reliable and efficient manner.

	System I	**System II**
Computer system	Dell Precision T3400 (Desktop)	Qosmio X500-S1801 (Laptop)
Processing power	Intel Core2 Duo E8400 at 3 GHz	Intel Core i7-720QM
System memory	3.25 GB RAM	8GB RAM
Graphics	NVIDIA Quadro NVS 290 graphics adapter with 256 MB RAM	NVIDIA GeForce GTS 360M graphics adapter with 2.8 GB RAM
Operating system	Windows XP Professional	64bit Windows 7 Ultimate and Ubuntu 11 Linux

TABLE 3.1: TECHNICAL SPECIFICATIONS OF THE COMPUTER SYSTEMS USED IN THE RESEARCH

The latest available hardware configuration (Table 3.1) available during the time of research was used. The software (Table 3.2, *see below*) reflects the current standard in GIScience and digital cartography. These were complemented by extensions and scripts to be able to perform the required data operations.

Major methodological works have been undertaken with the software ArcGIS, using the release 9.3 in most cases, and the latest release 10.0 in some of the finalising works. In terms of functionality for this thesis, both versions used are not significantly different and provide similar capabilities. ArcGIS is a collection of geographical software products that allows creating, editing, analysing and visualising geographical data. These software products are known as geographical information systems (GIS). Products such as ArcGIS excel in their variety of ever growing functions that go far beyond the core task of working with geographical data (Ormsby et al. 2010).

ArcGIS is distributed by the California-based Environmental Systems Research Institute, Inc. (ESRI) which was founded by its current president Jack Dangermond. Its first commercial product was ARC/INFO, released in 1982 and the origin of today's ArcGIS versions. This triggered an increasingly widespread use of such geographical information systems in geographical research and cartography (ESRI 2011). The further development of ArcGIS and GIS-related products remains the core business of ESRI, but meanwhile a number of competing commercial products, as well as freely available so called open source[29] GIS products, have become available with similar basic characteristics and capabilities.

	Description	**Major tasks**
Tools mainly relevant for the analytical tasks		
ArcGIS 9.3 and 10	Geographical Information System	Geostatistical analysis, basic visualisation
Xtools Pro	ArcGIS extension	Spatial analysis, data conversion
Cartogram geoprocessing tool	ArcGIS script	Cartogram transformation
Tools mainly relevant for the visualisation tasks		
Adobe Photoshop CS5	Raster image editor	Raster conversion, visualisation
Adobe Illustrator CS5	Vector image editor	Map design
Other tools used with subordinate relevance for the cartographic methods		
Adobe InDesign CS5	Design and publishing tool	Final visualisation
Adobe Acrobat CS5	Publishing tool	Map conversion for the intended output medium

TABLE 3.2: OVERVIEW OF THE SOFTWARE USED IN THE RESEARCH

Various components of ArcGIS 9.3 and ArcGIS 10 have been used throughout this research study, and were the main tools for the map drafts in this thesis. The main applications used from ArcGIS were ArcMap, ArcCatalog and ArcToolbox.

XTools Pro and the Cartogram Geoprocessing Tool were used as external ArcGIS extensions for some advanced geoprocessing tasks. XTools Pro[30] extended the capabilities of processing the large amounts of data used in the research. The

[29] Open source software is a software application where the source code is freely available and open to modifications by anyone, while commercial software generally remains in the domain of the producer and the source code is often kept secret. Open source software does not only have the advantage of being free of charge, but allows the user to see how the software is working and improve it where necessary.

[30] XTools Pro adds a range of vector spatial analysis, shape conversion, and table management tools for ArcGIS. It is distributed by DataEast LLC Russia (see http://xtoolspro.com/, last accessed 2011-06-01). A free license has been provided kindly without conditions for this PhD research.

Cartogram Geoprocessing Tool[31] was the main script for the cartogram transformations which are a key element of the methods employed. It uses the Gastner/Newman algorithm for generating density-equalising cartograms (see section 2.2.3.2). The maximum resolution for data being processed using the script is 4096 cells (in width or height), which is an important threshold for the methods used in this research.

ScapeToad (Andrieu, Kaiser & Ourednik 2008) is an alternative solution for the generation of generating density-equalising cartograms. As is a Java-based[32] application, is has limited capability to process data in the computer's internal memory, regardless of the highest technical specifications of the computer system itself (Campione, Walrath & Huml 2000). Compared to the ArcGIS script, ScapeToad is less powerful in working with a large amount of data such as the population grid generated in the methods presented here, so that this tool was rejected as an alternative solution[33].

In addition to specialised geoscientific software, a range of software for the actual visualisation of the mapping results was used, as GIS software has only limited capabilities to enhance the visual appearance of the processed data. The main multimedia software used here was the Adobe Creative Suite Premium (Adobe CS5). Adobe CS5 is a software collection distributed by Adobe Systems Inc., a California-based computer software company also founded in 1982, which is focused on the development of a wide range of multimedia and publishing products (Adobe 2011). The main tools used in this research are Acrobat, Illustrator, InDesign and Photoshop which took over visualisation tasks to generate high-resolution versions of the produced maps, enhance their layout and produce the final visualisations.

3.2.2 Files and file formats

Computer files are the main repositories of digital information. Because of the huge variety of digital information, the vast amount of different platforms and software products, and the diverse character of digital data, there is now a countless range of different file formats, even for similar types of information. A basic understanding of the differences is necessary when working with the different kinds of digitally coded information.

[31] Cartogram Geoprocessing Tool version 2 is an external ArcGIS compatible script created by Tom Gross (Gross 2009), using the programming language C++. It is a cartogram creating tool which is available as a free extension in the ArcScript repository of ESRI (http://arcscripts.esri.com/details.asp?dbid=15638, last accessed 2011-06-01).
[32] Java is a so-called cross-platform developing environment released by California-based Sun Microsystems, Inc., which builds on the Java programming language (Campione, Walrath & Huml 2000).
[33] Gridded cartograms using a limited amount of data have been created with this tool and were compared to the results from the ArcGIS script. They revealed no overall differences in their capabilities, so that the tool is a viable alternative for the processing of smaller datasets.

Data type	Description
Shapefile	The shapefile format created for the ESRI GIS products has been established as a quasi-standard for storing vector-based geodata. It contains all the information about the base geometries and spatial location of geographical vector data and includes a database in which all additional attributes linked to a geometry are stored. A shapefile consists of a set of different files containing the different styles of information (geometry, location, attributes) and each shape can only store one type of geometry (point, line, or polygon).
BIL image	BIL stands for band interleaved by line. It is an image file format that contains raster format information and can consist of several layers of information (which are the different bands), each representing a unique layer of information. BIL images contain spatially-based data which are stored in the pixel values of each single pixel of the image. BIL images can be complemented by additional data files that include information about the data structure of the image (e.g. spectral information for a layer, data ranges, data types, and the geographical reference).
TIF image	TIF (or TIFF) stands for tagged image file format and is a raster based graphics format that can contain various layers of information including spatial references (known as GEO TIF) and even basic vector information such as outlines. It allows different levels of compression which for reducing the size of a large amount of raster information within an image.
DBF	DBF stands for a database file which represents a range of formats storing data in individual records. It is the file format that is also used in shapefiles to store attribute information, but it can also be used in statistical software, spreadsheet applications, and database applications. It contains all information related to a table, including a header for the different data fields, and the individual rows of the table as separate database entries. Databases are a key file format that is needed to perform many statistical analyses of quantitative data.
CSV	CSV stands for comma-separated values, which describe an ASCII-file that contains spreadsheet-style data separated by comma values to indicate the different columns of a table. Because they are ASCII-style data, CSV files contain plain text information that can be easily exchanged between different software platforms.
PDF	The Portable Document Format (PDF) is a standard created by Adobe Systems, which is a widely used document format that can be viewed on most operating systems and has the advantage of including its content in a fixed format that does not change on different system environments. As such, it can be seen as a digital version of a printed paper where the layout does not change.

TABLE 3.3: FILE FORMATS RELEVANT IN THE RESEARCH METHODS
(information compiled from Mayhew 2004, ODP 2011, Ormsby et al. 2010, SEDAC 2011c, Turner 2006)

Table 3.3 shows the key file formats that are relevant in the techniques that were used in the research (for details see Mayhew 2004, ODP 2011, Ormsby et al. 2010, SEDAC 2011c, Turner 2006). Unless stated otherwise, these are binary file formats[34].

3.3 Data

Developing an alternative method for more accurate cartogram techniques depends crucially on the data that can be made available for the further processing steps. Gathering fully new data is not a viable option within the scope of this methodological research. But the release of ever growing amounts of geospatial data the internet data revolution (see section 2.4) made it possible to access data that met the requirements of a high geographic detail. The following section describes the data used in this research. Special consideration is given to the improvements on global population datasets, as population data and the gridded cartogram produced had a special relevance in the development of the new technique.

3.3.1 Population data

For a long time little progress has been made in creating a consistent set of population data on a global scale (see section 2.3.2). This only began to improve in the 1970s, but even today there are only a limited number of major resources available for worldwide population data that allows putting them on a comparative scale them at a higher level of detail other than the national-level estimates shown in the Worldmapper population cartogram. As cartograms compare shares of quantitative data, an adequate source at the highest possible resolution was needed.

The following sections describe the efforts of generating a comparable base population estimates for the world based on the multitude of existing national-level datasets. The strengths and weaknesses of these efforts to create a gridded dataset for the population of the world will be investigated in order to demonstrate their relevance in the context of this research.

3.3.1.1 Estimating global population data

Population data is key to most social and environmental sciences, as the human being is a key element in the terrestrial ecosystem. As such, population has a pivotal role in

[34] The storage of digital information is now usually contained in either ASCII or binary file formats (ODP 2011): ACSII stands for American Standard Code for Information Interchange and is a file format containing all information represented in a set of 128 characters, with each character being represented by a number from 0 to 127. It is a suitable format for transferring plain text and numbers between different computer systems and software, but inflexible to store more complex information. Binary files are encoded in the computer-only readable binary code consisting of the two binary digits 0 and 1, which can be further encoded to strings of 0s and 1s to store information. Most file formats and software products are encoded in binary formats.

physical and social research, and knowledge about the distribution of people is crucial across the disciplines. Similar to the debate of the 1960s about a standardisation of methods to collect (and visualise) population data, the 1990s have seen new efforts to compile a consistent set of data about the global distribution of population. These were aimed at overcoming limitations of administrative units as the major unit for demographic data (Cartledge 1995, Deichmann, Balk & Yetman 2001, Tobler et al. 1995). These limitations relate to the problems outlined for the limited capability of cartograms to display higher levels of detail.

The requirement for suitable data for a more detailed cartogram depiction is a reliable comparative scale. A consistent approach to how the data is gathered is therefore essential to be able to compare the shares, and eventually create a valid cartographic depiction. Another feature of cartograms is the problematic representation if there are gaps in the data that is used for the transformation. Missing data leads to a misleading representation because they appear as zero values and cannot be made visible as missing data like in a conventional map. A second essential requirement therefore is not only a consistent, but also a complete set of global population data at a high resolution.

Specific for this research was the demand of data that can be assigned to a more equal spatial reference, so that the new cartogram is less dependent on the size of a country, but a based on spatial units of a more standardised size. The optimal form for achieving that is an equally sized spatial unit. For its readability in the resulting cartogram, its shaped should also have a relatively simple structure. For the requirements of the underlying data this means, that the data can be transformed into such a format without losing the validity or accuracy of the data. These requirements are fulfilled by a gridded dataset that consists of equally sized raster cells. The key task therefore as a first methodological consideration is the identification of a suitable way to obtain such data, as populations are not counted on the base of an equal grid (or other equal areal units), but are estimated based on very differently structured administrative units, which themselves are of very different quality in the different countries of the world.

The hitherto existing datasets about the world's population distribution were mainly derived from national censuses, or, where these did not exist, from other surveys and estimates. These were useful for demographic studies and social sciences, although even there changing political units and thus altering boundaries within countries were sometimes problematic for consistent research over the years. To tackle this problem, methods for creating grid-based population data became part of methodological research. An early example for this is *Census Atlas of Britain* released in 1980 where 1971 census data was redistributed onto a 1 km grid (Population Censuses & Surveys Office 1980, Martin 1989, Martin 2009, Thomas & Dorling 2005).

This idea was later taken up by Martin (Braken & Martin 1995, Martin 1989, Martin 1996, Martin 2009) who elaborated a method to generate population grids of the United Kingdom's population data modelled from centroid data of the administrative areas. He followed similar geostatistical works that have been undertaken in other countries (see e.g. Goodchild, Anselin & Deichmann 1993, Tobler 1979). These works resulted in a joint methodological effort towards the release of the first version of a consistent set of gridded population data in the year 1995 (Tobler et al. 1995, Tobler et al. 1997).

3.3.1.2 The gridded population of the world

The methodology developed in this thesis has been realised with the latest release of population data that descended from this first global population database. The latest release is the *Gridded Population of the World, version 3* (hereafter GPWv3), which has been updated in 2005 (CIESIN & CIAT 2005).

The underlying data sources and methodology of the GPWv3 database need to be explained to estimate the data quality and to be able to understand the implications on the resulting maps. Apart from standardised data conversion techniques, no modifications of the population data have been made, so that the sources and methods used to assemble the GPWv3 data are those, which are relevant for the data used in connection with the research introduced in this chapter. The following section outlines the key elements of the GPWv3 data as described in Deichmann, Balk & Yetman (2001) and with additional reference to Tobler et al. (1997) Balk & Yetman (2004).

The GPWv3 is published by the *Socio-Economic Data and Applications Center* (SEDAC) of the Columbia University, New York in the USA (CIESIN & CIAT 2005). The data of the Gridded Population of the World project is freely available to registered users as an online database providing data on the spatial distribution of world's population on a gridded base in various resolutions. The SEDAC calculated the data by converting spatial units usually derived from administrative units to geo-referenced quadrilateral grids.

As there is no other reliable primary source for population data, GPWv3 builds upon population data derived from the various national censuses. These are collected at national levels in varying detail, all generally related to some form of official administrative unit or similar irregular spatial units. GPWv3 works with publicly and commercially available boundary data for the base geometry. The latest updated version contains more than 375,000 administrative units with a heterogeneous resolution. The current resolution of the largest administrative units is 386 km for Saudi Arabia (see appendix B). Especially those countries with the lowest resolution of the underlying administrative areas are important for the accuracy assessment of the resulting population grid. They reflect the still existing gaps in internationally available prime data sources, which are then also carried forward to the best available population data for these areas.

The next step in the generation of the global population database was the integration of population estimates with the aim to include the most recent census data. GPWv3 aims to provide a comparable population count for the year 1990 and in the later revisions for 1995 and 2000, so that some basic estimates needed to be calculated where only older data was available. This was done by calculating average growth rates from earlier population counts and applying those to the latest available official census figures. Similar techniques were also used to generate subsequent gridded population estimates in five-year steps until 2020. Political changes were also taken into consideration and the sources and statistical operations are documented in detail for each country. The total population per administrative unit in the second revision varied between 1,500 for Iceland to 3,415,400 for Bosnia Herzegovina. The high variability is caused by the differing quality of national data and the different population densities. The average resolution in the third revision could be enhanced considerably, but the major concern remains the already mentioned differences in the administrative units.

The administrative-level population data was then merged with the underlying geometry, resulting in a basic set of internationally comparable population data based on the best possible administrative unit. The Gridded Population of the World (with its first release in 1995 and the then improved subsequent versions) represents the first set of population data ever created on such a high level of detail, which makes this raw data itself a substantial contribution to globally coherent population data. The quality of that data can generally be considered as quite reasonable, with a "*fair degree of consensus with the UN estimates*" (Deichmann, Balk & Yetman 2001: 5). Given the fact that this is the best available resource, some more significant differences between UN (United Nations) and national estimates have to be accepted when working with that data, and they reflect a more general problem of unresolved international practices in population counts rather than a flaw in the GPWv3's methodology. These problems will be more relevant to other disciplines, which depend more on very accurate population estimates, while they appear to be acceptable for the mapping purposes in this thesis. The relevant countries and areas are put under special scrutiny in the assessment of the maps.

The last and main methodological step in the generation of a population database is the actual transformation of the data into an equal grid. That approach itself has undergone several changes in the three versions of the database. The current version uses an unsmoothed population density over the administrative units. The population within each administrative unit thus is evenly redistributed over the overlaid generated grid, rather than an earlier approach which smoothed population densities depending on the population densities in the neighbouring administrative units. The proportional redistribution may appear visually less appealing but does not pretend a non-existent level of accuracy beyond the administrative level. It makes the used approach also straight forward and replicable, while some additional adjustments were made in areas where larger natural features (lakes etc.) made an even redistribution problematic.

3.3.1.3 Data evaluation

The approach used in the latest release of the GPWv3 database may be seen as conservative because it involves mainly standard statistical operations, while newer approaches of modelling population surfaces are not taken into account, although they were considered in earlier stages of the work on the data. This can be explained with the wide-ranging data quality of the various national data sources with GPWv3 matching these levels of accuracy as detailed as possible. The current state of the database can be regarded as the best possible solution representing the actual accuracy of available data (see appendix B). The distribution in the largest administrative areas, however, needs to be seen as a crude representation of the real conditions rather than a precise representation of the global population distribution. Further adjustment of the GWP data on a global scale was not considered for this thesis because the main aim of the research was an improvement of the methodological approach to create population maps rather than an improvement of the globally available population data itself. An approach for the refinement of data will be discussed in the next chapter.

Demands from climate science for higher levels of detail and advances of national population estimates will lead to improvements of global population data in future (Gaffin et al. 2004). The past developments in this field as outlined in this chapter show that the progress made here is slower than the methodological advances on national levels, which in some countries already provide much better population data than the overall quality of the GPW grid suggests. Usually, these are also the countries that already show a very good accuracy in the GPWv3 data. Therefore, it can be expected that like in the first two revisions future updates will improve the data for the currently still less accurate regions.

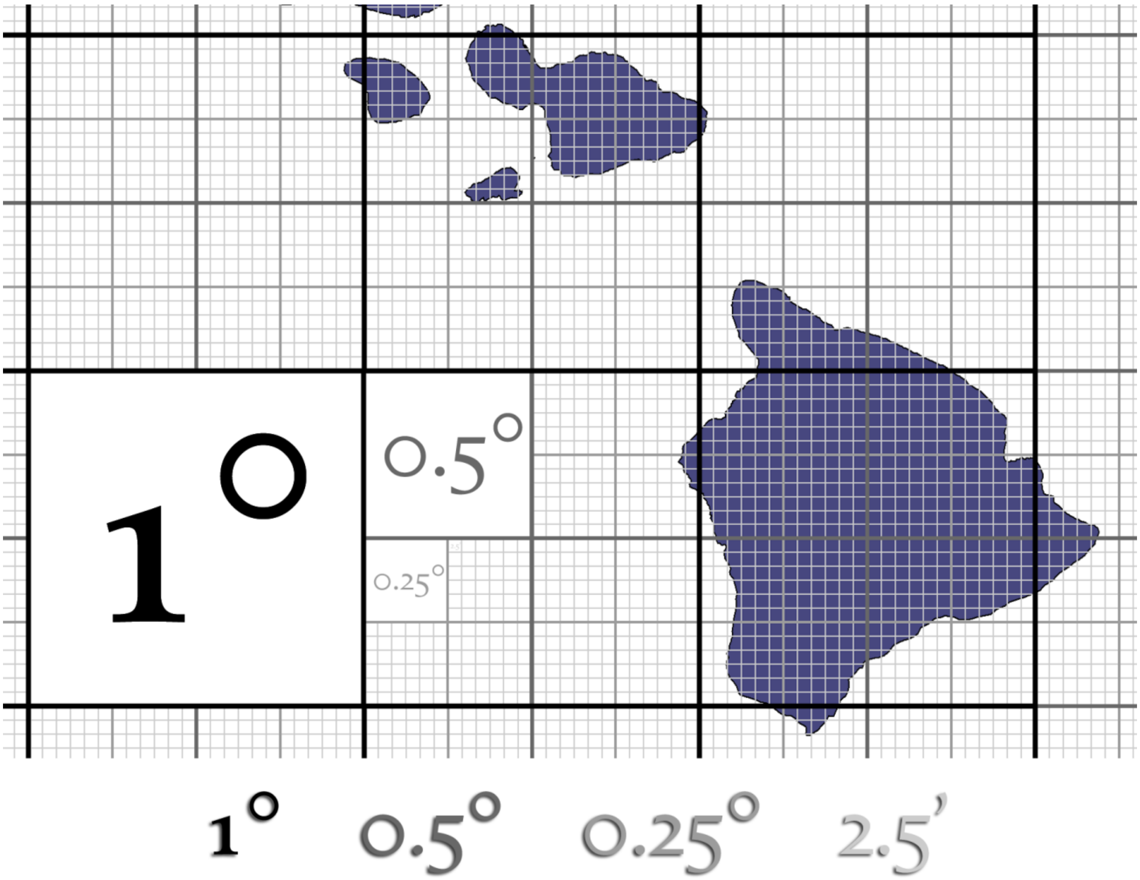

FIGURE 3.1: COMPARISON OF GRID SIZES
The figure compares the four grid sizes in which the GPWv3 population grid is available. Displayed in the background are parts of the Hawaiian islands as a reference (with the Big Island in the bottom right of the image) (own depiction by the author)

The final population grid generated using this approach is based on a geographic coordinate system with a maximum resolution of 2.5′ (approximately 5 km a side at the equator). Aggregated grids are also available in ¼°, ½° and 1° resolution (Figure 3.1). This reduces the problem related to the level of detail and in turn gradually increases the data accuracy as the size of the administrative units becomes less relevant with a smaller scale. They relevant areas that need to be observed closely when working with the data thus are these identified as having the largest administrative units.

In the course of the research I have worked with several versions of the GPWv3 data. The initial research was undertaken with the 2000 data in order to allow a direct comparison of the data with the existing Worldmapper map. In the later stages of the research other years were also taken into account and the data used in the subsequent chapters uses the 2015 population estimates from that database. Data resolutions used were depending on the level of detail needed.

The main reason for the choice of a certain resolution from the GPWv3 grids was generally to reach the highest possible level of detail, although constraints in computing capacity made it necessary to generally use the ¼° grid for the work with the global population data. On a global scale thus a total of 1,036,800 grid cells were used (including the sea areas). The best available version of the GPWv3 data consisting of a 2.5′ grid has also been used, resulting in a grid of 8640 x 3432 pixel extent (29,652,480 grid cells). Computing times of several weeks for each step of data processing on a state of the art computer made it not viable to use this data for the main research objectives of a new world population map, but they were of further interest in the subsequent research.

This data is significantly different from that used in the Worldmapper world population map, which is based on national statistics published by the United Nations. The new data now allows visualising the varying distribution of population within national borders and with less relevance of the national boundaries. The approach taken for GPWv3 still gives those boundaries some relevance, but provides the currently best possible way to work with global population data that is to some degree independent from administrative units.

3.3.2 Socioeconomic and environmental data

Further data was used in the context of this research to evaluate the utility of the gridded cartogram technique as an alternative map projection and for gridded cartogram transformations based on other quantitative data than population. This section gives an overview of the additional datasets that have been used (Table 3.4).

The identification of suitable datasets for the gridded cartogram approach followed several considerations. Due to the exploratory nature of the research, a large number of data repositories were consulted and many of the datasets were tested on the gridded cartogram approach. The examples presented in this thesis constitute a small selection of the maps that have been produced over the last three years. Special care was taken that a representative selection of results from the mapping process was made in order to explore the effect of different kinds of data in relation to the gridded cartogram technique.

The different concepts of mapping with and onto cartograms were tested in relation to issues of scale (from global to urban-level data), resolution (national-level to different subnational-levels) and data type (vector / raster). The features selected were chosen from examples from human and physical geography to highlight the versatility of the technique, as cartograms are often seen as less suitable for applications related to environmental issues (or to physical geography). An assessment of data covering not only the land surface, but also the extent of the sea areas was also taken into account.

Data	Type	Resolution	Source	Results in section
Population for Japan	Vector	30x45 arc second grid	SBJ 2011	4.3.1
Population for London	Vector	Subnational-level Lower Layer Super Output Area (LSOA)	ONS 2010, ONS 2011	4.3.3
Happy Planet Index	Vector	National-level administrative areas	Abdallah et al. 2009	5.3.1
Infant Mortality	Vector	Subnational-level administrative areas	SEDAC 2011b, CIESIN 2006	5.3.2
Gross domestic product	Vector	1 km^2 grid	Ghosh et al. 2010, NOAA 2010	5.3.3
Earth at night	Raster	0.022° grid	NASA 2006	5.3.4
Ecological footprint	Vector	National-level administrative area	Ewing et al. 2010	5.3.5
Election results of the United Kingdom	Vector	Subnational-level constituency areas	BBC 2010, Guardian 2010, ONS 2009	6.2
GTOPO30 elevation	Raster	0.0083° grid	USGS 2009	6.3, 6.4, 6.5
ETOPO1 bathymetry	Raster	0.0083° grid	Amante & Eakins 2008	6.4
Hotspots of biodiversity	Vector	n/a	Mittermeier et al. 2005	6.4.1.1
Treecover	Raster	0.25° grid	ISCGM 2005	6.4.1.2
Precipitation	Raster	10 arc minute grid	Hijmans et al. 2005	6.4.2
Ocean chlorophyll levels	Raster	0.25° grid	Hengl 2009	6.4.3
Travel times / accessibility	Raster	10 arc minute grid	Nelson 2008	6.5

TABLE 3.4: SOCIOECONOMIC AND ENVIRONMENTAL DATA USED IN THE THESIS
The data is sorted in the order of its appearance in the results, showing the highest resolution used in the methods deployed in this thesis

Table 3.4 shows the data used in addition to the GPWv3 dataset for the maps presented in this thesis in the order of its appearance in the results section. The following overview describes the relevance and structure of this data using the same order:

The *Japanese population* from the 2000 census has a higher resolution than GPWv3. The population grid used in the research contains data from the Japanese national population census of the year 2000[35]. The population data used is based on the '*Basic Grid Square (Third Area Partition)'* dataset, which consists of a raster of 30 arc second intervals in latitude and 45 arc second intervals in longitude. The grid approximately covers the extent of 1 km length of a side, depending on the exact geographical location (SBJ 2008).

[35] Professor Tomoki Nakaya of Ritsumeikan University (Japan) compiled the data from the original sources and provided it in support of this PhD research. It can also be obtained over the website of the Japanese National Statistics Center where it is accessible in a Japanese-only language version: http://www.e-stat.go.jp/SG1/estat/eStatTopPortal.do (last accessed 2011-06-01)

The *population data for the city of London* was used for the generation of a high-resolution population grid for London (see section 3.4.2.2). The data is based on data from the Office for National Statistics (ONS) in the United Kingdom. The ONS provides population figures on a yearly basis as mid-year estimates projected from the last census counts. The latest available 2009 estimates were selected for this work[36]. The data is provided on the extent of Lower Layer Super Output Areas (LSOA) which are built from units of the 2001 census in the United Kingdom (ONS 2011).

The *Happy Planet Index* (HPI) is a national-level social indicator merging various sources that determine our ways of living in the human space. The HPI was developed by the *New Economics Foundation* as an alternative to established indices like the *Human Development Index* (UNDP 2010). It combines concepts of well-being (‘*long, happy and meaningful lives*’), and the rate of resource consumption. All indicators are based on measurable statistics, and besides general ideas of well-being they contain a strong focus on sustainability issues, which decreases the impact of high living standards in the richer nations in the results of the study. The 2009 released second edition has been calculated with data on life expectancy, life satisfaction, and the ecological footprint, using data sets for 143 countries and covering 99 percent of the world’s population. Scores range from 0 to 100 (Abdallah et al. 2009).

Infant mortality data is part of a mapping project that covers some of these most pressing issues in relation to global poverty and inequality. The *Atlas of Poverty* (CIESIN 2006) includes infant mortality and other poverty-related data on various sub-national level administrative areas as a component that can help to better understand global inequalities and the distribution of poverty. Reducing child mortality is one of the eight millennium development goals that aim to tackle the worst problems related to poverty, health and education in the world. As these goals target problems in the poorest countries of the world, their success can only be assessed by monitoring the progress of the implementation of particular policies. This resulted in major efforts to monitor key indicators of socio-economic development in these countries, making some of the statistics available at an unprecedented level of detail (SEDAC 2011b, UNDP 2010, UN 2010).

A gridded dataset of *gross domestic product (GDP)* activity has been published by the NOAA’s *National Geophysical Data Center* (Ghosh et al. 2010, NOAA 2010) and is made

[36] The 2009 estimates are included in this table: http://www.statistics.gov.uk/statbase/Product.asp?vlnk=15389. The overview of available data sets is given here: http://www.statistics.gov.uk/statbase/Product.asp?vlnk=14357. Corresponding geometries are available under an Open Government Licence as GIS-compatible shapefiles from the Open Government website (http://data.gov.uk/dataset/lower_layer_super_output_area_lsoa_boundaries, all websites last accessed 2011-06-01) (ONS 2009, ONS 2010, ONS 2011).

available in a resolution of up to 1 km². It is created using the alternative LandScan population grid[37] (Dobson et al. 2000) to redistribute statistics on economic output across the countries and then adjust this redistribution by using night time lights derived from satellite imagery. These three data sources were used in an advanced geospatial modelling approach to display economic activity on a grid. Besides the advantage of separating the information about economic activity from the administrative units, the authors also claim to better consider unofficial economic activity in places where nightlights indicate more activity than that expected in these areas. With informal economy being an important part of the overall productivity in many economies, this is an important improvement to show the real productivity of the world's population, rather than the officially registered activity (Gaffin et al. 2004, Ghosh et al. 2010).

The *night time lights satellite image* shows the intensity of illumination at a certain place (NASA 2006, Sullivan 1991). The raster image is a composite image because it comprises several separate post-processed images to derive a consistent clear view of the night view of the surface of the planet. According to NASA, the "*image of Earth's city lights was created with data from the Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS). Originally designed to view clouds by moonlight, the OLS is also used to map the locations of permanent lights on the Earth's surface*" (NASA 2006).

The *ecological footprint* quantifies the amount of resources that are used by a country's population and transfers this national-level data into a measure that estimates the ecological resources needed if all people were living at the same level of consumption and waste. The key unit used in the footprint concept are global hectares, in which the pressure of the countries is expressed for their use of resources. These can be translated into the world footprint, which shows how many planets with the same resources like the world were necessary for that specific level of consumption (Figure 5.9A, *see below*). A one-planet footprint equals a sustainable living. The current level of humanity is at approximately 1.5 planets, with high differences between single countries (Ewing et al. 2010).

General election results from the United Kingdom were used covering the winning party of each constituency from the 2005 and 2010 elections (election results obtained from

[37] The LandScan Global Population Database is one approach for improving data quality on a global level. It uses satellite data and aerial imagery as well as additional geographic features such as roads and topography to address the constraints of GPW (Dobson et al. 2000, Salvatore et al. 2005). The GPWv3 data was preferred to the LandScan data not only because of the different licensing conditions and accessibility, but also because it included a time series allowing additional possibilities to test the capabilities of visualising temporal changes on gridded cartograms. However, LandScan may be valuable to use for visualisations where only large-scale administrative population counts are available.

Guardian 2010, BBC 2010). Further information about the electoral areas was obtained from the Office for National Statistics (ONS 2009).

Information about the *world's topography* is part in the datasets provided by ESRI's ArcGIS software. Topographic data is based on the *GTOPO30* digital elevation model from the US Geological Survey (Barto 2000, USGS 2009). In addition, the alternative ETOPO1 raster dataset was used. It combines a bathymetric[38] and-topographic digital elevation model, provided by the US National Geophysical Data Center[39] in a 1 arc minute resolution (Amante & Eakins 2008).

The *hotspots of biodiversity* identified by *Conversation International* aim to draw a global picture of the richest and the most threatened reservoirs of plant and animal life (Mittermeier et al. 2005). The data consists of a vector dataset that outlines the geographic extent of these areas over land and sea in separate polygons for each identified hotspot area.

The *global tree cover* is data about the relative tree canopy cover classified from a 1 km^2 resolution satellite sensor (MODIS[40]). Although the data derived from there is only expressed in percent of an area, it can be used as quantitative information about the amount of forest, because the underlying grid covers an equal geographical extent that can be used to calculate the absolute area covered by forest within each grid cell. The data is part of a global map of vegetation compiled by the Geospatial Information Authority of Japan, Chiba University and collaborating organisations (ISCGM 2005, Potapov et al. 2008).

Precipitation data is part of the possibly most advanced global scientific data that is currently available in geosciences. With climate science heavily relying on accurate and reliable data to put into models that predict future climates, but also to improve short-term weather forecasts, the underlying data for these models is constantly improving and getting more and more accurate (not least climate change research is a major driving force for the improvement of population grids to better estimate the human influence on the changing climate). Climate databases thus are of much higher quality and precision than any information that exists about the population distribution (Hijmans et al. 2005, Hijmans, Cameron & Parra 2005). Raster-type precipitation data

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[38] Bathymetry describes the underwater topography of the world's oceans.
[39] The ETOPO1 Global Relief Model is included in the ArcGIS software, and also available on the NOAA website at http://www.ngdc.noaa.gov/mgg/global/global.html (last accessed 2011-06-01) (Amante & Eakins 2008, NOAA 2009).
[40] MODIS stands for Moderate-resolution Imaging Spectroradiometer. It is a satellite imaging sensor operated by the US National Aeronautics and Space Administration (NASA). The sensor has a spatial resolution of up to 250 m, with a lower resolution of 1000 m in the full spectral coverage. The sensor records in 36 spectral bands, covering wavelengths from 405 to 2155 μm that allow a classification of the recorded pixels based on spectral differences. This classification is useful to extract information about vegetational cover (amongst other information) (NASA 2011).

from the *WorldClim* database (Hijmans et al. 2005) interpolated to a resolution of 10 arc minutes was used to map the current conditions over land area based on climate observations from the last 50 years (1950-2000). It contains information about the average monthly precipitation (in mm) from that time period. For the annual precipitation, this data was aggregated in ArcMap. A separate dataset covering parts of the land and sea area was also used (Hengl 2009, Hengl 2011).

To put a particular focus on the sea area, a raster dataset on the chlorophyll concentration in the sea was used. The data shows long-term chlorophyll concentration estimates in mg per cubic metre (Hengl 2009) derived from the analysis of MODIS remote sensing data. The chlorophyll concentrations in the oceans indicate the density of algae and other photosynthetic organisms that are important to investigate the ecology of the sea areas (Reise 1989).

As an example for the use of more complex geographical information, the multifaceted dataset of travel times combines a number of different data sources from the physical and human environment to estimate the *average travel times to the nearest major city*. Therefore the data differentiates the concept of remoteness in a more detailed way by differentiating the least populated areas further than only making a statement about the population density. The indicators used to assess the travel times include all means of transport (rail and road network, rivers), travel times depending on the mode of transport and the kind of transport infrastructure, and the character and structure of the terrain (elevation, slope, land cover) (Nelson 2008, Uchida & Nelson 2010). The raster-type dataset used in this thesis consistent of information about the absolute travel time in hours from the centre of each raster cell to the nearest major city.

3.4 Methods

The most time-consuming part of the methods consists of the data preparation for the cartogram transformation. Although the cartogram transformation itself can take a likewise long time, one has little influence on the actual transformation once the computer started the calculation. A diligent preparation of the basedata is therefore inevitable for the success of valid results.

The following sections outline the process of preprocessing the existing population data from the GPWv3 database (section 3.4.1) that can then be turned into a gridded cartogram transformation. Other raster-type data can be prepared using the same techniques, but it must be emphasised that a meaningful and valid transformation can only be achieved with absolute quantitative data that must not contain any gaps or is not interpolated correctly onto the desired grid resolution. Solutions to improve or generate own gridded datasets will be presented at two examples in section 3.4.2. The principles and the actual procedure for the creation of gridded cartograms are then explained in section 3.4.3.

3.4.1 Vectorising a population raster

The gridded population data from the GWPv3 database is the key dataset that has been used throughout most of the work in this study. A few conversion steps were applied to the data before it was suitable to work with in a GIS environment and to be applied in the further processing steps. The main reason for a modification is the data format in which the population grid is available from its original source. This is not suitable for advanced GIS analysis and needs to be converted to be in a format compatible with the requirements of the main GIS tasks.

3.4.1.1 Introduction to raster and vector data

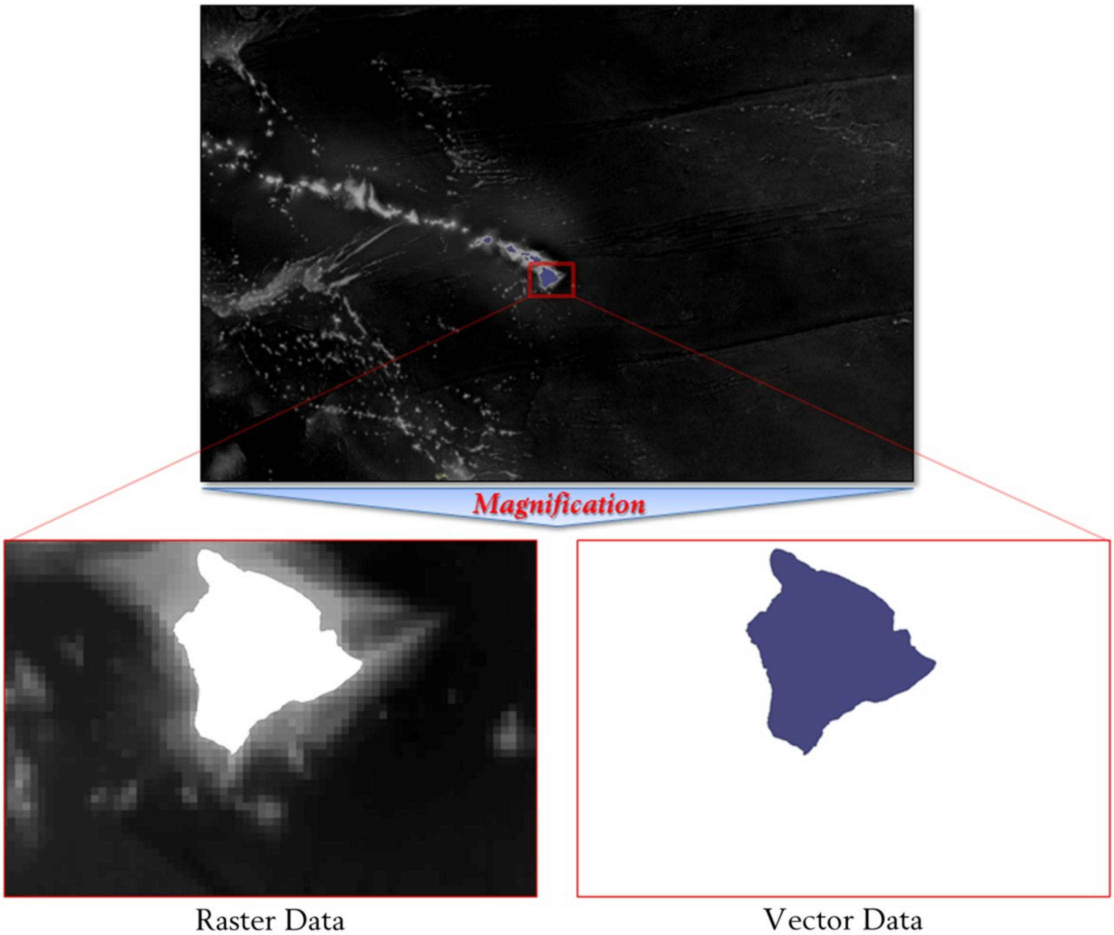

FIGURE 3.2: COMPARISON OF RASTER AND VECTOR DATA
The top image shows a clipping of a seafloor raster image and the chain of the Hawaiian islands superimposed as vector polygons. The bottom images split the raster (left) and vector (right) layer at the selected area (which is the Big Island of Hawaii). The views are enlarged to show the changing appearance of the different data types at larger scales: the vector shapes retain sharp edges, while raster images show single pixels when they are zoomed into (own depiction by the author using data from NOAA 2009)

Geographical data used in geographical information systems can generally be divided in raster and vector data (Figure 3.2). Both formats are general graphic formats which are not restricted to be used in GIS environments, but become geographical data when they have spatial information about the location assigned and can then be used in combination with other geographically referenced data.

Raster data is available as a regular arrangement of pixels, consisting of cells in which the data is contained in the form of a unique value for each pixel. A digital photograph is an example of a raster image file, which as such is not necessarily suitable for use in GIS. To be suitable for geographical analysis, raster data needs to have additional information about its geographical reference attached, meaning that each pixel must have a spatial reference. If that is not the case, a raster image has to be georeferenced (or georectified) before combining it with other geodata.

The resolution of raster data describes the number of pixels for a defined area. For photos and graphic this is usually defined as dots per inch (DPI), whereas the resolution for geographical raster data is described by its geographical extent represented in each pixel (e.g. km per pixel, or geographical degree per pixel). Changing the resolution inevitably results in the modification of the underlying data (Figure 3.2, bottom left). Wherever necessary it has to be executed with careful consideration of the applied method of conversion.

Vector graphics are graphical representations of shape objects. These can be points, lines or polygons, with each of these shapes defined by their vector information, i.e. the location of a point, the start and end of a line, or the vertices of a polygon. Their visual appearance never becomes blurry as raster data gets when zooming into raster data (Figure 3.2, bottom right), because the vectors are drawn based on a mathematical equation (e.g. a line is generated as a stroke between two defined points). Geographical vector data contains the spatial information in these vertices and can thus be located in a geographical space. In addition, geospatial vector data has additional attributes attached to its vector elements which describe type and characteristics of the elements. Attributes can also contain quantitative data that can be used for further spatial and statistical analysis (Greenberg 2007, Mayhew 2004).

3.4.1.2 From raster to vector

Population data of the GPWv3 database are provided in raster format as BIL image files. In order to use them in further geospatial analysis, the raster information needed to be converted into shapefile formats which make the population data available in vector format and also accessible for the use in databases (and consequently for additional geostatistical processing).

GIS software has a range of tools to automate the process of converting raster to vector data (and vice versa), although the conversion process is not always straight-forward and can use different approaches (Van Der Knaap 1992). To preserve the highest degree of accuracy I have chosen to create the basic world population grid manually following a few basic data conversion steps:

(1) The geographically referenced BIL format population raster was imported into ArcMap.

(2) Then an empty polygon grid was generated using the XTools extension of the ArcToolbox, with the size of the grid cells matching the resolution of the selected population grid (¼° for the global population data).

(3) The raster map was then vectorised to a set of point data, with each pixel of the raster map being converted to a point feature located in the centre of the pixel and containing the total number of people living there. This number was created in the conversion process and derived from the BIL image data. The conversion was done using the *Raster to Point* feature in the conversion tools of ArcToolbox.

(4) Using the *Spatial Join* analysis in the Analysis Tools of ArcToolbox, the point and grid polygons were then merged into one polygon shapefile. The analysis applies to the population value of each point feature to each grid cell in which the point is located. As the size of the grid was created equal to the image resolution, each grid cell contained exactly one point feature which can be matched with the grid cell as the population value representing the number of people living in that area.

The resulting new shapefile was a raw grid containing the world population data for the total extent across the globe. To simplify some visualisation tasks, the same data operations used in steps (1) to (4) have been performed using the GWPv3 population density raster (in the same resolution), so that the final grid consisted of a ¼° resolution polygon grid containing the total population value and the population density value for each grid cell as attached attributes.

(5) As the grid covers the whole geographical extent of the globe, including the oceans (with 0 values for attributes there), a final processing step was performed to clip the continents and reduce the amount of data in the grid. To create this grid limited to land-area, the polygon shapefile from the

Worldmapper project was used to perform an *Intersect* analysis in the Analysis Tools of ArcToolbox. This processing step clips the shapes of the continents out of the overall population grid, also clipping the rectangular shapes of the grid cells where the coastline does not exactly match the full extent of a grid cell, while applying the total population value to the remaining polygon area there.

While the clipping of the land area reduced the amount of data considerably from 1,036,800 grid cells to 365,022, this was also necessary for some of the following methodological steps where the key area of interest for the data analysis was the land area, and including the oceans would have affected the appearance of the resulting maps.

A comparable approach of pre-processing the GWPv3 raster data was performed for other resolutions as well as other raster-type quantitative data that needed to be converted to a vector grid. The creation of a highly detailed population grid based on the highest resolution population data from the GPWv3 database needed a more complicated and laborious approach, because of limitations in the capabilities of ArcGIS and because the used extensions failed to follow the same workflow for the creation of a 2.5 arc minute resolution vector population grid. To create this set of data, the raw data was prepared in four separate steps, each covering a quarter of the planet's surface. This made pre-processing the data a still time-consuming task, but allowed the creation of four separate population grids for the land surface of the four regions, which then could be merged into one full population grid with a 2.5 arc minute resolution. It was not possible to create a similarly sized grid covering the whole surface of the globe (land and sea) because of limitations in the computing capabilities of the computer systems used in the research. The high-resolution grid was therefore mainly used in those methodological steps where it was essential to use such a large amount of data in the geospatial analyses[41].

3.4.2 Generating and improving gridded populations

The original data used for the gridded population cartograms was derived from the GPWv3 database, which contains a population raster up to a scale of 2.5 arc minutes. For testing the scalability of the gridded cartogram approach, the highest resolution data was used to make country cartograms at larger scales by clipping continents and,

[41] The reason for not using the 2.5 arc minute world grid in most of the calculations was a memory failure in ArcGIS (tested in versions 9.3 and 10.1) or a general and repeated crash of the software when working with the data.

countries[42] (which refer to very differently-sized areas but are treated as one spatial extent that should be looked into) from the gridded data. In addition, larger scales and higher data resolutions were investigated, which required further data preparation to derive suitable datasets beyond the level provided by the GPWv3 dataset. The 2.5 arc minute resolution covers a reasonable level of detail for most countries. The effects of a higher resolution could be tested with an already pre-processed gridded population dataset for Japan (as described in section 3.3.2). Where such higher resolution data does not exist, and the highest resolution of the GPWv3 database is not good enough, alternative approaches need to be found. For smaller countries or regional level depictions as well as on city level the 2.5 arc minute grid only has tens of data values rather than a more suitable number of thousands of data points. For that reason, some additional datasets and methods were used evaluate, how data accuracy can be improved and missing gridded datasets can be generated.

Additional works towards a higher resolution population grid were applied on two areas: One is the Occupied Palestinian Territories as an example of a smaller-sized regional area, which provides very limited GPWv3 data for the full extent of the territory. A higher resolution of the population data here is essential to understand the settlement structures of both Palestinian and Israeli populations in the region, which is a politically highly relevant issue (Weizman 2007). The other example is the urban area of London, which needed a much higher level of detail in the population grid to be able to test a gridded cartogram approach on city level. London was chosen because it is often cited in urban analysis of the world cities network (see e.g. Smith & Timberlake 2001, Swyngedouw 2004, Taylor 2004b) and provides an interesting large scale example of an area with a much lower variation in the population density than most countries or the global view.

3.4.2.1 Allocating Palestinians

The Occupied Palestinian Territories[43] are among those administrative areas that generally have a medium-quality resolution in the GPWv3 population grid. They cover an area of 6006 km^2 and contain 16 administrative units (*Governorates*) that build the

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[42] Used were the territories of the Worldmapper project: "*all 191 recognised by the United Nations are included. […] we include some other territories that, whilst not recognised as independent by the United Nations, might consider themselves to have some degree of independence. Some of the territories we include may not be recognised as independent countries by other territories. Our main criteria in including a territory is that it is distinct enough for us to obtain data for that territory*" (Sasi Research Group & Newman 2006 Sasi). Also not included in the list is the country of South Sudan, which has just become independent in the last days of completing this thesis at July 9, 2011.

[43] At the time of writing in early 2011 the Occupied Palestinian Territories are not recognised as a country, although there are political efforts to declare a Palestinian state (for the geography and politics of the conflict see e.g. Quigley 2010, Shoshan 2008, Weizman 2007). This thesis is not meant as a political statement of any kind in this regard, but looks at the mere problem of accurate population data in order to create different maps of the region.

base for the GPWv3 population grid. The average input resolution[44] of the generated population grid thus is 19 km. This is above the average resolution of the GWPv3 database, although the overall average of 46 calculated over all countries equally is quite misleading when taking the highly variable country sizes into account.

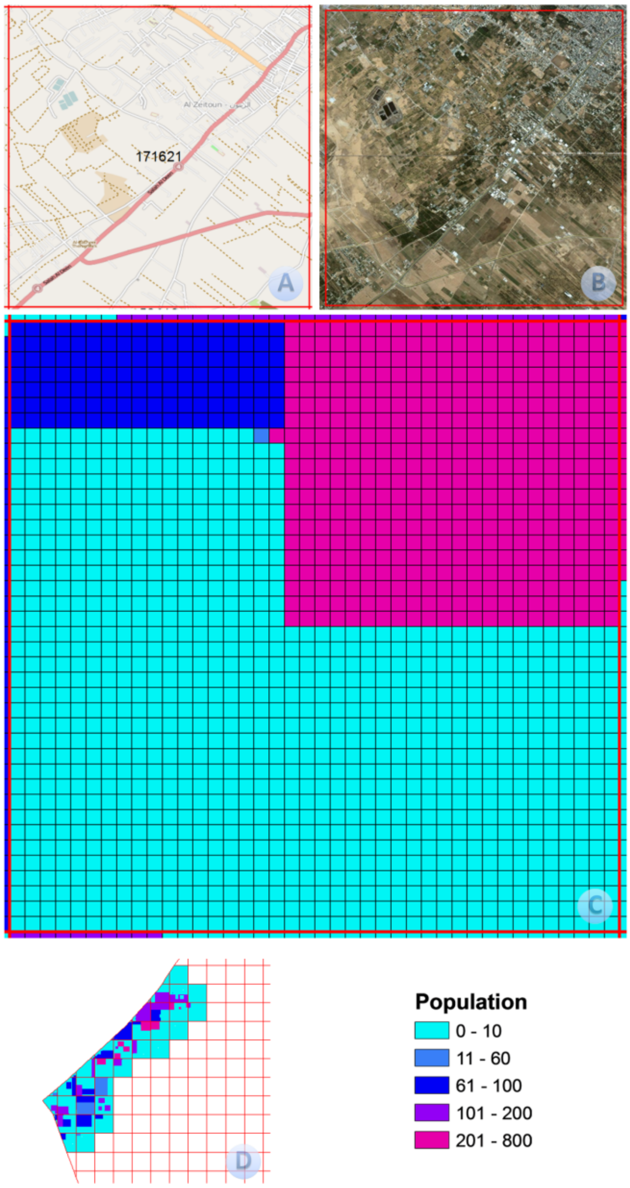

FIGURE 3.3: SCHEME OF IMPROVING THE POPULATION GRID USING MAPS AND AERIAL IMAGERY
A+B: The original 2.5' population grid is analysed using online map services (OpenStreetMap left with the total population count for that area, GoogleMaps right), C: The overall population is redistributed on a finer grid according to the appearance of the build-up areas, D: The refined grid is merged with the original grid in these areas where no refinement was made. The overview shows the refined grid for the Gaza Strip region (depiction by Joe Harriman and the author; airphoto and map display obtained from Google Inc. 2011c, OSM 2011)

What makes the population data for the Occupied Palestinian Territories worth improving is the fairly small size of the country with a generally high difference between populated and unpopulated areas, which the population grid cannot adequately take into account when only using the 16 Governorates as the main geographic reference for the population counts.

The large differences in the population density of the Occupied Palestinian Territories and the manageable size make it a good example to try a semi-automated approach of mapping population densities by combining the existing data with manual adjustments to enhance data accuracy in the more populated areas. In addition, the settlement structure is a highly relevant issue in the political geography of the region. A disputed

[44] The average resolution is calculated by using the square root of the land area and dividing it by the number of administrative units that build the original population data source. More administrative areas thus increase the average resolution that can be seen as a general indicator for the accuracy of the data for a country.

settlement policy of the Israeli Government and a de-facto occupied status of most parts of the Palestine areas require a different level of detail when looking at population-related issues there (Weizman 2007). The political implications shall not be looked at any further in this thesis, but demonstrate why a higher level of detail can be very relevant when looking at smaller scale geographies.

The 2.5 arc minute population grid provides only a limited amount of population values, which do not adequately picture the scattered settlement structure in the region. Therefore, an automated redistribution of population based on existing approaches for generating gridded population models (see section 3.3.1.1) is not suitable to mirror that highly relevant dispersed structure in that region. Other public data sources providing more accurate gridded population counts are not accessible either, so that a different approach was developed that allows to get a more precise representation of the population distribution in the region.

The work stages to refine the population grid for the Occupied Palestinian Territories included a semi-automated way of identifying the most densely populated areas and manually adjusting those areas using additional information from other resources (Figure 3.3). The target resolution was a tenfold enlargement of the population grid compared to the GPWv3 database.

The first step in improving the grid included the work with the original GPWv3 population grid. All grid cells that covered the Occupied Palestinian Territories were extracted from the data using the *Extract Analysis Tools* in ArcToolbox.

The reduced grid now covered the full extent of the Occupied Palestinian Territories. In addition, the areas with the largest population densities in Israel were manually selected from the original grid and included in the extracted grid cells. Included were also smaller neighbouring parts of Israel on the borders where the extent of the grid cells reached over the border line. This was done to focus the scope of refining the grid on the most densely populated areas across the region and get a full picture of the population distribution for both countries.

For the extracted grid cells covering the Occupied Palestinian Territories (including the areas of Gaza Strip and West Bank) and the most densely populated areas of Israel a more detailed (empty) grid was generated using the XTools extension. The resulting grid increased the number of grid cells in each of the original 2.5 arc minute grid cells forty times, so that each original grid cell was split into 1600 smaller grid cells (40 x 40 grid cells). The resolution of approximately 0.001 decimal degrees was chosen because it provided a significantly higher resolution than the original grid. The resized grid cells covered areas large enough to still make reasonable estimates about the areas where people live. A more accurate grid may be more difficult to still make valid assumptions about the residential areas and the number of people living there.

The automated steps of selecting and refining the grid using standard GIS operations was followed by a manual approach of refining the actual population values in the newly generated grid of the higher populated areas in the region. The basic concept behind the creation of the new grid is a redistribution of the original population and is based on the idea that is part of other gridding approaches[45].

The high level of detail that is desired for the grid of the most populated areas of the Occupied Palestinian Territories cannot be achieved with such global sets of data on built-up areas or night-lights, but the idea incorporated in other refinement approaches is useful for a manual approach using more detailed additional data layers. Much and very detailed information about the settlements in the region can be extracted from online sources such as OpenStreetMap (OSM 2011) and GoogleMaps (Google Inc. 2011b). These are digital repositories of geographically referenced information about built-up areas, infrastructure and other features as well as a source for airborne imagery. Such sources are less suitable for global refinements of the existing population grids, as they require high manual efforts to process them. For current GIS software they would exceed the limit of processable data and needed to be done in specialised computer environments.

The refinement of the grid is achieved via a manual redistribution of the overall population value of the 2.5 arc minute grid cell across the newly generated higher resolution grid. The total number of people living over the extent of one original grid cell does not differ from the original value, but the redistribution takes settlements patterns into account that are derived from a visual examination of the geographical information on the built-up areas and the patterns observed in the aerial imagery[46].

The redistribution of population included an iterative reallocation of the total population shares. In a first step it was distinguished between the less populated areas and the populated ones. The population shares were equally redistributed across the less populated areas, not taking local variations there into account. For the more

[45] The Landscan population database uses additional layers of information not directly related to population counts to remodel existing population grids. Such layers of information contain information about the extent of urban or built-up areas and similar information related to human settlement structures, which can be extracted from satellite data and other sources (Dobson et al. 2000). Such approaches result in more detailed estimates but are more suitable on a global scale because the level of detail of these additional sources is not larger than that of the original 2.5 arc minute grid.
[46] The outlined approach has been developed as part of the research for this PhD thesis. Most of the manual work at the reallocation of the population values was done by Joe Harriman of the University of Sheffield as part of his research for a Master dissertation on inequalities between Israel and the Occupied Palestinian Territories and is also described in his unpublished technical documentation of this collaborative project.

populated areas this iterative process was repeated in a similar way, but not with more regard to the variation within each of the original 2.5 arc minute grid cells. First, the overall patterns were being looked at and these were split into less- or non-populated parts and the more densely populated areas. The total population was split and redistributed accordingly based on an estimation on the overall share of each of the areas, going into more and more detail in the more populated areas. The main decision about the overall redistribution and the estimates about the approximate population shares were based on the information about built-up areas. The further adjustment then included an assessment of the type of buildings (residential versus non-residential) and the size of the buildings (larger blocks of flats, detached houses, etc.).

The redistribution of people across the areas follows similar rules of automated approaches performed using similar estimates from classified satellite imagery on a manual but therefore more detailed level. A human mind rather than an automated algorithm makes the decisions for the actual redistribution of population in this method, similar to common practices within the field of air photo interpretation that is still used for land cover detection where automated classifications fail to produce meaningful results (Hennig, Cogan & Bartsch 2007, Löffler 1994, Mather & Tso 2009).

The edited refined grid was then merged with the original grid using the merge tool in ArcToolbox. The refined dataset consisted of two-level data with the larger 2.5 arc minute grid cells covering the less densely populated areas, and the extended grid covering the Occupied Palestinian Territories and the most densely populated areas of Israel. The total number of refined grid cells was 820,560. Including the remaining areas in 2.5 arc minute resolution, the total grid now consisted of 821,619 grid cells, of which 1059 were in the original GPWv3 resolution. The completely refined grid for the Occupied Palestinian Territories contained 631,706 edited grid cells.

3.4.2.2 Gridding Londoners

The area of Greater London refers to the area of the 33 London Boroughs that are under the administration of the Greater London Authority. This area will generally be referred to as London[47] (GLA 2011). London covers an area of 1,572 km^2 and has a population of approximately 7.7 million. It is the largest city of the United Kingdom and situated in the densely populated southeast of the country. London and its surrounding region is the economic centre of the country and as such it is a highly disparate city with large socio-economic differences. This makes the population of

[47] The City of London refers to the City of London Corporation in the centre of the mapped area.

London a highly polarised society, which finds a geographic manifestation in the emerging social patterns there (Dorling 2008, Zehner 2010, Zehner & Wood 2010).

The GPWv3 population grid covering the extent of London consists of 151 grid cells in the 2.5 arc minute resolution. As a base for a refinement of the grid this resolution and the underlying data was regarded as less suitable because it was assumed that a city level population grid requires more detail but also more accurate redistribution than the method that was used to create the refined grid for the Middle East. A city-level map should be able to show a more accurate variation not only between populated and less populated areas. With an urban area generally being densely populated, the redistribution of population onto an equally distributed grid should take significant differences in these overall high densities into account without being based upon a rough estimate. A larger scale map is generally expected to bear more detail, and the more detail is displayed, the more accurate it needs to be.

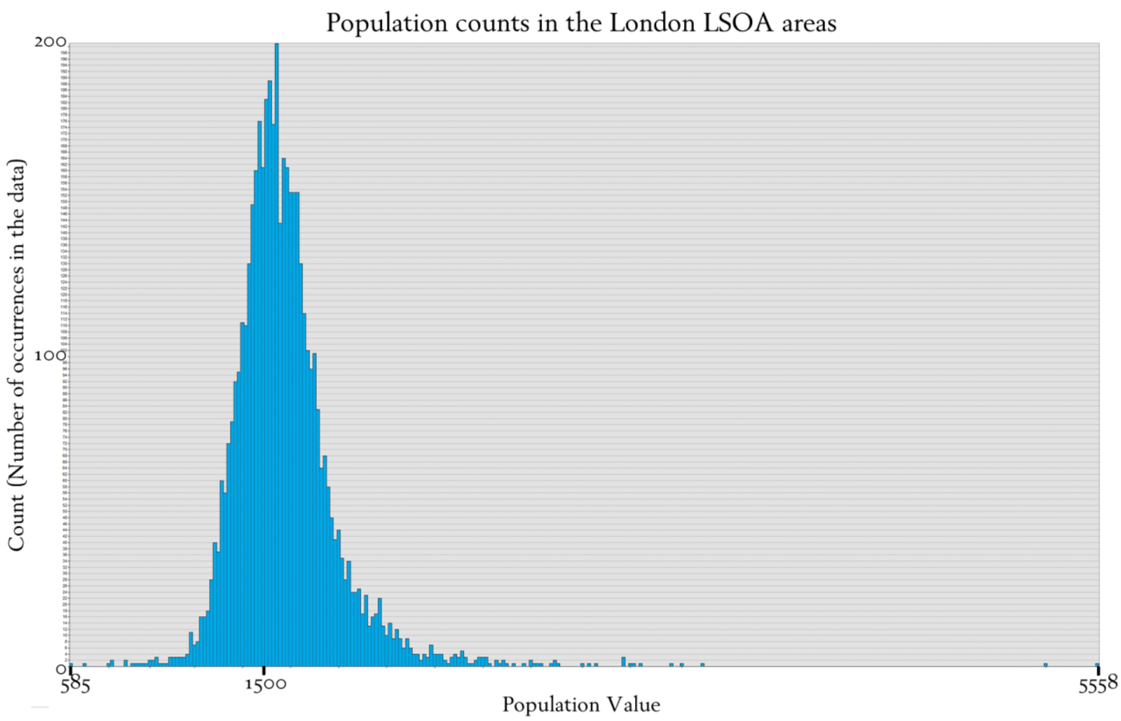

FIGURE 3.4: POPULATION DISTRIBUTION IN THE LSOA AREAS OF LONDON
The graphs show the total occurrences of population values in the Lower Layer Super Output Areas (LSOA) within the urban boundaries of London
(own depiction by the author using data from ONS 2009a)

The generation of a higher resolution population grid was realised without using the GPWv3 data. Instead, a total number of 4765 areal units from the Lower Super Output Areas of the Office for National Statistics each containing a unique population estimate for the 2009 population was used as base data. According to that data, the area contained a total population of 7,753,555 people which feature almost a Gaussian distribution of population values across the areal units (Figure 3.4). The mean population per LSOA unit thus is 1627 people, with a standard deviation of 257 (ONS 2009, ONS 2010, ONS 2011).

The generation of a gridded population dataset for London was based on the approach that has also been used in the creation of the GPWv3 global population database (see section 3.3.1). The redistribution undertaken here did not consider advanced modelling approaches because these reached beyond the scope of the research to test the general applicability of gridded population cartograms for an urban area. Modelling approaches based on additional information about land use patterns may be valuable for future studies on the creation for an even more accurate population grid than the present one.

The methodology used to create the gridded population data for London based on the LSOA units included the following work steps: firstly, the grid size was defined with a 100 x 100 m resolution to potentially cover enough detail for an urban area. The grid was generated over the area of London and clipped by the outer administrative boundaries, resulting in a grid containing 161,052 grid cells. Secondly, the LSOA level population data was converted to a raster layer with the same resolution, in which all LSOA-level population counts were equally redistributed over their areal extent. Thirdly, the population values of the LSOA population raster were then joined with the raw population raster, resulting in a vectorised 100 m resolution population raster for London.

3.4.3 Producing gridded cartograms

The following section explains the principles of a diffusion-based gridded cartogram transformation and outlines, how the gridded data can be used for the creation of gridded cartograms.

3.4.3.1 Basic principles

The gridded cartogram technique presented here builds on the population grid that was generated from the GPWv3 data (and functions in the same principle with other likewise preprocessed suitable gridded vector data). The polygon shapefile containing the world population distribution based on an equally-distributed ¼° grid is the initial data used hereafter. The main tasks were performed using the grid clipped to the land area (based on the Worldmapper geometry), because land area is the main area of interest when human population distribution is analysed[48]. For experimental reasons, the described approach was also tested on a dataset comprising the full extent of the globe, including the sea areas (with their 0 value grid cells), and in the presentation of the results variations using other data than population, and covering varying areal extents over land and/or see are also explored.

The basic idea of transforming the grid goes back to the density equalising cartogram algorithm developed by Gastner and Newman (see section 2.2.3.2), which is also the underlying technique used in the Worldmapper project (see section 2.5) and its world population cartogram, where it is applied in the common way of transforming the shape of each country according to its total population. The method can now be explained with special consideration of gridded datasets, which explains the basic principle that has been developed as part of this research.

Density-equalising cartograms using the Gastner/Newman method are a transformed representation of a map in which each unit (usually countries or other administrative areas) of the map is resized according to the total value of a defined attribute (e.g. population). The algorithm tries to maintain the unique shape of each aerial unit as much as possible, while also preserving the relative location of each element towards each other. The idea behind this new methodological approach does not contain any modification of the underlying algorithm itself, but its novelty lies in a new way of utilising and implementing it in order to create a new kind of cartograms, which I call gridded cartograms.

The realisation of the Gastner/Newman algorithm suggests a gridded cartogram approach, even if it has not been applied in that form before and was not the underlying goal of the method. Initial ideas to use a grid have been outlined by Tobler (1979), who discusses the use of a regular polygon structure or a hexagonal grid in his works. This was hard to achieve with the computational capabilities in the 1970s, and has not been revisited in the more recent methodological works on cartograms (until now in this thesis).

Gastner/Newman's method is usually applied to countries or other larger administrative units; the actual computation of the cartogram virtually creates an equally distributed grid over the whole area and redistributes the attributes of the areal units equally over that grid within the different areas. This means that when calculating a world population cartogram based on single population values for each

[48] One could argue that there are people living on the oceans (see e.g. Pugh 2004), but the total numbers matter less when looking at the global population distribution. In addition, the nomadic way of life does not allow an accurate location of that population (and even *settled* population is constantly on the move as well). They are also not taken into consideration by the GPW data.

country, that unique population value is redistributed equally within the boundaries of the country, so that the density equalising transformation treats each cell in that land area equally and results in the (desired) preservation of the country's shape. The final step in the cartogram creation applies transformation from this grid back to the input geometry (such as the country polygons) and resizes these areas accordingly.

The technical way in which the cartogram transformation works is basically already a gridded cartogram transformation in the existing examples including the Worldmapper population cartogram. Here, the grid that goes into the transformation would have very low data accuracy when a unique population value is used for a country, and the user does not notice the redistribution of the data on the grid that happens during the transformation. The underlying mathematic operation, however, is basically nothing else than a grid-based transformation. The algorithm converts the data into an equal raster before it is transformed and eventually converted back into a vector polygon. That explains why the algorithm itself needed no modification to create a *real* gridded population cartogram based on a (more accurate) population grid.

Gridded cartograms as proposed in this thesis are created using an equally distributed grid as the input area geometry for the cartogram production (Figure 3.5). The key unit in the cartogram transformation thus is not an arbitrarily or artificially defined administrative or other area, but a defined section of a map, with each areal unit having the same geographical extent[49].

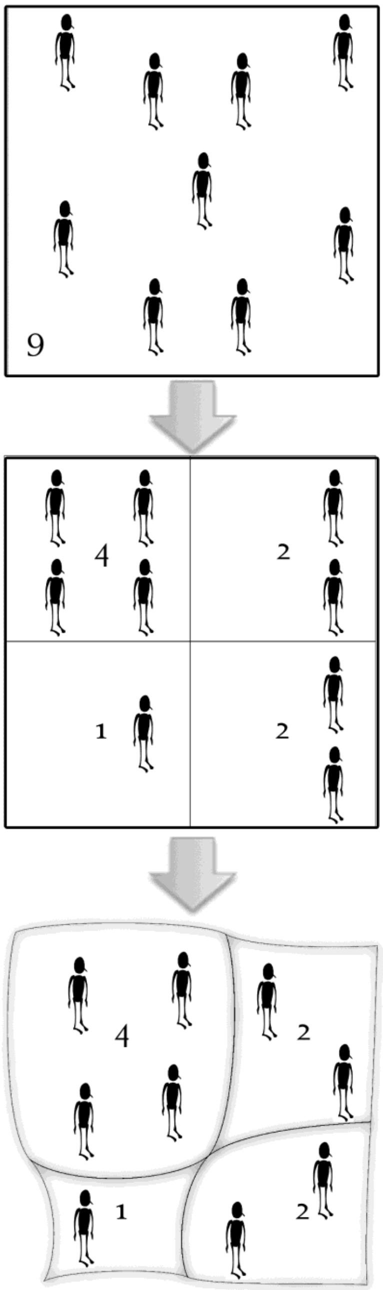

FIGURE 3.5: SCHEME OF MAKING A GRIDDED CARTOGRAM
The total population in an area (top) is distributed onto an equally sized grid (middle) which is then resized according to the number of people in there while preserving the relative position of each grid cell towards its neighbouring cells (bottom) (own depiction by the author)

[49] The geographical extent can vary on the coastal zones if – as it has been done in the input grid – the underlying grid is intersected at the continents. Unlike administrative borders which can change, these irregular fractions of a grid cell do not change over time unless major geological events change the shapes of the continents. There may also be slight divergences in the Worldmapper geometry and that of GPWv3. They are so small that they can be neglected in the mapping operation and they do not

For a new gridded world population cartogram the generated ¼° population grid was selected as the input data that is processed in the cartogram transformation. The number of grid cells covering the land area in this resolution totals up to 365,022 (out of an absolute number of 1,036,800 grid cells for the whole world).

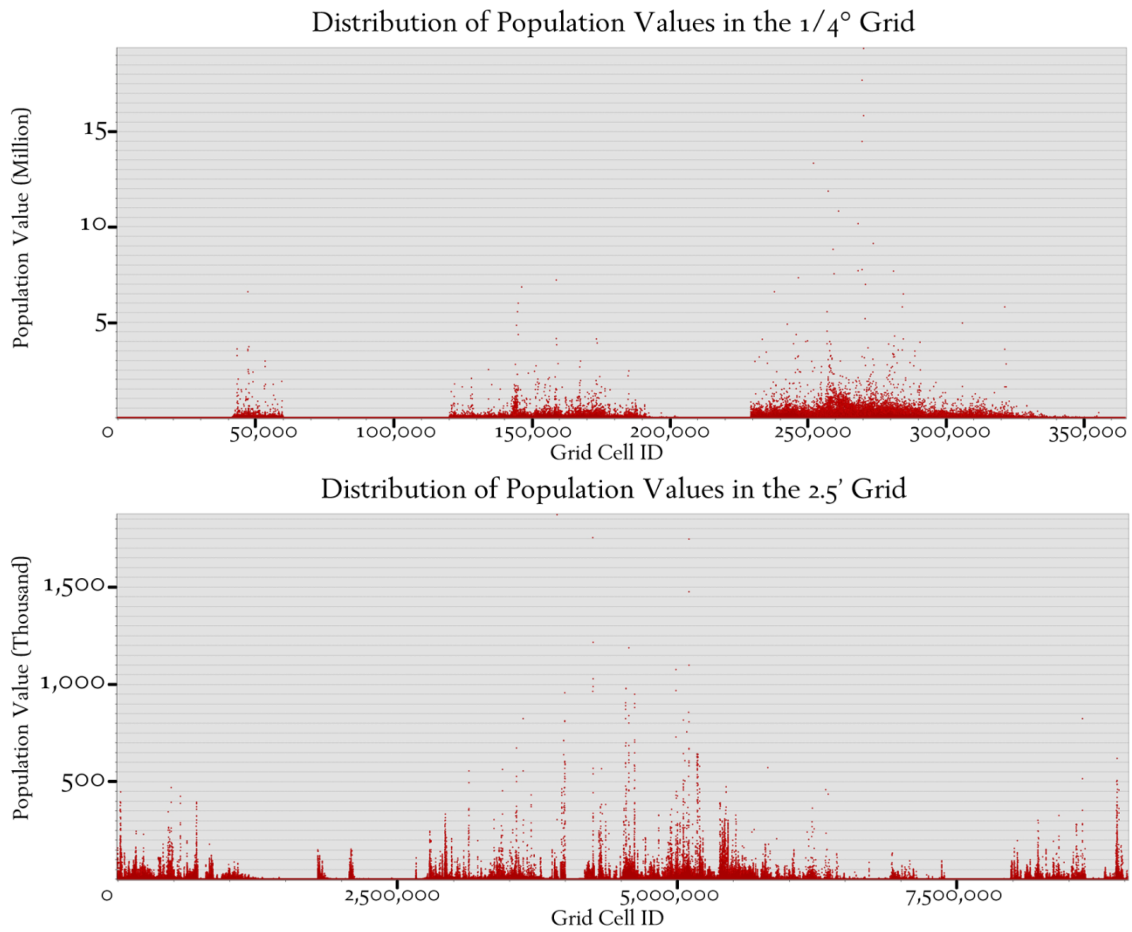

FIGURE 3.6: COMPARISON OF THE DISTRIBUTION OF POPULATION VALUES IN THE GLOBAL GRID
The grid cell IDs refers to the unique cells included in the grid and were generated as a continuous identifier which indicates a close geographic proximity of the immediately consecutive IDs. The pattern shows that there are some population clusters in the data with different manifestation in the two differently sized population grids. The IDs of the two grids do not correlate (own depiction by the author using data from CIESIN & CIAT 2005)

The input population grid was checked and validated for its suitability for a cartogram transformation, meaning that no negative or *no data* values were included in the data. From the perspective of a meaningful visualisation, using such a large amount of individual data units also requires a heterogeneous structure to the data itself, which can be investigated via the statistical analysis tools of ArcGIS (Figure 3.6 & Figure 3.7, *see below*). If there is a more even distribution with little deviation within the data at a certain resolution, the general idea of a transformation according to that data attribute would be meaningless and a real advantage over a conventional mapping method would not be achieved.

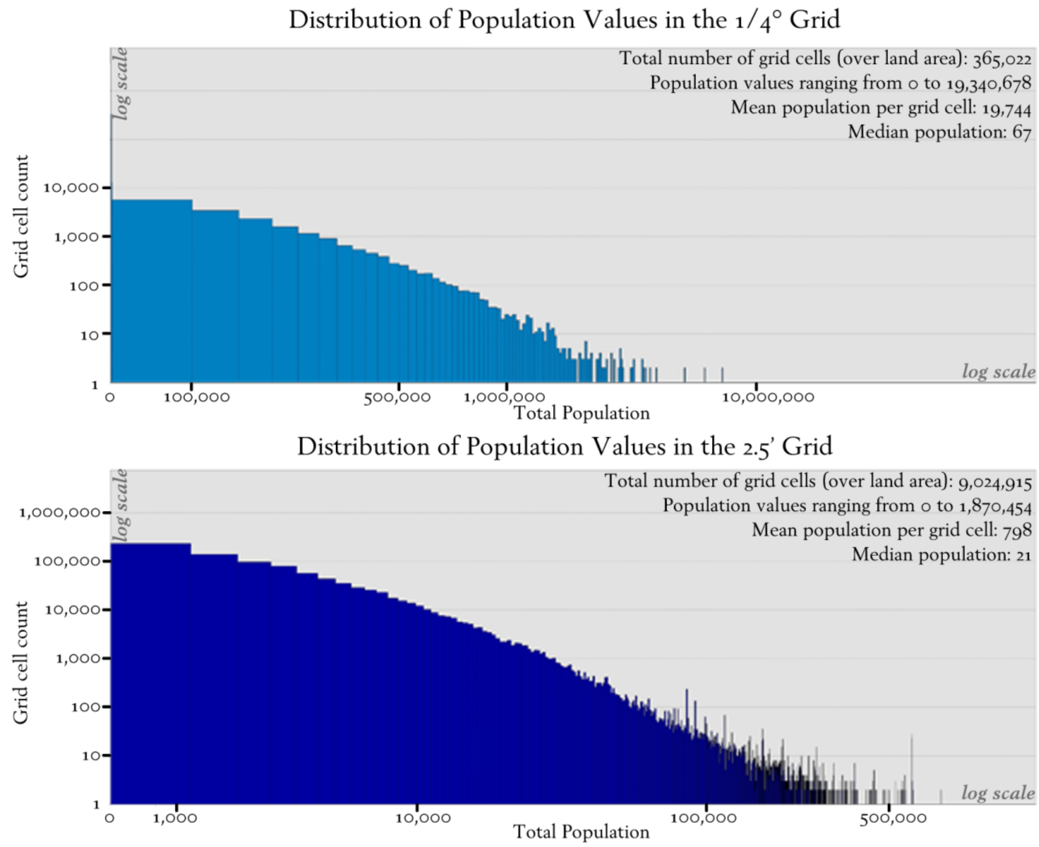

FIGURE 3.7: COMPARISON OF THE FREQUENCY OF POPULATION VALUES IN THE GRID CELLS
The graphs show the total occurrences of population values in the grid cells of the ¼° and 2.5' population grids (own depiction by the author using data from CIESIN & CIAT 2005)

The actual cartogram transformation of the gridded population data can be performed using a number of different tools that deploy the Gastner/Newman algorithm. The ArcGIS script Cartogram Geoprocessing Tool was the main tool that has been employed because it can be directly integrated in ArcGIS and in the workflow of pre-processing the data and visualising the final results, without the need to transfer data between different software environments. As the preparation of the data and further analysis were a major part of the work, the script proved to be suitable. To compare the results and evaluate the methods, ScapeToad was used as a second application to perform the cartogram transformation. This allowed assessing and comparing the implementation of the algorithm in different software environments and to evaluate the resulting cartograms in more detail.

3.4.3.2 Technique

The transformation of the data using the Cartogram Geoprocessing Tool was executed via the ArcToolbox in ArcMap. The vectorised population grid was used as the original polygon feature, selecting the total population attribute as the cartogram transformation value. The desired output file name was assigned and several additional settings were applied to adjust the transformation.

The quality and extent of the transformation can be influenced in its degree of distortion applied to the original data. This can be adjusted using the so-called density blurring factor to smooth original density, which ranges from 1 to 500. A factor of 500 results in the least possible transformation (almost like the original map), and a factor of 1 means the maximum possible transformation. Creating a series of cartograms and gradually changing the density blurring factor in each transformation enables the generation of a series of maps that visualise the transformation process from a normal map to a fully distorted cartogram.

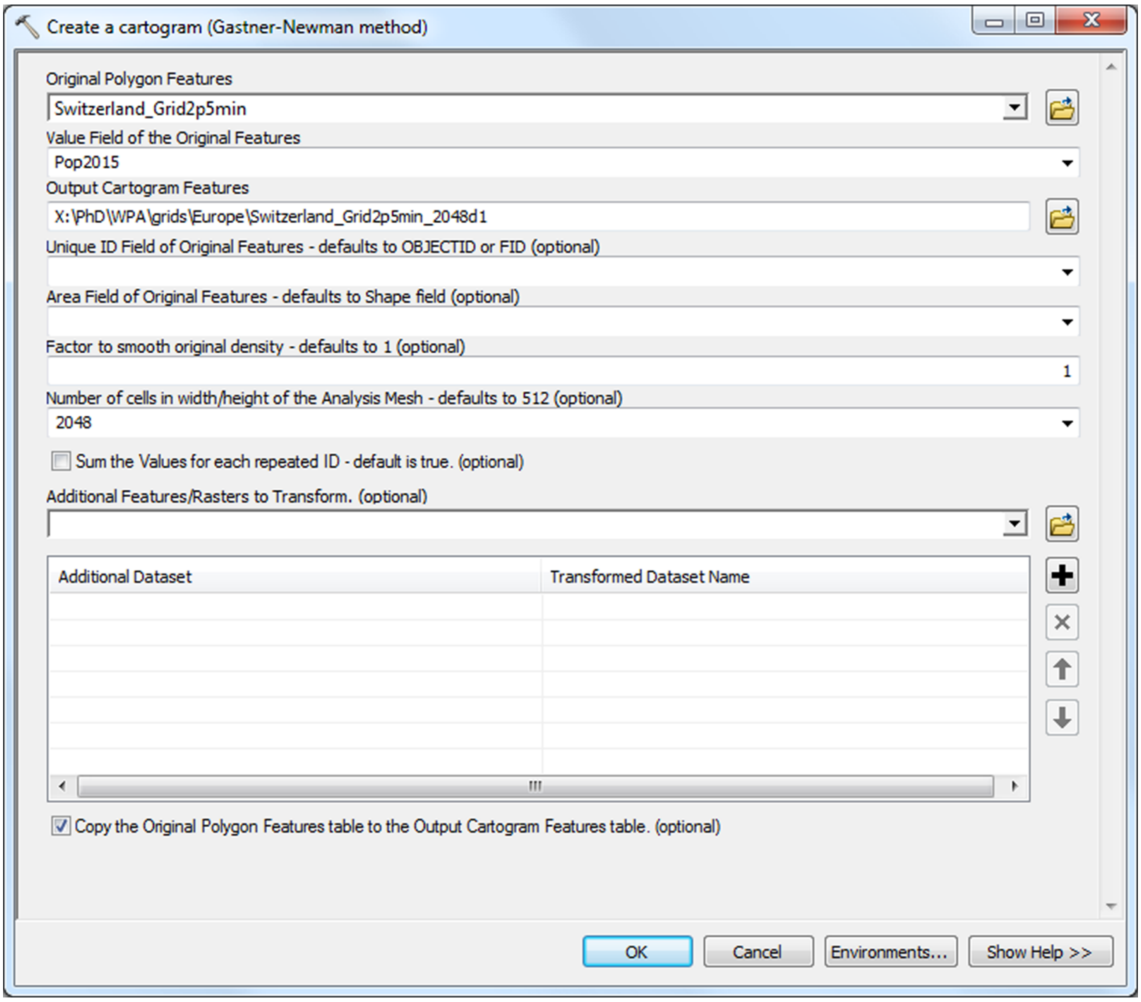

FIGURE 3.8: USER INTERFACE OF THE ARCGIS CARTOGRAM GEOPROCESSING SCRIPT
The script requires several input information: the gridded dataset is used as the original input feature, the transformation value is defined, and the output feature name is chosen. Additional options allow the definition of several customised settings to influence the density-equalising algorithm. The option to define additional features allows to transform other layers of geographic information in accordance with the main cartogram transformation (screenshot taken from software by Gross 2009)

The script allows further settings to influence the transformation (Figure 3.8). The accuracy of the cartogram can be adjusted by modifying the default value for the analysis mesh, which stands for the maximum number of columns or rows that the script is able to process and that the algorithm uses for the generation of the grid on which it builds its transformation. For highest possible accuracy, this value should at least match the resolution of the grid used in the transformation, which has a 1440 x 720 resolution for the ¼° population grid. The value in this transformation was set to 2048[50].

The maximum threshold for the analysis mesh value of the transformation is also relevant for the creation of a higher resolution cartogram. As the 2.5 arc minute resolution data was also used to test the highest possible resolution from the GWP population grid, it has to be mentioned that this population grid is resampled down to the maximum mesh value of 4096 by the script, so that the higher resolution of the population data for a world population cartogram has little benefit using currently available cartogram transformations. The 2.5 arc minute grid results in a full grid of 8640 x 4320 cells[51].

Using the 2.5 arc minute grid with the Cartogram Geoprocessing Tool thus does not make the best use of this high resolution. The analysis mesh threshold for the transformation even needed to be reduced to 512 while working with the 2.5 arc minute grid because the script failed at higher values due to a lack of working memory in the computer. Although in this research it was always the aim to reach the highest possible quality setting, it should be considered that to reduce accuracy settings can be productive in order to reduce processing times[52].

3.4.3.3 Implementation

In addition to the assembled global population grid, a series of larger scale gridded cartograms was produced. The countries of the world were extracted from the Worldmapper geometry and saved as separate polygons. For each country then a 2.5 arc minute grid was generated and combined with the GPWv3 population data, so that separate population grids were created for each of the countries. To reduce processing time and the manual effort that went into the creation of the country grids, a faster approach was used for the creation of the population grids. The simplified approach converts the raster data directly into polygons instead of creating a point layer and merging this with a polygon grid. This approach reduces the manual effort that is needed to create the population grid, but results in some grid cells being merged with others to simplify the polygon structure where duplicate values exist in neighbouring

[50] The allowed values in the script must be multiples of 128 to maximally 4096 – a value larger than the actual grid does not result in a *better* quality of the cartogram transformation, but it should also not be below the grid size

[51] The resolution is calculated as follows: 1 geographical latitude/longitudinal degree consists of 60 arc minutes, hence a resolution of 2.5 arc minutes means 24 grid cells in 1°. 360 degrees longitude result in 8640 grid cells and 180 degrees latitude in 4320 grid cells.

[52] Computing times for the techniques outlined in this chapter ranged from hours to several days on the described computer configurations that were outlined in section 3.2.1.

grid cells. This has little effect on the overall map transformation because the overall population values for each polygon are still correct after the transformation, but can in some cases lead to a different appearance of the grid. This restriction was accepted to allow the efficient creation of a series of gridded population cartograms for all countries within a reasonable time[53]. For every country[54] a separate gridded population cartogram based on the 2.5 arc minute resolution was calculated. The transformation was performed using a density blurring factor of 1 (resulting in the highest possible transformation) and a maximum analysis mesh of 2048 (depending on the overall extent of each individual country grid). Some smaller countries with only very few grid cells were transformed together with one of their larger neighbouring country. This was e.g. the case for Vatican City, which is only covered by one fraction of a grid cell in the 2.5 arc minute resolution and was thus included in the population grid of Italy.

A coherent population grid using the 2.5 arc minute resolution has also been created and transformed for the African continent and Europe to test the effect of the transformation on an intermediate scale between the global and the national perspective. Here the full manual approach has been used to create the grid, so that no automated simplification of the resulting grid cells could happen. Additional gridded population cartograms using the same settings were created from the high-resolution data for Japan, and the refined data for Israel and the Occupied Palestinian Territories, as well as for London.

In the further course of the research, separate gridded world population cartograms based on the ¼° population grid were created in combination with additional geographic data layers. Furthermore, gridded cartograms from other basedata were also created on different scales. The detailed selection of topics will be presented in the results.

3.5 Visualisation

The visual presentation of a cartogram is a crucial element in the process of creating these maps. Because of their – compared to conventional maps – more unusual form, a conscious reflection on the design elements and the possibilities they offer is inevitable to produce meaningful and understandable maps. The presentation-style of maps

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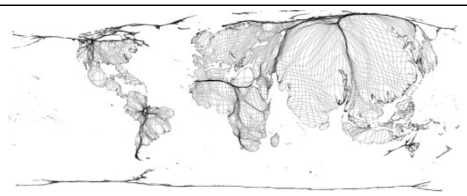
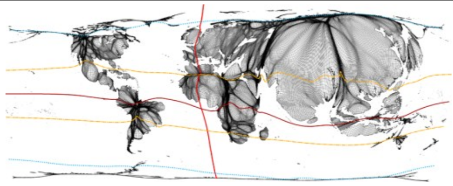
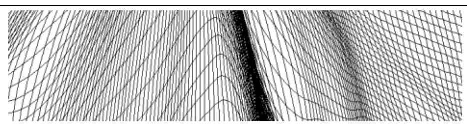
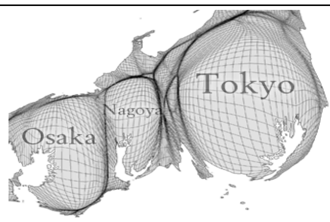
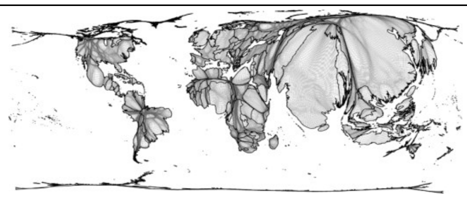
[53] The series of gridded country cartograms was created in the first year of research and took approximately six months of work, which was conducted in parallel to the continuation of the research for this PhD thesis.

[54] Used were the territories of the Worldmapper project: "*all 191 recognised by the United Nations are included. […] we include some other territories that, whilst not recognised as independent by the United Nations, might consider themselves to have some degree of independence. Some of the territories we include may not be recognised as independent countries by other territories. Our main criteria in including a territory is that it is distinct enough for us to obtain data for that territory*" (Sasi Research Group & Newman 2006 Sasi). Also not included in the list is the country of South Sudan, which has just become independent in the last days of completing this thesis at July 9, 2011.

stands between the fields of cartographic practice (as discussed e.g. by Darkes & Spence 2008, Dent 1999, Fairbairn et al. 2001, Harrower, Keller & Hocking 1997, Jenny, Jenny & Räber 2008, Jenny, Patterson & Hurni 2009, Krygier 1995, Krygier & Wood 2005), cognitive research (for cartography-related notions see e.g. Andrienko, Andrienko & Wrobel 2007, Harrower 2007, Harrower & Fabrikant 2008, Lateh & Raman 2005, Reichenbacher & Swienty 2007, Slocum et al. 2001, Swienty 2008, Uttal 2000) and graphic design (see e.g. Klanten et al. 2008, Reas & Fry 2007, Samara 2007).

In the visualisation of the gridded cartograms created in the context of this research, a special focus was put on criteria that take special consideration of density-equalising cartograms (as outlined by Oyana, Rushomesa & Bhatt 2011). Design decisions were also made with regard to the specific graphic features of the gridded cartograms and how these are implemented (Table 3.5).

Design element	Implementation in the thesis	Visual example
Orientation	North up using the Prime Meridian as the map centre (the exact orientation varies with the distortion and is reflected in the grid)	
Graticule	Equator, Prime Meridian and polar circles are included in some maps as distinct guides to highlight the distortion in gridded cartograms created from data other than total population	
Grid	Essential map element that visualises the underlying base used in the map transformation	
Labels	City labels are included in the gridded country cartograms to support the orientation in the map They deviate from the main subject in topical maps and are therefore not included there	
Boundaries	Country boundaries are included to enhance the interpretational value	

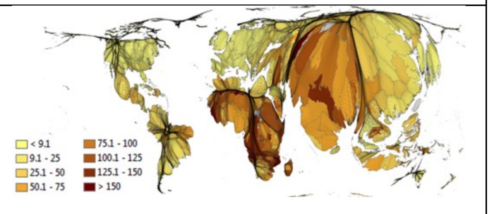
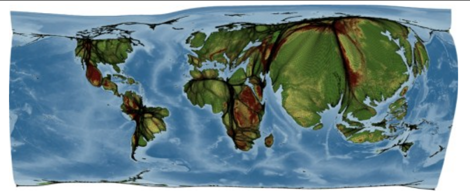
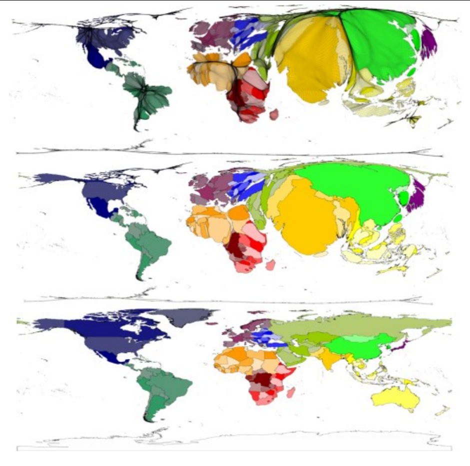
Design element	Implementation in the thesis	Visual example
Colour	Colour schemes are adapted from conventional mapping approaches and visualised in the same manner	
Data overlays	Topography and bathymetry is included to enhance the visual appeal in those cases where the space in the grid remains unused	
Comparative maps	A conventional map projection, and where a comparative argument is made also a conventional cartogram, are included to clarify the differences between the mapping techniques Alternative solutions are a background display of the original physical shape of the map, or a thumbnail reference from the conventional map projection	

TABLE 3.5: DESIGN ELEMENTS OF GRIDDED CARTOGRAMS AND THEIR IMPLEMENTATION

The design decisions taken in this thesis were set in a consistent manner to allow an easy comparison of all results and applications without a distorted view caused by changing design principles. The map orientation was oriented on the widely used conventional map projections (as outlined in section 2.2.3.1). The Prime Meridian therefore stands in the centre of the north-south oriented map[55].

The graticule can be visualised to highlight its changing location on the distorted land areas (Figure 8.2 on page 212 shows these lines drawn on the gridded world population cartogram). In the presentation of the results this feature was not included to allow a focussed interpretation of the main map subject. In the presentation of the case studies the graticule was included for those maps that were not based on population data, but on other gridded data types. As the shapes of these maps change with every different data type, the grid can here help to adjust the eye faster to the distortion in the map. The visualisation of graticule lines can therefore be a supporting visual element in the cognitive understanding of the map transformation.

[55] These orientations are not completely accurate descriptions, as it lies in the nature of the gridded cartograms that the Prime Meridian does not exactly split the map in two equal parts, as well as the North-South orientation of the grid cells is not always a straight line from top to bottom.

The grid on which the gridded cartogram transformation is based on is a crucial and the most important distinctive element in the gridded cartograms compared to any other map projection. As the key characteristic that explains where the physical space has been distorted to what extent, the visualisation of the grid is essential for the map understanding. From a design perspective it also supports the visual appeal and the vivid appearance of the gridded cartograms. Depending on the intended output medium and the final map size, the thickness of the lines of the grid cells has to be carefully balanced to make them still recognisable but not too dominant to allow for other map layers to be adequately visible.

The labelling of cities or particular agglomerations[56] is an aid that guides through the unusual shape of the countries. As some agglomerations are often formed by several cities, generally the largest of these cities was picked to label the area. In addition, some minor cities were labelled where it seemed appropriate. This is the case for cities of trans-regional relevance (e.g. Belfast in the United Kingdom) and on cartograms where some striking areas remain unlabelled when taking the largest agglomerations in the country. These city labels were derived from a manual examination of each individual map. From the unique identifiers of each grid cell, the location of the transformed areas could be related to their original geographic position and so be combined with the information about the location of the major cities. The number of cities labelled in each cartogram varies according to the specific layout of a cartogram: More cities are labelled the more striking agglomerations appear to be in a cartogram. Labelling the gridded world cartograms was not realised in the maps shown in this thesis to preserve comparative character of the results and, as outlined above, to allow the concentration on the actual topic depicted in each map. A labelled version of the gridded world population cartogram can be accessed in the online world population atlas (http://www.worldpopulationatlas.org, Hennig 2009).

A consistent visualisation of the gridded country cartograms was necessary for the online publication of the world population atlas within the context of the Worldmapper project in October 2009. A major aim here was therefore an adaption of the Worldmapper style for all gridded country cartograms, using the Worldmapper colour scheme for the unique background colour of each country. Additional elements for guiding the map reader through the interpretation of the maps included a background display of the original country shape and the visualisation of an overlaid square raster that emulates the transformation and shows the areas of largest and smallest distortion in relation to that raster. Furthermore, the final map included the

[56] Information about the largest cities of a country was obtained from the GeoNames database (Wick 2010).

city labels as described above. The city labels and additional design elements for the online maps were created using Adobe Photoshop. A total number of 172 maps were created for the world population atlas (including a version of the gridded world population cartogram).

Country boundaries and other administrative areas are supportive elements that can support a faster orientation in the transformed map. Unlike in conventional density-equalising cartograms, in gridded cartograms these do often not resemble the original administrative shape, but appear distorted. This can be a disadvantage in the initial readability, but e.g. with a limited number of countries on a world map, the map reader can use these as guiding lines in addition to the grid and use these for an interpretation of variation within countries. Where a certain familiarity with administrative areas can be expected (or where reference maps are shown), boundary lines are therefore useful design elements in gridded cartograms. The visualisation of these lines should be made distinctive from the grid lines, but not stand in opposing contrast to them. In the results, boundary lines were included in the world maps in those cases where the country outlines did not become apparent from the additional layers shown in the different maps.

The use of colour in diffusion-based cartograms correlates closely with the spatial patterns of the data that wants to be visualised. While smaller areas where there is a lot of variation in socioeconomic variables tend to be no longer obscured in cartograms, colour "*enhances the quality of both map types with strong visual attractiveness, even more so for maps produced using cartograms instead of conventional maps*" (Oyana, Rushomesa & Bhatt 2011: 113). Colour concepts from conventional mapping were therefore adapted for the cartograms, not only to support the comparative element, but also to increase the visual appeal and enhance the readability of the displayed topics. A special case is the colour scheme adapted from Worldmapper, which is used in all those maps where the countries remain the main map theme and should remain distinguishable (Figure 1.2 serves as a reference map for these colours). The background colour of the gridded country cartograms included in appendix C also corresponds to the colours from this colour scheme.

Additional data overlays that do not directly relate to the subject of a map (i.e. population as the underling base for a gridded population cartogram, or the choropleth visualisation of the actual topic) can be included where these map spaces remain empty. Useful data overlays can be data visualising the gridded cartograms in form of an atlas-style geographic display of the topography. The visualisation of the topography was therefore included in the applications section in those maps, where no additional choropleth layer was used. Furthermore, bathymetric information (about the topography of the oceans) which surrounds the gridded world cartograms was also included in these examples to enhance the visual appeal.

Map comparisons are not a single design element, but a feature that addresses the issue of map readability. The degree of distortion can be a problem for the map reader who is not familiar with cartograms, and even an experienced map reader may find some cartograms difficult to interpret. Including other map projections as a reference can therefore be a useful element that allows adjusting to the different projection. It also allows comparing familiar projections to the gridded cartogram to achieve an improved interpretation not only on the gridded cartogram itself, but of the data displayed on the cartogram. The key results include a conventional map projection as a reference map and a conventional density-equalising cartogram to allow a comparison and the interpretation of the new technique.

A different approach has been taken in the creation of the gridded country cartograms for the world population atlas (see appendix C): Here the original shape of a country was included as a grey background that is overlaid by the gridded cartogram. The physical shape therefore remains included, but is partly eschewed by the gridded cartogram, and no additional information is shown in the background map. This is a compromise to include a supportive element in the cartogram without including an additional full map display of the conventional map projection. The applications presented in chapter 6 include a thumbnail sized conventional map projection below the gridded cartogram, which has been done to give an indication of the original data shown in the gridded cartogram transformation.

3.6 Conclusion: Equalising population densities

The work on the methods started with the hypothesis that diffusion-based algorithm can be adjusted for a more accurate visual representation of geospatial information in cartogram form in order to address the aims of this research. This chapter gave an introduction into the basic principles and techniques that are needed for the adjustment of the cartogram technique. The concept of creating gridded cartograms addresses the problem of inaccuracy in the spatial base of conventional cartograms by aiming at a considerably improved resolution of the underlying basedata that is then applied to the cartogram transformation. The investigation of a new method followed an open and exploratory approach. As the search for a new method does not provide any standardised direction, this involved testing different paths of working with the set of GIS methods and techniques before the final solution presented here was found.

The steps necessary to create gridded cartograms start with essential preliminary considerations of appropriate data that bears the potential to be turned into gridded cartograms. Identified as ideal to tackle the weakness of existing cartograms were equally sized data units at a high resolution, that allow the cartogram to be created more independently from the arbitrary shapes and sizes of countries. How such data can be obtained for the further methodological efforts was elaborated in detail at the example of population data, which has been identified in the previous chapter as a key element in the understanding of the human geography and the complex human-environmental relationship in the context of global change research. With the new method investigated in-depth for population, it was then tested likewise with other kinds of quantitative geospatial data.

The discussion of suitable population data showed the efforts in creating a gridded set of data for the global population distribution and highlighted the problems of the different data sources that went into the generation of a gridded population of the world database (GPWv3). The changing quality of data in certain areas needs to be considered in the assessment of the resulting cartograms, as the basedata for a cartogram transformation significantly influences the resulting transformed map and decides on the validity and accuracy of the new map.

The actual methods for the gridded cartogram technique were explained, with the preparation of a vector grid from the GPWv3 population data in the ArcGIS software standing in the beginning of the efforts. Problems with inaccurate or non-existent data were investigated by suggesting alternative ways of generating a higher-resolution population grid. This was demonstrated for the highly variable areas of the Occupied Palestinian Territories using the manual interpretation of maps and aerial imagery to redistribute the population values from the GPWv3 population grid onto a higher-resolution grid. For the city of London it was shown, how large scale population data can be converted into a high-resolution population grid suitable for a gridded cartogram transformation.

The final step in the creation of creating gridded cartograms was then explained with an investigation of the basic principles of the transformation of gridded population datasets using a diffusion-based density-equalising algorithm. The technical procedure was then described and the different options to influence the cartogram transformation were highlighted. For the presentation of gridded cartograms, a design strategy was introduced that concentrated on elements that take the specific nature of gridded cartograms into account.

Chapter 4 The human shape of the planet

4.1 Introduction

The approach for the creation of gridded cartograms has been introduced as an alternative concept for a more accurate way of using cartogram techniques. The method introduced is not entirely new, but builds on and aims to improve the use of an existing diffusion-based density-equalising algorithm. The resulting maps created with this new approach need to be evaluated to assess the success and value of the methodology in comparison to other approaches. This chapter introduces the basic results for an alternative mapping of population distribution as the basic outcome of the methodology and evaluates, whether the outcomes constitute an improvement of the existing Worldmapper population cartogram.

Section 4.2 introduces a new world population cartogram using the gridded cartogram technique and compares is appearance based on different grid resolutions. The effects of creating cartograms that are not restricted to the land surface are also shown by creating an experimental version of the gridded world population cartogram that covers the full spatial extent of the globe. Section 4.3 investigates how the technique can be applied to larger scale versions of gridded population cartograms. Maps are presented for the individual countries of the world, and the effects of different population structures on that scale are evaluated. In addition, the gridded population cartograms using a refined and improved population grid at regional (for the Occupied Palestinian Territories) and urban level (for the city of London) are introduced and assessed. The outcomes are then summarised and discussed in section 4.4 with a focus on the different scale cases for gridded population cartograms.

4.2 A gridded world population cartogram

The gridded world population cartogram can be seen as the primary outcome of this research, as the exploratory approach started with an investigation into the improvement of the original Worldmapper population cartogram[57]. The differences between the original cartogram and the new version therefore stand exemplarily for the basic achievements of new technique that allow an evaluation of its further potentials and limitations. The initial inspection in this section is therefore done in more detail than the subsequent maps in the remaining sections of this chapter.

[57] The assessment of the map results will be done using the Worldmapper colour scheme as a guiding visual element throughout the global and country maps presented in this chapter (Figure 1.2 can be used as a reference map).

4.2.1 A gridded world population cartogram

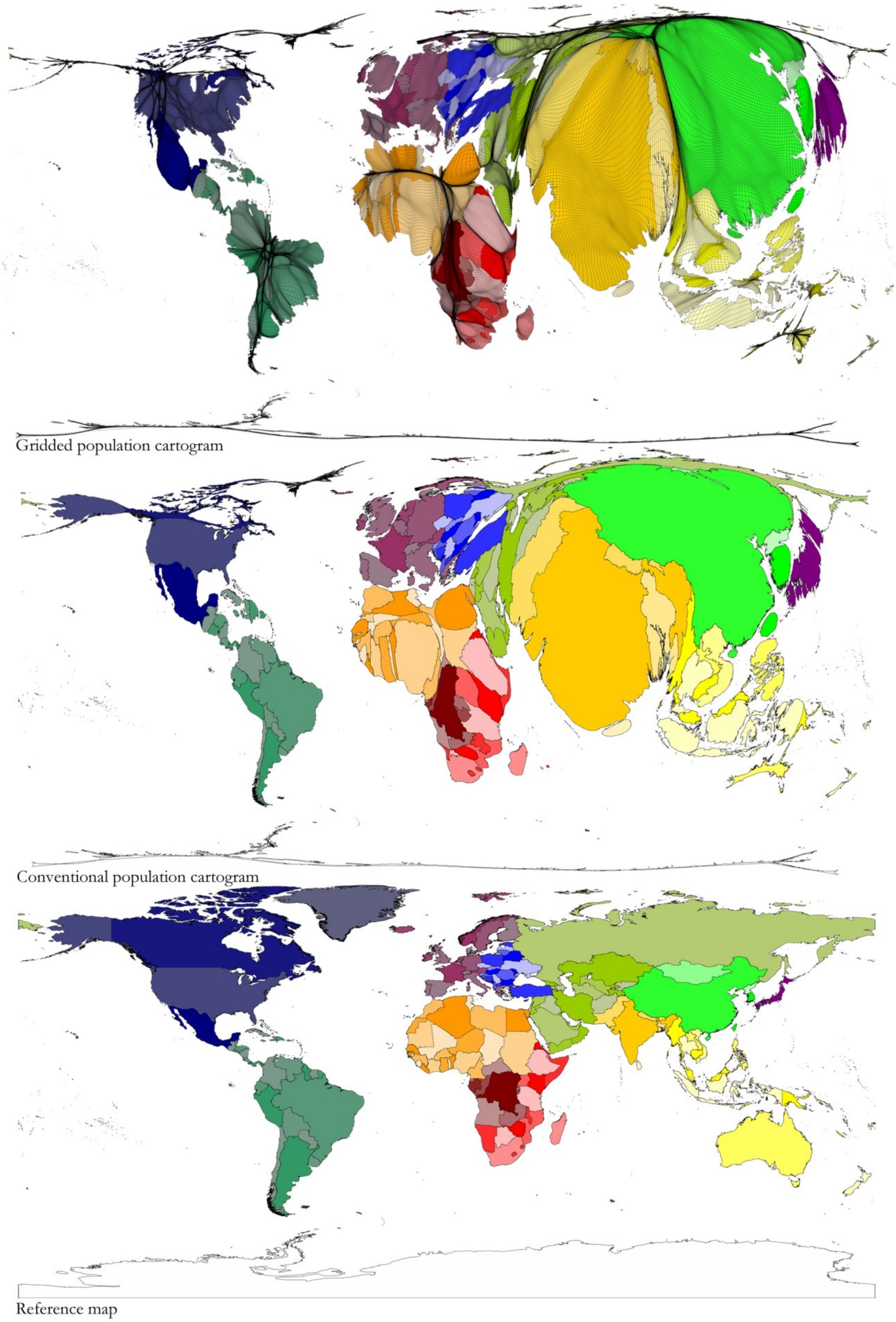


FIGURE 4.1: COMPARING POPULATION CARTOGRAMS AND A CONVENTIONAL MAP
(own depiction by the author using data from CIESIN & CIAT 2005, UNPD 2011)

The transformation of the new map can be compared to the original (*conventional)* population cartogram and a conventional map projection (Figure 4.1). Both population cartograms are a map transformation based on population figures, and both use the same algorithm in their transformation, yet look very different. These differences are the effects of the gridded approach that has been developed in this research. The shapes of the countries in the original Worldmapper population cartogram still allow in many cases a comparison with the original country shapes, often mainly differing in their (sometimes extremely altered) sizes. The shapes of the corresponding countries in the new map, based on the gridded cartogram transformation, show a sometimes very different appearance of the individual countries.

In the new map, the area that represents China appears to have been squeezed together in the western region and extended hugely in the east. The main part of the United States is slightly bigger in the east as well, but more strikingly, Alaska in the north-western corner of the map almost disappears in the gridded cartogram, only being a small long stretch on the global view. Few other countries, such as Germany or Poland in Western Europe, appear to be more similar to their original land area shape. The overall size of the countries generally matches the spatial extent of the countries in the original Worldmapper cartogram, while the shapes of the countries appear to be significantly different in many cases.

The relationship between the shapes of the countries and the map transformation can be assessed by examining the appearance of the transformed grid itself and interpreting this in comparison to the changing shapes of the country outlines (which are superimposed onto the grid and have been visualised on the resulting in a Worldmapper colour style). The interaction of the grid and the country shapes help to get a clearer picture of the corresponding and related patterns. This comparison and analysis can be executed in detail for almost any area of the land surface.

China is a dominating feature on the map, with its huge extent and large area. When taking the underlying grid into account, the distorted shape of the country corresponds to some apparent variations in the grid pattern. The extremely reduced western parts of the country (Figure 4.2, *see below*) follow a dominating reduction of the size of the grid cells along the transformed western borderline. This is one of the regions where the grid merges into one of the very dense accumulations of grid cells. In contrast, the expanded size of the east of China is accompanied by a more even distribution of larger grid cells. There is some variation in that expanded area, and some areas are even more expanded than others, but generally the east of China (together with India in South Asia) strikes out as one of the largest continuous areas with large grid cells.

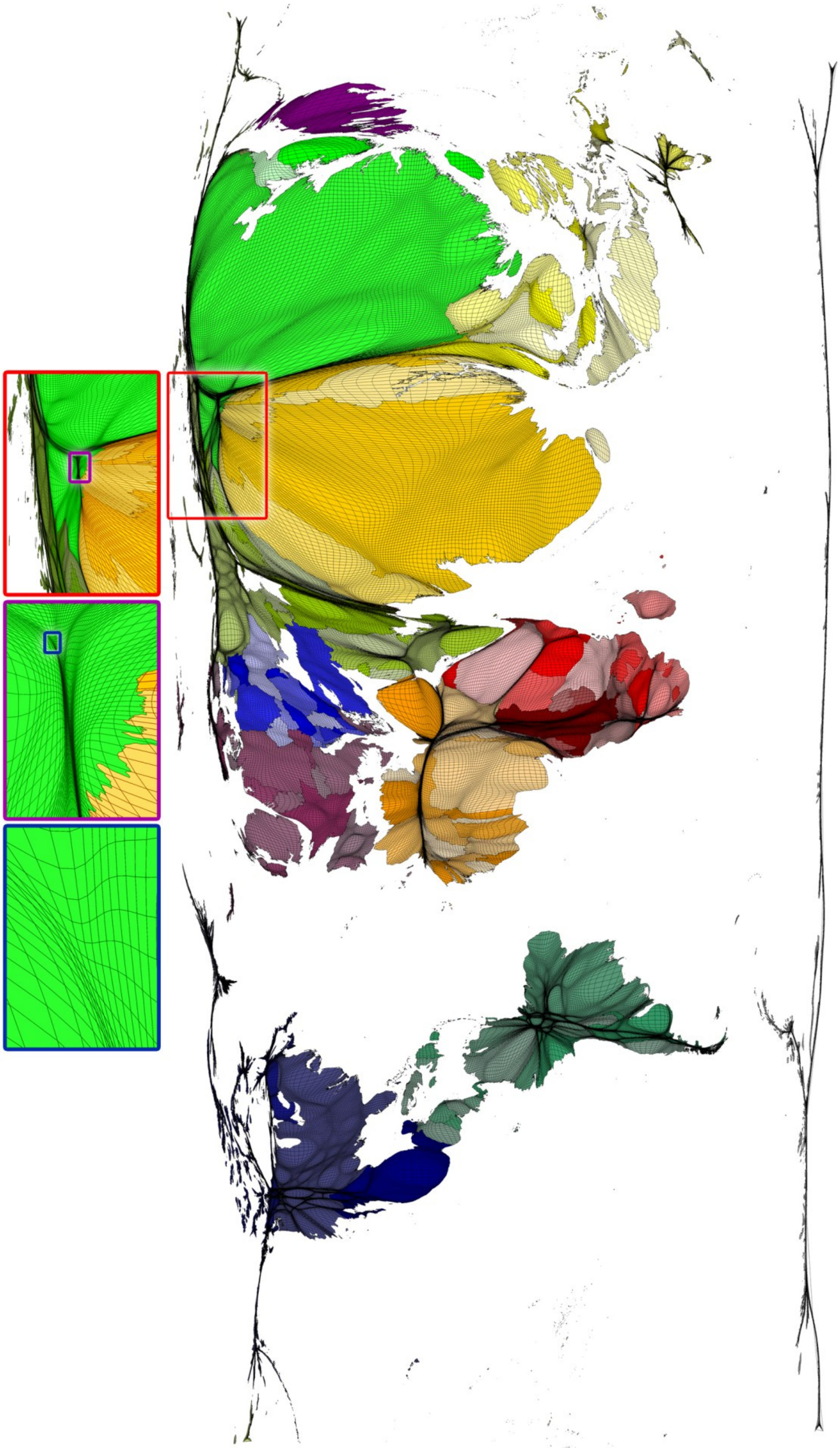


FIGURE 4.2: GRIDDED WORLD POPULATION CARTOGRAM
Transformation based on a ¼° population grid containing 2015 population estimates. Above the map are magnifications of the correspondingly coloured rectangle areas with growing scales from red to the blue. See Figure 1.2 for a colour reference to the countries
(own depiction by the author using data from CIESIN & CIAT 2005)

On a first conclusion of the appearance of gridded population cartogram (Figure 4.2), some general patterns and characteristics can be highlighted: The outer shape of the grid-covered areas displays a hugely dominating grid-covered bulging area in the eastern half of the map. The bulging character of the outer shapes is a prominent feature throughout large parts of the map, while some other parts, such as in the north-western corner are reduced to a minimum area, remaining only very thin artefacts.

In some areas, such as that corresponding with the South American continent, this succession of separate bulges can be observed in a regular manner, while in other areas, such as those corresponding roughly to the location of East and South Asia, they are more characterised by extremely large and more homogeneous bulges. The overall impression of the emerging shapes almost makes a three dimensional appearance. Similar to maps showing isolines, the merging cells remind the viewer of merging contour lines that display steeper slopes, while the areas with the larger grid cells appear to be blown out of the map surface like inflated balloons.

When looking at the grid in more detail, it can also be seen that the grid cells themselves generally have a rectangular shape, although not always a regular square but often a more distorted shape. The grid lines themselves do not follow a regular oblong pattern, but are oriented at the grid patterns of their surrounding vicinity. In their surrounding context they are thus quite regular and each grid cell connects accurately to the surrounding grid cells. As the gridded cartogram is based on a transformation of vector data, and the results are put out in that format, the map allows zooming smoothly into the map (Figure 4.2 shows a series of magnifications above the main map). The magnified region is displayed without any loss in display quality and the lines of the grid readjust to the selected zoom level. Hence, the map result can also be assessed at the areas where the grid appears to merge completely in the overall view extent.

The series of enlarged views into the Himalayan region where the grid cells shrink to a dark, almost homogeneous region on the map shows, that in detail the same patterns and characteristics appear as in the large grid cells of the exposed bulging areas, only at a much larger scale. The general appearance of the map features is not different here, and here as well the grid cells are regularly connected at their edges. This connection is seamless and generally achieve at almost right angles, which can be explained by the principle of the density equalising algorithm. The transformation applied to a gridded high-resolution dataset therefore follows the principles of a conformal map projection without gaps or an offset between the individual grid cells. The size of the original grid cells therefore determines the spatial accuracy that is preserved in the transformation.

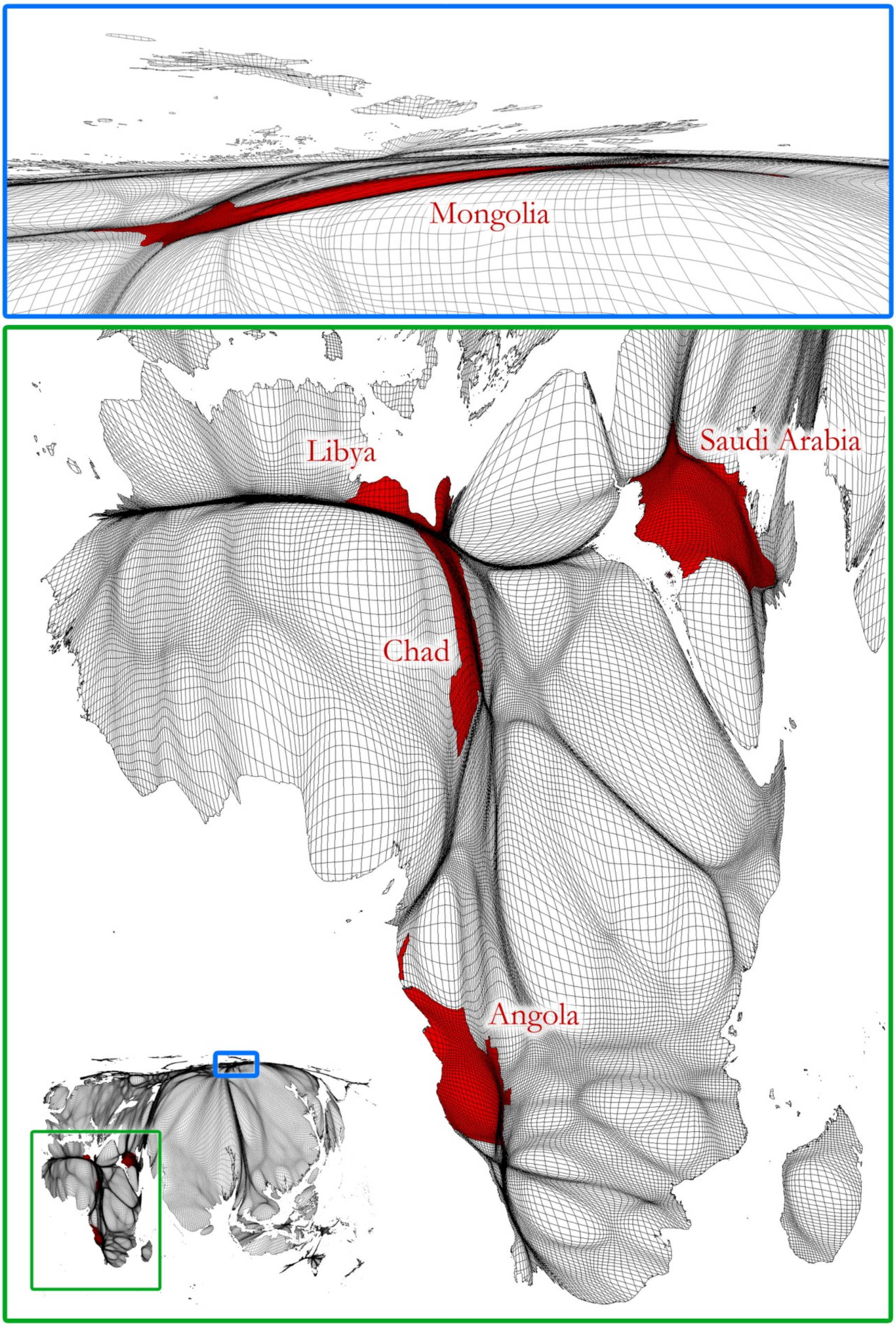


FIGURE 4.3: ASSESSMENT OF LOWER-QUALITY POPULATION DATA IN THE GRIDDED CARTOGRAM
Highlighted are the five countries with the least accurate population estimates in the GPWv3 population grid (lowest resolution of the population reference data, see appendix B). The enlargements correspond to the coloured rectangles in the thumbnail map in the bottom left corner (own depiction by the author using data from CIESIN & CIAT 2005)

Another assessment of the results can be made when looking at those areas of the map which according to the documentation of the GPWv3 database bear the least resolution of the underlying population data. These are the regions with the presumably least accurate population estimates, so that a look at the population patterns is of special interest to assess the effect of data quality on the map transformation.

The five countries with the lowest resolution of administrative reference areas in the originating population grid are Saudi Arabia, Chad, Mongolia, Angola and Libya (see section 3.3.1.2 for details and appendix C for the reference data). The observations made for all five countries are very similar: The countries in question generally are not the most prominent features on the global map[58], although they are also not only small countries (in terms of total population). Their population sizes range from 2.5 million (Mongolia) to 20.3 million (Saudi Arabia), thus they also cover some countries from the lower spectrum of the medium sized countries.

The emerging shapes of the five countries with less accurate population estimates in the gridded population cartogram (Figure 4.3) do not match their original physical shape on a conventional map projection. They show, however, some internal variation in the underlying grid, such as that Saudi Arabia features smaller grid cells towards the eastern and northern region, with a centre of larger grid cells in the southwest. Libya has two areas with larger grid cells in the northwest and northeast respectively, and a north-south stretching extent of larger grid cells in the south. Generally, the countries are embedded in the changing patterns in the population grids that partly connect neatly to the overall patterns of the world population grid. Even in the sparsely populated area of Mongolia some variations and differences can be spotted in the gridded cartogram, while the country itself is as much influenced by its surrounding grid patterns. A particular difference in the countries' distribution of the grid compared to other countries (with presumably higher accuracy in the population grid) cannot be made. This is especially the case from a global perspective, but can generally also be stated for detailed views of the relevant regions.

To conclude the observations for the various depictions of the gridded world population cartogram, the new map allows a detailed interpretation of the emerging patterns as shown by the population grid. The largest grid cells correspond to the highest population numbers, with gradual transitions to the least populated areas on the land surface. While the underlying grid consists of an equally sized raster, the grid

[58] The geographical conditions in these countries are also characterised by large desert areas, which contribute to the emerging shapes in the transformed maps. However, this characteristic alone does not explain the lower resolution of the reference areas, as other countries in those regions with similar geographic assets feature higher resolutions in the administrative reference areas (see appendix B).

cells retain a geographical reference with an accuracy as precise as the size of the originating grid itself (in this case 0.25 decimal degree). The emerging patterns do not only reveal the extent of the most densely populated regions of the planet, but also give a detailed picture of the population distribution throughout the various regions. The transformed map differs significantly from a conventional world map through its idiosyncratic deformation of the continents and the country shapes, but it is also distinctively different from the Worldmapper population cartogram that follow the same basic principle of distorting the physical shape of the world by population values.

4.2.2 A highly detailed gridded world population cartogram

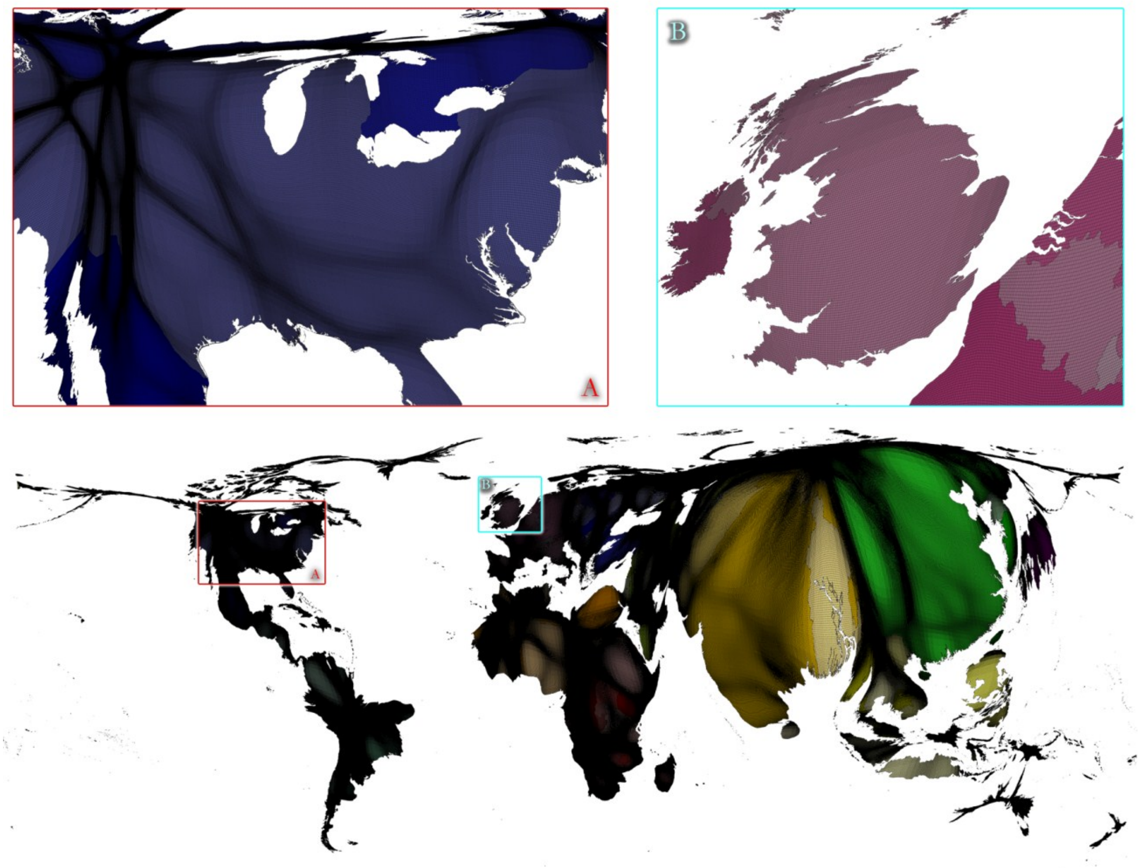


FIGURE 4.4: GRIDDED WORLD POPULATION CARTOGRAM BASED ON A HIGH RESOLUTION GRID
Transformation based on a 2.5' population grid of 2015 population estimates. The top images show magnifications of the correspondingly coloured rectangle areas in the full cartogram (own depiction by the author using data from CIESIN & CIAT 2005)

The gridded world population cartogram was also created using the highest possible resolution data from the GPWv3 database, which is the 2.5 arc minute population grid. This constitutes a sixfold higher resolution than the ¼° grid[59] that was used in the

[59] The ¼° resolution can also be expressed as a 15 arc minute resolution, which is six times larger than the 2.5 arc minute resolution.

gridded cartogram transformation presented in the previous section. The result is a high-resolution gridded world population cartogram with a very fine grid that makes an adequate visualisation on a smaller size more difficult, as the multitude of distinctive lines in the grid result in an almost coherent area in many parts of the map (Figure 4.4). The high-resolution cartogram has a comparable overall shape like the ¼° world population cartogram (as shown in Figure 4.2). As the much finer resolution of the grid cells makes it hard to identify individual grid cells in the resulting map, further magnifications were added to demonstrate the details (Figure 4.4, *top images*).

At a higher magnification the 2.5 arc minute gridded cartogram reveals the distribution of the grid cells, so that prevailing patterns become more apparent. The differences between larger cells and smaller cells seem much less striking than in the lower-resolution cartogram[60]. Nevertheless the smallest sized grid cells in some areas, such as the mid-western parts of North America, can clearly be distinguished from the areas with larger grid cells, such as those in the eastern region there.

The highest population value in a grid cell of the 2.5 arc minute grid is 1,870,454[61], compared to the highest value of 19,340,678 people in the ¼° resolution grid[62]. This explains why the largest grid cell shown in the higher-resolution grid is *only* approximately 1.8 million-times larger than the smallest fraction with only one person living there (and the 0 value cell being close to 0 size area), compared to the largest grid cell size of approximately 19 million times larger than the smallest populated area in the ¼° grid (see statistics displayed in Figure 3.6 & Figure 3.7). At the same time, many more grid cells need to be displayed in the finer grid. To be able to see those finer differences one must zoom in at a very high level, but one loses the overall perspective on a normal computer screen or a printed map on an A4-sized paper.

On the magnification of the British Isles on the 2.5 arc minute-population cartogram (Figure 4.4, *top right*) it can also be seen that there appears to be a more gradual transition between the most expanded grid cells and the smaller sized grid cells. Similar transitions become visible in regions with much higher variation in the population distribution, such as in North America (Figure 4.4, *top left*).

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[60] An important constraint here besides the described data and display issues is the technical capability of ArcGIS and the cartogram generating scripts used in this work. They can process a raster of an extent of maximally 4096 cells (width or height). Any higher resolution therefore has a negative effect on the desired accuracy of the gridded cartogram. A much higher resolution grid has even a negative effect on the processing times, as the higher resolution needs to be calculated down to the maximal resolution.

[61] Located in the Chengdu area of central China.

[62] Located on the Arab Peninsula in the city of Sana'a, Yemen.

4.2.3 An experimental gridded global population map

A more experimental approach to the creation of the gridded world population cartogram included the transformation performed on the full extent of the grid using the ¼° resolution. Cartogram transformations are usually applied to land area, not least because this is where the data to be visualised is located. Due to the experimental and open approach taken in this research, this was not seen as a restriction or limitation, but included the investigation of the full range of options are possible with the newly developed technique to tests its capabilities. The experimental world population cartogram for the whole planet therefore used the full ¼° grid involving the land area and the sea alike, making no difference between the two and taking every grid value equally into account in the process of transformation. As the GPWv3 does not include data about the areas outside land, the general assumption of 0 people living in this space was made and applied to the grid before the transformation (see section 3.4.3.3).

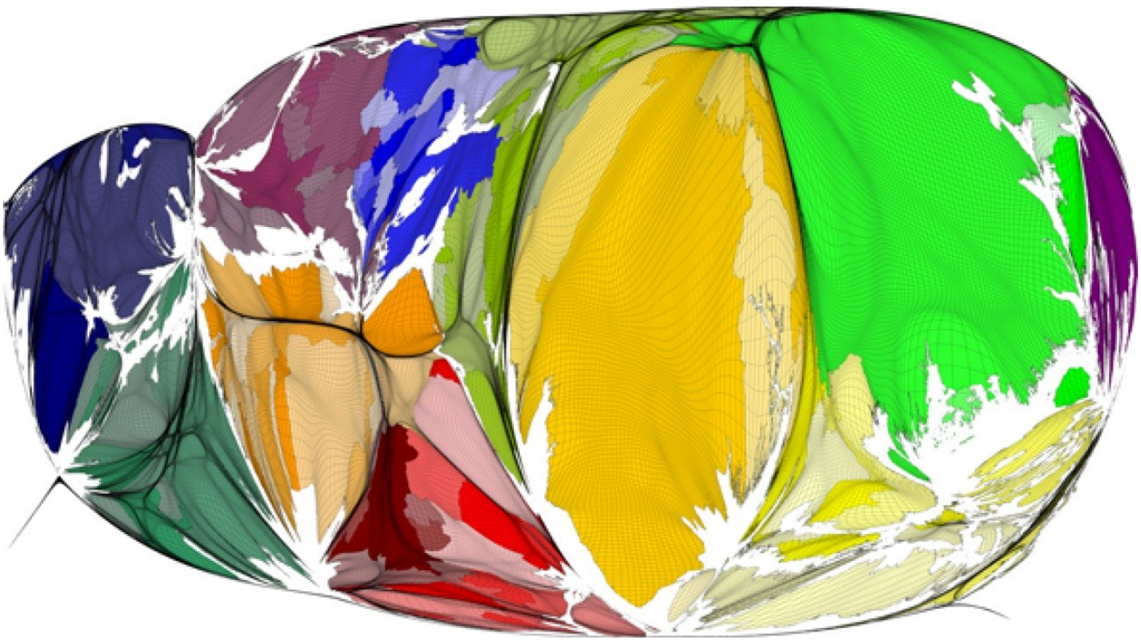


FIGURE 4.5: EXPERIMENTAL GRIDDED POPULATION CARTOGRAM
Cartogram transformation based on a ¼° population grid generated over the whole surface of the planet (including the oceans). The grid over the sea is omitted in this map to highlight the appearance of the land area and the countries (see Figure 1.2 for a reference map) (own depiction by the author using data from CIESIN & CIAT 2005)

The gridded global population cartogram based on the full population grid of the whole planet has been visualised using the additionally transformed shapes of the countries displayed in the Worldmapper colour scheme, and showing the transformed grid lines only over land areas only in order to be able to compare their shapes to other maps presented in the previous sections (Figure 4.5). The resulting visualisation is an almost egg-shaped representation of the continents cramped together with very little (but existing) spaces between them, rounded at the edges of the land areas. Shapes of the different countries are similar to the shapes in the gridded world population cartogram but generally appear with a much larger distortion, which is even more extreme especially towards the edges. Small parts of the sea areas are visible in this depiction because the merging grid lines has been removed, which would otherwise have resulted in almost dark spaces here similar to the least populated areas over land.

4.3 Matters of scale

The different depictions of the gridded world population cartogram provided a global view of the transformed social spaces of humanity. The general observations suggest already a more geographically accurate perspective than comparable cartograms, while still using the concept of distorted spaces as a key element of the visualisation. The higher level of detail shown raises the question of whether the technique is suitable for application to scales other than the global perspective, as this has the potential to allow even more detailed insights into population patterns at almost any resolution. With a general suitability at different levels, this approach could be valuable for reducing the gap between conventional map projections and the more sketchy nature of many cartograms. As outlined in chapter 2, this question was investigated by using smaller areas at a larger scale as the base for the gridded cartogram transformation.

Using the gridded cartogram technique on various scales and for different defined areas may also be valuable to enhance the level of detail that can be achieved for each of the areal units that is looked at separately. The appearance of the gridded world population cartogram is determined by the differences between the largest and smallest global population values, which in some areas with lower populations or less regional variation may be less suitable to show the regional population distribution. Neighbouring areas also affect the patterns because of the density-equalising effect of the algorithm, so that it can be useful to look at larger scale areas independent from the global picture, just as conventional maps are specifically adapted in their level of detail when changing the scale.

4.3.1 A world population atlas

The series of gridded country population cartograms created in the course of this research resulted in the creation of the Worldmapper world population atlas which was published as a new content feature on the Worldmapper project website[63] (Hennig 2009). The full series of maps included in the online world population atlas is included in the appendix of this thesis (see appendix C). The maps in the appendix show the original layout used in the online version, including the additional visual elements as described in the methodology (see section 3.5).

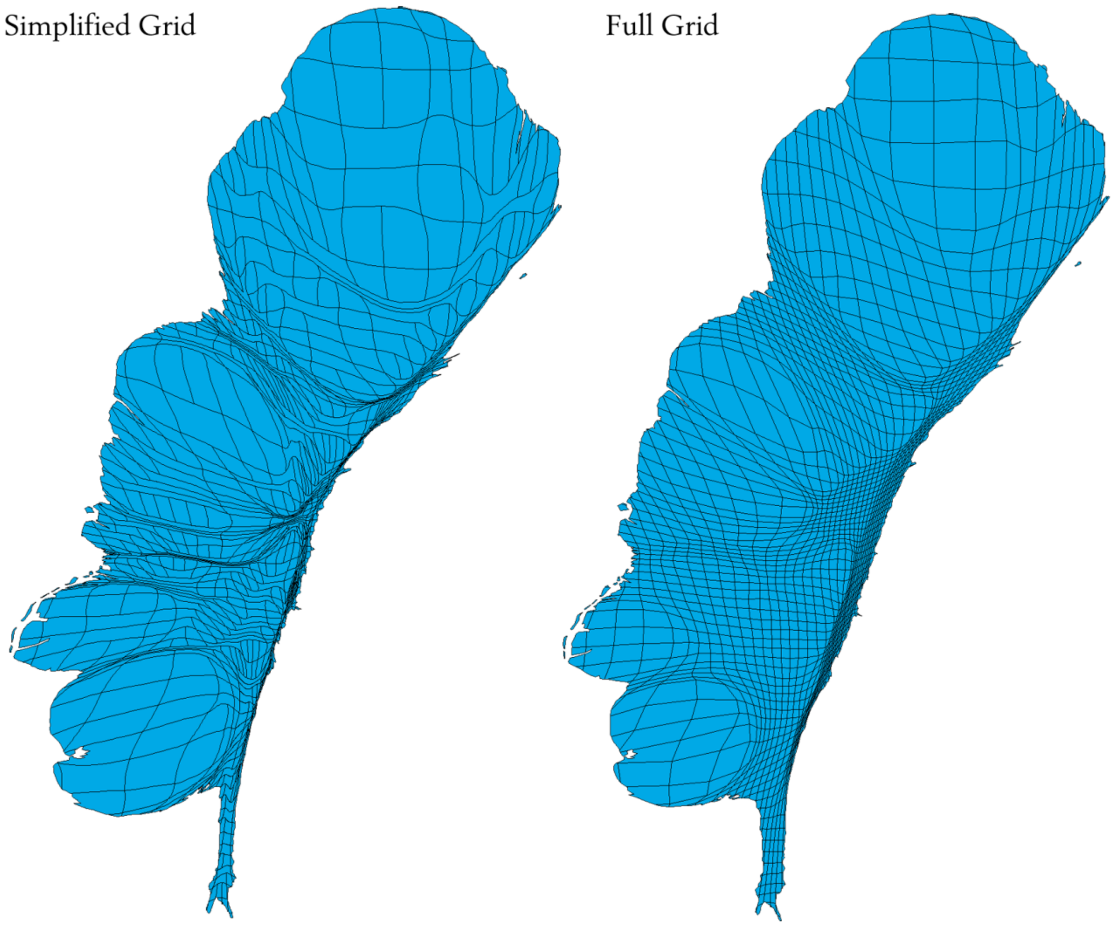


FIGURE 4.6: COMPARISON OF GRIDDED POPULATION CARTOGRAMS OF TAIWAN
Transformation based on a simplified (left) and the full (left) versions of the 2.5' population grid. The simplified grid merges neighbouring polygons with the same population values (own depiction by the author using data from CIESIN & CIAT 2005)

Some of the maps[64] included in this results section show revised versions of the gridded country cartograms that were created without the simplified polygons that are part of some of the online maps. A comparison between two of the maps shows that the overall shape of the cartogram remains the same in both approaches, but that a

[63] The online version of the world population atlas is integrated in the internet presence of Worldmapper and also directly accessible via the address http://www.worldpopulationatlas.org (Hennig 2009). The release was accompanied by some press coverage, which helped to present the maps to a wider audience and get responses that supported the further research process (see e.g. AkhbarWay 2009, BBC 2009, Cervera 2009, Mail Online 2009, McCafferty 2009, UoS 2009, Pernsteiner 2009).

64 The maps created for the online atlas (as shown in Hennig 2009) can be distinguished from the newly created maps by their distinct layout based on the visual style of the Worldmapper project.

generalisation of the polygons also results in changes in the internal structure that suggest a lower accuracy in the grid pattern (Figure 4.6). For the full series of country cartograms, this disadvantage was accepted to be able to produce an individual map for every country in a reasonable time.

For an interpretation of the gridded country cartograms the initial statement can be made that they feature similar overall patterns as the gridded world population cartogram, because their technical procedure followed the same steps, and the underlying principle therefore leads to the same general outcome. More populated grid cells are increased in their size relative to their absolute population values, and less populated grid cells are reduced in size accordingly. The varying distortion of the grid cells is smoothed out in areas where larger differences appear to preserve the interrelation of each grid cell towards its original neighbouring grid cell. The population patterns get the same appearance as on a global scale with bulging bubbles of populous areas and converging contours in the least populated regions of a country.

The shapes of the countries appear more unique than their corresponding areas on the gridded world population cartograms with more distinct contrasts between the most and least populated areas. This results in these very characteristic shapes for every country, which usually look very different from the country's original physical shape. The shape and the grid pattern add a visually appealing feature to each map which makes the map series for the world population atlas rich in visual variety. The Worldmapper colour scheme adds to this very characteristic eye-catching appearance, which becomes very apparent when looking at a collage that gives a bird-eve view of the map collection (Figure 4.7, *see below*). The cartographic value also depends on the expressiveness of the maps and their ability to give an insight into the topic shown in them. A visually appealing character may support the engagement with the map, but this then needs to be substantiated by the quality of the content displayed in the map.

The level of detail at which each of the gridded country cartograms can be analysed differs between the maps. This depends a lot on the original size of a country and partly also on the accuracy of the underlying population data. Both factors determine the further value of the maps considerably. The original (physical) size of a country from which a population cartogram is generated determines the overall accuracy of the gridded cartogram. The larger a country is, the broader become the population patterns that are shown here. The following selection provides an overview of the different characteristics of the 171 maps of the atlas. It investigates the advantages and disadvantages that this technique has for a national-level depiction of population distributions with the currently best available set of consistent population data.

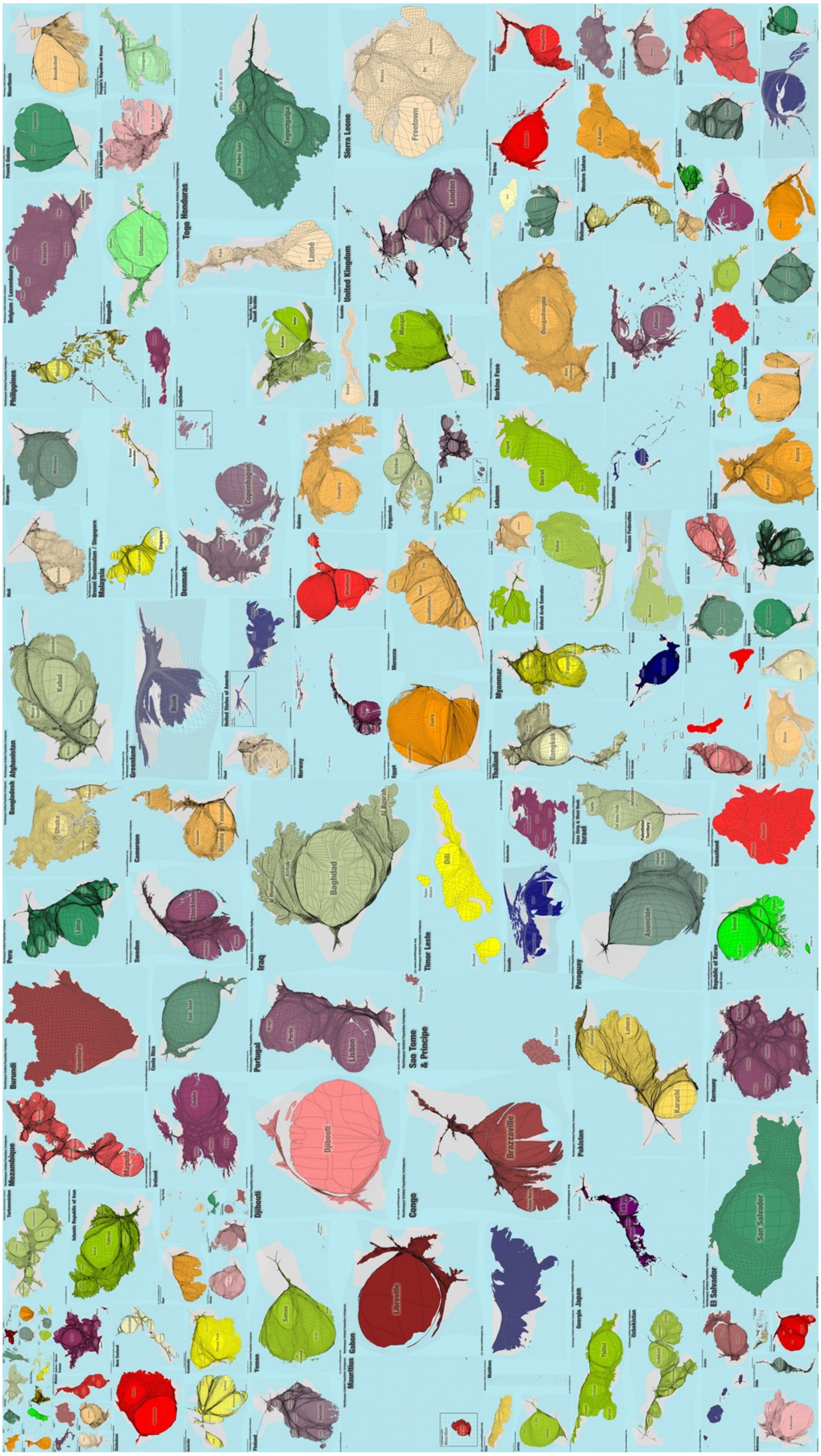


FIGURE 4.7: OVERVIEW OF GRIDDED COUNTRY CARTOGRAMS
See appendix A for a full view of the country cartograms (own depiction by the author)

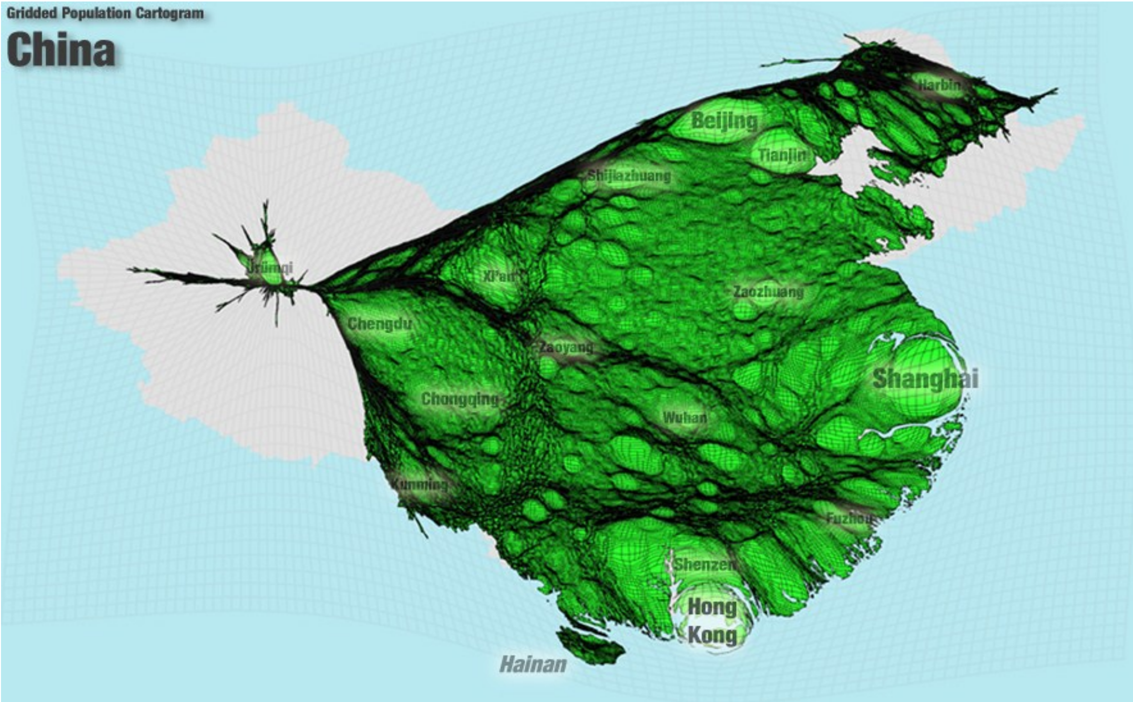


FIGURE 4.8: GRIDDED POPULATION CARTOGRAM OF CHINA
Transformation based on a 2.5' population grid of 2015 population estimates
(own depiction by the author using data from CIESIN & CIAT 2005, Wick 2010)

The example of China (Figure 4.8) demonstrates the character of larger countries displayed in the population cartograms. The underlying 2.5 arc minute grid results in a high variability in the patterns that emerge in the cartogram. At the same time, the patterns appear more accurate because no neighbouring areas outside China affect the overall pattern. The cartogram shows the stark contrast between the densely populated coastal provinces in the east and the sparsely populated west. The densely populated east appears like a bubbling sea of people, while the western areas reveals one still distinctively visible major population centre (Urumqi), and show other urban centres only when zooming into these areas in more detail. Like in the world map this cartogram can be examined at all scales, and all grid cells can be traced to their approximate original rectangular shape. While this characteristic is especially relevant for investigating gridded cartograms that comprise larger areas like the world, or China, it is a general feature of all gridded cartograms and will therefore not be repeated in the further evaluation of the country maps. The variation of the population patterns appears more distinct in the country cartogram than in the world cartogram.

Smaller countries can often be seen more similar to their original physical shapes, especially when they have a generally more coherent population distribution. In such cases, seen e.g. at the Netherlands (Figure 4.9, *see below*), the differences between the highest density population centres and the slightly less populated areas can still be seen, but the overall distribution stays much more uniform at this scale.

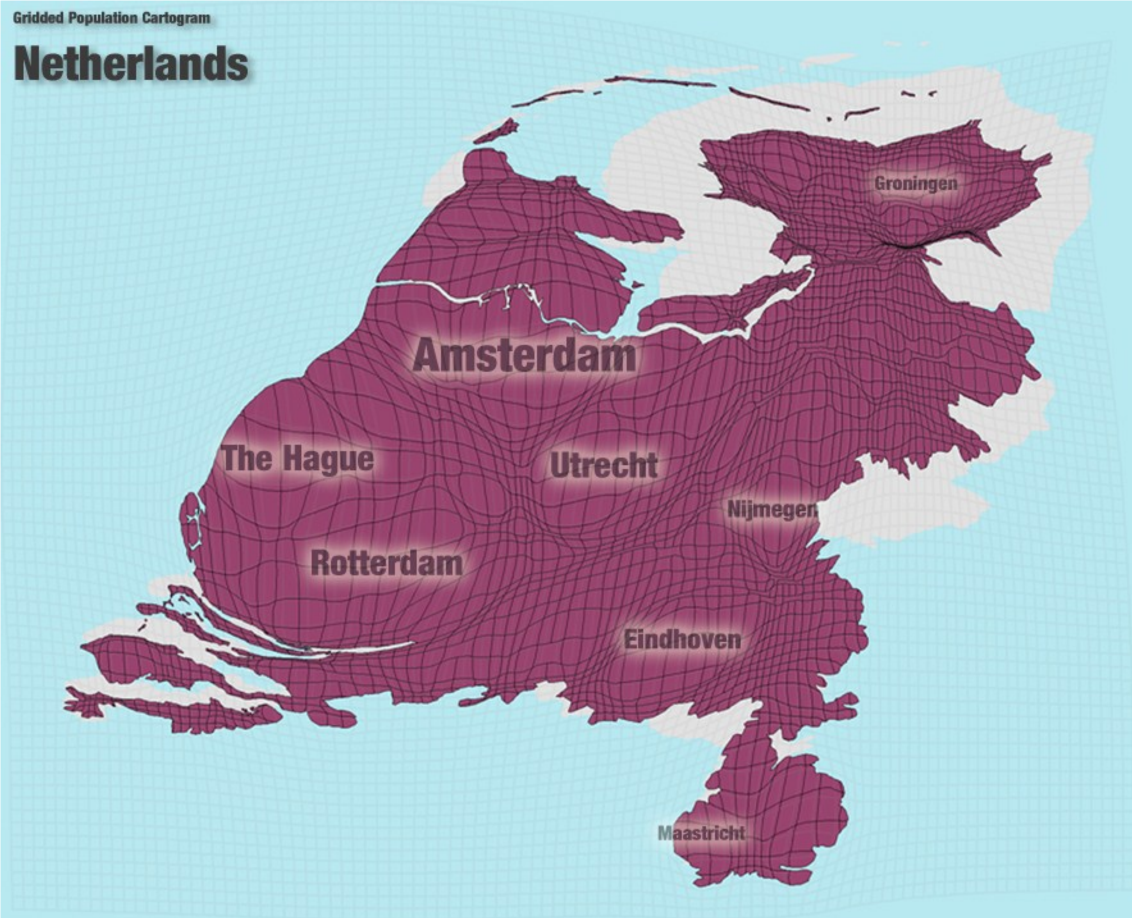


FIGURE 4.9: GRIDDED POPULATION CARTOGRAM OF THE NETHERLANDS
Transformation based on a 2.5’ population grid of 2015 population estimates (own depiction by the author using data from CIESIN & CIAT 2005, Wick 2010)

Other similarly sized countries but with larger differences in the population distribution show these differences very extremely and result in distinctively different shapes. One example of that is Sri Lanka (Figure 4.10) with a sparsely populated north and a densely populated south.

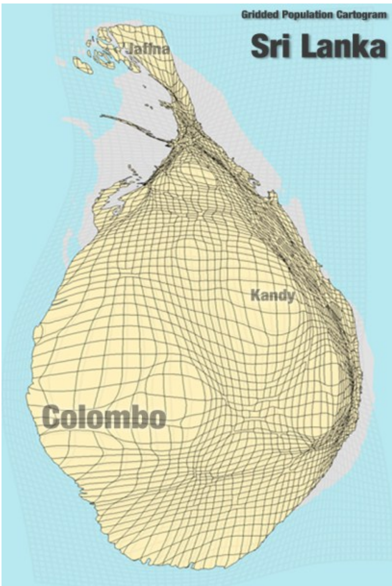


FIGURE 4.10: GRIDDED POPULATION CARTOGRAM OF SRI LANKA
Transformation based on a 2.5’ population grid of 2015 population estimates (own depiction by the author using data from CIESIN & CIAT 2005, Wick 2010)

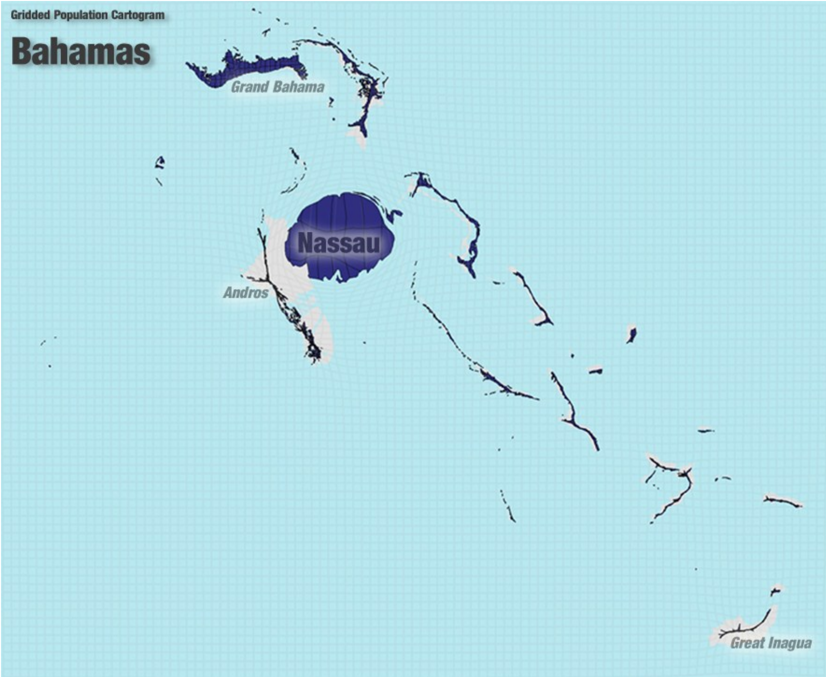


FIGURE 4.11: GRIDDED POPULATION CARTOGRAM OF THE BAHAMAS
Note on Figures 65 & 66: Transformation based on a 2.5' population grid of 2015 population estimates. The islands of the Maldives are considerably smaller than the grid and are hardly visible in the cartogram (own depictions by the author using data from CIESIN & CIAT 2005, Wick 2010)

FIGURE 4.12: GRIDDED POPULATION CARTOGRAM OF THE MALDIVES

Some examples, such as the Bahamas (Figure 4.11), have a less advanced value, as they *only* reveal which islands are the most inhabited, and which remain less populated, but show no further variation. Countries with only very few grid cells have the least interpretative value. The Maldives (Figure 4.12) and many other countries composed of one or several small islands are too small to be adequately covered by the 2.5 arc minute grid, so that their gridded cartograms remain meaningless at this resolution.

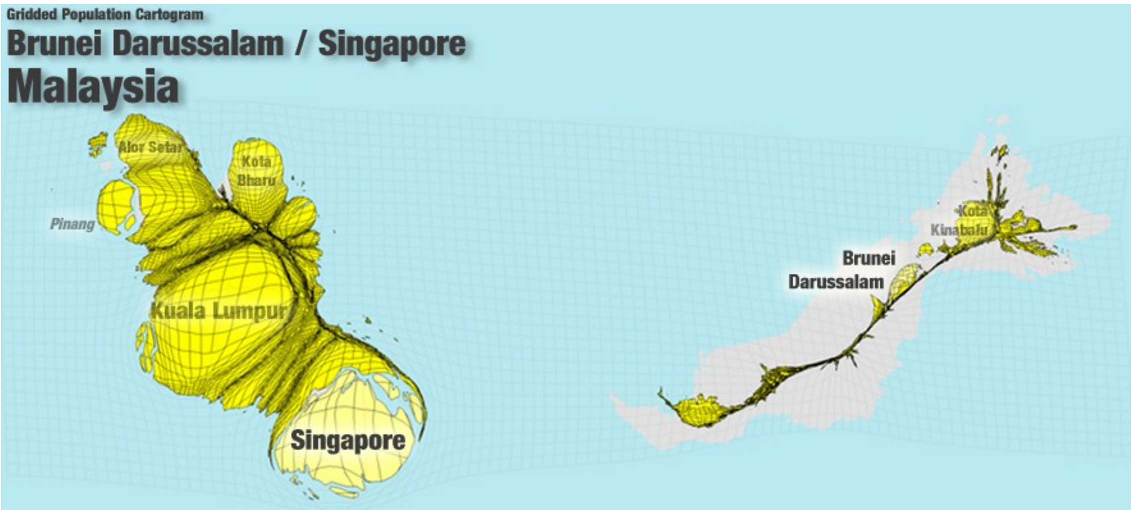


FIGURE 4.13: GRIDDED POPULATION CARTOGRAM OF MALAYSIA, BRUNEI AND SINGAPORE
Transformation based on a 2.5' population grid of 2015 population estimates
(own depiction by the author using data from CIESIN & CIAT 2005, Wick 2010)

If a higher resolution grid is not available, very small countries are therefore more sensible to be mapped together with their neighbouring country rather than as separate gridded population cartograms from only a few grid cells. Singapore and Brunei as part of the gridded cartogram of Malaysia (Figure 4.13) show these two countries in their regional context and demonstrate Singapore's relatively large significance in the regional population distribution. The map also shows Brunei as one of the few populated areas on the northern part of the island of Borneo.

The generation of gridded cartograms on country level is also capable of making the differences between urban and rural populations visible. The gridded cartograms do not only show the urban areas as big bulges, but represent every person that lives in the mapped area. Since the cartogram gives every person the same amount of space in the map extent, the projection treats rural populations just as urban populations.

FIGURE 4.14: GRIDDED POPULATION CARTOGRAM OF BANGLADESH

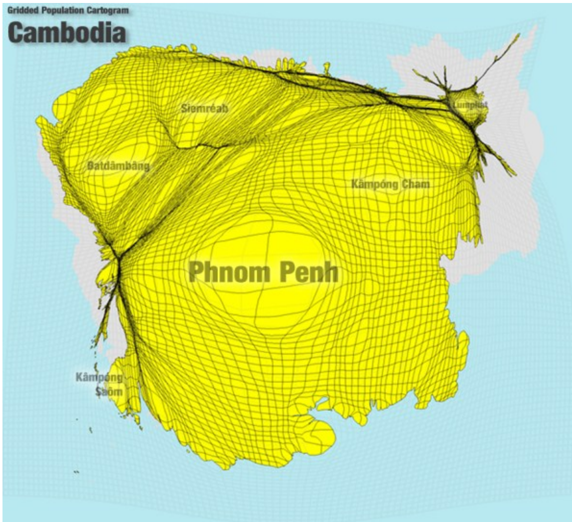


FIGURE 4.15: GRIDDED POPULATION CARTOGRAM OF CAMBODIA

Transformations based on a 2.5' population grid of 2015 population estimates (own depiction by the author using data from CIESIN & CIAT 2005, Wick 2010)

The examples of Bangladesh (Figure 4.14) and Cambodia (Figure 4.15) illustrate how large rural populations appear in gridded cartograms. Both countries are amongst the least urbanised countries with a larger geographical extent and a larger total population within its borders. Bangladesh's rural population for 2010 was estimated to be at 72%. Cambodia's rural population share was even higher with approximately 77% people living in rural areas (UNPD 2008, UNPD 2009, UNPD 2011).

The patterns emerging in the gridded population cartograms of Cambodia and Bangladesh are similar in their characteristic appearance, despite their differences in shape and distribution. Similar is the large extent of medium sized and much less distorted grid cells in large parts of the map. These relate to and therefore reflect the large and evenly populated rural areas. Only few areas strike out from this pattern. These are the most densely populated urban centres, such as the capital cities (Dhaka in Bangladesh and Phnom Penh in Cambodia). Compared to much more urbanised countries, these urban areas are much less separated from the huge surrounding rural areas. The appearance of the gridded cartogram is shaped by a smoother urban-rural transition of these large rurally characterised countries.

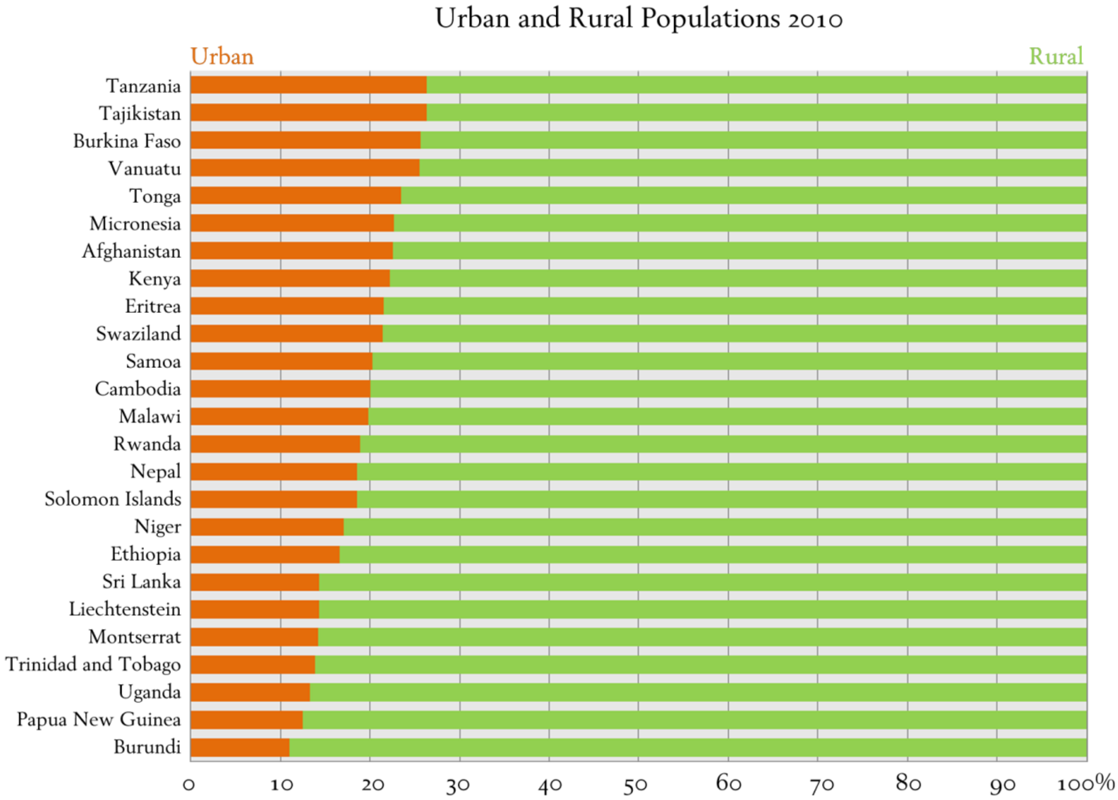


FIGURE 4.16: POPULATION DISTRIBUTION IN THE MOST RURAL COUNTRIES
Shares between urban and rural populations in the most rural countries in 2010. The data must be seen as a rough indicator for the population shares, as the two categories cannot be clearly separated and vary in their national context
(own depiction by the author using data from UNPD 2009, UNPD 2011)

Gridded cartograms are therefore capable of visualising countries with large rural populations, just as the most urbanised countries (Figure 4.16). The differences between Cambodia and Bangladesh reveal the varying distributions of rural populations and how this is shown in the gridded cartogram. The gridded cartogram of Bangladesh shows generally smaller grid cells, but much more evenly spread across most of the country apart from a small north-south reaching stretch in the east of the country. Cambodia, in contrast, has generally slightly larger grid cells and several major regions of settlement besides the main population centre in the south. It has a larger variation in the overall population patterns with rural regions not as uniformly populated as is the case in most of Bangladesh. To some extent, the cartogram also is an expression of the very populous character of Bangladesh, which is the most densely populated large country in the world[65] (UNPD 2009). The cartogram reveals how almost every large space of the country is shared equally by a similar number of people, while the example of Cambodia shows that some areas of the country are much less populated than others despite its large share of rural populations.

Differences between urban and rural matter for understanding the human geography of a country, but often these statistical and more arbitrary measures give an incomplete picture of the real population patterns. The distributions are not least defined by the administrative extent of cities or per definition of a certain area, for which China is a good example. Here until recently the birth status determined an urban or rural registration status of people. With the increasing levels of urbanisation in the last decades, many formerly agricultural rural areas became part of the growing urban regions, but maintained their official status as rural areas (with a number of political and economic implications). Their populations appear in official statistics as rural populations rather than urban populations. The differences between urban and rural are thus still larger in official statistics than in reality (Kojima 1995, Wang, Wang & Wu 2009).

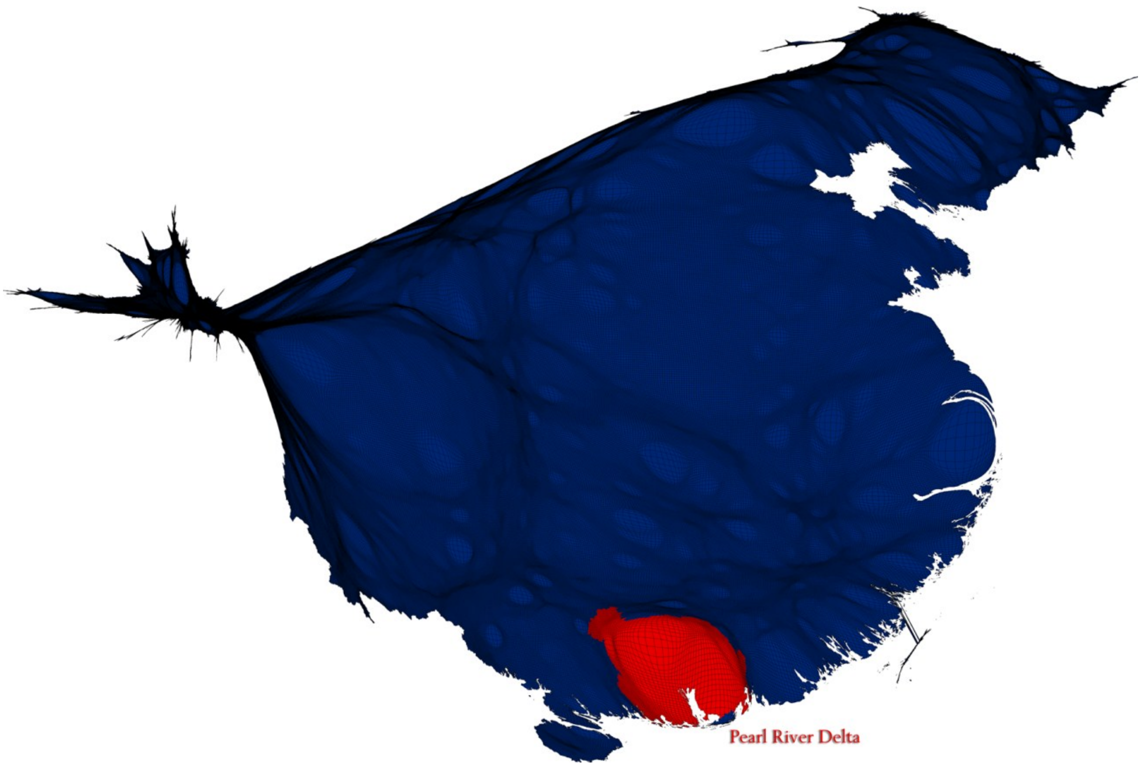


FIGURE 4.17: LOCATION OF THE PEARL RIVER DELTA IN CHINA'S GRIDDED POPULATION CARTOGRAM
Transformation based on a 2.5' population grid of 2010 population estimates
(own depiction by the author using data from CIESIN & CIAT 2005)

[65] According to the UN world population prospects (UNPD 2008), Bangladesh currently has a population density of 1,142 people per km², only outnumbered by much smaller countries such as Malta, Singapore or Monaco.

The extent of urbanisation becomes visually apparent in the gridded cartograms, where the extent of population distribution is shown[66]. Rural migrants to the large cities who are living in far distance to their officially registered areas cannot be shown, as the population grid depends on these official statistics. What the gridded cartogram can show is the extent of high population densities regardless of any administrative boundaries. The heavily populated eastern provinces, which are home to more than 90% of China's population, are visualised in their real extent in the gridded cartogram that gives each person the same space. A very recent news coverage about a proposed new megacity in the Pearl River Delta region[67] can be understood in a new light when looking at the gridded cartogram (Figure 4.17). The cartogram shows that the area that according to the plans was to become a mega-urban region actually already is a megacity in which the urban boundaries cannot be told apart anymore when looking at the overall population distribution in the cartogram. The gridded cartogram created at the national scale therefore can be useful in the identification of such more detailed patterns that are featured more generalised on the gridded world population cartogram.

The changed scale also adds another interpretative element to the maps that is different from its global equivalent. Most country cartograms allow a comparable interpretation between them and expose the very distinct population geographies of the different countries regardless their global context. Changing the scale adds that level of detail that is needed for such a comparison as it was demonstrated above for Bangladesh and Cambodia.

Only few examples stand out because their gridded country cartograms appear less significant and seem to show little additional value. This is mainly the case for some countries of the Balkan Peninsula in South-eastern Europe. Most of the countries of the former Yugoslavian state in the western part of the Balkan do not feature significant variation in their population patterns. The simplified online versions of the country cartograms for Serbia and Montenegro and Bosnia Herzegovina display patterns that are hard to interpret or analyse, and the revised versions do not improve the visual appearance (see maps in appendix C).

An examination of the countries in question in the original population data source and the data description of the GPWv3 database showed that these countries are the most problematic areas in terms of data quality. They only provide a very crude

[66] The accuracy depends on the data quality as it is reflected in the population grid. This depends very much on the original data sources that have been used to create this grid.
[67] "*China is planning to create the world's biggest mega city by merging nine cities to create a metropolis twice the size of Wales with a population of 42 million*", reported in the British Telegraph newspaper in January 2011 (Moore & Foster 2011).

redistribution based on very few administrative units. The area of Bosnia Herzegovina, for example, is only based on estimates from three administrative areas on a lower district level, which makes it difficult for a distinction between urban and more rural areas, or even more or less populated regions. The same applies to the other countries in question.

The problem of inaccurate population estimates also exists in a few other countries apart from the western Balkan countries. However, these countries with very few administrative reference units are mainly much smaller and are not shown in separate country cartograms anyway (but as integral part of another country cartogram instead, such as Brunei, which is included in the cartogram of Malaysia). Population grids of some much smaller countries, such as Singapore or Andorra, even contain more administrative reference areas and have more detail in their smaller areal extent than these countries of former Yugoslavia. Only Croatia as part of this region has a significantly higher quality in its population data. A comparably problematic visual appearance of the gridded country cartogram can be found on the maps of Swaziland and Lesotho with similar levels of (in)accuracy.

As long as the underlying population grid does not have an improved data quality, the most viable solution to visualise their population in gridded cartogram form is the combined transformation of these countries in question together with their neighbouring countries. This can at least result in an overall impression of the regional population distribution and the general context in which these population patterns can be interpreted. The cartograms of Lesotho and Swaziland can therefore also be shown together with the gridded cartogram of South Africa, and give a better understanding of the overall population distribution there. Similarly, the countries of the former Yugoslavia can be re-united on the map and be shown in a combined gridded cartogram. For an adequate accurate gridded cartogram transformation, the data of GPWv3 however is of a too low quality and the resulting cartograms remain problematic.

If global population grid is not improved in these problematic regions, only individual efforts on national or regional population grids can improve the quality of the resulting gridded population cartograms. One approach to achieve a better quality population grid has been tested for the case of Israel and the Occupied Palestinian Territories and will be presented in the next section (4.3.2). A similar semi-automated approach may be suitable to improve the data quality for these countries discussed here.

For other countries much higher resolution population data does already exist. Japan is one of the countries with official data of population and other socio-economic indicators at a very high resolution. Japanese authorities provide these data already on a gridded basis, so that additional efforts in pre-processing the data are obsolete.

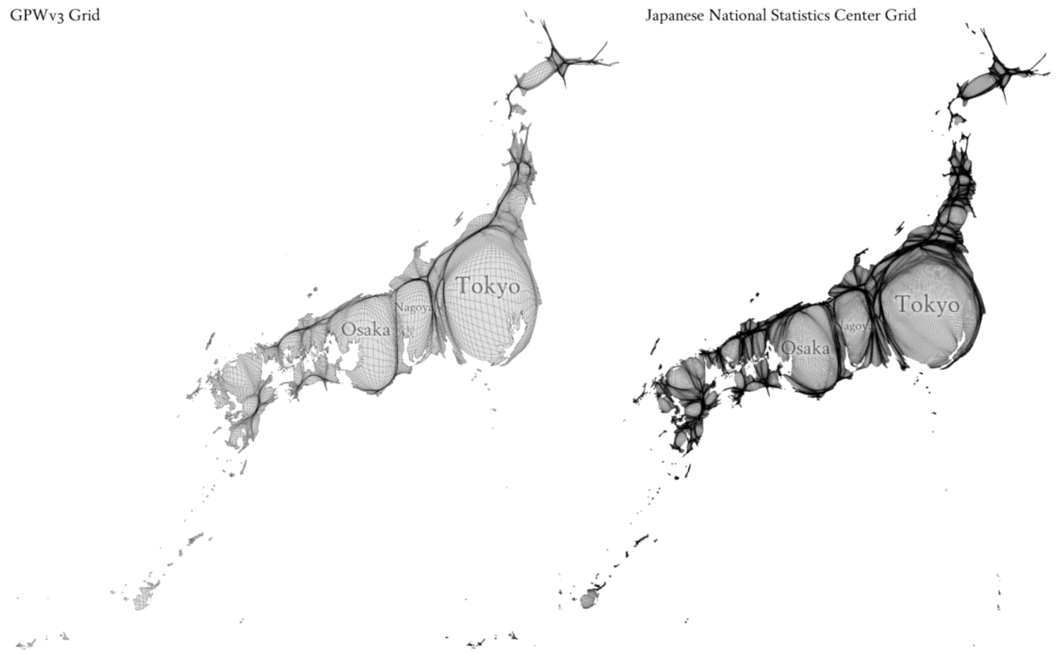


FIGURE 4.18: COMPARISON OF GRIDDED POPULATION CARTOGRAMS OF JAPAN
Transformation based on the GPWv3 2.5' resolution population grid (left) and a 30x45'' resolution grid of the Statistics Bureau Japan (right)
(own depiction by the author using data from CIESIN & CIAT 2005, SBJ 2008)

Two main gridded population cartograms have been created for Japan, using the GPWv3 grid and the higher resolution Japanese grid (Figure 4.18). Both gridded cartograms show the same overall patterns with the major population centres lined up along the south-eastern coast of the main island of Honshu[68]. The cartogram shows how heavily populated the island is, but it also displays some very significant contrasts between heavily populated areas along the coastal regions, and almost depopulated regions towards the hinterland (which in Japan mainly is the central mountainous region of the narrowly stretched island). The dominance of the Tokyo metropolitan region and its position in the country's urban system is subsequently followed by the two other major urban conglomerations Osaka and Nagoya. The other – still very populated – urban centres appear in much smaller densities in both cartograms.

The advantage of the 2.5 arc minute version of the cartogram is its obvious identification of the largest grid cells there in the smaller display as shown here. The grid cells are visible due to their larger size (as they have a smaller resolution), which allows a quick overall comparison of the population shares throughout the area. The grid cells on the higher resolution cartogram appear less large and as such do not as

[68] This work has been done with data that was gathered before the March 2011 earthquake and tsunami, which will tragically have resulted in some changes in the overall population patterns especially in the north of Honshu.

quickly allow this direct comparison between largest and smaller distorted grid cells, especially when portrayed in the size as presented here. This characteristic is very similar to the higher resolution gridded world population cartogram (see section 4.2.2) where there is too much detail contained in the map to be adequately shown in smaller map displays. However, the overall patterns in the population distribution emerge equally in both cartograms of Japan.

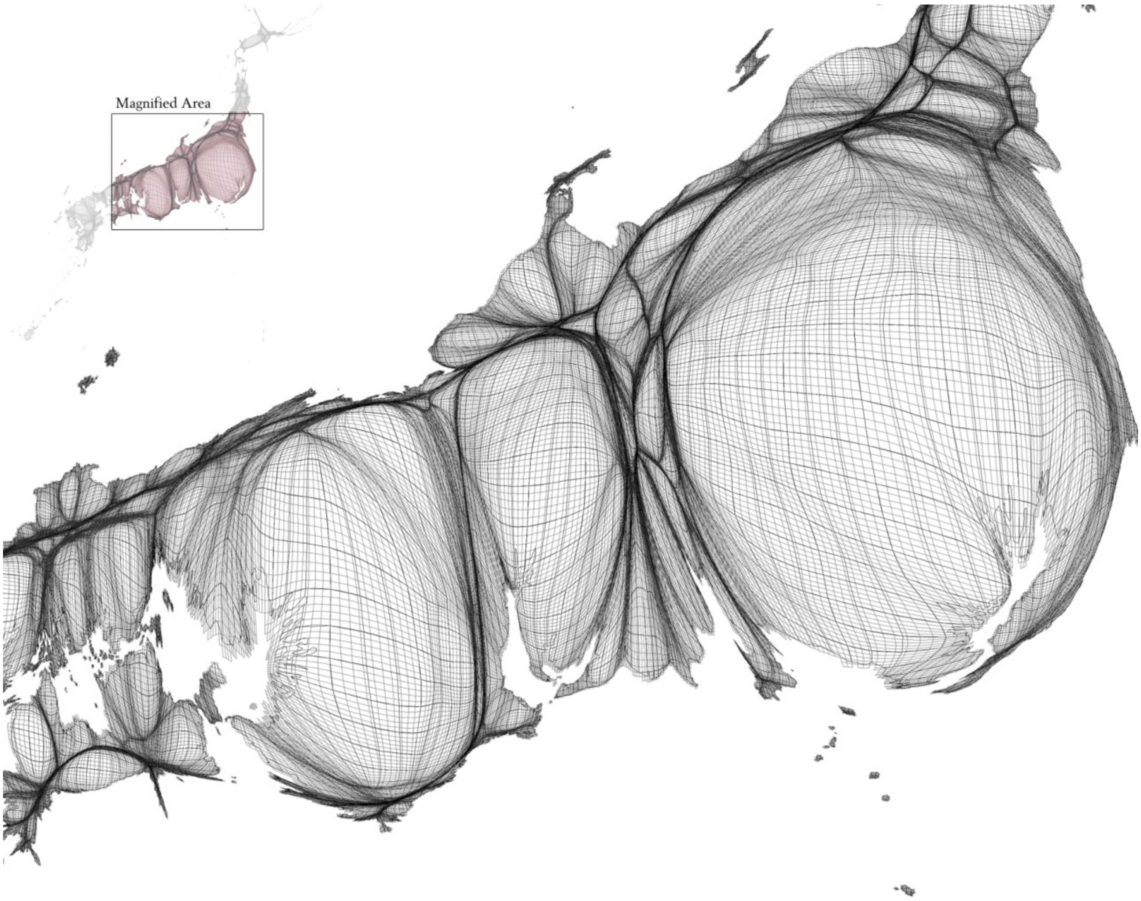


FIGURE 4.19: GRIDDED POPULATION CARTOGRAM OF JAPAN SHOWING DIFFERENT GRID SIZES
The cartogram uses two differently sized grids shown with a different thickness of the lines, so that the lower resolution grid stands out from the higher-resolution grid. The higher-resolution grid only becomes visible in an enlarged view. Shown is the magnification of the major urban agglomerations on the main island of Honshu superimposed over the full gridded cartogram in the background. The magnified region is highlighted in the background images and lines follow the magnification to the edges of the magnified part of the cartogram.
(own depiction by the author using data from CIESIN & CIAT 2005, SBJ 2008)

The higher resolution version of the gridded cartogram of Japan in displays variations within the most densely populated areas and makes differences visible within these major urban regions of Japan. The change of scale therefore becomes a potential advantage for enlarged versions of the map. Unlike in the highly resolution world population cartogram, this high resolution gridded cartogram of Japan has a meaningful appearance at all scales and does not feature significant transitional areas that make it harder to analyse the variation between most and least populated areas. The only disadvantage compared to the lower resolution version is the overall impression of the largest grid cells (similarly problematic in the high resolution world population cartogram, see section 4.2.2), which can be tackled by overlaying a less detailed grid that visually strikes out in the overall display, while the finer sized grid cells emerge when zooming into the map[69] (Figure 4.19).

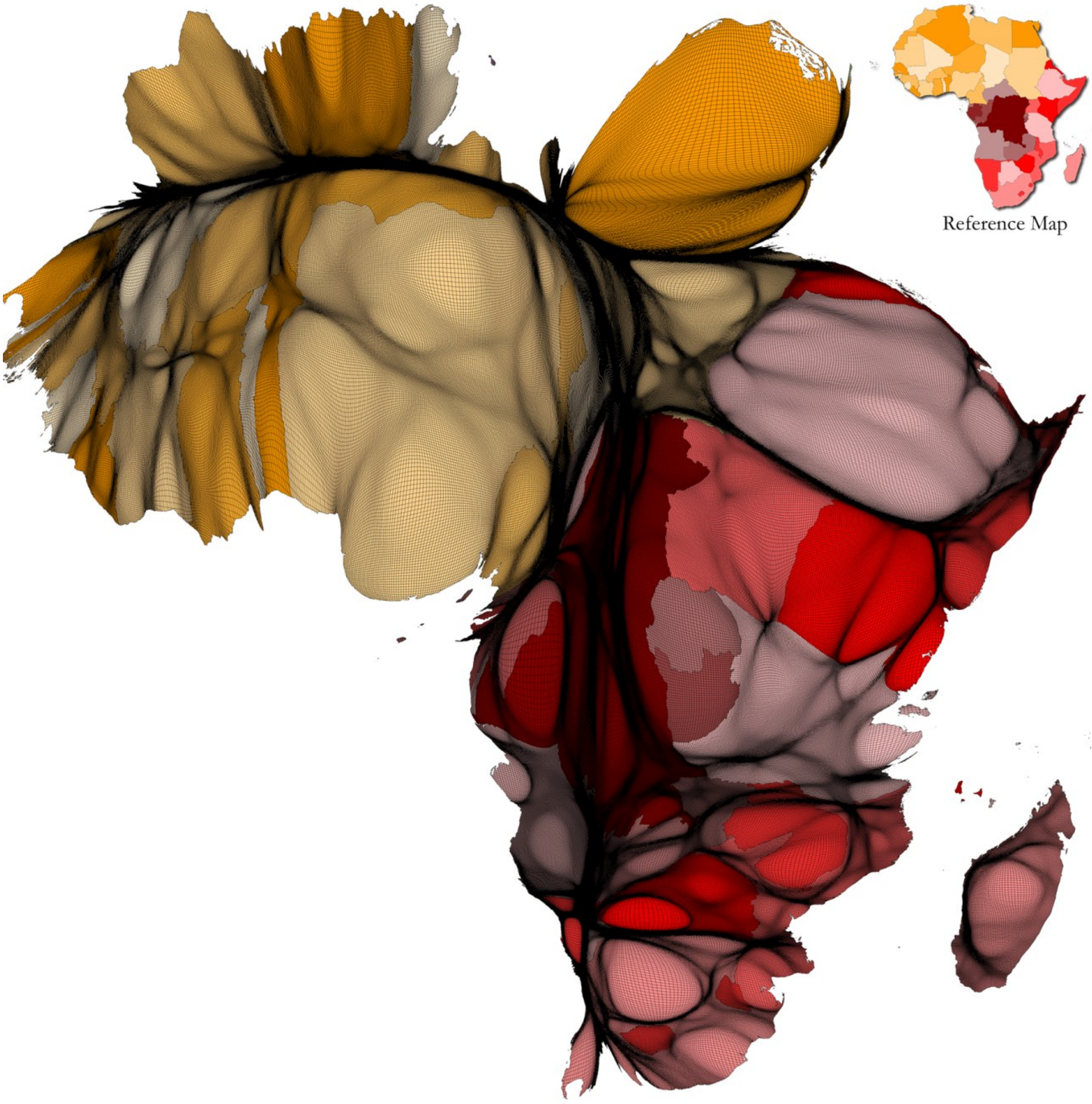


FIGURE 4.20: GRIDDED POPULATION CARTOGRAM OF AFRICA
Transformation based on a 2.5' population grid of 2015 population estimates. The reference map indicates the colours of the different countries in a conventional map projection (adapted from the Worldmapper colour scheme, Figure 1.2)
(own depiction by the author using data from CIESIN & CIAT 2005)

[69] Limitations in the computational capacity of current computers would make this approach less suitable for the 2.5' world population cartogram at the moment, although it could be suitable when these constraints are resolved and these large amounts of data can be processed and interactively displayed on in future more advanced computer systems.

On an intermediate scale between the global and the national view, advantages of the gridded cartogram technique applied to a defined limited area become apparent in the resulting cartograms. For assessing this, two gridded cartograms based on the 2.5 arc minute grid were created, covering the continental extents of Africa and Europe.

The gridded population cartogram of Africa (Figure 4.20) has a similar shape to the African continent on the gridded world population cartogram (Figure 4.2). Main differences can be seen in the northwest, where the neighbouring Middle East in the world population cartogram affects the shape of the African continent, while it has no influence in the separate cartogram for the continent only. Apart from that, the patterns emerging in the transformed grid are very similar, but reveal more detail and more variation in the newly created gridded cartogram. The change in the resolution of the grid results in a more detailed depiction in the variation of the population patterns that are still significantly distinct and recognisable in a smaller map display. This higher level of detail can be seen for example along the south coast of West Africa, which on the gridded world population cartogram shows less variation in the ¼° grid cells there. The higher-resolution grid provides a more distinct image of the less densely populated areas along some of the borders between the countries and in the northern hinterland. The resolution of the 2.5 arc minute grid preserves a readability of the map, although a magnification may be helpful to fully benefit from the new level of detail.

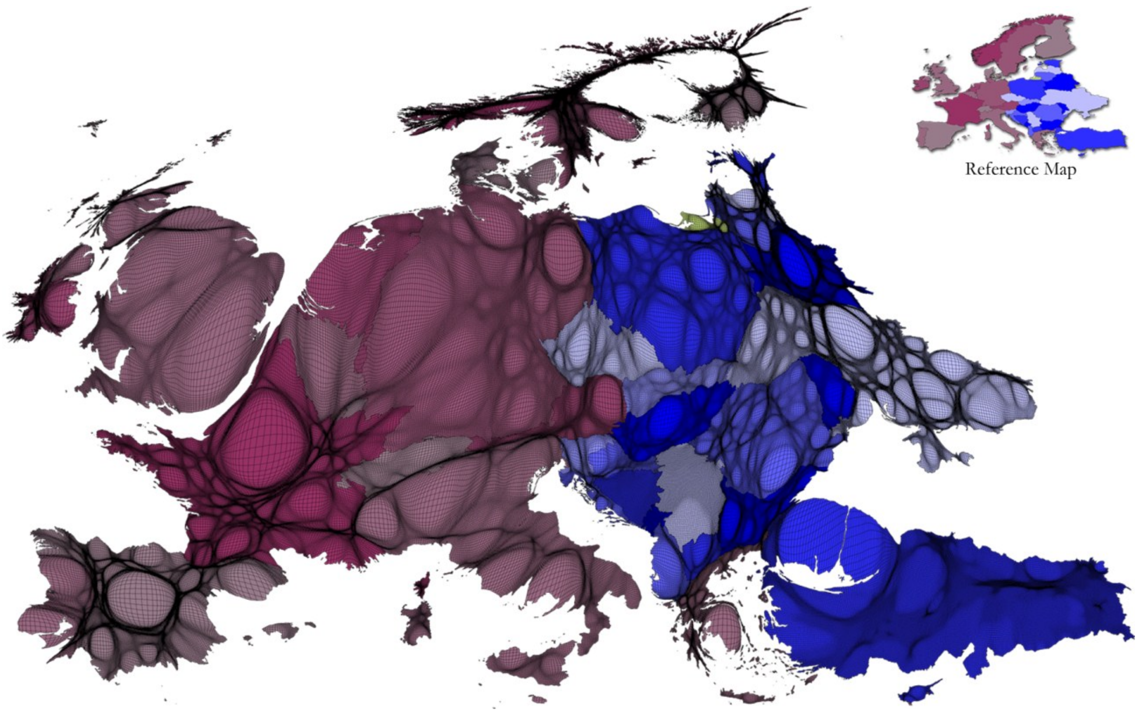


FIGURE 4.21: GRIDDED POPULATION CARTOGRAM OF EUROPE
Transformation based on a 2.5' population grid of 2015 population estimates. The reference map indicates the colours of the different countries in a conventional map projection (using the Worldmapper colour scheme, purple/blue distinguish the west/east of Europe, green is an exclave of Russia) (own depiction by the author using data from CIESIN & CIAT 2005)

The gridded population cartogram of Europe (Figure 4.21) has more differences in the overall appearance compared to the same area on the gridded world population cartogram. With Europe being a much more urbanised continent, these differences between urban and rural areas are the key features of the cartogram. This is displayed in more spatial accuracy in the cartogram generated specifically for Europe compared to the same region in the gridded world population cartogram. On a global scale, the population density across Europe appears more homogeneous, mostly characterised by a general transition between higher population densities in some western European countries to lower densities in the east. Single cities in form of bulges are harder to identify here.

The patterns in the higher-resolution cartogram of Europe are more similar to the patterns that are shown in the individual gridded country cartograms of the world population atlas. Population patterns can be interpreted within countries, but in addition also in their regional context and in relation to the population distribution in the neighbouring countries. At the same time, the differences between the most densely populated areas and the less densely populated regions become more obvious on the European cartogram as compared to the world cartogram. Cities and urban areas become visible as large bulging areas. This is now not only the case for the largest (often capital) cities, but also for other secondary urban centres.

The differences in the level of detail between the gridded cartograms of Africa and Europe reflect one other significant difference between the two areas. While the underlying population grid of Europe is based on the most accurate population data that currently exists worldwide (apart from the Balkan region, which reflects the lower accuracy in a more homogeneous appearance of these countries), the base data existing for Africa still is based on larger administrative level population counts or estimates (as documented in the GPWv3 technical notes, see appendix B). This results in less variation in the grid patterns and the resulting transformation, so that a combination of differently structured population patterns (urban-rural) and a different data quality lead to two differently detailed cartogram depictions. Both are an improvement in the level of detail that is shown as compared to the gridded world population cartogram.

4.3.2 Settlement patterns in the Middle East

Data quality of the underlying population grid was a problematic issue in some areas where the currently available population grids still rely on less detailed referential units, or where a higher resolution is essential for a better understanding of the population geography of a region. For the view on a whole continent, but also for the look at larger countries, this is less relevant to highlight the overall population patterns, as long as a considerable number of administrative units is used for the generation of the population grid. It matters more where specific settlement patterns want to be understood and a general view on the populations of the main administrative regions is the only (publicly available) data source. This is the case in the Middle East and for the countries of Israel and the Occupied Palestinian Territories (as discussed in section 3.4).

An improved version of the population grid has been generated within the scope of this research, and two versions of the gridded population cartogram were visualised for this region: (1) a gridded cartogram based on the 2.5 arc minute resolution population grid, and (2) a gridded cartogram based on the grid resolution that was refined in the highest populated areas.

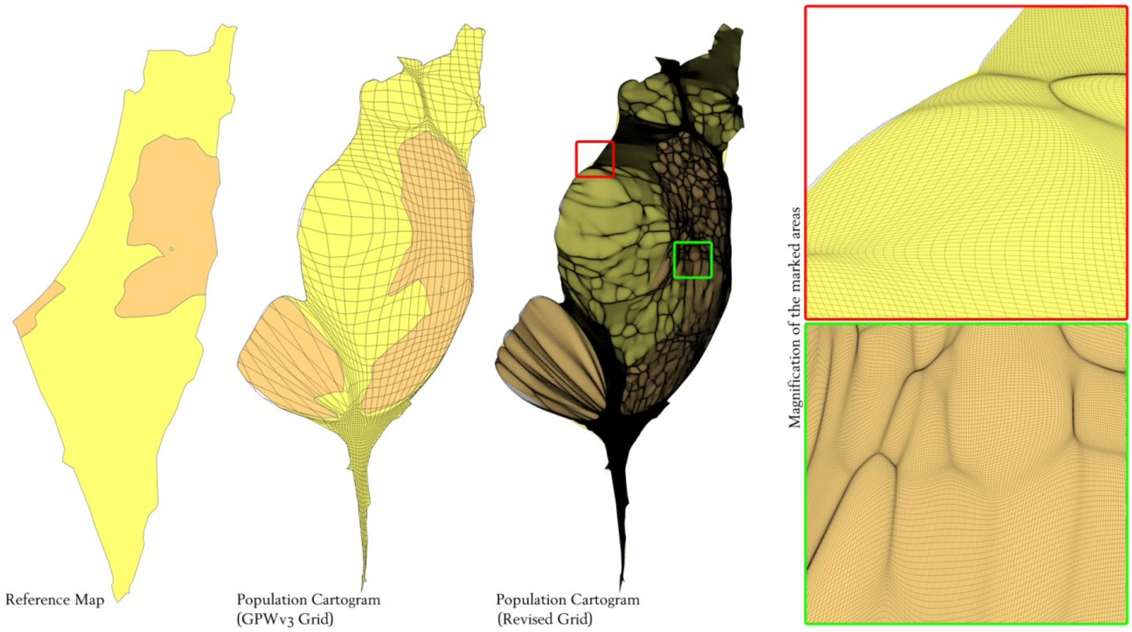


FIGURE 4.22: MAP SERIES OF ISRAEL AND THE OCCUPIED PALESTINIAN TERRITORIES
The map series shows a conventional map (left), followed by a gridded population cartogram transformation based on the GWPv3 2.5' population grid, and a gridded population cartogram transformation based on a refined higher-resolution grid. The right images are magnifications of the correspondingly coloured rectangle in the revised gridded cartogram. The yellow colour relates to Israel, rose to the Occupied Palestinian Territories
(own depiction by the author using own data and data from CIESIN & CIAT 2005)

The two gridded population cartograms of Israel and the Occupied Palestinian Territories have a comparable distribution and appearance because their base data that has been used for the transformation remains identical (Figure 4.22). Since the original overall population value within a grid cell has been redistributed, the total number in that area stays the same, and so does the overall transformation. Differences in the overall grid patterns thus exist mainly in smaller variations of the 2.5 arc minute grid shape, and become apparent when investigating the higher resolution grid in its finer detail at a magnified view.

The cartogram based showing the refined grid now allows to see the varying population patterns within these grid cells. The resulting population patterns do not relate to any of the previous grid cell boundaries. The highly diversified settlement patterns in the West Bank area of the Occupied Palestinian Territories now become visible in the grid, with altering areas of high and low population densities within the old grid cells (Figure 4.22, *green rectangle magnification on the bottom right*).

In the Israeli parts of the refined grids, the variation within the refined grid cells is less diverse, showing the larger extents and characteristics of the major urban areas of Tel Aviv (Figure 4.22, *red rectangle magnification on the top right*) and Haifa which lies in the northwest of the map. As these were the main areas where the refined grid was created, smaller settlements within Israel are only shown in some parts of the newly created cartogram (such as north of Tel Aviv shown in the magnification).

The new cartogram demonstrates the capabilities of refining the population grid and shows a considerable enhancement of the level of detail in the areas of the refined grid cells. The settlement structure, but also the varying sizes of the different settlements become clearer with the refined grid and can be a significant improvement to use the resulting gridded cartogram for an understanding of the region's human geography. Problematic in the maps presented here is the very basic visual nature of the maps, which make the interpretation of these detailed patterns a difficult task that needs further improvements. Without clear distinctions, such as the colours that were added to the gridded world population cartogram, or the city labels in the country maps created for the world population atlas, these examples remain highly abstract.

4.3.3 London back in shape

London represents the largest scale (and smallest areal extent) that has been used to test the gridded cartogram approach. To be able to compare the cartogram not only to the original map of London, but also to other cartogram approaches similar to the comparison of the gridded world population cartogram and the Worldmapper population cartogram, an additional cartogram based on the borough-level population counts was created. To enhance the readability of the maps, a distinct colour scheme has been applied to all maps, giving each London borough a unique colour[70].

[70] This style of visualisation uses a similar distinct colouring to the approach used in the Worldmapper cartograms, which may appear less valuable in this specific context, but was also created with a wider application for cartograms for the London in mind where the distinctive and unique colours help to identify the areas in the more distorted maps.

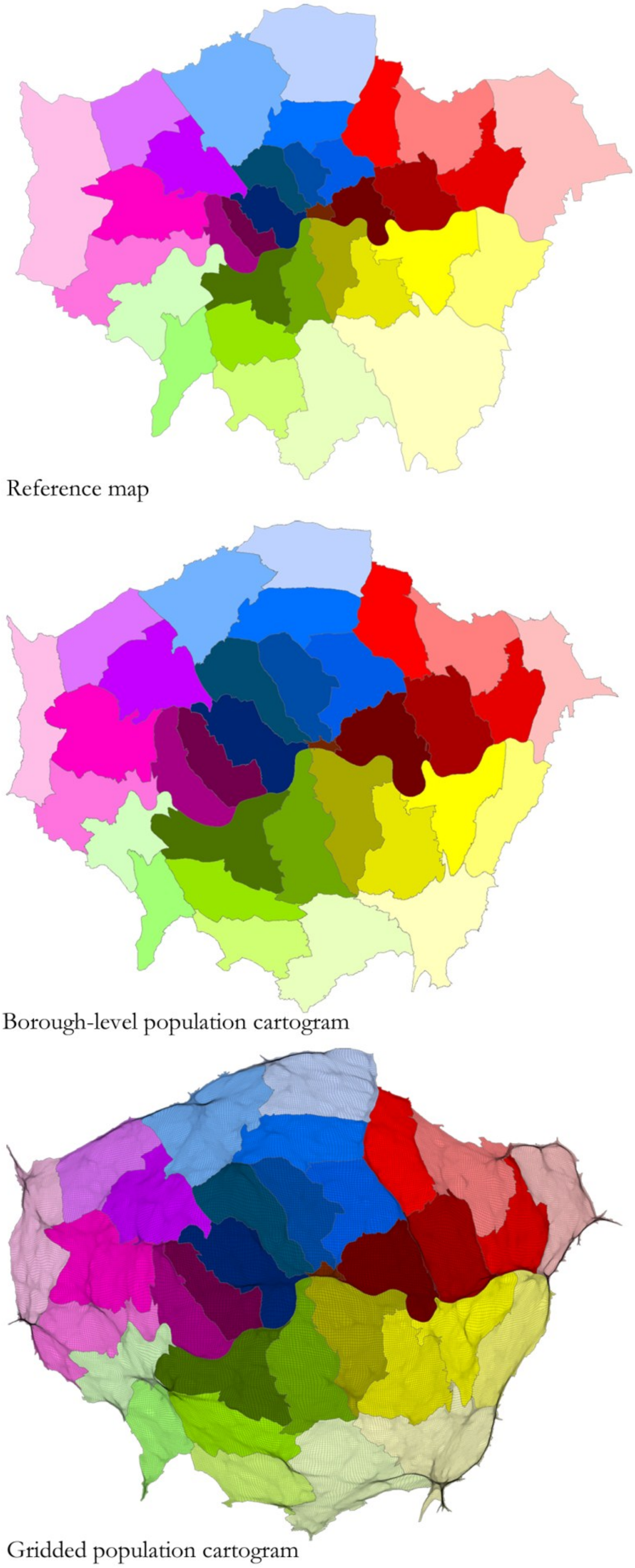


FIGURE 4.23: SERIES OF POPULATION CARTOGRAMS FOR LONDON
The three maps compare the physical area (top) and two cartogram transformations based on different reference areas (borough-level in the middle, grid-level on the bottom). The colours used in the cartograms relate to the London boroughs to allow a quick comparison. (own depiction by the author using data from GLA 2011a, ONS 2009a)

The grid surface of the gridded population cartogram (Figure 4.23, *bottom*) shows the varying population patterns in the urban areas with much lower significant differences as in many of the other examples presented at different larger scales before. The grid remains an important visual aid to interpret the different patterns and to understand the variation. Generally, there are no areas standing out like the cities in the country cartograms. This shows the high and more even density within the urban extent of London. But nevertheless, differences can be recognised to some extent, with a plastic appearance of changing higher and lower population densities, as well as some areas with significantly smaller population numbers (and converging grid cells). These could e.g. the parks, commercial and industrial areas, as well as the less densely populated residential areas in the outer boroughs.

At a first glance, the two different population cartogram approaches tested in this section appear very similar, and even remain much less distorted compared to the original physical shape than some other examples presented before. Differences between the gridded population cartogram (Figure 4.23, *bottom*) and the borough-level cartogram (Figure 4.23, *middle*) can be recognised mainly when looking at the different shapes in a more detailed examination and use the borough-colours as a guide for the orientation in the comparison process. As the borough-level cartogram has been based on a single population value for each of the boroughs, it is very crude in its level of details that it can show, and the borough shapes are even closer to their original physical shape (as a result of the basic principles of this cartogram type). The internal variation within each of the boroughs cannot be displayed here while only a broad comparison of the population shares of each borough can be seen.

Both population cartograms of London come very close to the original physical shape of the city and seem thus quickly accessible to a map reader. They reflect the high population density of a city, while at the same time the different cartograms can show at two different levels of detail the population structure within London. The gridded cartogram does this at the highest level of detail, without having a significantly different overall appearance than the other cartograms, or indeed the physical basemap.

4.4 Conclusion: Spaces of humanity

Depictions of population in map form are necessary to understand people's distributions, densities and structures and as such they are an important way of illustrating population data and gaining new insights and understandings of the data (Witt 1971). In this chapter, an alternative solution on mapping population in cartogram form but with an unprecedented accuracy was examined using the newly developed approach of creating gridded cartograms presented in the previous chapter. The new cartograms preserve spatial geographical reference in their transformation by retaining the grid during the cartogram transformation. The results for an alternative world population cartogram was introduced and examined by looking at two versions of the map created from different grid resolutions. Building on improved grid resolutions, the issue of scale was then assessed using a range of gridded population cartograms created for changing scales and different areal extents, looking at continents and countries, as well as two examples for a region and a city.

The following conclusion evaluates the key findings and makes a critical reflection of the main achievements in relation to the general capabilities of gridded cartograms and their use with different data resolutions and at changing scales. The assessment of the results is undertaken in more detail, because here the key findings relating to more general issues for gridded cartograms will be revisited and carefully evaluated. These results will then be used in chapter 5 to develop further cartographic concepts for the gridded cartogram technique beyond the focus on creating population cartograms.

4.4.1 Resolution

The gridded cartogram technique has been successfully applied to create a new version of a population cartogram that considers the most accurate population estimates that are currently freely available on a consistent global basis. In addition, the gridded world population cartogram does no longer rely on arbitrary spatial units (such as countries), but is based on a neutral and uniform geometric base. The use of equally sized grid squares, each containing a unique population value that determines the extent of the distortion, result in specific characteristics and in a different visual style featured in the resulting cartograms that distinguish the new map considerably from the reference Worldmapper population cartogram.

In comparison to the Worldmapper population cartogram, the gridded population cartogram no longer resembles the individual country shapes. At the first appearance, this makes the new map harder to understand, as familiar shapes disappear even more, rather than only being oddly distorted as in the Worldmapper version. The use of a consistent colour scheme and the comparison to a conventional reference map however helps to assess the emerging shapes and relate the new patterns to their geography.

The most distinctive feature in the new map is the varying pattern of the underlying grid cells that provided the base for the cartogram transformation. Each grid cell related to an equal area in a conventional map, so that the pattern in the gridded cartogram can be interpreted in relation to the transformation value without prior knowledge of any other random areas (what the country shape basically are). With a basic understanding of the underlying principles, the grid pattern can therefore be accurately interpreted, and understood to where people are and where not depending on the degree of distortion in each individual grid cell.

This can be seen as a considerable improvement in the accuracy of the cartogram transformation. The base for the cartogram preserves an accurate spatial reference and transforms this accordingly, so that every point on the new map can accurately be related to in the physical space. Therefore the resolution of the grid determines the accuracy of the gridded cartogram. This accuracy in in the gridded cartogram technique allows an interpretation of the map in great detail and with a geographic reference that the Worldmapper cartogram fails to show. Worldmapper depends on country shapes which are sometimes disputed, and are subject to regular changes (as pointed out earlier, the new country of South Sudan appeared on the world map during the final stage of this research in 2011, which e.g. would affect the shape of the Worldmapper population cartogram while in the gridded cartogram this would only be a matter of drawing the new border onto the existing basemap). The gridded cartogram transformation is independent from these changes. Countries can be shown in a colour overlay (as shown), but the shape of the cartogram does not change whatever borders and countries are drawn on top. The resolution based on the ¼° grid is high enough to identify many details in the global population distribution and understand their geographical reference. Critical – and much more crucial than it is the case for the Worldmapper cartogram – in all this detail therefore is not the technique, but the treatment and quality of the underlying data.

Going into more detail and looking at the effect of higher data resolutions, using the (currently best existing) 2.5 arc minute population grid as base data for a gridded world population cartogram proved to be a time-consuming work due to the large amount of data that needed to be processed (which brought the computer systems used in this research to the limit of their current technical capabilities). The results are therefore disillusioning to some extent, but quite understandable. It is not always advisable to aim for the highest possible resolutions in order to achieve the presumably best results. The high resolution gridded world population cartogram showed no advantage over the map created from the less detailed ¼° population grid. The difference between the largest cell values and their surrounding areas is less extreme when using a much higher resolution grid. This results in a less significant display of the differences between the most densely and the least densely populated areas, also because at the same time a much larger number of grid cells needs to be visualised. While the grid cells themselves only become visible when zooming in to a very high resolution, the details being shown in the extent of a very high zoom level differ much less because the extent covers a much smaller area. Zooming out in turn makes the single grid cells unidentifiable, so that the advantage of smaller grid cells and a higher resolution disappears with a certain level of detail.

The grid resolution needs careful assessment before it is used in a gridded cartogram. Too low resolutions are too crude[71], but too many data values are counterproductive as well. The ¼° grid proved to be an optimal grid size for the display of a gridded world population cartogram, with enough detail to be analysed, but not going further than the level of detail that the current population grid is able to reveal. With improving accuracy of the underlying population grid, and with improvements in computing capabilities that allow a higher resolution to be applied to the cartogram transformation, the creation of higher resolution gridded cartograms on a global scale may result in better visualisations than those currently created with this approach. Specific solutions for a more readable design of the additional detail would then be needed.

Data availability and data accuracy are problematic for some parts of the GPWv3 data. Countries such as Mongolia or Libya are relevant areas for further improvements of the gridded population data. On a global scale, however, it could also be shown that these inaccuracies affect the global image only to a small degree. Most of the countries show significant variation between each grid cell that relate to the country's overall population distribution. Not least, the density-equalising transformation helps to smooth out problematic areas across the borders and to create a valid global picture of the population distribution.

4.4.2 Scale

When changing to larger scale gridded cartogram depictions, data accuracy becomes more relevant and is essential for the expressiveness of the resulting cartograms. A higher resolution is inevitable to achieve results with further interpretational value. The use of gridded population cartograms at various scales has successfully been applied to a continental, regional/national and city scale. The techniques of generating and improving the accuracy of the grid outlined possible ways to tackle the problem of

[71] Eventually they also have no higher accuracy than the Worldmapper population cartogram, but instead quite certainly a worse readability and sketchy appearance more similar to the rectangular cartograms introduced in chapter 2.

a lack of gridded population data at larger scales, as the examples of the Occupied Palestinian Territories and London demonstrated. Larger scale depictions also lead to more abstract appearances of the gridded cartograms which are hard to interpret without additional information, or – as shown in the case of London using a distinct colour scheme – with a clear visual guide that structures the resulting map.

The examples presented in this chapter make it clear that improvements in the accuracy of the population grids are necessary to fully benefit from the gridded cartogram technique that could be established in this thesis. While the global scale needs little improvement to create a meaningful gridded cartogram, the country cartograms of regions such as the west Balkan region in Europe and other countries that have a less accurate population grid demonstrate the need to improve the data quality in these areas. Most of the cartograms created for the new world population atlas show that the maximum 2.5 arc minute resolution of the current GWPv3 database is sufficient for meaningful country cartograms, so that these need no additional level of detail. An improvement in the areas with poorer overall data quality is desirable.

The gridded country cartograms also show that they are not mere cartographic displays of the largest cities in a country (or the largest cities of the world on the world population cartogram). They are accurate geographic depictions of the space that people take up in the defined area of interest, and show the differences between the most densely and least densely populated areas. In addition, they are able to visualise the different densities at which people live in a specific area, regardless of artificially defined boundaries they are living in. Gridded population cartograms are an expression of an increasingly urbanised world, but they also reveal the regions with large rural populations spread across the land. The technique does not differentiate between urban and rural categories, but (depending on the data accuracy of the underlying grid) shows the real extent of population distributions. At an urban level, gridded population cartograms can give a vivid impression of the differing densities within a city and show the heterogeneous nature of highly populated areas.

Showing populations in their quantitative extent and distribution at an unprecedented scale is one example of some of the advances of the gridded cartogram technique and how the new maps can enhance the understanding of the human geography of an area. The ability to zoom into more detail and always be able to orient towards the changing pattern of the population grid makes the new technique a suitable cartographic display that works at various levels. To some extent, it functions like a conventional map that adds further detail when looking at larger scales, and that generalises the content when zooming out to smaller scales.

Different scales require different levels of detail, just like in a normal map, but with the difference that a different level of detail brings up new map shapes rather than only new or more precise map elements. Unlike in a normal map, the level of detail can affect the general appearance of the new basemap significantly when using the gridded cartogram technique. A higher resolution can be useful depending on the purpose of the map, just as a lower resolution can be useful to get an overall understanding of population patterns. Depending on the scale and the area that wants to be visualised, the resolution therefore has to be carefully evaluated and adjusted accordingly, following the principle in conventional maps to add more detail at larger scales.

Some of the maps presented in this chapter must be regarded as more conceptual maps with little value at a first glance (such as the experimental gridded world population cartogram covering the whole surface of the planet), and some of the shapes that emerge in the country cartograms contain a certain level of serendipity in their result, but yet all maps created in this stage of the work make clear that the gridded population cartograms are a distinct new way that challenges the views that we are accustomed to. They are neither better nor worse than conventional maps, but they are different. Despite one has to learn how to read these maps, their accuracy and neutral basis they provides some advantages compared to other cartograms.

To a certain extent the analogy of the human shape of the planet to the physical shape of the planet is a valid metaphor. The physical shape of the planet is not a static picture and does change, although it changes much more slowly than the human shape. Both shapes are key layers that are in constant motion while maintaining an overall stable picture over a certain period. Both shapes are less subject to sudden major changes although they are in continuous transition. And with maintaining a fairly accurate geographical reference of the people's location in a conformal way by connecting the grid cells in almost square angles in the gridded population cartogram, this cartogram may has potential for the utilisation as a map projection that adds more information to the map than the only dimension that is currently contained in the transformation value. A conventional projection results in an equal-area or equal-angle (or similar) transformation of the real world. This chapter demonstrated, that the gridded cartogram projection is an equal-population transformation with the same retained geographical reference. Chapter 5 builds on these finding to evaluate, to what extent the gridded cartogram technique meets the requirements of other map projections by testing more complex cartographic concepts with this technique.

Chapter 5 **Towards a gridded cartogram projection**

5.1 Introduction

Gridded population cartograms are an alternative way of applying the principle of value-by-area maps with a higher geographical accuracy that provide novel analytical and visualisation capabilities. The previous chapter assessed these basic features of the new cartograms in relation to population at different scales and resolution. The results led to the conclusion, that gridded cartograms embody a conformal reprojection where the connecting areas of the grid connect each grid cell seamlessly and at almost square angles and make gridded cartograms more similar to a (unusual) map projection rather than being a sketchy map like other cartograms. This characteristic requires further investigation into whether gridded cartograms can provide a reliable base for a map projection.

This chapter explores the further utility of the gridded cartogram technique, and assesses the results in comparison to other map projections. The basic idea how population data is reflected in gridded cartograms stands in the beginning of the investigation by explaining how the grid relates to the underlying population data (section 5.2). Building on this introductory conceptual case, the gridded world population cartogram is then examined by adding different kinds and types of data as overlays[72] (section 5.3). In addition, the concept of a gridded transformation will then be expanded beyond the use related to total population distribution (section 5.4) to assess the wider applicability of the technique. The diversification of conceptual approaches to gridded cartograms presented in this chapter will allow a broader conclusion of the significance of the technique in the context of map projections (section 5.5)

5.2 What a difference a grid makes

Gridded population cartograms show land area distorted to the extent that every person living within the surface of a square are is given the same amount of space on the transformed map. In the resulting map every areal unit for which the total population is counted is transformed accordingly. Consequently the grid cell as the smallest areal unit in a gridded cartogram is the smallest geographical reference from the physical space. The area that is covered in the original raster is the same area in the resulting gridded cartogram, hence the new maps show the number of people living in

[72] An overview and description of all data used in this chapter beyond is given in chapter 3.3.2.

the same geographical space. How the GPWv3 population data relates to its appearance in the gridded cartogram can be better assessed, when seeing it in comparison to how other projections show that same data in their specific distribution.

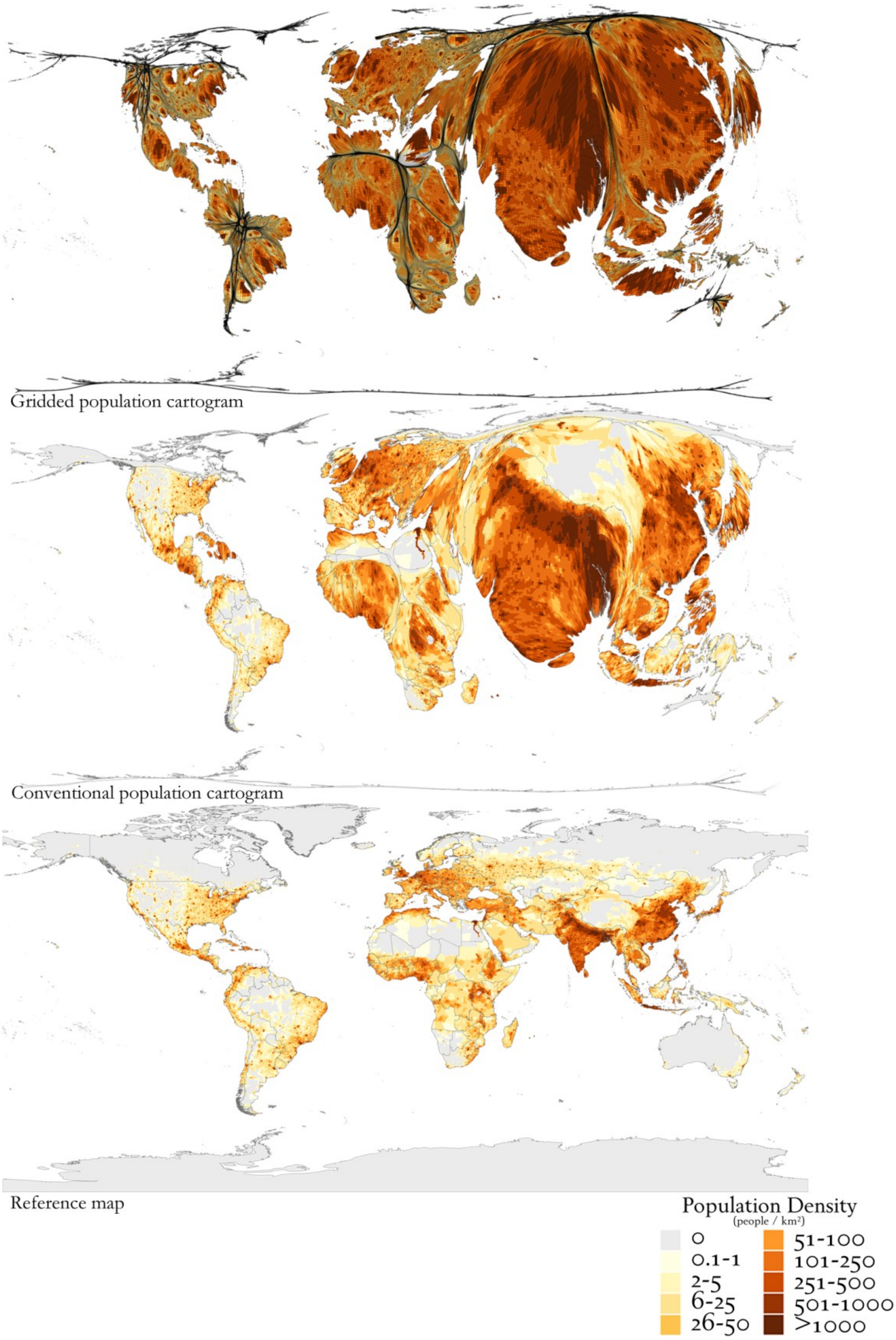


FIGURE 5.1: GLOBAL POPULATION DENSITIES ON DIFFERENT MAP PROJECTIONS
(own depiction by the author using data from CIESIN & CIAT 2005, UNPD 2011)

When transforming additional layers of geographic information accordingly, these topics can potentially be interpreted likewise and thus may prove valuable to provide a deeper understanding of the topic in relation to population. In areas with few people, this additional layer is reduced in size because it does not relate directly to a larger amount of people. The underlying information is not removed in these areas of low population, but reduced in size and can be made visible by enlarging the area of interest. All original grid cells can be recognised in the gridded cartograms and no information is lost in the transformation process, although some information is condensed significantly in the least populated areas.

Showing population densities on a conventional map projection (Figure 5.1, *bottom*) provides little surprising views, as this is a common display of population values in map form that many are accustomed to. The map display is the representation of the densities for the population data that was used from the GPWv3 data (which provided the base for the gridded population cartograms). Following the argument of others that described the spatial display of density patterns on a conventional map (see e.g. the assessment of diffusion-based maps by Oyana, Rushomesa & Bhatt 2011), the choropleth display remains limited in understanding the extent of the underlying quantities in their full relation. The class ranges for the choropleth layers can provide means to highlight differences, but have to follow certain standards of defining class ranges. Showing quantities in colours can therefore be a limitation to assess the full extent of data distribution. Using the gridded data rather than more generalised administrative units however provides a fairly accurate picture of population distribution, even if it fails short to make the quantities comprehensible.

Making quantities comprehensible is the purpose of cartograms. Visualising the population overlay shows, how different the use of gridded and conventional population cartograms as a basemap appear when displaying the same kind of data that they aim to represent Figure 5.1, *top and middle map*).

The normal population cartogram[73] (Figure 5.1, *top*) stretches and squeezes the underlying information on the changing population densities equally within each country. This leads to an even distribution of higher and lower population densities within a country, which basically mirrors the display that appears in a conventional map projection. The resulting impression is that of expanded land areas that contain low population densities in some parts. Problematic here is that real geographic

[73] As the maps in this chapter no longer use the worldmapper colour scheme, the Worldmapper-style population cartogram will now be referred to as a *normal population cartogram*. It still shows the same shapes, but a distinction is necessary because all examples shown here have not been shown or used in the original Worldmapper project and serve the purpose of providing a comparison to this map type in general.

reference is not retained, as non-populated areas get the same space as populated areas, while the underlying map transformation applies the principle of showing equal population shares.

The invalid cartographic nature of the appearance of population densities in the normal population cartogram can be explained by the combination of different scales of data that are applied to this map, and which result in the misleading overall picture. One could argue, that here the total populations are reflected in the country size, while the densities within a country can be interpreted as well. However, from a cartographic perspective, this remains problematic, because it provides a comparison of two dimensions of information that are misleading in the overall view. High population densities in very small countries disappear and cannot be interpreted in any relation, so that the global picture does neither relate to a *real* geographical distribution (and therefore distorts the densities), nor does it show the two layers of information at the same resolution. This problematic display can be compared to showing absolute data as a choropleth overlay in a normal map, which is against cartographic principles out of the very same reasons[74].

The display of population densities in the gridded population cartogram (Figure 5.1, *top*) appears very different to the (in this regard very similar) conventional map projection and normal population cartogram. The transformed population density reflects the correct geographic redistribution and shows highest densities in the largest areas and vice versa. The data overlay here is basically a confirmation of the correct map transformation. The display of population density data here adds no value to the gridded population cartogram itself other than demonstrating the principle of the visualisation, but it explains how the transformation works differently than compared to the normal population cartogram. It also shows how the data as displayed in the conventional map projection is turned into the gridded population cartogram.

All three population density maps represent the same data layer, but the projection in all three maps results in a very different appearance that explains what a difference a grid makes. The choropleth-style depiction therefore also allows a closer observation of the correlation between population distribution and population density in the gridded cartogram. The map does not only show where the largest population densities are to be found, and what extent and magnitude they have, but also shows the areas with lower population densities and their real extent. Not always live most people in the areas with the highest population densities. In some regions large parts of the

[74] Further information provides every cartography textbook and needs no further explanation here (see e.g. Darkes & Spence 2008, Dent 1999, Robinson et al. 1995).

population live in lower- and medium density areas. One example for that on a global scale are some areas in the southern countries of the African continent, where larger number of people are distributed over large areas with medium population densities. On a larger scale similar observations can be made in Eastern Europe, with an overall higher population density than in the previous example, but with many people living at lower densities than in the parts of Western Europe, such as large parts of Germany. North-south differences in the very high densities within India are the most immediate impression in the map. Gridded population cartograms do not only display cities and the highest population densities, but display all people equally, also if there are larger quantities living in comparably lower densities in some places.

5.3 Gridded cartograms as a basemap

Displaying population densities on a population cartogram demonstrates how the principle of the different cartogram transformations work. Apart from that, these maps display are not more than an academic exercise in which the information displayed remains mono-dimensional. The following maps elaborate the implementation of an additional dimension to the gridded world population cartograms to assess and demonstrate new concepts for using the transformation as a map projection. In all of the following maps the gridded population cartogram is therefore used as a basemap onto which further geographic layers are projected equally. Two additional maps provide alternative views of a conventional map projection and a normal population cartogram that allow to investigate the differences between the different map types and the specific effects on appearance of the data overlays.

5.3.1 National-level: An unhappy humanity

National-level data is amongst the most commonly available information that is currently available for an extensive range of geographic information. Especially for demographic and socioeconomic data, this data-level is often the best possible source of information for that globally comparable datasets (this issue is not least reflected in the difficult efforts on the compilation of a global population database at larger scales). An increasing accessibility of international datasets from institutions such as the United Nations and the World Bank is part of the *data revolution* (see section 2.4.1) that also made projects such as Worldmapper possible in its remarkable range of topics that are covered. Worldmapper relies largely on such national-level data and presents alternative maps based on this information (although in many cases additional efforts to complete the available data were needed). National-level data should therefore be the minimal dimension that can be displayed on gridded population cartograms. And with this also being the reference level for Worldmapper maps, national-level data displays should work similarly well in combination with a normal population cartogram that is based on the Worldmapper technique.

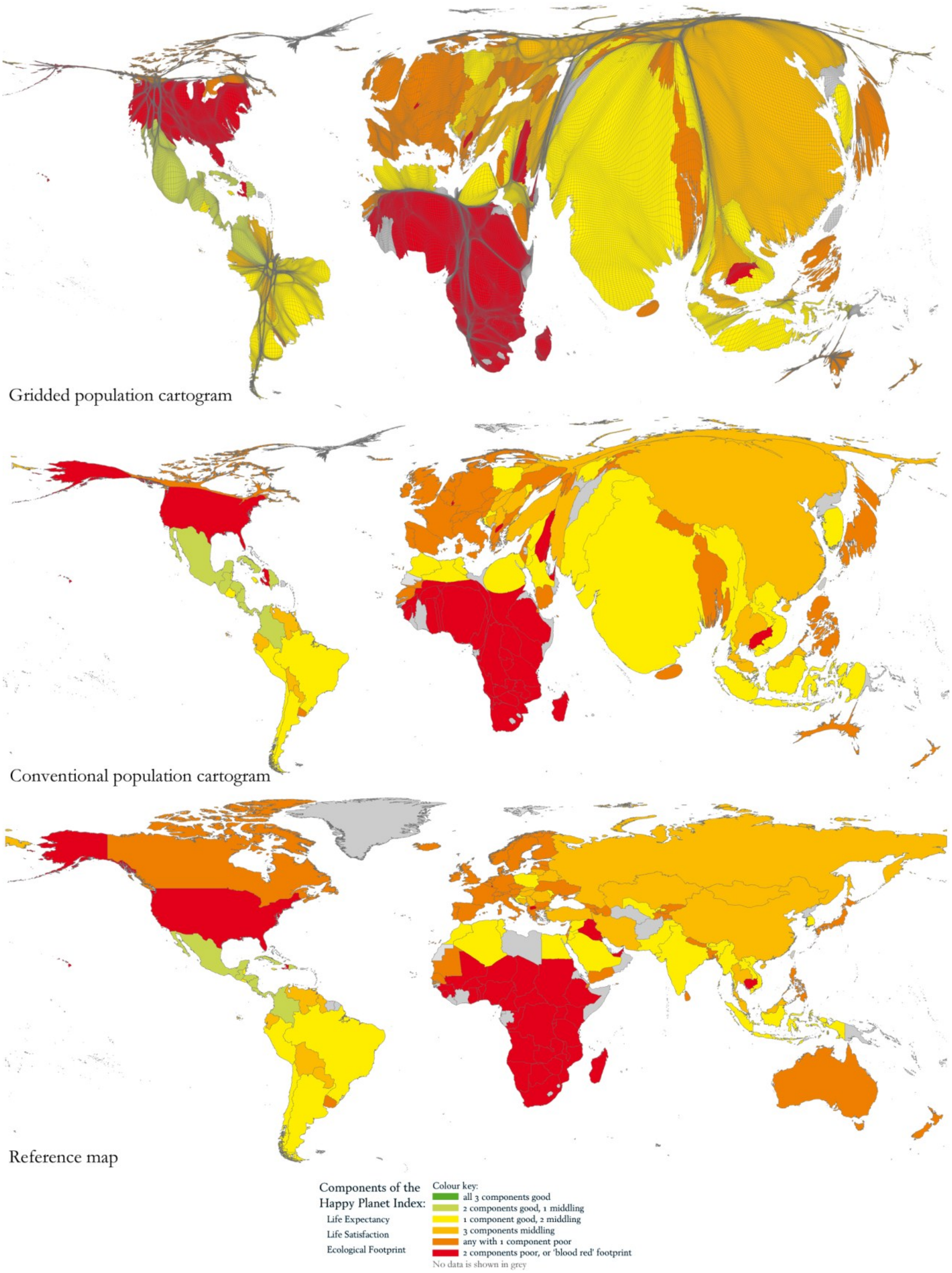


FIGURE 5.2: MAP PROJECTIONS OF THE HAPPY PLANET INDEX
Gridded population cartogram (top), normal population cartogram (middle), conventional map projection (bottom)
(own depiction by the author using data from Abdallah et al. 2009, CIESIN & CIAT 2005)

Quality of life and the evaluation of well-being are important concepts used in social science to assess international standards of living from a different perspective. A wide range of measures are used to describe these concepts and allow global comparison. The Happy Planet Index (HPI) was used to further assess the visualisation of national-level data, not only because it is one of the countless examples for that data type, but also because the very close relationship between people as the main dimension that the index aims to represent and their representation in the map is has very direct cartographic implications. The question therefore also is, whether different map types displaying the same information can lead to different interpretations, even if the style of the displayed information remains the same.

As an index of a number of indicators, the HPI already stands for a simplification of the complexity of the data that is included in it (life expectancy, life satisfaction, and the ecological footprint). The additional categorisation that has been made by the authors of the study (Abdallah et al. 2009) contains a further generalisation by defining six categories of how the differently categorised measures compare and are interpreted. The colour scheme, ranging from green (for the most positive expression of the data) to red (for the worst values) already makes very clear statements about how the data wants to be understood. The cartographic display using this scheme therefore needs to be taken into account when evaluating the maps. These considerations taken by the authors of the HPI predetermine a large part of the map appearance before one or another map projection has been applied to the data.

The colour choice is the dominating feature in the three different map projections of the HPI data (Figure 5.2[75]) which distracts the first impression of the maps from the shapes towards the colour pattern. The colours appear to dominate the three maps more than the different appearances of the three projections, which makes the element of colour a crucial part of the message that the HPI maps convey. Considering this, the size of the different countries has a huge impact of the impression that the reader gets from the map. This has implications on the relevance of a population cartogram (in general, so related to both cartograms shown here).

Due to their large size, some countries and their appearance in relation to the HPI appear considerably big in the normal map projection (Figure 5.2, *bottom*). This applies to countries such as Russia and Canada, which take up much space and whose colours dominate large shares in the northern parts of the map. Similar observations apply to Australia and Greenland, but to a smaller degree, and in detail to further countries. In

[75] The map was first created as part of a poster contribution for an exhibition to mark the re-launch of the Interdisciplinary Centre of the Social Sciences (ICOSS) organised in December 2009 by the Centre for Health and Well-being in Public Policy (CWiPP) of the University of Sheffield.

the two population cartograms (Figure 5.2, *top and middle*), these two countries almost disappear from the map, and their dominating colours are equally reduced.

A reverse observation can be made for the dominating features in the two population cartograms. Here India becomes very big, and its yellow colour core from the HPI become much more prominent shown than in the conventional map. To some degree, the full area of Europa gets more significance as well. Gradually this also applies to China, which is already one of the larger features in the normal map projection, but becomes now as dominant in the population cartograms as Russia is in the normal map. Further detailed observations with corresponding differences can be made for most of the countries that are displayed. Because of their distinct colouring, their representation in the map does not only change by shape, but also by the image of the (not so) *happy planet* that the data aims to convey.

A comparison of the two population cartograms allows no general differences in the display of the HPI data shown here. The proportions of data remain equal in both depictions. However, the normal population cartogram (Figure 5.2, *middle*) has a much closer relation to the normal map projection as many of the country shapes correspond well to the original shapes, while they are considerably distorted in some areas in the gridded population cartogram (Figure 5.2, *top*, most remarkably to be seen in the case of China with its east-west differences as discussed in section 4.2). A map reader not familiar with the gridded population cartogram projection will therefore have more difficulties in reading the gridded cartogram as compared to the normal population cartogram with its (despite the distortion) more familiar shapes.

A last observation is the behaviour of the representation of missing data in the maps. The HPI has some gaps in its global coverage, which are displayed as grey areas (as it is often realised in normal map projections). Cartogram transformations themselves allow no gaps in the data, or they result in a misleading distortion in which no data is shown as zero value data while it could potentially have a very high value. In the use of population cartograms as basemap onto which other data is displayed, missing data can be represented in the same way as in the normal map projection because this information is equally distorted. Missing data overlays do not result in the disappearance of that area from the map, but the shading of the transformed area informs that the data overlay contains missing data for that space.

All of the three map approaches have their own advantages and disadvantages. The conventional map projection quite naturally is the most accessible for the majority of map readers who are used to these maps. However, the specific nature of the HPI as an index that relates directly to the living standards and well-being of people, the population projections appear more appropriate for the display of this data in order to make a correct representation of these relations, and about the state of humanity that the index aims to explain. The gridded population cartogram shows that, and has no flaw in the correct data representation. It therefore is suitable to be used as a basemap for national-level data. The normal population cartogram however appears more readable and in this regard superior to the gridded population cartogram because of the closer relation to the original country sizes. The normal population cartogram transformation is based on national-level population data, so that the display of other data using that same level of detail functions without misrepresentations.

5.3.2 Subnational data

National-level data has the advantage of its wider availability that allows the wider range of mapping diverse geographic dimensions. Similar to national-level cartograms however, such data lacks more detail and can therefore remain limited in its interpretational value even at a global scale. Large countries or regions with a high diversity require more detailed representations of data to interpret and understand the underlying geography that they represent. The evaluation of national-level data displays on population cartograms in the previous section showed, that missing data does not have to be a limiting factor for data that is used as data-overlays on cartograms. Showing subnational level information on population cartograms therefore does not require a full global coverage and may be useful to highlight more geographic detail in regions, where the map topic is of special interest.

The effect of subnational-level data displayed on gridded cartograms is tested at data that is of special relevance in relation to the *millennium development goals* (MDG) that focus on inequalities and poverty (UN 2010). In order to achieve goals to tackle some of the most pressing global problems in this field, key indicators were chosen that started to be monitored in those places where the problems of poverty are most pressing. The need for subnational data is essential to identify the worst affected areas (SEDAC 2011b, UNDP 2010, UN 2010).

The reduction of child mortality is one of the eight millennium development goals that provides exemplarily data on subnational level. Like the other indicators within this framework, it also relates very directly to population, which in the previous example of the HPI has been identified as a valuable link that can be represented more appropriately in population cartograms. The data is based on subnational-level administrative areas that have changing levels of detail that are more detailed in those regions, where infant mortality is to be found at higher rates. The classes and colour scheme for the choropleth overlay in the maps were adapted from the original map source (CIESIN 2006, SEDAC 2011b).

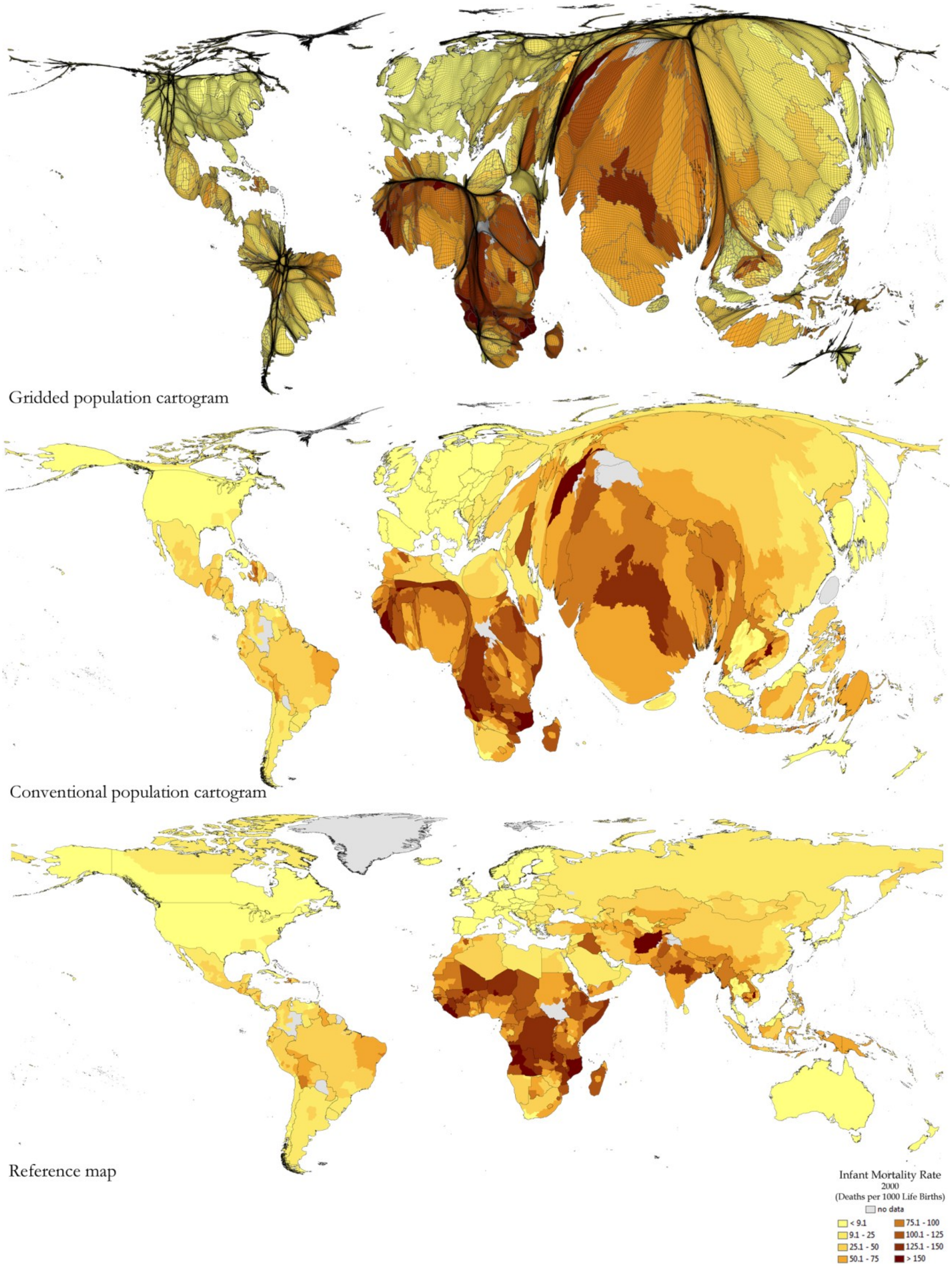


FIGURE 5.3: MAP PROJECTIONS OF INFANT MORTALITY RATES
Gridded population cartogram (top), normal population cartogram (middle), conventional map projection (bottom). Rates are shown for the year 2000
(own depiction by the author using data from CIESIN & CIAT 2005, SEDAC 2011b)

The additional level of detail results in a more complex map display than that showing very crude national-level data. This requires a larger effort into reading the map and assessing the information that is contained in it. The gradually changing colours from brighter to darker tones assist in the immediate overview of higher and lower rates throughout the map display (where the map reader has to rely on the sensible choice of classes made by the cartographer). The general appearance of the conventional map projection (Figure 5.3, *bottom*) puts the prevailing darker tones that dominate the African continent in the centre of attention. A second hotspot of higher infant mortality rates in southern Asia appears much less dominant in comparison. Further areas of gradually higher rates can clearly be distinguished in their distribution in parts of Central and South America. Most parts of the richer world especially in Europe and North America are overall homogeneous regions, but some areas of increased infant mortality are visible in the southeast of the United States and in the north of Canada.

The normal population cartogram (Figure 5.3, *middle*) changes the appearance of these distributions especially for India, which due to its considerable increase in size becomes more prominent as a second region with higher rates of infant mortality. The larger size of Europe increases the visual appearance of the very low infant mortality rates there, while the other patterns observed are generally reflected in similar ways compared to the normal map.

In the gridded population cartogram, this picture changes again (Figure 5.3, *top*). The effect of an increased size of India appears very similar, but neighbouring China now shows a different pattern compared to both other maps. Not only is it increased in size in comparison to the conventional map projection, but more significantly gets the distribution of infant mortality a different appearance. In the conventional map projection as well as in the normal population cartogram, this distribution is shown with a clear difference between the lower infant mortality rates in the eastern coastal provinces, and the higher rates in the hinterland stretching over large parts of the rest of China. The gridded cartogram makes the large population shares of the coastal provinces visible. By superimposing the subnational distribution of infant mortality rates, it becomes visible that for large shares of China's population this problem is less relevant than it may have been assumed by the display in the other two maps. A reverse observation can be made for South America, where the central areas with medium rates of infant mortality disappear largely in the gridded cartogram, while in the eastern areas particularly for Brazil a clearer distinction between higher rates in the northern populated areas and lower in the southern population centres can be told apart. With very low population shares, the higher infant mortality rates in the north of

Canada are hardly visible in this view, and some detail of the least populated areas across the planet are disguised by the grid pattern of the cartogram.

An assessment of the three maps can again not make a general judgement about the most appropriate map display. Where a spatial distribution wants to be understood such as the differences in Canada, or the internal differences in China, a conventional map projection makes this spatial distribution quickly accessible. To understand the implications on the affected population, further background knowledge is needed in this display. Here the gridded population cartogram becomes superior. It decreases the size of the least populated areas and therefore allows a quick impression of the global distribution of the prevalence of infant mortality in relation to population. Both views can be enlightening and are justified: small areas with large populations become a fairer share in the gridded cartogram and help to assess, where most people are affected by a certain problem. For the adequate display related to the objectives of the MDG, the gridded population cartogram may be the more significant way of highlighting (and understanding) the population perspective as demonstrated for China. A display of the physical space in contrast can help to understand spatial patterns and identify spatial disparities. In a wealthy country such as Canada, the emphasis of the most populated places (which on the global map are small) may be less interesting as disparities are much more an issue of spatial disparities between regions. Outside the scope of the MDG, political action will here focus much more on these differences rather than looking at such social problems in relation to population.

The normal population projections appears to be a compromise, as it contains elements of the two other map displays. Here the subnational-level, however, becomes the downside that makes this cartogram unsuitable for this data. As investigated earlier in this chapter (see section 5.2), the normal population cartogram unites two levels of accuracy within its map that result in a distorted view of the information that the map displays. While the transformation itself is based on population values, the depiction of infant mortality within the countries is based on a spatial distribution. The map therefore includes two different projections at the same time that do not allow a valid interpretation of the subject either in relation to the population distribution or the spatial distribution. Therefore the map must be rejected as being a wrong map concept.

The choice of the appropriate map projection of the other two versions depends on the dimension that is looked at. For subnational-level data, the gridded population cartogram has potential to provide new insights in map form that otherwise could only be understood with further background information that cannot be similarly integrated in a conventional map projection.

5.3.3 A productive humanity

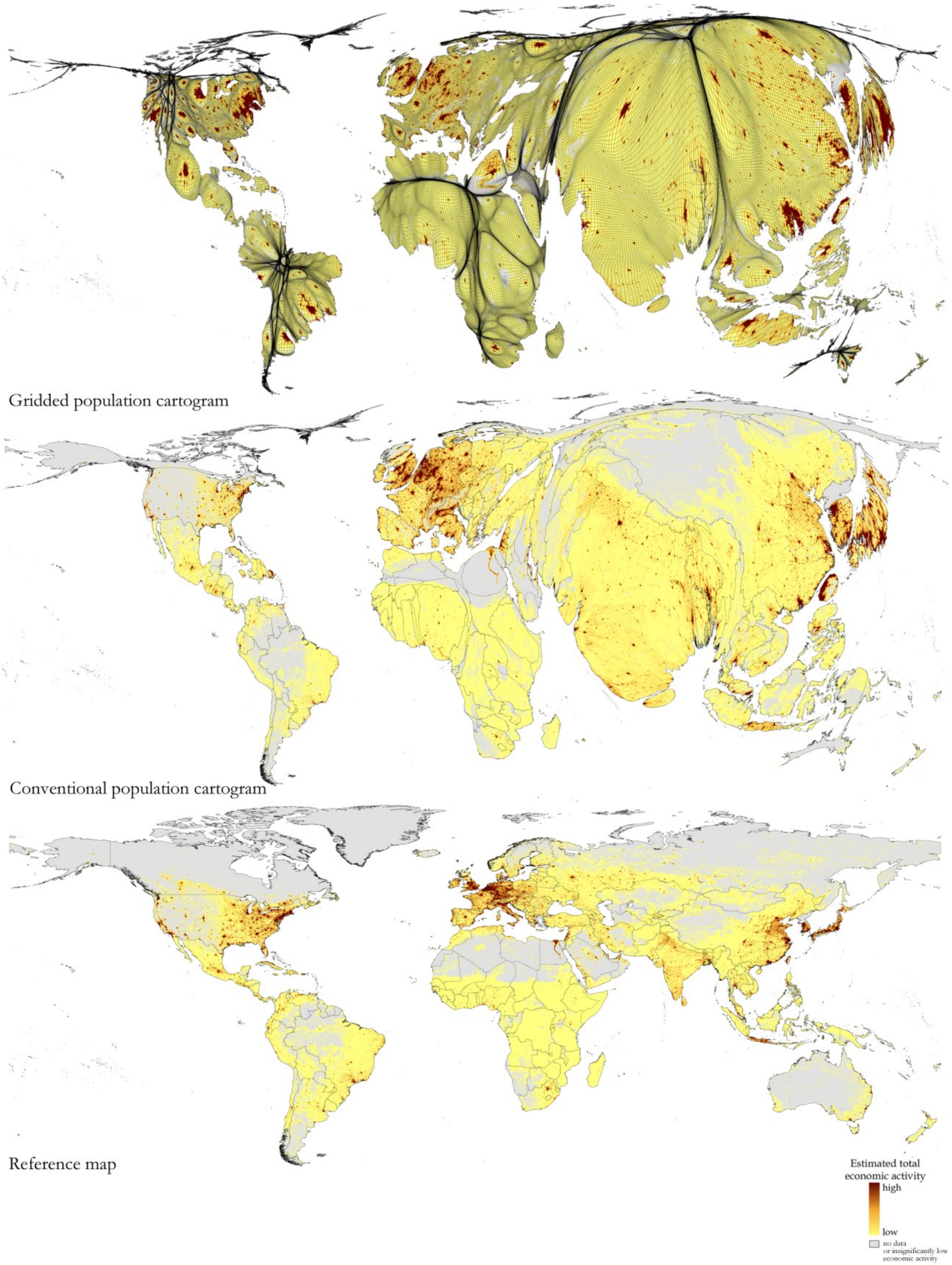


FIGURE 5.4: MAP PROJECTIONS OF ECONOMIC ACTIVITY
Gridded population cartogram (top), normal population cartogram (middle), conventional map projection (bottom). The economic activity relates to the GDP output density and is based on a gridded dataset
(own depiction by the author using data from NOAA 2010, CIESIN & CIAT 2005)

Gross domestic product (GDP) can be seen as an indicator for the economic wealth of a country and correspondingly of the people living in that country's population. Mostly it is presented in national-level proportions for a global view (CIA 2011, IMF 2011, The World Bank 2011), although there is a high variability within the countries. Recent methodological efforts that build on advances in improved population estimates and the combination with remote sensing technology achieved similar results in the creation of a gridded dataset of GDP activity like the GPWv3 modelled population counts on that level (Gaffin et al. 2004, Gallup, Sachs & Mellinger 1999, NOAA 2010). These two sources are among the little socioeconomic information that currently exists on a gridded base. The GDP grid was therefore used to explore the gridded population cartogram as a base map projection at the highest level of detail using socioeconomic data that is detached from an administrative area like the previous examples. Unlike the example of displaying population densities overlaid on a population cartogram, the GDP grid has no direct relation to the data used for the actual cartogram transformation (although it of course relates thematically to population). This is also an example for the display of data that has a higher resolution that the GPWv3 grid itself that was used in the gridded cartogram transformation.

For a general assessment of the data, the GDP density is displayed in a continuous gradual choropleth overlay with darker colours representing higher GDP activity. The particular values are not shown and a display in class-ranges was not realised, as the main emphasis here is the appearance of the gridded dataset rather than other detail or a comprehensive assessment of the global economic situation. Very low GDP activity close to 0 is shown in grey, as is missing data that is not differentiated in the dataset.

The display of GDP activity on a conventional map projection (Figure 5.4, *bottom*) seems to resemble the global distribution of population densities. The map shows that most of the highest economic activity is limited to comparably little space. A very similar impression emerges in the GDP data display on the normal population cartogram (Figure 5.4, *middle*). This is a surprising observation, as the previous example of infant mortality showed that the increase in size resulted in an increased appearance of some areas with higher significance. GDP is different data than infant mortality, but the level of detail as a result of the gridded dataset has the higher impact, as the differentiation between the separate information in the map is considerably higher so that not large extents of areas are shaded. The density of economic output interpolated over the much finder grid results in that extremely detailed pattern onto which the increase of map areas has a less significant impact. A further assessment of the normal population cartogram can be skipped, as the differences have only conceptual relevance. Like investigated in the previous example, the display is a false cartographic depiction that provides a misleading picture.

The display of GDP activity of the gridded population cartogram (Figure 5.4, *top*) demonstrates the probably most significant conceptual relevance of the technique for the use as a map projection. The grey areas of no (or insignificantly low) GDP activity virtually disappear from the map as those areas, where no people live (remaining areas of grey in the gridded cartogram can be assumed to be mainly those of missing data, such as North Korea). In comparison to the conventional map (and also the as problematic identified normal population cartogram), the darker spaces are given more space as the highest activities are often in the most populous places.

The interpretational value of the gridded population cartogram lies in the comparison of population distribution to GDP activity. The patterns in Europe and North America generally reveal a close correlation between the two dimensions, where the most increased spaces of population also have the darkest GDP overlay. In many other parts of the world this correlation is much less prevalent, in many places almost non-existent, without discussing these correlations in more geographic detail at this point.

The gridded data overlay increases the interpretational value of the gridded cartogram compared to the previous examples, which suggests that gridded cartograms benefit considerably in their value with data overlays that contain higher levels of detail. Generally, the higher level of detail should not exceed the resolution of the underlying population grid, as this is a similarly invalid comparison of higher levels of detail than the underlying spatial base. The GDP grid exceeded that resolution, but does not lead to similar problems that are part of the normal population cartogram, as the higher level of detail would only become visible when a particular grid cell would be interpreted in that precision (which would require the map to be displayed in poster size to be able to see this detail).

As stated in the previous sections already, the aim of what a map wants to show defines the most appropriate projection. Showing GDP in relation to population can therefore be as relevant as understanding it in relation to its spatial distribution.

5.3.4 Light and shadow

The previous concepts for an alternative gridded population projection built on socioeconomic and demographic data that was transformed with the gridded population cartogram in vector form. Geographical information is much more diverse than these layers that mainly represented the social spaces of the world (and, one may argue, therefore contain a certain suitability of using them with a gridded population cartogram as the manifestation of social space in map form).

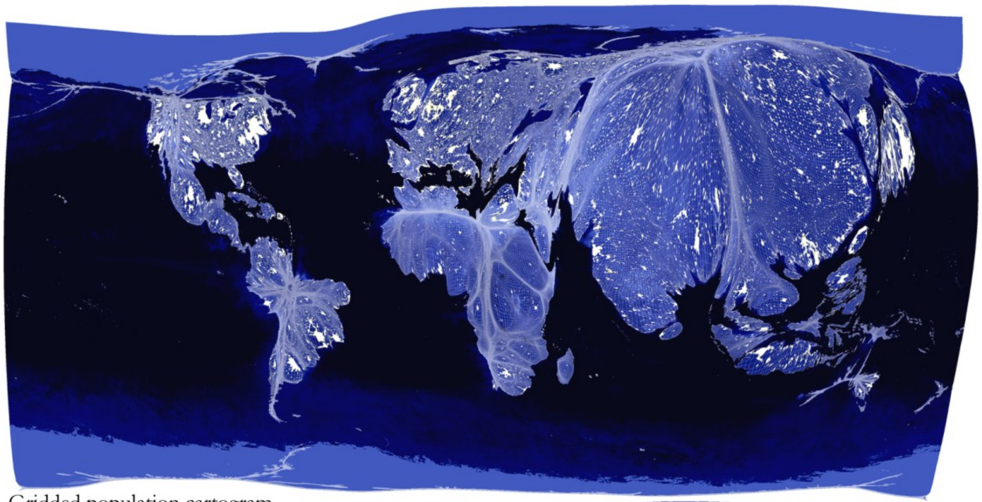
A map projection should be more versatile than displaying certain geographical dimensions, but provide a universal solution to adequately show any geospatial information. These can be physical features (of humanity as well as of nature, such as roads or rivers), or the full image of the planet in any expression. A multitude of examples would be possible to demonstrate this aspect and discover the significance of the proposed projection. As the previous examples built on humanity, investigating this aspect looks at an example that aims to connect the human and physical space, and also uses another data type for the map transformation. Satellite images survey the physical space while they orbit the planet, thus provide an image of our world does not have to rely on adequate data surveys on the ground. Remote sensing data per se is not an unbiased and neutral view, as the technical settings determine the kind of information that is taken. However, for this example this is not relevant, because a consistently recorded satellite image provides an undistorted view of the information that it recorded in a comprehensible manner[76]. Raster data (see section 3.4.1.1) displays a unique value of information for every pixel, and the exact location of that pixel has a spatial reference. This is in principle very similar to the gridded dataset used in the previous example, but the nature of a satellite image does not involve any other data modelling but shows the information as it has been recorded.

Satellite images of the whole planet exist in many different variations. Connecting to the issue of population, a satellite image of the night lights provides another type of social image of the world that builds on a very different data collection resulting in the above described different type of data (NASA 2006, Sullivan 1991). This has been used to demonstrate the effect of the three different map displays onto the data to evaluate the general concept of adding physical features to a gridded population cartogram.

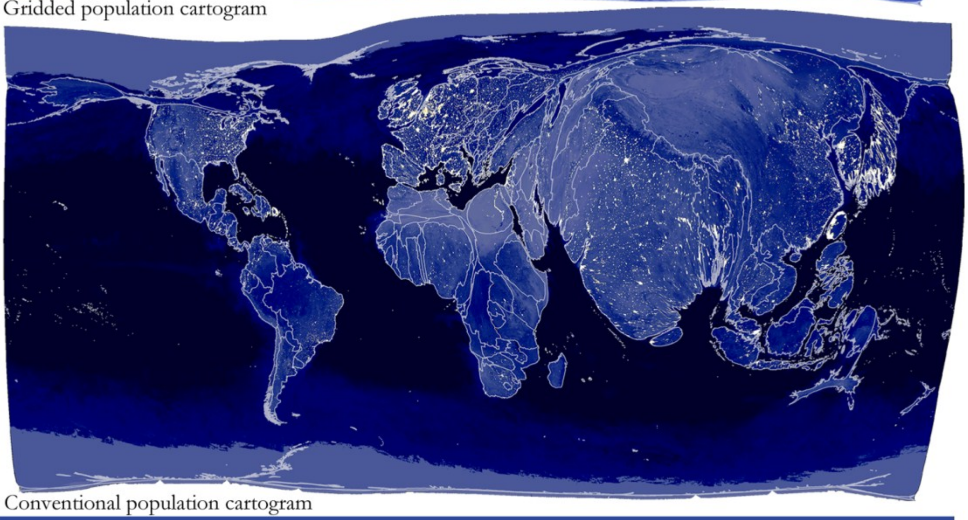
The technique needed for the transformation of the satellite image does not differ in its general procedure from the previously introduced vector data examples. Any layers of geospatial data can be used for a cartogram transformation, so that the only essential precondition is an accurately georectified raster image that contains the correct spatial reference in the image. To mirror the appearance of the previously introduced maps, the aim to visualise underlying population grid and to display country borders on the two other map depictions was adjusted to the dark nature of the image. The grid cells in the gridded cartogram and the country borders were therefore visualised using light

[76] There are many technical caveats attached to this much generalised claim (more details are introduced e.g. in Richards & Jia 2006), but that matters less in this context and is a negligible issue for the intended application here.

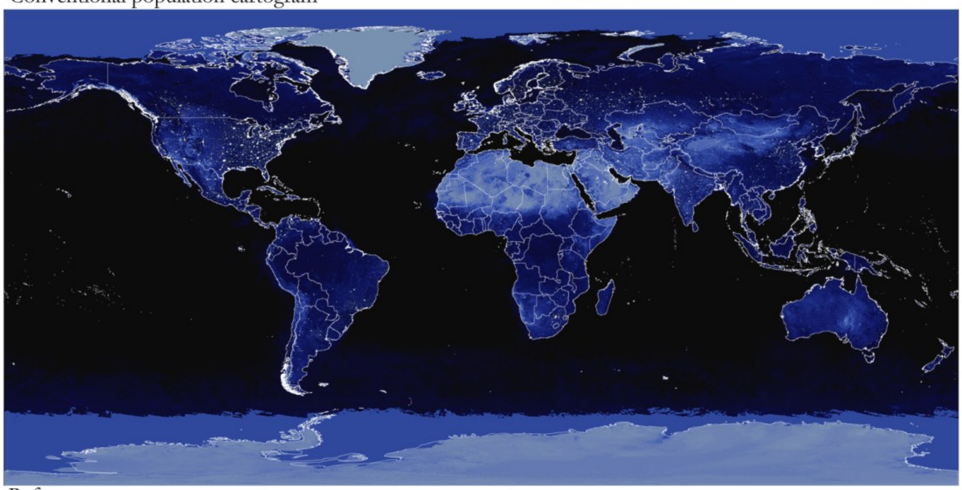
grey lines. The colour levels were adjusted to match the overall colour appearance which resulted in a slight variation of brightness between the maps.



Gridded population cartogram



Conventional population cartogram



Reference map

FIGURE 5.5: MAP PROJECTIONS OF THE WORLD AT NIGHT
Gridded population cartogram (top), normal population cartogram (middle), conventional map projection (bottom). The brightest areas show the nightly illuminated regions, while the silver-white patterns indicate the patterns of the population grid (top). Country borders are shown in bright lines (below). Land and polar areas stand out from the oceans as brighter parts (own depiction by the author using data from CIESIN & CIAT 2005, NASA 2006)

The general observations of the three different displays of the night light image are similar to the GDP activity maps from the previous section. The basic character of the data with individual grid cells (here these are the single pixels of the image) is the basically the same, so that the interpretation leads to similar conclusions.

The conventional map projection (Figure 5.5, *bottom*) shows the image closest to how it was taken by the satellite while it orbited the planet (the images were then assembled to the full view). As the satellites take observations of the physical space, this display appears most appropriate. The display on a normal population cartogram (Figure 5.5, *middle*), in contrast, can be regarded as the most inappropriate cartographic depiction for the reasons that were outlined in the previous sections.

The artistic appearance of the satellite image, standing between a piece of art and a work science, may justify an interpretation of this map having some value outside the scope of the purely scientific world. The interpretational value remains invalid, but the display of less directly relevant geographic information (such as the data presented in the previous sections) has an aesthetic value that should not remain unmentioned.

The gridded population cartogram (Figure 5.5, *top*) stands between the two displays. Quite obviously, this map distorts the information from the physical base on which it was obtained. If one argues that e.g. infant mortality relates to population and should therefore be shown in that relation rather than on its physical distribution, than one could similarly argue that a satellite image relates to the physical space, and should therefore not be shown in any other spatial relation. Both arguments were not made, but the argumentation demonstrates, that an evaluation of the significance of either of the map displays has not a single answer. In this case, the gridded cartogram depiction can also be seen as adding further interpretational value (while losing the spatial representation).

Lights at night relate to population, and seeing an image of the distribution of night light projected onto population space highlights those areas that remain darker, but contain a large share of the world's population. Large parts of the African continent remain dark, standing in direct contrast to the illuminated populations in Europe and North America. The map display included here highlights these differences in the projections. In the case of the gridded population cartogram, further detail can be better assessed in larger displays because the visualisation of the grid and the lights are conflicting visual elements that are less disturbing in slightly larger map displays[77].

[77] To make a consistent presentation of the results and allow all three map displays to be seen in direct comparison, larger displays of the gridded cartograms are not included in this chapter.

5.3.5 Conclusion

The previous cases tested the use of gridded population cartograms for its applicability to different types of data with the aim to explore the further potential of the technique to be used as an alternative map projection. This was examined in comparison to a conventional map projection as well as a normal population cartogram to demonstrate the specific advantages and disadvantages to two kinds of maps which are often seen as contradictory. By including elements of both map types (accurate spatial reference and a value-based transformation), gridded cartograms do not only stand between the two, but are tested to close the conceptual gap between cartograms and conventional map projections.

By using the gridded cartogram as a base projection, the examples demonstrated the general applicability of different data types, ranging from national-level data down to data on a precise grid level. Similarly valid were the results for the use of raster data which represented the general range of any geospatial information, independent from the direct or indirect relation to the topic of the underlying basedata (which here was population). The assessment included general assumptions on the value and significance of the depiction in comparison to the other two maps, although it must be stated that no general valuation can be made. The use of an appropriate map projection always depends of the intended background of a map. Where the population distribution stands in the centre of interpretation, a gridded cartogram can indeed provide a *better* cartographic representation of geographic information, while to a certain degree the reference to the spatial distribution diminishes.

Readability of gridded cartograms adds to the problematic side, which also lies in the novelty of these maps (map readers are accustomed to conventional map projections). Only for national-level data a normal population cartogram can provide an alternative solution with a potentially superior readability for the average map user, as here the country shapes are still recognisable. This advantage of a normal cartogram turns into a disadvantage when displaying other data levels on top, as these receive an invalid cartographic distortion. In this regard, the gridded population cartogram has a much higher flexibility, and might for some map topics be a viable alternative base projection with added value and a high potential to display information that conventional map projections show in inaccurate ways. There the gridded population cartogram unfolds its full potential as a new basemap for the social mapping of the world and reveals the real extent and distribution of topics such as demographic development, poverty, or unequal living conditions.

5.4 Gridded cartogram transformations of quantitative data

The use of the cartogram technique in the Worldmapper project and in other works that choose to use cartograms as cartographic displays of quantitative data does not build on the concept of using a single cartogram as a basemap. Although normal cartograms do not show more data than for example a pie chart, they are instantly understandable from the additional geographical dimension in them. However, interpreting in more detail is not possible, so that the country shapes predetermine the level of accuracy. Gridded population cartograms improved on this problem (see chapter 4), which raises the question, to what extent gridded cartograms can be used in a similar diversity of map topics as the base for the actual map projection as the range of maps displayed in the Worldmapper project.

This section investigates the concept of applying a gridded cartogram transformation to gridded quantitative data in general. While the population distribution stands in the centre of a globalised world and is a coherent base for any geographical topic, a transformation of other data can give a unique insight into the dimensions contained in that data and their particular global distribution. Such cartograms would then be thematic gridded cartograms that use an equally distributed grid of the topic of interest and transform each grid cell according to the total value of that topic.

The requirements for a gridded cartogram transformation are datasets that meet the same standards that have been investigated for the initial development of the gridded population cartograms (see section 3.3.1). Where these requirements are met, the same methodological considerations and procedures as outlined in detail for population data can be followed to create a gridded cartogram transformation (see section 3.4).

The main constraint for drawing gridded cartograms from other relevant topics is a comparably accurate set of data on an equally distributed raster. The resolution should be similar to the population grid which proved to be working best on a global scale with a ¼° resolution grid. Higher resolutions for creating distorted world maps are not needed, but lower resolutions than ¼° would not show that level of detail that is needed to produce gridded cartograms with meaningful and detailed enough patterns.

5.4.1 Changing populations

The time series of the gridded population data from the GPWv3 database provides the base for the further assessment of other gridded cartograms. The different years that are contained in the database (covering the extent of 1990 to estimates for 2015) allow the calculation of absolute population changes for each individual grid cell, which provides the base for the compilation of a grid that contains the population change rather than the absolute population distribution[78]. Because these trends provide a more complex picture, and the resulting gridded cartograms introduce a new conceptual approach to the cartograms, these geographic details will be investigated in slightly more detail than in the previous sections, as they support the initial understanding of the concept behind the new map concept.

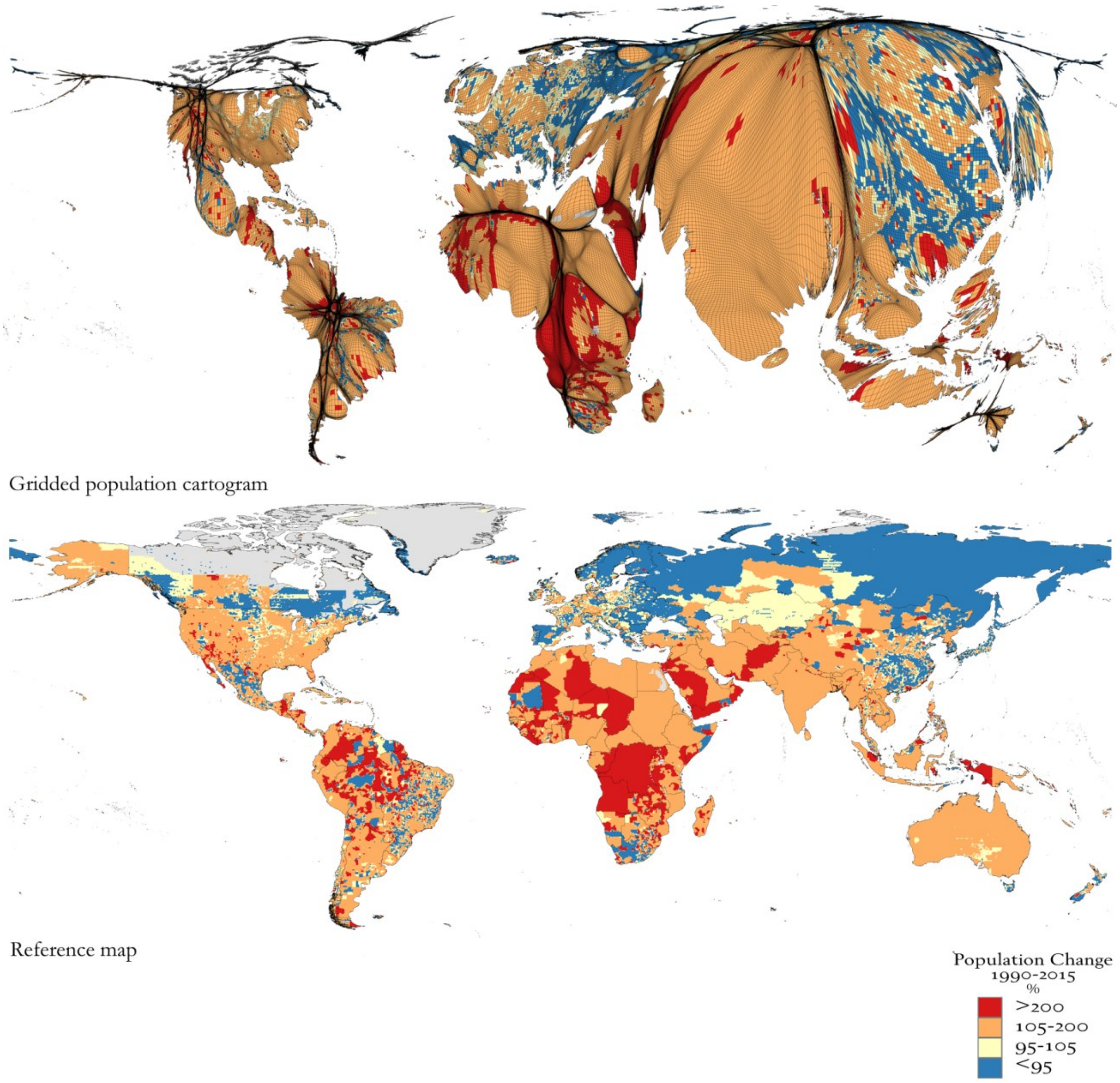


FIGURE 5.6: POPULATION CHANGES 1990-2015
Mapped on a gridded world population cartogram (top) and a conventional map projection (bottom). It can be seen that especially China stands out as having a diverse pattern of growth and decline within its borders, while most of the other regions of the world have either a dominating trend in growth or in decline. The map is based on a ¼° population grid containing 2015 population estimates
(own depiction by the author using data from CIESIN & CIAT 2005)

[78] This example is still directly related to population, but the main interest in this conceptual assessment is the potential of any other data quantities, for which the population grid provided a reliable basis that builds on the previous findings. Further applications using other quantitative information will be presented in chapter 6.

The absolute changes show a highly variable picture when assessed in their spatial distribution on a conventional map (Figure 5.6, *bottom,* displayed here are the proportional changes in percent because total values must not be shown as a choropleth layer). A similar investigation of the generated data can also be made in relation to the population distribution (Figure 5.6, *top*). The declining populations in large parts of Europe and the old industrial centres of North America dominate the shrinking world. But also parts of the largest countries in the world, India and China, start to show trends of declining populations. In India, this is split between the major populations of the south and the still growing northwest, while the main growth in China takes place in the economically most active agglomerations and the decline starts to matter in the surrounding areas of the densely populated eastern provinces. With many of Africa's populations growing, the poorest parts of the world are those areas where most of the increase dominates the gridded population cartogram.

The absolute data behind those changes cannot be applied directly to a gridded cartogram transformation, because negative values are invalid data for a cartogram (negative areas are not possible). The information about growth or decline between has therefore to be split and both can then be used for separate gridded cartogram transformations. The population changes between 1990 and 2015 were distributed onto a ¼° grid (using the same resolution as the initial world population cartogram) and two separate gridded cartograms for each of the grids were generated. The original Worldmapper colour scheme was used in the resulting gridded cartograms, because these are now once again mono-dimensional and do not feature an additional layer of information.

The resulting two gridded cartograms (Figure 5.7 & Figure 5.8, *see below*) show, where populations are estimated to shrink and grow in the 25 years between 1990 and 2015. The dimension of shrinking populations in (mainly Eastern) Europe is juxtaposed to a population decline in similar dimensions in the east of China. Similar trends in slightly lower areal extent can also be seen in South America and in the south of the African continent. Opposed to these trends stand the population increases that dominate most of the African continent, and distinguish the population changes in India from its similarly populous neighbour China. Due to the preserved geographical reference in the gridded cartogram, the amount of expanded grid cells allows the interpretation that that population increases in China are mainly concentrated in very few areas, above all the Pearl River Delta region (Figure 4.17 shows that area highlighted on a gridded population cartogram). In contrast to these trends, Europe almost disappears from this map, and only some areas such as the southeast of the United Kingdom are bulging out, although in much lower dimensions than the main centres of growth in other areas (for a geographical assessment of current demographic trends see Bloom & Canning 2008, RCEP 2011).

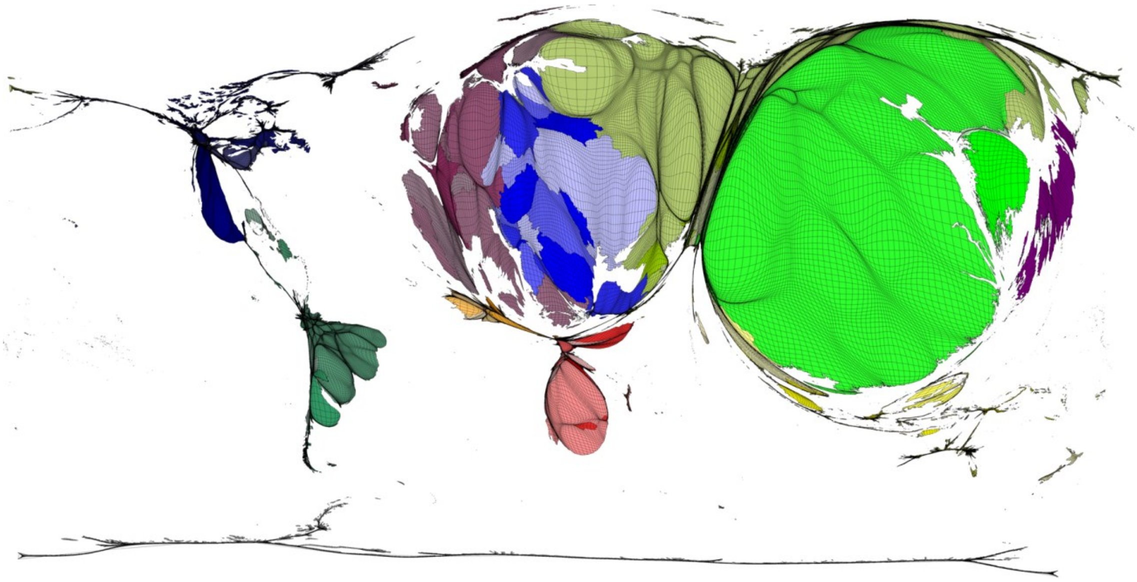


FIGURE 5.7: GRIDDED CARTOGRAM OF POPULATION DECLINE BETWEEN 1990 AND 2015
The transformation is based on a ¼° grid containing the number of population losses in that area in the given time (own depiction by the author using data from CIESIN & CIAT 2005)

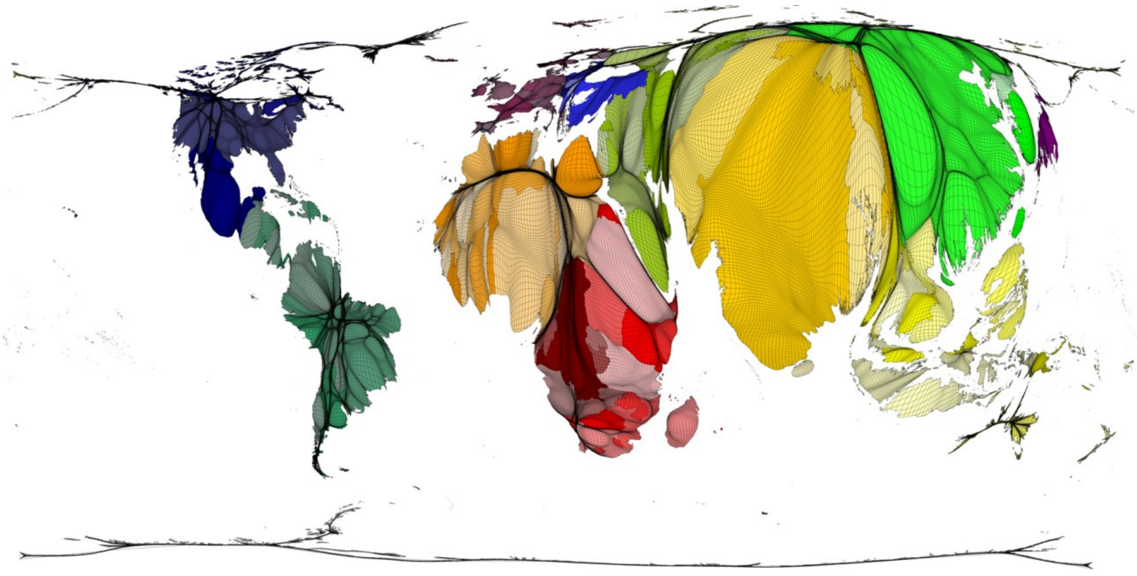


FIGURE 5.8: GRIDDED CARTOGRAM OF POPULATION GROWTH BETWEEN 1990 AND 2015
The transformation is based on a ¼° grid containing the number of population gains in that area in the given time (own depiction by the author using data from CIESIN & CIAT 2005)

The visual examination of the two gridded cartograms of population changes as shown in Figure 5.7 are the return to the original concept of Worldmapper cartograms, in which different topics determine the transformation of a map. The gridded cartograms combine this principle with the additional concept of creating gridded cartograms to be able to map more detail. This combination led to a new kind of maps that the original Worldmapper approach in the depicted example would not be able to create. With one single figure per country, a normal cartogram would either represent a growing or a shrinking population for a country, while in gridded cartograms many countries appear in both maps. What sounds contradictory at first makes sense when thinking back to the geographical distribution of growth and decline (see above): growth and decline are processes that happen within a country at the same time. Some areas grow, others shrink, as populations also move within areas, and as overall national trends are opposed by more variable internal trends. This capability can be seen as a significant improvement, not only because of the increased detail (that is part of all gridded cartograms), but because of a much higher flexibility to show such matters in this way.

More than in the previous mapping concepts using gridded population cartograms as a basemap, these two maps are more difficult to understand to the untrained map reader. With every changing topic, the map shapes change considerably. It can be seen as a downside of gridded cartograms that the country shapes cannot be retained (while the constantly changing shapes in the Worldmapper-style cartograms aim to preserve that element in the map). The advantage of the detail therefore requires a much higher ability of the map reader to read the map and makes it inevitable to understand the principles and display techniques of gridded cartograms.

5.4.2 Human impact

Gridded socioeconomic data is currently a rare commodity (this is different for environmental geodata, for which chapter 6 will present applications for gridded cartograms). The number of gridded cartograms that can therefore be created remains limited, and a similar extensive range of topics as they are part of Worldmapper is not yet possible. The example of population growth and decline already required own (although very simple) geospatial analysis to create that gridded dataset. Where other grid data is desired to be mapped in higher detail, it would have to be modelled. A very simple way of achieving this is a mere redistribution of national-level data over the population distribution. This will result in often crude estimates, but where a gridded cartogram transformation is wanted, it may provide a starting point for the generation of own gridded data that are more or less directly related to the population distribution. The concluding example uses this approach to revisit the different concepts that have been introduced in this chapter to highlight the key differences between a conventional map projection, the use of a gridded population as a basemap, and a gridded transformation of other quantities. The example that is used to show this progression of maps is the ecological footprint of population, which is one of the indicators that are also used in the Happy Planet Index (see section 5.3.1).

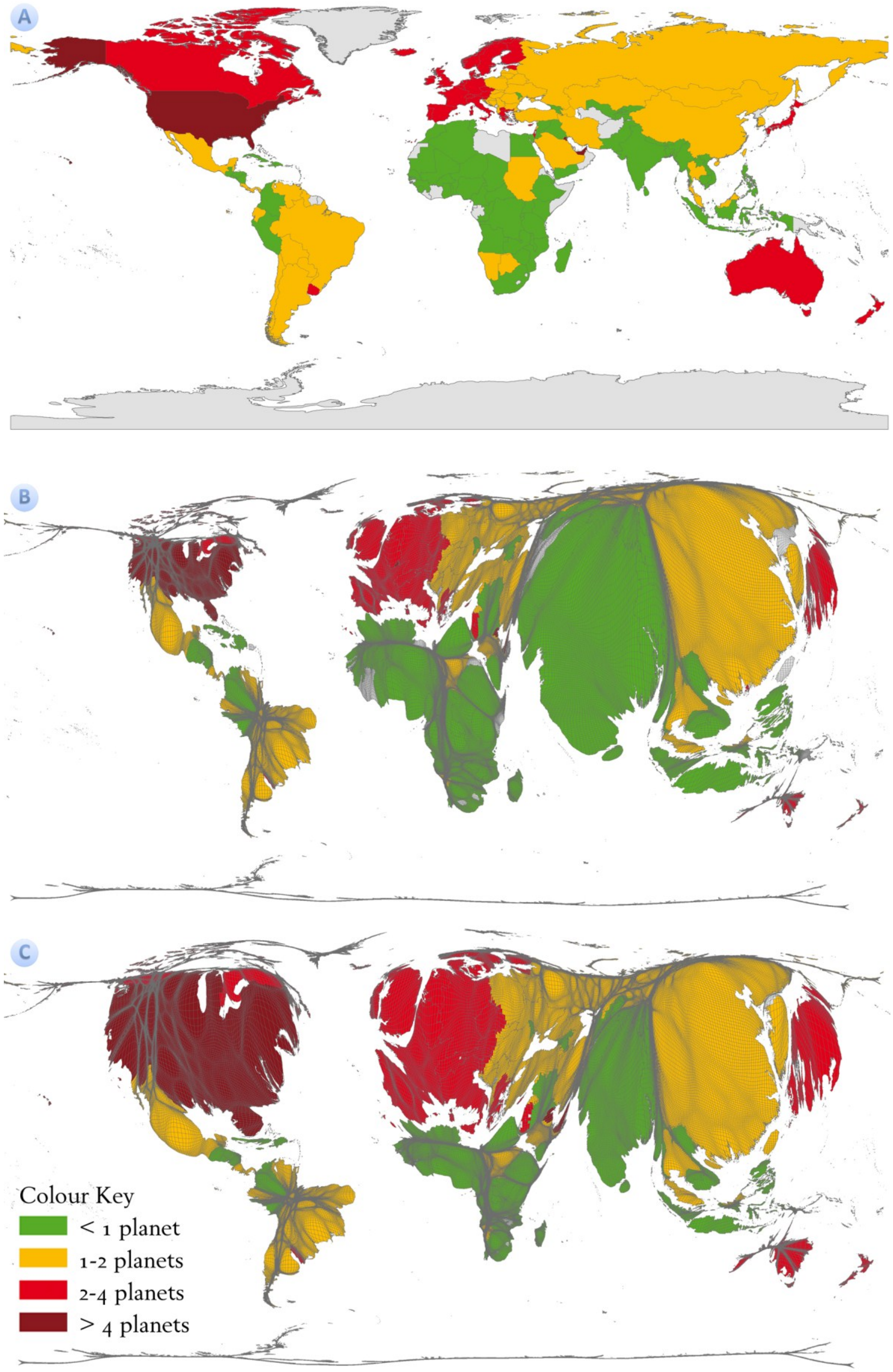


FIGURE 5.9: ECOLOGICAL FOOTPRINT MAP SERIES
The ecological footprint describes the number of planets that were needed for a sustainable future if all people on the planet were using the same resources. It is expressed as x-planet living for a country. A: Shown on a conventional map, B: Shown on a gridded population cartogram, C: Shown as a gridded cartogram where each grid cell is resized according to its total ecological footprint (own depiction by the author using data from Abdallah et al. 2009, CIESIN & CIAT 2005, Ewing et al. 2010)

The ecological footprint is a measure for the resource use by the population of a country and aims to make a statement about the sustainability of a country's way-of-life (see section 3.3.2 and Ewing et al. 2010). The data of the ecological footprint is based on national-level estimates, with all the constraints and limitations attached to them that were explained earlier. These are negligible in this example, as the different appearance of the map shapes is the relevant aspect that is assessed in this example.

The map series (Figure 5.9) demonstrates the basic principles that are behind the gridded cartogram approach. The top map (Figure 5.9A) displays the ecological footprint categorisation (from sustainable to very unsustainable following a traffic light scheme from green to red) displayed on a conventional map projection. The map allows seeing which country has which sustainable way-of-life, and how this relates to the physical size of a country. The perspective changes in the gridded population cartogram as a basemap for the same data (Figure 5.9B). Leaving the earlier discussed caveat aside that national-level data on a gridded population cartogram needs not a grid to be understood[79], the population projection shows the footprint in relation to that subject that causes the footprint. It displays relatively few people globally living very unsustainable lifestyles, while large shares have less impact on the resources available. The view changes again when the impact of the lifestyles is taken into account in the gridded cartogram transformation (Figure 5.9C). That gridded cartogram of the human footprint was created by multiplying the global hectares per capita with the total population living in each grid cell. This makes the quantitative impact of people visible and reverses the pattern of the gridded population cartogram by demonstrating the high impact on the resources that the few people in the most unsustainable areas have in comparison to those living more sustainable lifestyles (Ewing et al. 2010). The Global Footprint Network, publisher of the ecological footprint data (Ewing et al. 2010), uses depictions of the number of planets for showing this impact for each country. The gridded cartogram approach could provide an alternative graphical display.

The map sequence from the conventional via the gridded population to the gridded footprint map shows the unique advantages and characteristics of each map form, of which again none is to prefer, but needs to be chosen according to the intended focus. Although based on a crude, but therefore easy comprehensible dataset, the three maps summarise and highlight the differences of the different map forms in relation to the same topic. Mapping other (and more detailed) socio-economic indicators in a similar way remains difficult because of the constraints in getting or creating reliable data.

[79] But at the same time the grid still is the more accurate population reference.

With new modelling approaches and increasing levels of globally available data, this problem will become less relevant in future, and similar visualisations for any imaginable quantitatively measurable topic relevant for humanity should result in meaningful new gridded cartograms.

5.5 Conclusion: The versatility of space

This chapter extended the utility of the gridded cartogram technique by providing comparative depictions of a representative range of mapping concepts using gridded cartograms as well as a normal cartogram and a conventional map projection. The improvement of the technique is based on a spatially independent and accurate base unit for the map transformation. The resulting maps are more abstract than normal cartograms because of the lost reference to the familiar country shapes from a conventional map projection. That disadvantage is the gridded cartogram's strength at the same time, as this makes it more suitable for an alternative map projection than a normal (country-level) cartogram.

At a series of increased level of detail using different data types from national to grid-level, it could be demonstrated, that gridded population cartograms benefit from that increase in detail, and more detailed data adds further interpretational value to the population cartogram that features similarly accurate displays like conventional maps. The main difference is the changed dimension in the underlying basemap, which relates to the potential (and limitation) of gridded population cartograms in their use *as* a basemap. The added value of a gridded cartogram lies in its ability to visualise other data in relation to population, while a conventional map projections visualise other data in relation to physical space. A gridded population cartogram therefore shows geographic information in relation to the human space, what can be a desired aim. This also allows new information to be obtained from the map, which a conventional map projection cannot include. The spatial reference does not get lost, but is much less immediate comprehensible because the information in the least populated areas is hidden under the merging grid (but is not lost, as is would become visible if the map was investigated in a detailed examination at a larger scale).

When gridded cartograms are used as a basemap, same considerations to map design based on common cartographic principles have to be made. The choice of colour, potentially also symbols and other map elements that may wish to be added in more comprehensive applications, have to be considered in the design process. Here straight forward approaches were realised, generally based on existing visualisation concepts adapted from the conventional map that has been used in the different examples.

Is a gridded population cartogram the better map projection? The answer is yes and no. This justifies the classification as a map projection, because there is no best projection (see section 2.2.3). There are only appropriate map projections for the intended message of a map. The choice for the right map projection therefore depends on the verdict of the cartographer, and whether a certain depiction makes sense to be shown in that particular projection. That related to the circles drawn as distances on a Mercator map introduced earlier in this thesis (Figure 2.2). The intended information could be shown on a Mercator projection, but then the circles would have to look very different (and are not circles at all). Potentially more appropriate may have been an equal-area projection, where the circles remain the same to make the information of the equal distances immediately accessible to the map reader. The same principle applies to a gridded population projection (which therefore is an equal population projection). Drawing geographic information on top of it is a more complex process, as the different concepts outlined in this chapter showed (and circles on that map would be just as inappropriate areas of equal distances as they are on a Mercator map – here a gridded population cartogram is not very different in its nature). Where a topic wants to be shown in relation to population and that information is made quickly accessible to the map reader, a gridded population projection may be an appropriate choice with an added value to the map.

Data is the issue that becomes repeatedly relevant in the use of this technique. Data resolution and higher levels of detail are crucial to benefit from the increased accuracy. Where higher data levels do not exist, a gridded cartogram remains less useful compared to the use of a normal cartogram as a basemap. Data that is not available on a gridded base is also unsuitable for a gridded cartogram transformation itself, so that further advances are essential for a more versatile range of applications. These advances must also include the improvement of methodological approaches to model socioeconomic data onto a grid on a more reliable basis that the interpolation of national-level data and population distribution.

Where such data is available, a gridded transformation of any kind of data may be an alternative way of visualising these quantities in their distribution. This concept relates to the initial idea of the Worldmapper project and has successfully been applied to showing population growth and decline. A similar range as in Worldmapper is currently not viable because of the above outline data constraints.

The readability of gridded population cartograms is a disadvantage because of its complex structure and its (at the moment) novel approach. This can be changed by making the gridded population cartogram a more common picture in the range of maps, which requires further efforts into the wider use of the projection by demonstrating its value for potential users. In comparison to other topical cartograms (gridded and others) that change shapes with every map theme the gridded population cartogram has the advantage of retaining the same shape in every map that only needs to be understood once. When this is achieved, the map reader can read gridded population cartograms with a more focussed view on the actual map theme that is displayed on the cartogram.

Chapter 6 **Applications for gridded cartograms**

6.1 Introduction

In most applications cartograms are still used as unusual visualisations, so that this element of unconventional and sometimes provocative mapping remains in the focus of cartographic display. This may explain the reluctant use of cartograms as a basemap to show additional information. The potential of using gridded cartograms as both, a basemap, and an adaptable map projection for a multitude of applications has been demonstrated in the previous chapters. Gridded cartograms open a wide range of new applications that redraw the diverse geographies of the world, but to demonstrate that potential, it requires further demonstrations of how this technique can be applied to uses that are of broader value to more than an enthusiastic group of peculiar geographers. While the previous chapters looked at conceptual issues and a general assessment of the cartographic values of the gridded cartogram technique, this chapter applies the technique to a broader range of application areas.

This chapter introduced potential uses for gridded cartograms. The investigation of potential uses (and potential users) is based on a selection of different thematic contexts of the large number of case studies that have been investigated in the final stage of this research project. The choice of examples included in this chapter was based on a decision to present the versatility of gridded cartograms in their utilisation that may go further than one may normally envisage for a cartogram transformation. The examples intend to liberate cartograms from their image as limited graphical representations of a single topic mainly from social sciences. The analysis of the case studies presented in this chapter includes a stronger emphasis on the geographic content of the maps in order to highlight their interpretational value for potential users. The design of the gridded cartograms has changed for the same reason. The comparative argument plays a subordinate role, and only where a comparative argument is made in the interpretation, a larger map comparison is included in the map display. Most other cartograms are shown without a reference map or include a thumbnail size reference map for orientation.

The case studies presented in this chapter are the following. The case of electoral mapping will be examined with a comparative set of different electoral maps for the 2010 general election in the United Kingdom (section 6.2). An alternative view on the basic geography of a country will then be demonstrated at the case of Germany (section 6.3). The view is extended back to the world in the following section with an emphasis on how environmental issues are displayed in gridded cartograms (section 6.4). The examples presented here include biodiversity, precipitation, and the world's oceans. The final case study of global accessibility examines the use of gridded cartogram transformations of complex datasets that contain more than one quantitative dimension (section 6.5). The conclusion assesses to what extent the depicted examples mark a methodological progress for the cartographic efforts of the Worldmapper project (section 6.6).

6.2 Mapping elections: Political views

Although the most common use of cartograms is the graphic display of quantitative information, the idea to use cartograms as a basemap for additional layers of information has been used for a while by other researchers. Most prominent examples of this are the works of Danny Dorling and the Social and Spatial Inequalities Research Group at the University of Sheffield, within which this research has also been conducted. Within their research whole books have been published which are based on cartogram techniques (e.g. Dorling & Thomas 2011, Shaw et al. 2008, Thomas & Dorling 2007, Dorling 1995, Dorling & Thomas 2004), but similarly extensive uses of cartograms that are treated as being equal to a conventional map are rare. Only very few other examples of a similarly complex use of cartograms exist. Other uses generally include an additional layer of information showing either the displayed topic as a relative value, such as showing the per capita emissions on a carbon emission cartogram (and similarly topics that are directly linked), or showing a topic in relation to population, such as electoral results.

Electoral cartograms have become a prime example for a more widespread use of this mapping technique because they give an honest representation of the vote share in relation to people. In the United Kingdom, Dorling's cartogram techniques (Dorling 1991) have become popular mapping techniques adapted by the media for their coverage of general elections. Based on Dorling's approach, the cartograms show a geometric structure for an electoral constituency and display the election result on it. Also Gastner/Newman's method has been demonstrated in their paper explaining the algorithm by using election results displayed on a population cartogram (Gastner & Newman 2004, for an application using the gridded cartogram technique showing US election results see Pattie, Hennig & Dorling 2011).

To demonstrate the application of the gridded population cartograms for electoral mapping in this thesis, the results of the 2010 general election in United Kingdom (May 2010) was chosen to map the results accordingly. Using this example also allowed to evaluate the resulting maps in comparison to other electoral mapping approaches in conventional map form and in Dorling cartograms (election results obtained from Guardian 2010, BBC 2010).

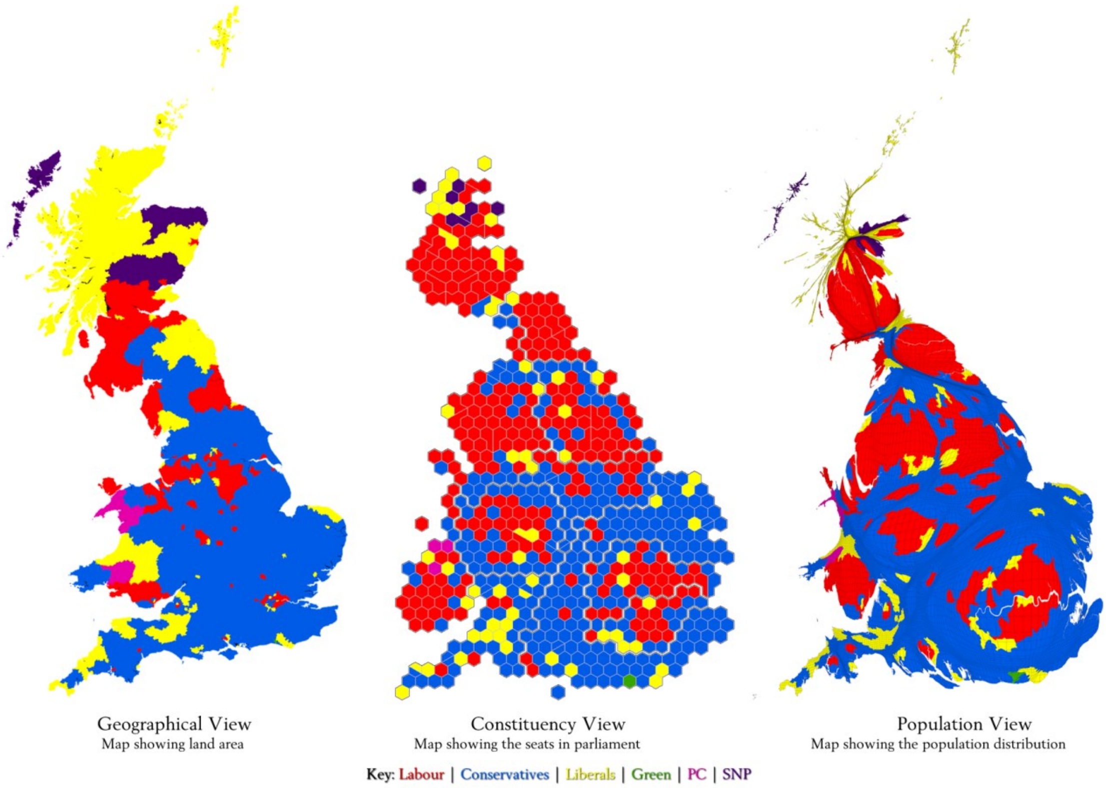


FIGURE 6.1: COMPARISON OF ELECTORAL MAPS FROM THE 2010 UK GENERAL ELECTION
The parties elected to the 2010 Westminster parliament in Great Britain shown on a conventional map (left), a hexagon Dorling cartogram (centre), and a gridded population cartogram (right) (own depiction by the author using data from BBC 2010)

The 2010 general election in the United Kingdom was mapped for Great Britain[80] using a comparison of different mapping methods, contrasting a conventional map with a hexagon-style and a gridded population cartogram (Figure 6.1). The three maps show the area on the map coloured by the winning party. The conventional map therefore shows the physical extent of the constituencies that went to a party, while the gridded population cartogram shows the number of people that are represented by a certain party. The hexagon-shaped cartogram uses the hexagons as representations for each constituency. This comes close to the population share, as constituencies aim to include a similar number of people. The hexagon cartogram is the most accurate representation of the shares of each party in parliament. The gridded cartogram, in contrast, is a more accurate picture of not only how many people are represented by a certain party, but also their geographical reference in the grid. The optimal geographical reference in the

[80] Northern Ireland is omitted in these maps. Most votes there went to local parties that only stand for election in that region.

physical space is given in the conventional map projection, which hugely distorts the impression of a party's dominance in the rural areas.

With the very specific characteristics and accuracies, the three different depictions all show a different reality, yet all give a legitimate representation of the election results. Nevertheless, they allow different interpretations when it comes to an understanding of the electoral patterns and a clearer view of the changes that took place in the voting patterns. All three maps of the British election results do not take any changes into account; neither do they reflect the real share of votes of the winning and losing parties in each area. Both are relevant issues for a deeper understanding of voting patterns and of gaining a better picture of the political landscape beyond the distribution of seats in parliament.

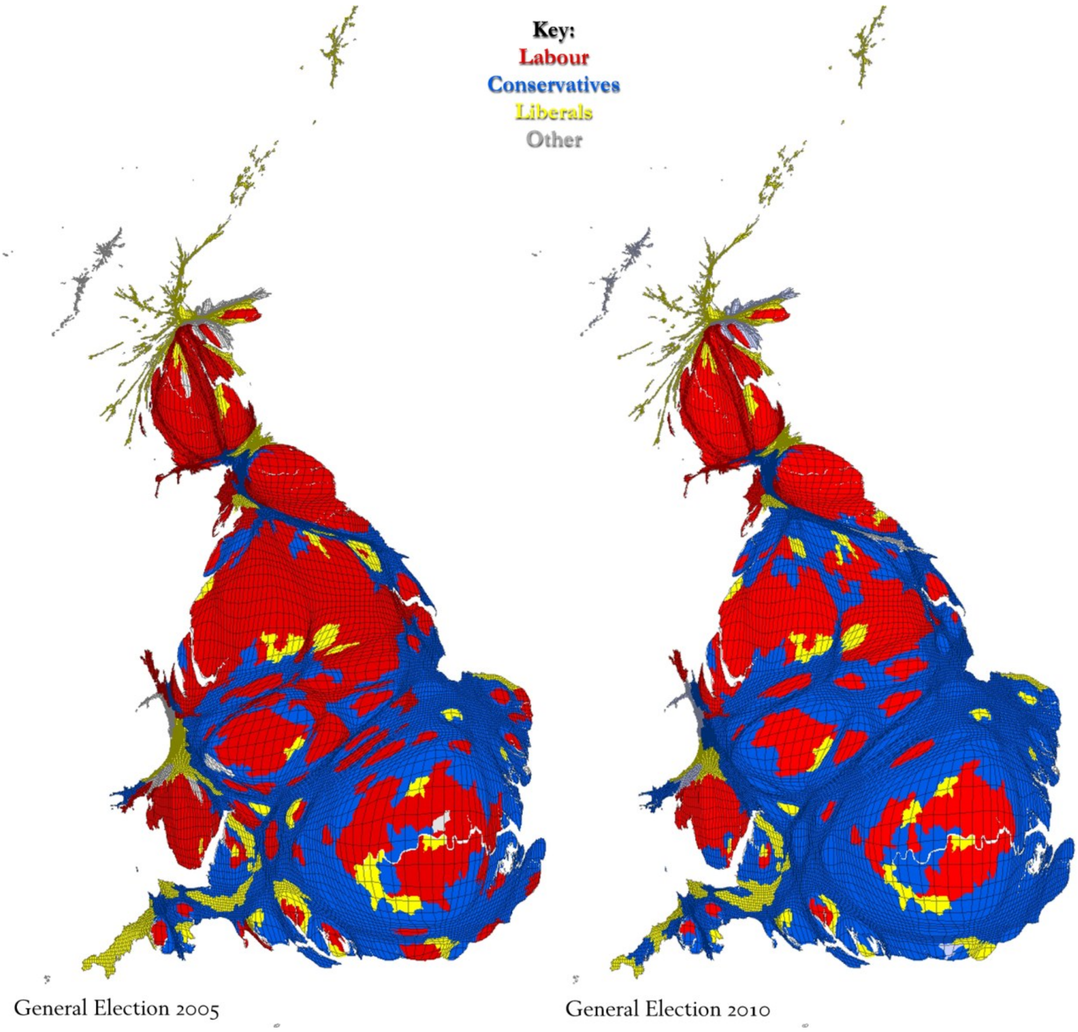


FIGURE 6.2: BRITISH GENERAL ELECTION RESULTS 2005 AND 2010 ON A CARTOGRAM
Map transformation based on a 2.5' population grid of 2010 population estimates
(own depiction by the author using data from BBC 2010)

An attempt to visualise the changes in the voting pattern was realised in two additional versions of the gridded cartogram (Figure 6.2). The first approach included the creation of the same cartogram showing the previous election results from the 2005 general election. On a static display, these two maps allow a comparison of the changes, while a digital version that overlays the two and slowly fades from the 2005 map to the 2010 map gives a vivid impression of the areas where changes took place. The digital animation adds a clear interpretational value because a static (or printed) version of the two maps requires more effort to identify the changes between them.

The other way of visualising the changes is a modified colour scheme. For realizing this, all constituencies were identified in which a change in the winning party has taken place, and the respective changes were transferred to a distinct colour scheme (Figure 6.3). The colours chosen for showing the changes were oriented on the original winning party's colour in the original map and adapted to imply the party's colour from which the changes originated from in the previous election. A Conservative Party gain from the Labour Party, for example, resulted in a dark lilac colour, which occurs when blue (standing for Conservatives in the map) and red (standing for Labour) are mixed. The design of the colour scheme had an intuitive understanding of the changes in mind and aimed for the least possible complexity that is able to reflect the changes that happened between the two elections.

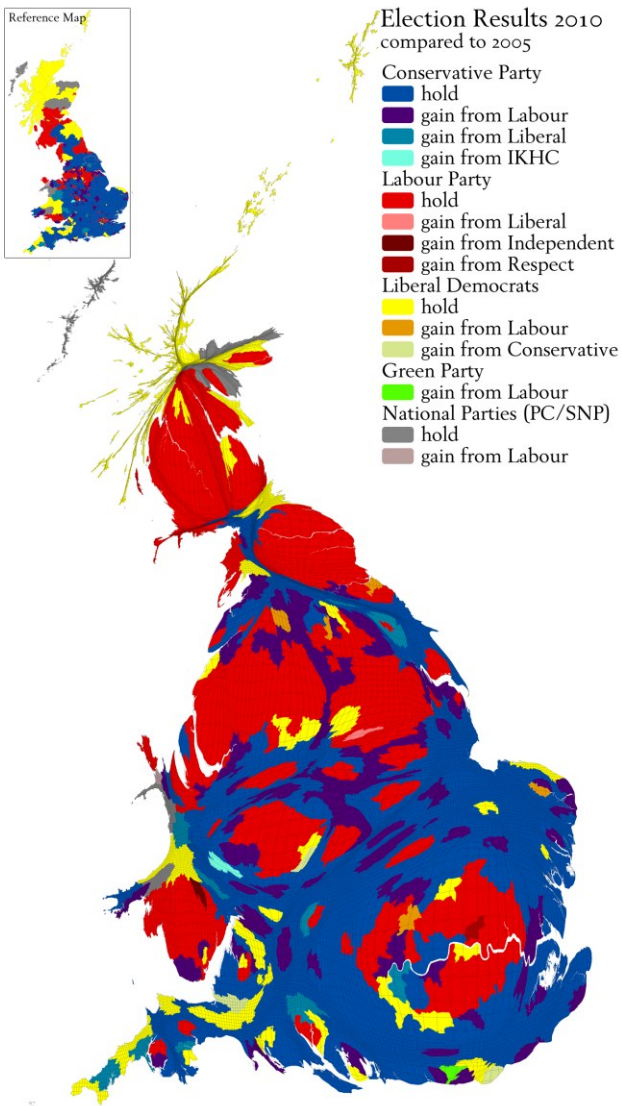


FIGURE 6.3: CARTOGRAM OF THE 2010 GENERAL ELECTION DISPLAYING CHANGES TO 2005
Map transformation based on a 2.5' population grid of 2010 population estimates (own depiction by the author using data from BBC 2010)

What is shown in the map of changes (Figure 6.3) reflects the difficult position in which the parties were after the election, with no overall majority of one party in the newly elected parliament. The map helps to partly understand this outcome, as it shows where changes took place, and where the Conservative Party failed to gain votes. Most of the changes from the Labour Party to the Conservative Party can be seen in the suburban fringes, often areas of higher-than-average affluence, such as around Birmingham or in some suburban parts of the Midlands. In the southern half of England, most of these suburban and some of the fewer rural constituencies that previously went to the Labour Party could be won by the Conservative party, while the urban centres in the North remained in the hands of the Labour Party. To gain an overall majority, these are the areas that need to be won, as the gridded population cartogram shows that there are a significant number of people living there (Dorling & Hennig 2010).

The revised cartogram displaying the changes falls short of showing another dimension of voting patterns, which is the real share of a party in the votes. As the candidate with the most votes is elected in the electoral system of the United Kingdom, a share of far less than 50% of the votes can still lead to a sufficient majority to be elected. The gridded cartogram in this form can only show how many people a certain party represents, rather than how many voted for a party. This does not matter politically in the current electoral system, but it is relevant in the debate about voting systems (Pinto-Duschinsky 2011), and it does matter in countries where proportional votes are counted.

The different maps show, that no map projection is superior. Even is the purpose of drawing an electoral map is already defined, there are still different options of how the results are displayed, depending on the emphasis that wants to be made. A gridded population cartogram adds to the already existing diversity, but it may be more interesting for countries that use a proportional voting system and the population reference reflects the political constitution of the parliament. In the case on the United Kingdom, conventional maps or those cartograms giving every constituency the same space (e.g. based on Dorling-cartograms) appear more appropriate to show the actual political implications resulting from the elections.

6.3 Mapping countries: A new look at the geography of a nation

The use of larger scale depictions such as the country cartograms, combined with more appealing full-colour visualisations are components to promote the value of the gridded cartogram technique and turn the resulting maps into attractive but also valuable alternative cartographic products. A *real* map projection should be able to visualise any geographically relevant feature accordingly. It should produce meaningful maps that add sense and a new value compared to other existing projections. It should also reflect people's expectations from a map, which often includes the display of *earthly* features.

Map projections have always aimed at finding appropriate ways to display the three dimensional physical space in a two-dimensional plane (see section 2.2.3). What makes the gridded cartograms capable of being an adequate map projection is their unique characteristic of preserving the underlying equally distributed grid raster as an independent geographic reference in the reprojection. This allows the exact localisation of every area in the physical space in the transformed cartogram down to the resolution of the underlying grid. Within each grid cell, the physical geography remains almost undistorted. With these specific characteristics gridded cartograms are distinctively different from other cartogram techniques.

A very common imagination of a map is that of mountains, valleys, hills and plains, a map of the topography of places that gives us an idea of the landscape of unknown and known places[81]. It is the image of a map from times of exploration and discovery of the back then still unknown places. These maps are the images that shape our understanding of the world and how we nowadays start to explore and discover the world in our minds. Topographic maps showing the very basic geography of the planet are the reason why we think we know about the Himalayas, although many of us may never have been there (or will ever go there). Only a map gives us the complete picture, even if we see films, photos or sophisticated multimedia presentations of these places – without maps these are hard to put into context, and a topographic map is often the start to gain new knowledge about a country.

How does the geography of a country change if the map projection is changed radically and shows us the basic geography of a country in relation to the people living there? The results using gridded population cartograms can be maps of the physical geography of the human space. They show where people live in relation to their environments. They add another dimension to the use of gridded population cartograms as new basemaps and gridded population cartograms as an alternative map projection that bridges the gaps between the geography of the physical and the human space.

Germany is a country that stretches from the North and Baltic Seas in the north to the mountains of the Alps in the south. A look at the demographic structure of the German population distribution shows that very-high-density living is less common than may

[81] If you do not agree to that unacademic notion of expectations of a map, you may not be a map addict (and should therefore try to align your mind by reading the thoughts of Parker 2009).

be expected from a highly industrialised country with a high population density. The population density drawn on a gridded population cartogram shows that the population distribution is much less concentrated in one or few particular regions. Berlin as the capital has the highest population densities in the country, but is not dominating and shows little gravitational force outside its small urban fringe. Similar as well is the Rhine-Ruhr area (stretching from Duisburg to Dortmund and Bonn respectively), one of the industrial heartlands at the border to the middle-mountain regions, where higher population densities occur over a very large area. There are some further concentrations in the largest cities spread across the country, but large parts throughout show a rather medium-density living pattern of Germans. There are even some significant populations in the low-density rural areas of Bavaria and East Germany.

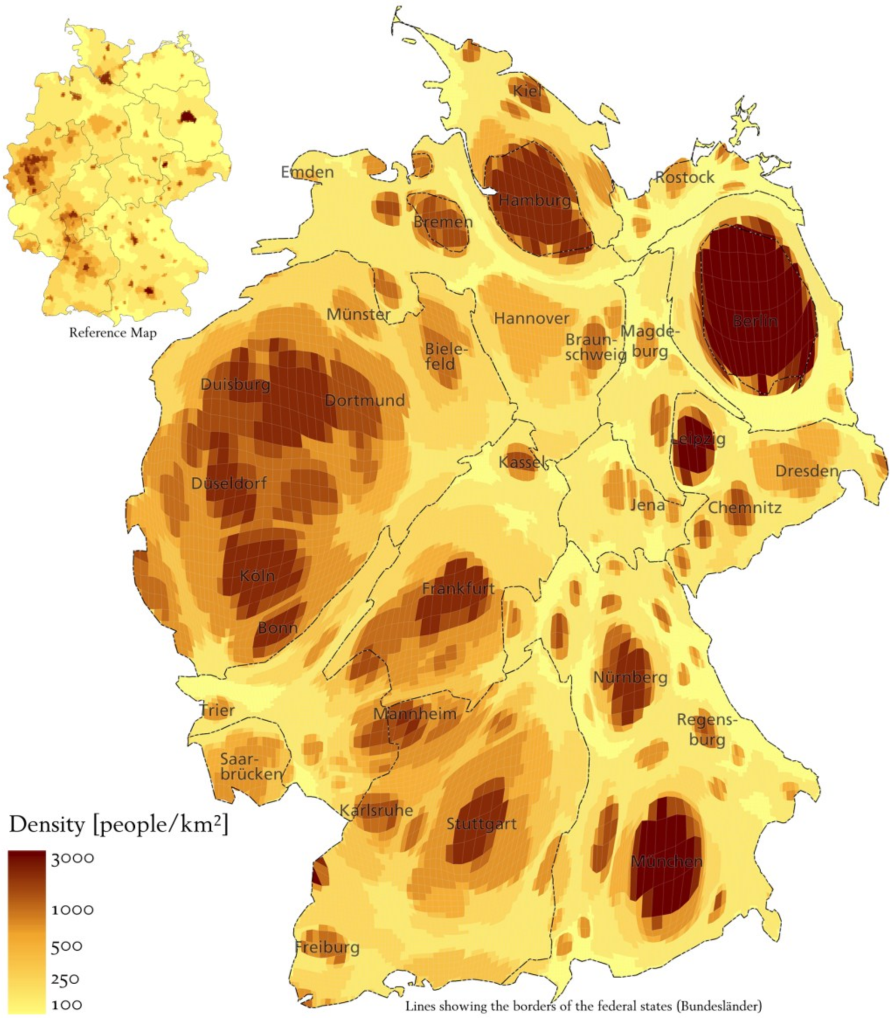


FIGURE 6.4: GERMAN POPULATION DENSITIES DRAWN ON A GRIDDED POPULATION CARTOGRAM
Including selected cities (own depiction by the author using data from CIESIN & CIAT 2005)

The combination of density and a gridded population projection allows getting a quick understanding of the population geography of the country as described above (Figure

6.4). At the same time, it makes visible how many people live at which densities, a fact that the conventional map projection can only indicate but fails to show in its quantitative dimension.

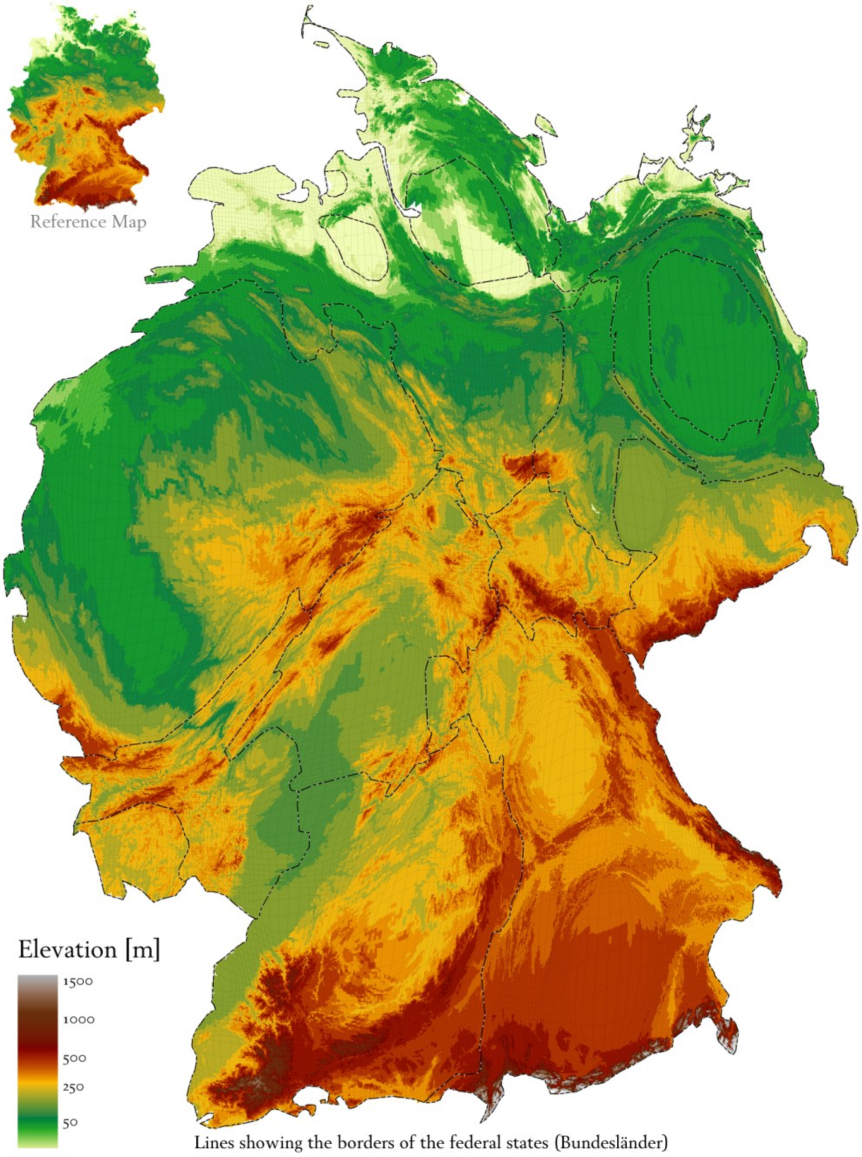


FIGURE 6.5: TOPOGRAPHY OF GERMANY SHOWN ON A GRIDDED POPULATION CARTOGRAM (own depiction by the author using data from CIESIN & CIAT 2005, USGS 2009)

The geographic areas that the ancestors of today's Germans decided to live in and where reunified Germans build their houses in, nowadays are a picture of a society (Figure 6.5) that still lives in and from its environmental surroundings (Glaser, Gebhardt & Schenk 2007). Large parts of the higher population densities in the northern half of the country are in those areas just north of the middle mountain region where fertile *Loess* soils were accumulated during the last ice ages, providing the base for a still strong agricultural base. Similar conditions on different topographic settings prevail in the south just at the foot of the Alps. In the Midwest where the Rhine leaves the Rhine valley and extends its bed into wider – greenly tainted – flood plains are the areas where people settle as well, taking the risk of being prone to flooding while benefiting from the river as a transport artery for the industry. Larger parts of the middle mountain region, in contrast, are considerably shrunk in size on the population cartogram.

The two gridded population cartograms (accompanied by their geographical narrative) provide an idea of how the rediscovery of the geography of a nation could be developed by drawing new maps. A national atlas of a country, showing how things matter to people may be an interesting proposition to reengage people with the realities in their countries. These are not complex academic exercises displaying complicated scientific findings, but relate to many people's basic understanding of their own country (or may provide new insights to the realities in other corners of the world).

6.4 Mapping the world: A multitude of environments

The case of Germany provided a simple proposal for seeing cartograms as an alternative to also display the physical environment on cartograms. This may be of potential interest to a wider audience, and could be a valuable contribution to geography schoolbooks and other educational resources. Other people engaging with the physical environment may be interested in more complex applications, and could still be quite critical of the suitability of gridded population cartograms to be shown in combination with environmental information. The following maps aim to expand on a potentially also more advanced use of gridded cartograms, not only for population depictions, but also for other gridded cartogram depictions.

6.4.1 Biodiversity

Biodiversity addresses earlier notions in this thesis in relation to global environmental change (see section 2.2.1) and its relation to the impact of humanity on the world's ecosystems. Physical depictions clearly are an important element in the assessment of this impact, and the need to understand and map the spatial distribution of species and biotopes is not questioned by the presentation of alternative mapping solution to these topics. However, to propose such maps to a broader audience will also be part of assessing potential future uses, and to receive critical reflections on the mapping approach. The following maps demonstrate the two main concepts outlined in this thesis related to ecological topics without extensive interpretation, but as proof-of-concepts that demonstrate, that these maps *are* possible to be created, and that they produce valid results.

6.4.1.1 *Hotspots of biodiversity*

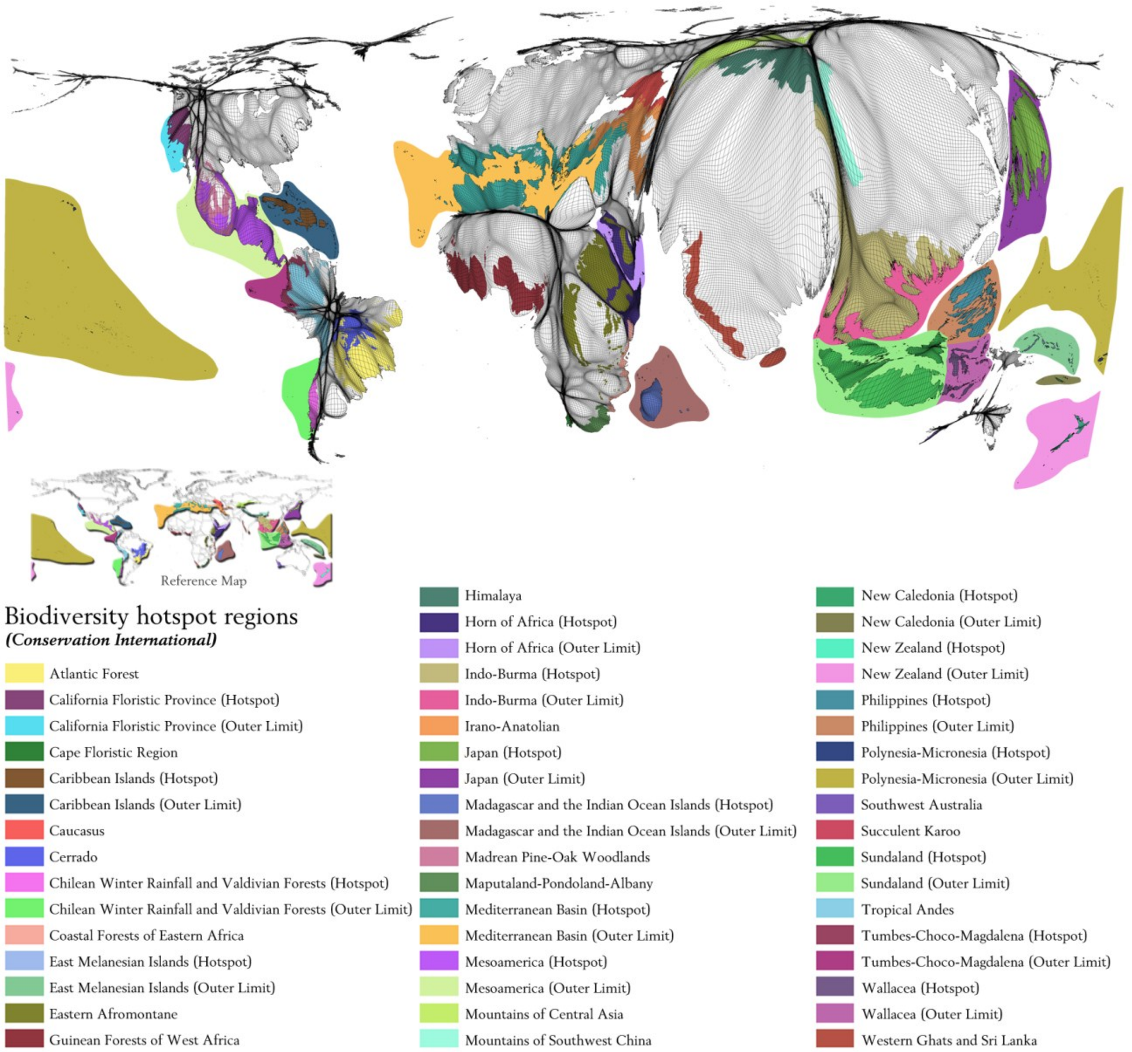


FIGURE 6.6: BIODIVERSITY HOTSPOTS SHOWN ON A GRIDDED WORLD POPULATION CARTOGRAM
The hotspots highlighted in this map represent the most threatened reservoirs of plant and animal life. The map is based on a ¼° population grid containing 2010 population estimates (own depiction by the author using data from CIESIN & CIAT 2005, Mittermeier et al. 2005)

The hotspots of biodiversity identified by *Conversation International* aim to draw a global picture of the richest and the most threatened reservoirs of plant and animal life (Mittermeier et al. 2005). Shown on the population projection (Figure 6.6) the map draws a picture of the most threatened unique ecosystems in their setting in and around human populations. A potential value could be the a picturesque depiction of the human impact on the biosphere. An interesting aspect in this display is the combination of information of threatened biosphere in relation to that dimension that poses the threat that is depicted.

6.4.1.2 Trees

"*The symbolism – and the substantive significance – of planting a tree has universal power in every culture and every society on Earth, and it is a way for individual men, women and children to participate in creating solutions for the environmental crisis*" (Gore 2006: 295). There is a long tradition in the emotional relationship between people and forests that Gore's quote mirrors. Forest landscapes can be mapped on population, but most of the spaces of humanity have little amounts of forest inside them. As the few remaining untouched forest landscapes only exist in those areas where the lowest population densities are, information about the total tree cover[82] of the planet derived from remote sensing surveys (ISCGM 2005, Potapov et al. 2008) seems more appropriate for a gridded cartogram transformation itself.

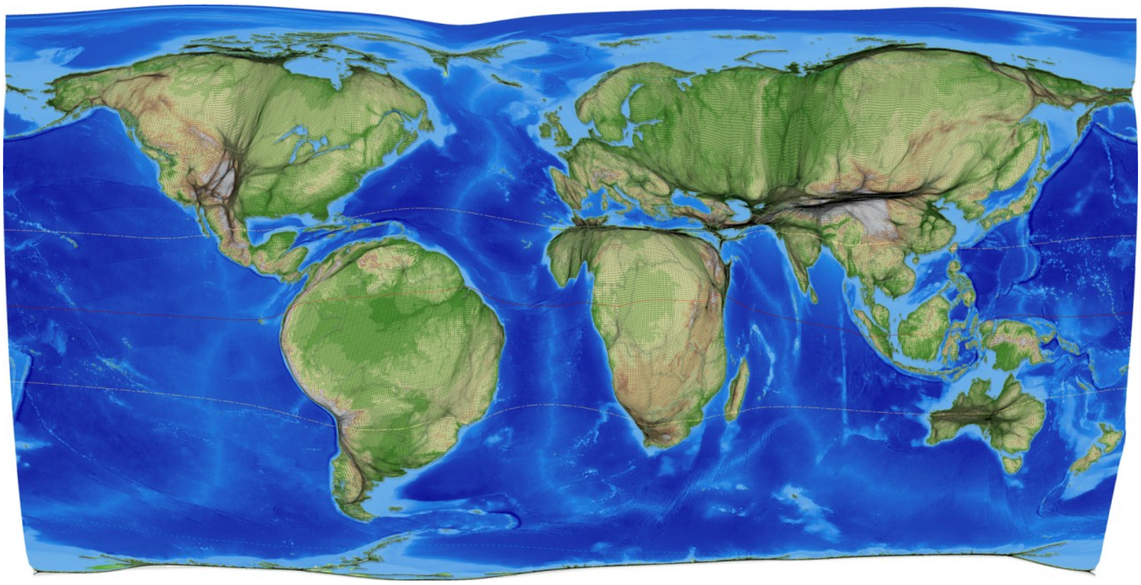


FIGURE 6.7: GRIDDED TREECOVER CARTOGRAM
Gridded cartogram transformation based on a 10' grid containing the total tree cover in each grid cell (own depiction by the author using data from ISCGM 2005, NOAA 2009, USGS 2009)

The gridded tree cover cartogram (Figure 6.7) shows the quantitative distribution of the world's forests. The map depiction makes for the first time in this thesis full use of the separately introduced capabilities of gridded cartogram by including additional geographical information in the map display. A conventional map projection would have to use the map display itself to depict the forest densities, while the densities in the gridded cartogram provide the base for the map, so that other geographical features can be displayed on top. Topographic features, indications of the graticule, and the surrounding bathymetry appear as guiding elements that can – despite the odd shapes – make the map easier to read and encourage the map reader engage more openly with the information that is contained. The differences between the largest and

[82] Information about the percent of tree cover is part of a mapping project by the Geospatial Information Authority of Japan, Chiba University and collaborating organisations (ISCGM 2005).

smallest grid cells in the transformed cartogram appear less striking, because the variation depicted is based on the proportional estimates on the tree-covered area that prevents too extreme differences (the maximum area of the grid cell can also only be the largest number in the grid, while e.g. the population figures exceed that value considerably). A more striking difference between the grid cells could possibly emerge when the total number of trees rather than the tree-covered area is used. However, such data does currently not exist and is very difficult to generate, and the resulting map would not so much be a gridded cartogram of the world's forests, but rather a more detailed display of a very specific investigation of forest ecosystems.

6.4.2 Precipitation patterns

Climatic conditions have contributed to the basic patterns of the world's population distribution. Topography and climate still determine crucially the agricultural potential of a region that can only partly become overcome by technological progress. Geographical determinism to explain human settlement patterns may be a controversial concept, but that there are some links remains less disputed (Werlen 2008). Drawing climate conditions using gridded cartograms may therefore be one of the obvious examples to be realised when looking into potential uses. Not least are global climate maps part of every school atlas, and part of the geographic literacy in many curricula.

Triggered by climate change research and the need for accurate climate data is also amongst the best available geospatial data on the global scale. Compared to the complex models of climate scientists, a gridded cartogram transformation of that data appears quite insignificant and small. From a cartographic perspective, the efforts are of course considerable and (still) less straight forward. But because climate data provides an interesting example in comparing the two gridded cartogram approaches themselves, this has been investigated in further detail by using global precipitation data in two ways. The accumulated annual precipitation data was projected using the gridded population cartogram as a basemap, as well as it was used for an own cartogram transformation itself that displays the distribution of precipitation itself as a map base. Both map displays were complemented by a bathymetric basemap for its aesthetic value. The gridded precipitation cartogram also includes a topographic display and for further guidance also the graticule.

The same data displayed with the gridded cartogram technique gets a very different expression. The gridded population cartogram shows, where people are, and how much rain they are exposed to (Figure 6.8, *see below*). Dry desert regions that we know from the conventional map projections in atlases disappear almost entirely. Only few dryer places show significant numbers of people living there, such as the Nile river delta region – which provides water (and fertile land) from the ground rather than from above. Regions affected by the monsoon rain in South and Southeast Asia in contrast are heavily populated, as this regular climate event provides the livelihood for wet rice agriculture and feeds billions of the world's population.

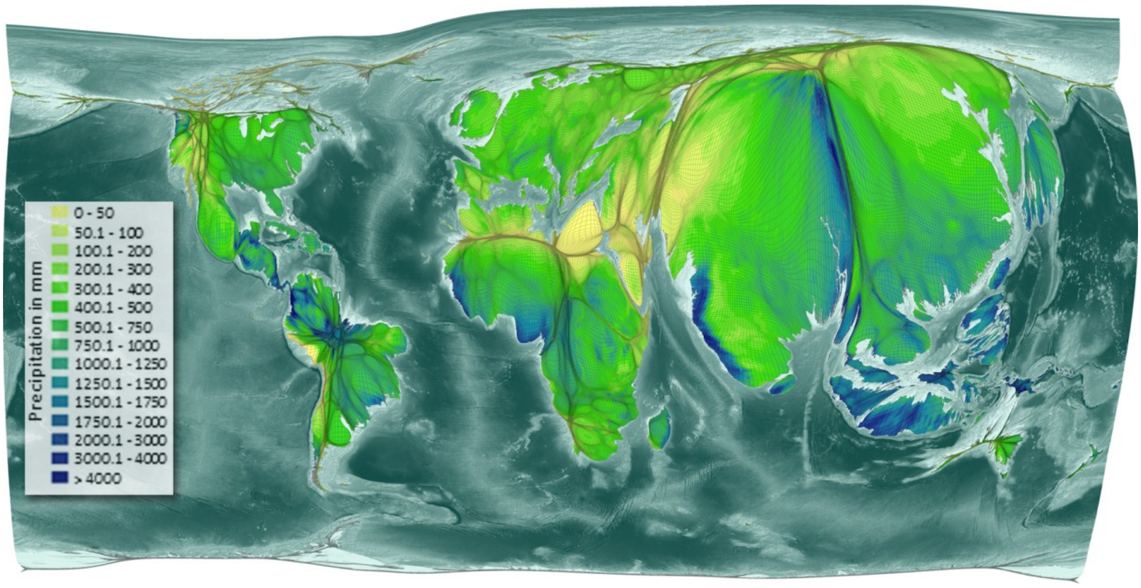


FIGURE 6.8: PRECIPITATION PATTERNS ON A GRIDDED WORLD POPULATION CARTOGRAM
Annual and monthly visualisations with using separate colour legends. The maps are based on a ¼° population grid containing 2010 population estimates (own depiction by the author using data from CIESIN & CIAT 2005, Hijmans, Cameron & Parra 2005)

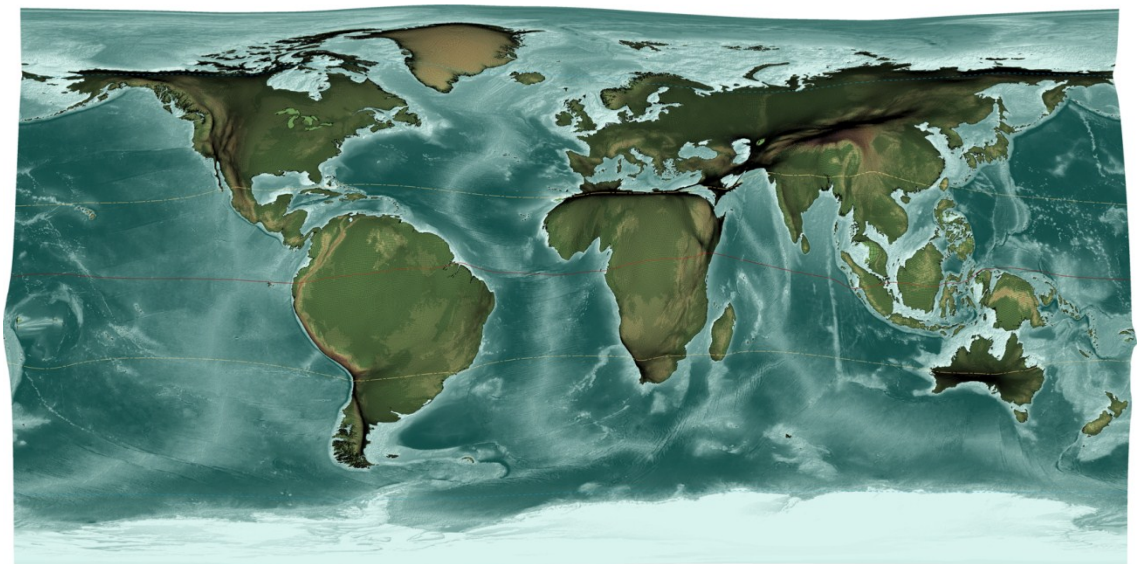


FIGURE 6.9: GRIDDED ANNUAL PRECIPITATION CARTOGRAM
Gridded cartogram transformation based on a 10' grid containing the total annual precipitation in each grid cell (own depiction by the author using data from Hijmans, Cameron & Parra 2005, NOAA 2009, USGS 2009)

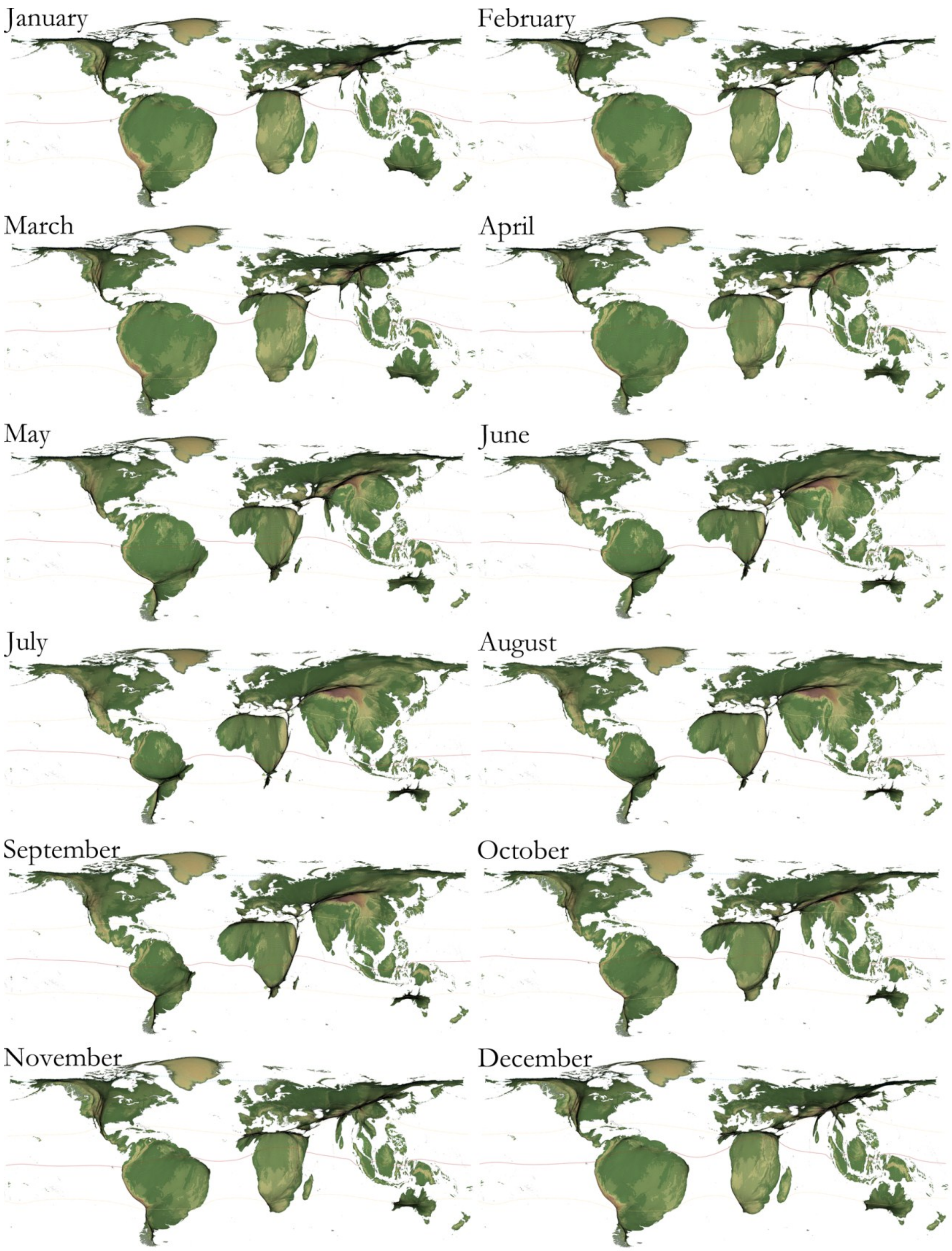


FIGURE 6.10: MONTHLY TIME SERIES OF GRIDDED PRECIPITATION CARTOGRAMS
Monthly time series of a gridded cartogram transformation showing the total precipitation in each grid cell (own depiction by the author using data from Hijmans, Cameron & Parra 2005, USGS 2009)

The gridded cartogram of the annual precipitation does not hide any of the precipitation data (which in the population cartogram can be hidden from the map reader's eye in those places where few people live). Here the full quantities are made visible (Figure 6.9, *see above*). The gridded cartogram provides a vivid impression of the high rainfall volumes in the tropical regions north and south of the equator. Areas of high seasonal precipitation volumes, such as the monsoon regions in Asia are less significant, but still strike out from the dry regions. Similarly, the areas where more even or more moderate precipitation levels (which covers also snowfall in the higher and colder climate regions) are prevalent, such as in Europe and parts of North America. The visualisation of the topography demonstrates the effects of mountain ranges as barriers where clouds lose their moisture while ascending (Dore 2005).

An more dynamic impression of the changing nature of precipitation patterns can be obtained by creating a series of monthly precipitation maps. The monthly rainfall patterns visualised as gridded cartograms (Figure 6.10) reveal the seasonal changes that are not shown in the annual precipitation cartogram in a high geographic detail. Monsoon rain in Asia, seasonal variation around the equator, winter rain in the Mediterranean climates and other patterns (see e.g. Adler et al. 2003) are shown in their full quantitative extent without losing their geographical reference. The meandering lines of latitude in the map are the expression of these changing patterns in the shape of precipitation distribution. The twelve maps could also be digitally assembled to an animated map series on the computer, which adds further visual appeal and a more direct comparison of the changing patterns and has the appearance of a map in motion (for details on map animation see e.g. Harrower 2009, Harrower & Fabrikant 2008, Tversky & Bauer Morrison 2002). The same information shown here in the individual maps in static form loses some of this vivid appearance.

The global precipitation data is also available on a global grid that covers not only the land area, but also most of the sea area. The available dataset used for this approach was derived from the Spatial-Analyst.net repository (Hengl 2011), which has a lower resolution and is limited to the extent between 60° northern and 60° southern latitude.

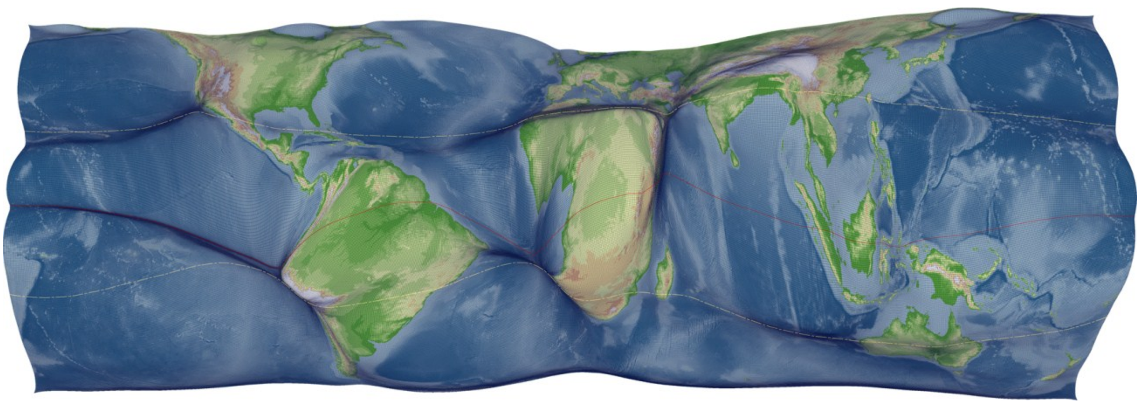


FIGURE 6.11: GRIDDED GLOBAL ANNUAL PRECIPITATION CARTOGRAM
Gridded cartogram transformation based on a 10' grid over the whole surface of the planet containing the total annual precipitation in each grid cell
(own depiction by the author using data from Hengl 2011, NOAA 2009, USGS 2009)

The gridded precipitation cartogram for the land and sea areas (Figure 6.11) is a smooth global picture of precipitation patterns that adds further detail by putting the precipitation patterns over the land area (Figure 6.9) in their overall context of rainfall over the sea area. The transitions between land and sea are generally quite smooth, so that land and sea area can be told apart and retain a certain degree of their original shapes. The grid patterns show less detail than the grid used for the land area, so that some variation on the land surface is not shown in this map, but therefore the full variation over the land and sea area becomes comprehensible.

In summary, the two concepts of turning precipitation data into gridded cartograms result in maps with changing interpretational value that both cover different dimensions that usual precipitation maps shown in conventional map projections. The direct comparison of the two approaches highlights the differences between the two approaches. The gridded population cartogram is capable of visualising geographical themes in relation to population, which results in decreased representation of data in those areas where fewer people live. A gridded cartogram from other data itself results in changing distortions that can be enhanced in their readability by applying familiar map information onto them. As the value of interest is already reflected in the map shape itself, the map overlay can flexibly be used for other information to support the readability.

6.4.3 Oceans

The ocean is the last frontier that has not been discovered by cartogram techniques before[83]. The experimental world population cartogram (see section 4.2.3) and the precipitation cartogram in the previous section (Figure 6.11) have already conquered that border by drawing gridded cartograms over land and sea. The inevitable last step therefore is the creation of a gridded ocean cartogram, a cartogram that is limited to the extent of the world's oceans.

To create a proof-of-concept of the gridded cartogram approach applied to the sea surface, a gridded dataset on the chlorophyll concentration in the sea was used. The data shows long-term chlorophyll concentration estimates in mg per cubic metre (Hengl 2009) derived from the analysis of MODIS remote sensing data. The chlorophyll concentrations in the oceans indicate the density of algae and other photosynthetic organisms that are important to investigate the ecology of the sea areas (Reise 1989).

The gridded cartogram of chlorophyll concentration in the world's oceans (Figure 6.12, *see below*) shows the global variation of chlorophyll levels and highlights the increasing

[83] During the research I have not found any work on cartograms that are not based on land-area transformations.

levels towards the land areas. Variations in the grid can be seen when investigating the patterns in more detail, with higher levels in the northern polar sea regions and the European Baltic and North Sea, where larger grid cells emerge. The general readability of the gridded cartogram is preserved because the continental shapes allow an orientation and a geographical reference, but their bizarre shapes distract considerably from the visual interpretation of the map. The map demonstrates the general applicability, while the further use of ocean cartograms remains questionable from this initial result. Cartograms of the oceans displaying for instance changing quantities of chlorophyll could be a helpful visualisation for monitoring anthropogenic climate change and other environmental indicators (see e.g. Henson et al. 2010, Eddy 1993, Hennig 2005, Hennig, Cogan & Bartsch 2007, Reise 1989), but the visual display requires further investigation before that may lead to a general interest in such maps.

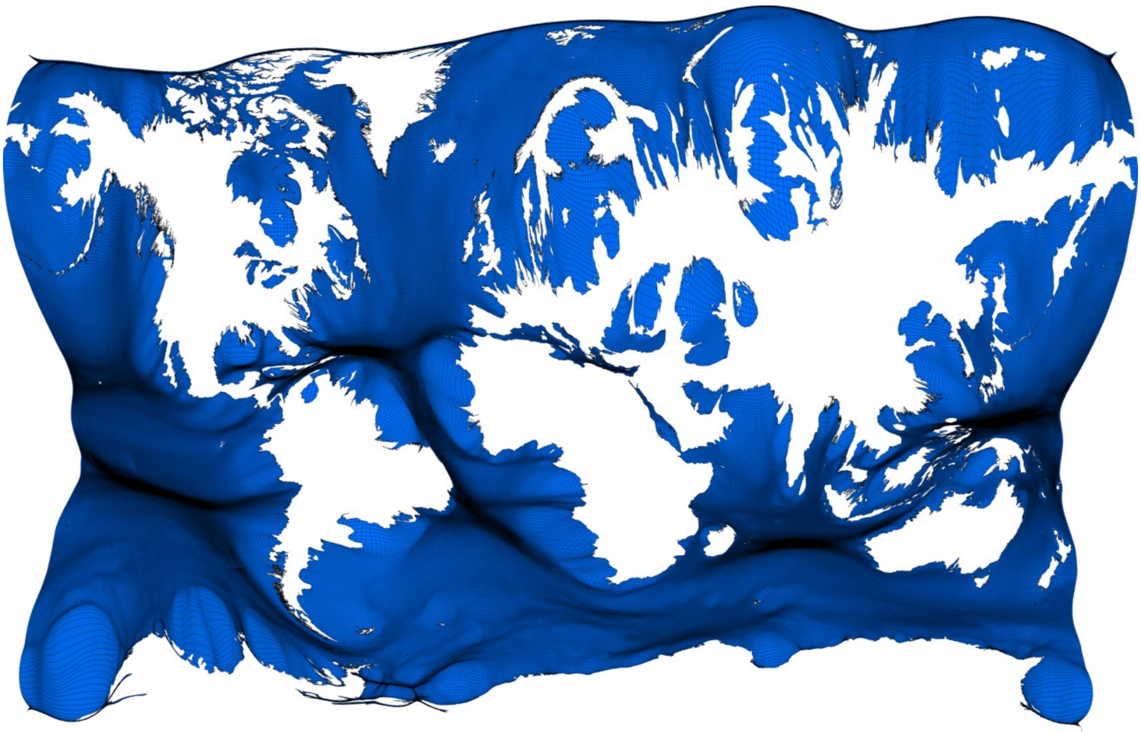


FIGURE 6.12: GRIDDED OCEAN CARTOGRAM SHOWING THE VARIATION IN CHLOROPHYLL LEVELS
The transformation is based on a ¼° grid over the sea area containing the total chlorophyll concentration in that area (own depiction by the author using data from Hengl 2011)

6.5 Mapping multidimensional data: Remote places

Some of the complaints made during the presentation of the gridded population cartograms at conferences included a certain degree of disappointment that the maps erased some areas from the maps that are important in people's perception of a country. These can be remote holiday destinations, or rural parts of a country, which undoubtedly are relevant to people's lives, but disappear from the gridded population cartograms because of their low population densities.

Many parts of Scotland, for instance, are not shown on the gridded population cartogram of the United Kingdom, because there are few people living outside the main cities there. That lies in the nature of the maps, and is an intentional effect of the map reprojection. But it also raises the demand for creating similar maps by reversing the data and showing the *natural* shape of the countries or the world. The easy solution is the referral to a physical map. But the concern can be interpreted further by thinking of a map the gives the most remote areas the most space, which can also provide the base for interesting other map topics. The problem relates to the methodological advances made related to gridded cartogram transformations based on other data than population. Here the topic of *population* and *no-population* is specifically interesting, because it connects the human and the physical geography, and touches an essential question of the general suitability of data for these transformations.

The usefulness of gridded cartograms, like other cartograms, depends crucially on the data that goes into the cartogram transformation. Not only do gridded cartograms require a different level of detail, but also a good variability of quantitative data to result in meaningful and valuable visualisations. This could be demonstrated for both, physical and social datasets in the previous sections and chapters.

The small amount of people living in sparsely populated areas is an expression of the strong organisation of human societies to maximise those living in close relative proximity. More than half of the world's population now lives in areas categorised as cities, and 95% of the population are concentrated on 10% of the land area (Uchida & Nelson 2010). This is one reason for the unique shapes and patterns created in the gridded cartograms, which would look very different with a more even distribution of people across the land area. With more than 95% of the world's population living in approximately only 10% of the land area, the remaining 90% of the land area vanish from a population cartogram (which, of course, is its purpose). This raises the question, whether the least populated areas can be shown with a similar approach.

The optimal grid data for a gridded cartogram transformation thus needs a high variation and a data distribution that has the highest values for the topic of interest in a limited amount of grid cells, like the major population densities cover approximately 10% of the full grid (which would make a reverse view of the unpopulated much less striking). If that is not the case it would be less valuable, as it would not result in that unique new shape and could possibly be similarly well mapped with less methodological effort on a conventional map.

The issue of less well-distributed data can be tackled if the underlying geographic dimension is more complex than a plain look at the depopulated areas. The interest in understanding less populated areas is also an issue of understanding the difference between the areas least and most touched by humanity, and the differences in their accessibility. Remoteness can be a different way of understanding population patterns.

In an analysis of people's closeness, Nelson (2008) points out that only 15% of people in rich countries live more than an hour of travel time from a city (of at least 50,000 people), while the same applies to 65% of people living in the poor countries of the world. The information about the absolute travel time from a given point can be transformed into a grid that translates remoteness into a quantifiable measure that combines the human and physical space in one layer. The gridded dataset can then be transformed according to the absolute travel time that is necessary to reach the nearest major city that was defined by the authors of the study as one of the 8,518 cities with 50,000 or more people (Uchida & Nelson 2010). The transformed grid thus shows each grid cell resized according to that absolute travel time that is needed from that grid cell to the nearest major city by land transport, giving the remotest places most space on the map.

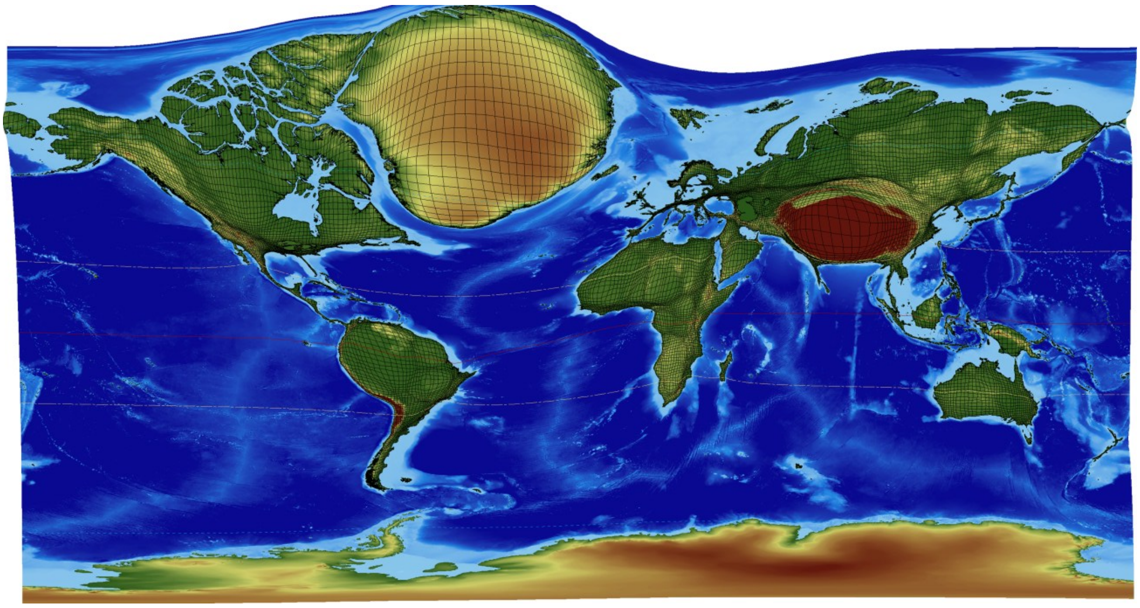


FIGURE 6.13: GRIDDED CARTOGRAM OF GLOBAL (IN-)ACCESSIBILITY
The map is resized according to the estimated land travel time to the nearest large city (over 50,000 inhabitants). Antarctica has not been included in the calculation, as there are no cities of that category. It is included in its original map extent (own depiction by the author using data from CIESIN & CIAT 2005, Hengl 2011, Nelson 2008, NOAA 2009, USGS 2009)

The gridded cartogram of the remotest places (Figure 6.13) visualises the picture of a lonely planet where the spaces shown are those that are furthest away from those places of civilisation that define the 21st century. More than half of the world's population according to UN estimates now lives in cities (UNPD 2009), and this map shows those places that most of the people living in the world need the longest time to get to. It draws an image of the areas that are almost disconnected from those shrinking effects of globalisation. This world map is the striking opposite representation of our image of a globalised and interconnected world, of those vanishing places that we thought do not exist anymore.

Following the same principles of gridded population cartograms, the method of showing remote places can also be applied to a limited area, such as continents or individual countries. The same effects that have been observed for gridded population cartograms are reversed in the resulting maps.

FIGURE 6.14: GRIDDED CARTOGRAM OF TRAVEL TIMES IN EUROPE
The map is resized according to the estimated land travel time to the nearest large city (over 50,000 inhabitants) (own depiction by the author using data from CIESIN & CIAT 2005, Hengl 2011, Nelson 2008, NOAA 2009, USGS 2009)

The remotest places of Europe (Figure 6.14) are situated the further north you travel. The southern regions mainly turn into remote areas where the terrain rises higher and the populated places dominate less of the landscape. Iceland is an island of remoteness in itself, with only its capital Reykjavík (situated in the southeast of the island) fulfilling the criteria for a major city. On the world map it is hard to see because much of the island is well connected only by a major ring road that circles around the island, but when changing the focus on Europe, it can be seen how the changing scope reveals different details and creates new shapes at different scales.

FIGURE 6.15: GRIDDED CARTOGRAM OF TRAVEL TIMES ON THE BRITISH ISLES
The map is resized according to the estimated land travel time to the nearest large city (over 50,000 inhabitants) (own depiction by the author using data from CIESIN & CIAT 2005, Hengl 2011, Nelson 2008, NOAA 2009, USGS 2009)

Even within the densely populated areas of Western Europe there are still some striking differences. The British Isles (Figure 6.15) as part of the larger very populated regions in Europe show the dominating distances that increase the further north you come in Great Britain, but also a relative remoteness of much of Wales and the *Emerald Island* of Ireland being largely a refuge of natural environments.

Germany (Figure 6.16, *see below*) shows a more even pattern with relatively remote rural areas and the urban centres being spread across the map. It reflects the more even population distribution and is also a picture of a more balanced urban system in the country (see section 6.3). The largest urban centres appear as nodes that are often connected to each other via denser lines of less remote grid cells like a network of people across the country, with the most remote places bulging out between this network of people and their connecting infrastructure.

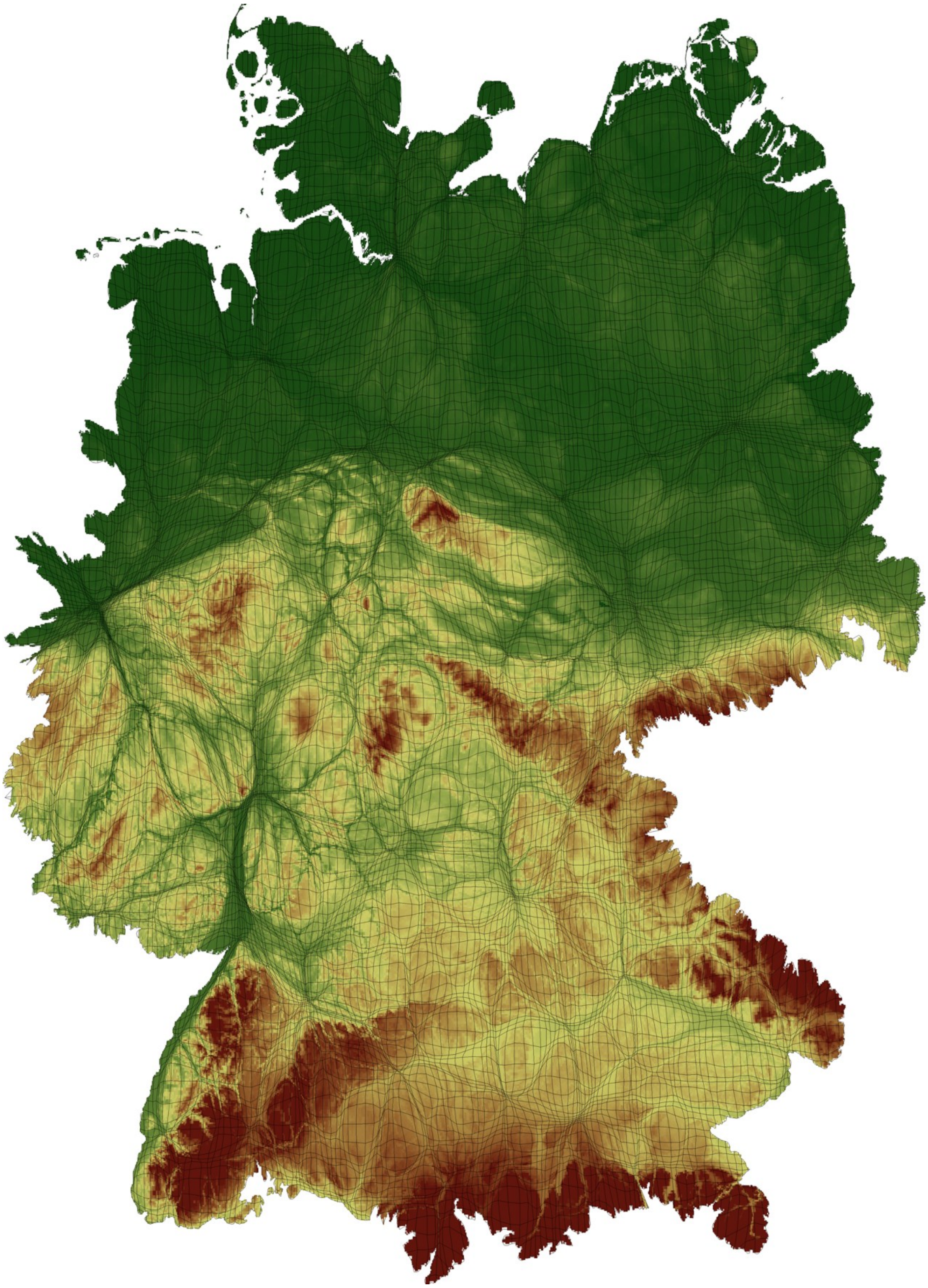


FIGURE 6.16: GRIDDED CARTOGRAM OF TRAVEL TIMES IN GERMANY
The map is resized according to the estimated land travel time to the nearest large city (over 50,000 inhabitants) (own depiction by the author using data from CIESIN & CIAT 2005, Hengl 2011, Nelson 2008, NOAA 2009, USGS 2009)

6.6 Conclusion: An alternative geography of the world

Gridded cartograms are not better. They are not worse. They are different than other map projections. The concepts for the use of gridded cartograms that have been developed in the previous chapters were put to the test in this chapter by demonstrating a wider range of potential applications from the diverse nature of geography. From electoral maps, which in some countries have started to embrace cartogram concepts even in the use in public media, to examples for new geographic insights of countries, and to the use of gridded cartograms with detailed data from the physical and natural environment, the range of applications seems endless.

The versatile utility of gridded cartograms may thus provide the base to present an alternative geography of the world by twisting and distorting maps at an unprecedented level of detail. The information contained in any of the maps shown in this thesis is not new, but the novel way of showing this information may provide the basis for a rediscovery of the world, which has been the central claim in the title of this thesis.

The complexity of the globalised world and the failure to understand this complexity can be seen as the need to think of new ways to visualise information. Trying to change our way of living requires us to understand the globalised world, and to understand the global change in all its dimensions. The ever growing amount of data collected from our (social and physical) environment contributes to that need of rethinking the capabilities to make that information visible, and eventually comprehensible.

There is not a single solution to achieve this, but maps have always been a part of trying to make sense of our world. An alternative way of drawing maps should therefore be a small contribution to find new ways of a better communication of the knowledge that many of us but sometimes fail to communicate adequately. Essential is not only the appropriate way of showing information, but essential is also openness towards alternative ways of communicating science. Every visualisation contains constraints and limitations, and also simplifications and distortions (sic!), but they may prove useful, as every simplification and distortion can also serve a certain purpose.

We see the conventional map of election results in the newspaper not as a distortion, because we believe this is how a map should look like. Many of us do not question the distortion and overrepresentation of the results in rural and remote areas that is displayed. But it therefore is not a bad or false map either. It only is different, and yet so useful to most of us.

Is there any usefulness in going new ways of mapping?

The good availability of highly detailed data on the physical features and conditions of the world is a great advantage to socioeconomic data, which makes the task of reprojecting the underlying data on a gridded population cartogram easier than the creation of similar maps for the social structure of the world. The physical environment has been subject of intensive research for centuries, and satellites, digital sensor networks and advances in computer technology have strongly supported the creation of detailed databases on the physical environment in highest resolutions.

The examples for gridded cartograms presented in this chapter cover views from a more common, sometimes *atlas-style* geography. While the first maps may still be appealing because of their unusual shape and character, the more commonly they are understood by the map reader, the higher the analytical value can become. A map reader who sees these maps just as any other map projection and is able to understand the grid patterns intuitively is a desirable outcome for a new mapping technique.

The demonstration of the wider applicability of the technique to a multitude of topics suggests an extension of the scope of the original Worldmapper project using the gridded cartogram approach to redraw the maps from that project. This, however, appears to remain an ambitious if – at the moment – impossible task. Gridded cartograms rely on appropriate data, which for many of the social issues covered in Worldmapper seems impossible. Will we ever be able to reliably interpolate births, deaths, diseases and other topics that tell the full story of humanity on a grid that can claim to adequately represent these issues for the 7 billion that we currently are? Environmental data seems therefore almost be the easy task, which should not be underestimated in its additional value to the existing Worldmapper project. Rather than a mapping madness, a sensible reflection on what is mapped best in which ways would be wise.

The same principle that applies to all maps, applies to gridded cartograms equally. Expressed in less scientific words it reads:

"*rubbish in, rubbish out*"
(quoted from Nature 2008: 264).

Chapter 7 **Discussion: The map ahead**

7.1 Introduction

Kessler & Slocum (2011) recently made the disconcerting finding of an overall low quality of map design in an analysis of thematic maps in two major geographical academic journals. They argue that geography as a core discipline of mapping should embrace map design as a vital component of geographic education, and that good practice of mapping needs to be actively promoted and easy to perform. In my research I tried to *reclaim the map* (Dodge & Perkins 2008) in a very own geographic manner by rethinking cartographic practice in the light of a world that today is very different to the days when mapping became part of academic disciplines.

Worldmapping beyond mere description was the working title for this research, and in the beginning stood the overall aim to improve the visualisation capabilities of cartogram techniques used in the Worldmapper project. This defined the base for an exploratory approach to the research and involved testing several technical approaches, of which the gridded cartograms presented in this thesis are the key innovation. However, it became clear during the work on the methods that part of the problem of some methodological works is a lack of effective demonstration of how the innovations made in these works can be applied, how they can make a difference in existing practice, and why these methods matter. Often the evaluation of new methods in cartography and geovisualisation is a very technical process, which sometimes even takes place outside the research of the geographical discipline. The techniques deployed in this research are products of computer science (and elementary physics), and so-called GIScience is interested in technical innovation of geospatial analysis, rather than contributing to academic geography in a more subject-focused manner.

This chapter investigates the wider relevance of my methodological research with an emphasis on the implications of cartographic practice *and* geographical thinking. The discussion will be split in three parts, separating the practical, theoretical and the future importance of the technique. First, I discuss the significance of the gridded cartograms from a methodological perspective (section 7.2), which is then put into the context of (the gap in) disciplinary debates of globalisation and space (section 7.3), and then concludes by suggesting priorities for a future research agenda that result from the findings (section 7.4) and their potential for a new way of showing new geographies of the world.

7.2 Revisiting methodologies

The research into cartographic methods follows calls to "*encourage and facilitate critical and creative research on mapping*" (Dodge & Perkins 2008: 1275). The aims to develop and investigate a new mapping technique in an open and exploratory way addresses those demands by not being restrained to a particular topic of geographic research, but by asking, whether the interdisciplinary nature of geography can be visualised in different forms than those of the century-old concept of a physical map. The investigation in new techniques does not stop with the presentation of the procedures how the technique is applied, but requires a broader investigation to demonstrate its potential in comparison to existing cartographic concepts. In this section I reflect on the objectives that relate to the conceptual and technical side of the research, onto which the wider intellectual geographical focus of the discussion will build upon.

The preconditions for the new mapping technique are first and foremost the unique functionality of Gastner/Newman's diffusion-based method, combined with advances in computational capabilities, and the availability of high-resolution geospatial data. It was shown, that digital technology has changed the common cartographic practices. This led to new possibilities how cartography can be conducted to become part of the efforts to use visualisation to make sense of the ever growing amounts of data that are not least also a result of the digital age. These are core elements that were inevitable and may have prevented others from drawing similar maps only 10 years ago. It was the right place and the right time for this research to be undertaken, and yet, it needed the right amount of endurance and patience to work out the right method to create these maps and move the ideas and concepts into reality.

The relevance of the digital turn in cartography and how this started to change cartography in manifold ways has not yet come to an end. The emerging *new mapmakers* are often untrained amateurs who developed a passionate interest in maps and are changing the public perception of cartography. The idea of an emerging *neocartography* (see section 2.4) is a response to these trends, which some professionals see as a threat to the discipline. A denial of the fact that the digital world has enabled anyone to participate in the process of creating maps (and to present the results to a wide audience) is the much bigger threat, as it would result in a continuing decline of the a cartographic identity. Cartography should embrace those new mapmakers and integrate their ideas in advances of cartographic practice. The more people engage in cartography, the more space will be left to concentrate cartographic research on finding new concepts and making sense of cartography in a digital age.

The technique of creating gridded cartograms has been introduced as a method for the computer-based creation of density-equalising gridded cartograms that was evaluated from the observation that cartograms face the problem of being perceived as a limited mapping technique that provides little flexibility in their application. Beyond explaining the principles behind gridded cartograms it was therefore essential to investigate these limitations at the resulting maps and to demonstrate, where gridded cartograms are different to other cartograms. Issues investigated included core elements of maps, which are design principles, scalability, and above all the further utility of the new maps that could justify the declaration of gridded cartograms as an alternative map projection.

The initial reason for developing the gridded world population cartogram was an improvement of the existing techniques that were used in the original Worldmapper population cartograms. The gridded world population cartogram addresses the problem of a very crude geographical reference in the Worldmapper population cartogram. This does not allow any interpretation beyond national levels, and is based on the (partly arbitrary) definition of countries. The gridded cartogram technique as such is independent from country borders and results in the same map no matter how the countries of the world look like. New countries can emerge and are displayed as a superimposed layer on the cartogram, while the original shape of the cartogram never changes as long as the overall population distribution does not change significantly. In comparison to the original Worldmapper population cartogram, the changing shapes can become more difficult to understand (which will be discussed below with critical notions on the general readability of gridded cartograms).

Scalability was demonstrated successfully at different scales that highlighted the additional benefit from seeing more detail by restricting the extent of the map transformation to a smaller areal extent. Where appropriate data is available or can be generated, larger scale depictions are similarly suitable to enhance details like the level of detail in conventional maps is increased when changing the scale.

Data resolution and scalability are closely connected. For small scale depictions of gridded cartograms, too high data resolutions can negatively affect the gridded cartograms. Technical limitations of the current implementation of the algorithm, but also a declining readability if too many grid cells are part of the map are the reasons why a careful balance between the necessary accuracy (as the presumable strength of the cartograms) and their readability and the ability to process the data needs to be found depending on the areal extent and the display size of the intended map. Larger scale transformations make higher data resolutions than those currently available on a global scale inevitable. The quality and accuracy of the gridded data remains the biggest obstacle in the use of a gridded cartogram approach when it is taken to larger scales and smaller areas. Alternative techniques to generate own gridded datasets from existing data as presented in this thesis demonstrate possible solutions, but need more in-depth-investigation.

Data therefore sets the boundaries into how much detail can be mapped. But also the specific nature of the data when topics beyond population are mapped is a crucial issue when using gridded cartogram depictions. The most suitable data for a gridded cartogram is data with some significant variation in the distribution of the data throughout the topic that is desired to be mapped. Too little variation makes the effort in creating a gridded cartogram rather useless, because the transformation does not change a great deal in relation to a conventional map projection (although it is not a *wrong* approach either – it may simply not produce the result that one expected). Too striking differences, in contrast, lead to very unusual, perhaps sometimes odd or hardly understandable maps, such as the global storm patterns and earthquake intensity cartogram, transformed either from a land-area perspective or even on a global grid. Nevertheless, it can be a wanted effect to highlight these eye-catching differences, but the nature of the data must always be assessed for its suitability and the desired outcomes.

Population data was a very dominating element in the research because it has been identified as crucial for an understanding of the human geography in contrast to the physical space. Proclaiming the gridded cartogram as an alternative map projection, therefore, remains a defining argument of this thesis. To be successfully accepted as a new projection, the underlying transformation should remain the same for every map, and from this point of view, the gridded population cartogram is a legitimate addition in the list of changing map projections from Mercator to Peters, which also always reflected new views of seeing the world in their particular times. We are living in a globalised world, and humanity has such a considerable impact on the planet's processes that we have to change our view to understand the interrelations between people and their environment. Changing the space to show people, and allowing to mapping the (physical and social) environment on top of that is a map projection for the age of humanity.

Drawing gridded cartograms from other elements of the human environment proved to be more difficult. At a global scale, we still know very little about the distribution of other socio-economic or demographic variables in the same detail as we know (or are able to estimate) population patterns. Where data is available, the gridded cartogram technique is an interesting addition to show cartograms with much more detail than those e.g. shown in Worldmapper. This has been demonstrated at population growth and decline, but can easily be imagined for other dimensions of the social space. Mapping without boundaries is essential to understand the complex variability of global issues, but very often still fails because of a lack of adequate data.

Specialised gridded cartograms have less potential to proclaim a similar versatility as alternative basemaps like the gridded population cartogram. It would get quite confusing if we were to map every aspect of the world's geography onto every gridded cartogram that can be created. It also does not always make sense to plot different topics against each other. While I see the gridded world population cartogram as a universal basemap to show the real geography of humanity, I would see other gridded cartograms as being more specialised applications of geographic visualisations where a different understanding of huge amounts of quantitative geospatial data is desired.

With gridded cartograms we can also rethink the value of cartograms for mapping the physical environment. A physical geographer may so far have seen little value in a cartogram as an alternative mapping technique, because just too much detail gets lost when mapping empirical data from observations onto a cartogram of the world's countries. It may be a too crude depiction to understand climate data when we only see a picture of the countries with most or least rainfall. Seeing changing rainfall patterns based on a gridded cartogram takes the higher level of detail from such data into account and can lead to more vivid depictions of the quantities contained in the data. The physical environment is now measured and investigated in so great detail that gridded cartograms can be drawn from this data in an alternative way.

Still problematic part of the workflow remains the effort that is needed to create gridded cartograms. A gridded population cartogram can already be a more straight forward creation when made using prepared gridded datasets. But even here – depending on the level of detail and the amount of data that is transformed accordingly – it takes significantly longer on a computer than a conventional reprojection of a map. When working with other unprocessed data, pre-processing works take even longer and may at present discourage a wider use of the proposed technique presented here.

Finally, the adequate visualisation of the gridded cartograms themselves needs to be addressed. The original Worldmapper cartograms have gained wide attention and have become very popular, not least because of their rather simplistic nature. With the evaluation of additional detail and advances on their capabilities to show more-detailed data, the gridded cartograms have inevitably lost their simplicity to some extent and require different forms of visualisation.

A crucial element in conveying the new geography of the gridded cartograms remains the visualisation of the underlying grid or of a lower resolution grid if the original grid is too detailed to be shown at a certain resolution (as demonstrated at the example of Japan). The grid provides the essential information to understand to what extent the transformation took place, and it is also part of the vivid appearance of the new maps. While other map projections may work without any graticule lines[84], the gridded cartograms need the full grid to understand the internal variation within the continents. The underlying grid and the appearance of its transformed shapes are therefore an essential element of the gridded cartograms. An appropriate visualisation of this element and how this can be enhanced and complemented by additional design features is an important part of making the unusual appearance of gridded cartograms more comprehensible. Central design elements have been addressed in this thesis and relate to the wider issue of readability of gridded cartograms.

The gridded cartograms, I argue, always show the same patterns of transformed rectangles, which once the transformation principle is understood can be read and understood even if unfamiliar administrative shapes exist or if boundaries change (which both affect the appearance of other cartograms considerably). While the grid results in more complex structures the nature of the patterns that are displayed in gridded cartograms remains the same. Despite its unusual appearance, concepts of map design and visual enhancements can improve the initial understanding of the map in general[85] and reduce the entry barrier to reading the map correctly without detailed explanations. However, an acceptance of alternative map forms is not only a question of its design principles.

Humanistic cartography faces the problem that new forms of mapping can cause confusion or even anger in the map reader. The very unfamiliar forms of cartogram-style maps may make people avert their eyes from these new forms of visualisation which they initially do not understand. Seeing something that cannot be understood immediately and which does not relate to one's idea of a map can reduce the acceptance of that map. But in turn, it can create a form of curiosity to dive into the topic of the map and try to understand what is shown and how it is shown. Triggering this curiosity without losing the map reader is perhaps one necessary consideration

[84] The differences between a Mercator map and a Peters map can be understood even if there are none of these lines shown in the map, although they make the projection easier to understand

[85] I used such enhancements for the gridded world population cartogram in several stages of the visualisation. The Worldmapper colour scheme can be seen as a simple example for that.

when developing new mapping concepts in general. The Worldmapper project made great efforts in this regard although it also lives from its controversial nature. The problems observed in worldmapper therefore apply similarly to gridded cartograms.

Gridded cartograms can provide a more provoking view that validates unwanted views and *realities*. Abler et al note that "*many people fear science will tell them something must be a certain way even though they don't want it that way*" (Abler et al. 1975b: 7). Such '*fear of science*' is not a unique character element of a cartogram. Peters' projection of the world from the 1970s demonstrates the implications that showing the known reality can be quite controversial (see section 2.2.3). Showing existing conditions in a different dimension can thus prove to be perceived as provocative even for undisputed facts.

A world population cartogram may appear to be such a challenging view, making the appearance of emerging economic world powers like China and India threatening for some western-centric world views. Showing a world population cartogram that has even more unusual shapes may thus be an even more provocative approach. But if one agrees on the assumption that there are a finite number of human beings living on the planet and each has a location at a point in time then there is a *real* geography to the map that is hardly deniable.

A gridded population cartogram does not show new information. Instead, it makes the dimension of human settlement patterns visible in a way that conventional map projections superimposed with choropleth-shaded population densities are not capable of. This is not particularly better (or worse), but makes the *magnitude* of these population distributions comprehensible and gives space in the map to show them in relation to other issues. The emerging picture may not always be one that a person with a Euro- or Western-centric view[86] wants see. A conventional map projection showing population density still shows unpopulated large countries being big, while smaller but more populated countries have less space on the map and thus may be perceived as less relevant. This turns the discussion from the practical considerations to the more theoretical side of the technique, and how this relates to its wider implications that were introduced by putting changing cartographic practices into the context of a globalising world and diversifying perceptions of space.

[86] The maps shown in this thesis can easily be criticised for building exactly on such views by the design decisions that were made to put Europe in the centre of the map. However, this followed a rather pragmatic decision to not overstretch the map reader's mind by moving from the perhaps most widespread map image at least in that part of the world where this thesis has been written. It should therefore be stated, that gridded cartograms do not have to build on that perspective, but can equally be created for other perspectives.

7.3 Theoretical implications

The research in this thesis was undoubtedly driven by methodological questions and investigated mapping as a *"practical form of applied knowledge"* (Perkins 2003: 341). Although questions of how different social and physical spaces can be shown in different ways in maps were important elements during the developments of the new techniques, this only touched the surface of a deeper debate about the relevance and forms of space that are discussed mainly in human geography. Hereafter I want to address the issues of space in a more detailed way and align my research with the broader implications that new forms of mapping could have not only for visualising and understanding quantitative science, but also for a better understanding of the theoretical battles that continue to divide geography (see section 2.2.2).

The range of applications for gridded cartograms demonstrated the geographical relevance of their use. The very abstract notion of different spaces that exist in theorists' minds can be made visible in a very material form by translating the abstract nature of the debate into cartographic representations. A geographical relevance in a more practical – and therefore also more substantial – way is the conclusion, that gridded cartograms used in their versatile range of concepts provide an alternative solution to visualise quantitative data in a new dimension. The significance of the method lies in its possibility to break free from the limitations of physical space in the map and give other dimensions space in the map. At the same time, space is not abandoned, as the spatial reference is preserved in the grid pattern.

This discussion cannot provide an entire solution to the problems addressed, nor can it claim to be a complete discourse on the theories of space. But it is an attempt to extend the views taken in this work and to substantiate some of the statements about the visualisation of space that were made in a rather simplified way in this thesis. Gridded cartograms were developed with the aim to visualise humanity in a different way than it is done at present. What is essential for the theoretical advances in human geography – but ultimately also for geography scholarship – is a new debate on mapping techniques as an essential element of communicating geography.

The prime outcomes of the work undertaken within this research are many new maps. But how do these very material products of methodological exploration relate to an understanding of theory? Notions of geography often consist of images of a map, at least popular notions outside the academic study of geography do so. There the talk of geography may recall a mental map of a place or of the world, of cities, rivers, mountains and continents. This popular or vernacular view of geography (Johnston 2004) may be irritating to the academic who feels that the discipline of human geography consists of much more depth, breadth and maturity than just maps or cities. But probably this apparently childish view of geography should not be immediately dismissed. Images of maps stick with us from our childhood and beyond because they are so powerful and represent a particularly effective method of communication and of conceiving of space. Why is the image of Mercator's world map so etched on our memory, why do we have immediate understandings of maps? Map-reading skills are not inherent, but we have been trained to see that image as a *normal* depiction of space. While human geography started to discuss new ideas of space that are different from those that we know from maps, it simply stopped using maps rather than trying to reflect those changing schools of though.

It is interesting to reconsider how far the discipline of human geography appears to have distanced itself from maps over recent times (as investigated in section 2.2.2), resulting almost in '*cartographic anxieties*' (Perkins 2004: 381) of some geographers. Kessler & Slocum's (2011) analysis of thematic maps may be seen as one proof for a decline in mapping practices themselves. Martin (2000) made similar findings while writing '*in memory of maps*', where he states a declining map use in the *Transactions* journal. This seemed to have little improved since then[87], even if it is not all just bad. Phillips et al. (2007) use several choropleth maps to aid the description of the density of ethnic minority settlement in Leeds and Bradford. Even more innovative are Burgess et al. (2008) by using maps to illustrate the flows of pupils from primary to secondary schools – a new conceptualisation of space becomes material here that is not only based on putting a static geographic reality onto the map. However, in both these cases it is worth thinking of how these very good maps might look had they been plotted over population space rather than using conventional cartography. Would the message have changed?

Recent editions of undergraduate human geography textbooks reveal large numbers of glossy and colourful photographs, frequently depicting scenes from exotic (and other) locations (see e.g. Cloke, Crang & Goodwin 2005, Daniels et al. 2008). Textbooks written in earlier decades, in contrast, tended to look rather dull, lacking colour and decidedly matt when held up against glossy modern ones. However, maps were used more extensively in the earlier copies of human geography textbooks[88] (see e.g. Cox

[87] Take for instance the three recent volumes of Transactions, 2007 to 2009 (Volumes 32 (1) to 34 (4)). Of the twelve issues, consisting of 92 papers, only 27% of all the papers contain at least one map. Furthermore, in many examples of papers in these volumes where a map has been included, it is questionable how much value the map actually adds to the paper's content or helps explain or reinforce the arguments put forward by the author.

[88] This observation correlates well with Johnston's (2009) observation that popular geography magazines, such as *Geographical* and *National Geographic* are characterised by large amounts of colour photographic material.

1972, Raw 1986). Do many geographers "*prefer to write theory rather than employ critical visualizations*" (Perkins 2004: 385)?

There are a number of reasons why maps have gone out of fashion, but at least partly it can be explained by the cultural turn in geography and maps' association with colonial, imperial and Eurocentric domination of the world and also connects to the earlier notions on map projections, with Peter's controversial world map contributing to an ignition of this debate about the negative role of maps in the 1970s (see section 2.2). Notwithstanding, however, mapping and cartography remain a regularly discussed topic. The earlier outlined works of Radcliffe (see section 2.2.2) for instance demonstrate the continually shifting power relations and how this process is reflected in cartography: "*Grappling with the social, technical and embodied interactions 'beyond the map' that shape national mappings remain the task of an emergent critical geography in Ecuador*" (Radcliffe 2009: 440). The implication of this then is that maps are not just the product of a ruling elite but can be shaped by a broader critical or radical perspective. Such sometimes more sometimes less radical mapping approaches all make a point that illustrates how something as apparently given, or objective, as a map of the world could be legitimately distorted and altered but still remain valid. In the case of Peters' world map, for many people this was the first time they had been confronted with such a challenge to the established mental maps. The fact that the Peters projection raised fresh questions and provoked new thought and new discussion was perhaps its most successful contribution.

The views of our world have changed considerably since the 1970s, and perhaps also the availability of new perspectives over the internet has helped to challenge the perspectives[89] that we have been exposed to in our childhood days, or that we simply just became accustomed to. But, nevertheless, we still rely very often on conventional cartography when we look at the state of the world, and when we try to understand the complexity of the world. By introducing an alternative mapping technique I hope that at the very least some questions will be raised and contribute to a new discussion, and that the perspectives created with the new maps reach beyond the narrow academic sphere within which this thesis is situated. The maps presented in this thesis and the techniques elaborated to create these maps are certainly not better than others, because each map serves a specific purpose. But they are different than other maps, and they provide alternative ways of showing the geographies of the world, and add a little piece of diversity to the ways in which we can communicate academic thinking.

[89] This is part of Worldmapper's scope and as outlined earlier, also a preconditions for its wider acceptance and appraisal within the cartographic community.

The values of communicating efficiently and effectively should be fundamental to academic work: "*The thinking subject can create ideas in the imagination. But ideas have at some stage to leave the realms of abstract knowledge and to enter into human practice if they are to be validated*" (Harvey 2001: 54). Combining abstract theory with evidence and examples is a way to progress towards what today may be termed critical reflexivity. It ensures a process whereby both theory and evidence are used to verify one another.

Dodge, Perkins & Kitchin (2009: 220) recently argued that "*we want to set out a manifesto for map studies for the coming decade. Its goal is to generate ideas and enthusiasm for scholarship that advances our understanding of the philosophical underpinnings of maps, and also enhances the practices of mapping. This is not a call for ever more introspective intellectual navel gazing about maps. Instead it traces routes and methods that might help people to do mapping differently and more productively, in ways that might be more efficient, democratic, sustainable, ethical, or even more fun*". They continue that "*Map studies needs to explore these educative moments of mapping in schools and universities.*" (Dodge, Perkins & Kitchin 2009: 238).

As a core discipline to explain our world, geography should be at the forefront of these developments (Ballas et al. 2005), and provide innovative and meaningful ways that make the complexity of the anthropocene understandable, because it matters so much for the future journey of humanity. Thus in cartographic research, just as within geographic scholarship, new ways of thinking are more and more frequently requested. There must be a different (or even better) way of working. What matters in what you think is what you ask. That in turn depends on what you know based on what you can see or are told is true. This thesis does not show anything we do not know already, but it rediscovers geography by simply changing the view.

Why not look at the world a little differently?

7.4 Future directions

It would have been easy to conclude the research by presenting the gridded cartograms as an alternative to other mapping techniques. The theoretical excursus, however, and the here discussed association of geographical theory and their relationship with cartographic practices lead to wider implications that set the framework for a research agenda resulting from this work. A changing world in the age of globalisation, and changing practices of processing and presenting information is a challenge that cartography is predestined to take on.

Gridded cartograms were presented as an alternative way of *visualising what we know*[90]. Visual power is used as an argument that the technique can also be useful to support a better understanding and therefore help to make sense of the complex reality of the world that reaches beyond the dimension of physical space. While theoretical debates have partially led to a rejection of maps in geography, *reclaiming the map* and engaging more in the revival of mapping outside the cartographic profession is essential to retain the relevance of geography. Maps as part of geographic identity stand in the centre of the interdisciplinary character of the discipline – abandoning maps is as if geography was disestablishing itself. There is a need to "*bring maps back to the centre of geographic scholarship*" (Dodge & Perkins 2008: 1275), and therefore the need to investigate alternative solutions to traditional maps is important to address the limitations of showing the growing complexity that we discover for the diverse dimensions of space.

The thesis successfully outlined an approach for the creation of gridded cartograms. To make them a viable alternative for cartographers (and *map makers*), further research is essential to establish the technique and to define its most appropriate uses in the toolbox of cartography. The problems and limitations that were identified in the research processes lead to the following steps that should follow this research. They do not suggest priorities, but build upon each other and should be seen as integrated needs that emphasise the different directions of work that are needed in an academic, educational, technical and practical context. Furthermore, future research should not concentrate on gridded cartograms alone, but always treat gridded cartograms as part of efforts on a reintegration of maps and mapping in the work of geographers.

(1) *New data*

At several stages the limited quality or availability of suitable datasets has been identified. Gridded cartograms rely on good and accurate data, of which the physical world provides plenty. For a wider application of gridded cartograms as a mapping technique for human geography, further efforts have to be made into the improvement of demographic and socioeconomic data at highest resolutions. Efforts to model these data onto a grid similar to the work of the GPWv3 database are needed, and for the existing data – including the GPWv3 database – further works to increase the resolution and improve on the lower quality data in some areas need to be undertaken. For a scientific use of the ever growing amounts of publicly available data, procedures of establishing good-quality data are inevitable to create not only striking, but similarly valid visual representations of the data that is contained in them.

[90] This phrase is borrowed from the *Atlas of Science* (Börner 2010), which examines how visualisation contributed considerably to the discovery and exploration of knowledge.

(2) *Cognitive research*

The investigation of the results in this thesis was based on a visual examination of the maps. This is justified by the conceptual nature that the exploratory approach followed. The gridded cartograms were put to the test against existing map concepts to explore their differences and assess their capabilities and their functionality. Cognitive research into the perception of gridded cartograms has to follow to identify their weakness related to map reading skills, and to find possible solutions, how the design of gridded cartograms can be improved to enhance their readability or to increase the acceptance of this map form. This should be performed as a more comprehensive task than developing a user survey, but should build on research related to visual representation and cognitive abilities.

(3) *Standardisation of cartographic principles*

Building on findings from studies that investigate user perception and cognitive abilities, the design principles of gridded cartograms should be put into a more standardised form. This problem is not only relevant to gridded cartograms, but to cartograms as a map form in general, for which a multitude of techniques exist, but little research is done into an adequate visual representation of these maps. There is a substantial range of cartographic principles for conventional map projections, many of which build on the research about the perception of maps. An investigation into the design of cartograms and their particular functionality can also contribute to a wider – and better – use of cartograms in general. Related to gridded cartograms, their particular visual nature and enhanced capabilities requires special consideration, as they stand between conventional map projections and other forms of cartograms.

(4) *Explanation and digital presentation*

Further investigation in suitable ways of explaining the maps and their creation and can help to make the underlying dimension understandable. If readability is an obstacle to the understanding of these maps, then this may be addressed by adequate explanations, how gridded cartograms can be read by explaining them in a more appropriate way. Digital technology may provide a suitable way to demonstrate how gridded cartograms evolve from those conventional maps that we are more familiar with. The digital presentation of maps with a multitude of new techniques provides potential to reduce the abstract nature by moving away from static map displays. Interaction and animation can not only be playful features, but add value to the cartographic display (Harrower 2007, Harrower 2009, Harrower & Fabrikant 2008, Midtbø & Nordvik 2007, Tversky & Bauer Morrison 2002). The development of suitable ways to utilise the possibilities of digital techniques should be an integral part of the work on the examination of cartographic principles for gridded cartograms.

(5) *Promotion of the technique*

Presenting something new without which we could get along quite well before requires a wider promotion of the technique by demonstrating its uses and its functionality. Many technical solutions that have been developed over the last years in the field of digital cartography, but are not deployed because they are hardly recognised. The example of an advanced flow mapping algorithm (which has been used in one of the explorations during this research) is a good example for uncountable other similar lost innovations. One recently developed technique e.g. translated manual cartographic principles of drawing flow lines into a digital algorithm (Phan et al. 2005b, Phan et al. 2005a) that results in elegant depictions of flows. Having been developed outside the field of cartography (but as part of informatics), and without a range of potential applications, it found little echo in cartography practices and has (so far) hardly been applied despite its potential and a multitude of failed efforts to put flows elegantly on maps with digital technology.

Gastner/Newman's algorithm is a more successful example for an introduction of a new mapping technique. The algorithm has been utilised by Worldmapper and not least because of Worldmapper, such cartogram depictions have become a more common way in cartographic practice. The demonstration of using gridded cartograms (that build on Gastner/Newman) at a wider range of applications is part of an (already ongoing) effort to demonstrate the capabilities and potential of gridded cartograms. The creation of the world population atlas followed these considerations, and the next step could be the development of an alternative world atlas that uses gridded cartograms to map the multitude of spaces and diversity of geographies that exist.

(6) *Creation of educational resources*

If our image of the world is shaped in our childhood, then educational resources are a way of changing the maps that we are learning with. Simply providing new maps is not enough. The development of educational resources is a practical but essential requirement for a wider use of gridded cartograms to establish alternative ways of geographical thinking. Suitable themes have to be identified for which specific educational resources with gridded cartograms should be created.

(7) *Simplifying the mapping process*

Further dimensions of encouraging a wider use not only by those academics who abandoned the maps, but by anyone engaged in cartography include a simplification of the mapping process. The complex procedure in preparing and processing adequate data to generate gridded cartograms require expert knowledge of geographical information systems, and some idea of geospatial data analysis. With a standard procedure outlined in this thesis, the next steps must now include the identification of those parts of the procedure that can be made easier. It is a useless exercise if everyone who wants to use gridded population cartograms needs to go through the procedure of generating a vectorised population grid. The preparation of a repository of data and the preparation of simple-to-follow procedures that allow these maps to be created by non-experts should follow to encourage a wider use.

A long term goal must be the easier implementation of the technique in common mapping tools. While other map transformations can often be applied by the click of a button, gridded cartograms are complex and time-consuming, even if suitable preprocessed material and instructions are provided. When working with digital mapping environments, technical obstacles should not be the reason, why a certain mapping technique is not used. The user should rather be able to choose the most appropriate base for a certain purpose, of which gridded cartograms, but also other types of cartograms are one of the many options.

Further methodological efforts to implement key technical principles in generating gridded data and applying cartogram transformations should be made towards a gridded cartogram tool. The vision of an equal-population projection in the range of map projections available in GIS software may sound overoptimistic, but with advancing technological capabilities is not unthinkable and something desirable.

Chapter 8 **Conclusion and outlook**

This chapter contains a summary of the results from this PhD research. Following an investigation of the objectives that were outlined in the introductory chapter, it is evaluated, how the aims from the research project were accomplished (section 8.1). Building on the final discussion in the previous chapter, the concluding remarks provide an assessment of the wider significance of the achievements for geographic thinking and practice in a more visionary manner (section 8.2).

8.1 Summary

Chapter 1 outlined the research by introducing the broader scope of the work and outlining the aims and objectives. The overall aim of this research was an improvement of the capabilities of the cartogram techniques used in the Worldmapper project. With geography and cartography being the central elements of Worldmapper, this aim has been embedded into the geographic context of a globalised world and the prevailing trends of the digital age that have a considerable impact on cartographic practices. These preliminary thoughts were used to specify the initial aim and define subordinate aims, for which a number of objectives were identified that are needed to achieve the aims of this research project. The following summary of the subsequent chapters addresses the objectives at the relevant places in reference to their order as outlined in chapter 1 (section 1.2). It is then evaluated how these objectives contributed to achieve the overall aims of the thesis.

Chapter 2 presented the research context of the research by following the objectives to (1) *investigate how globalisation processes changed our understanding of space*, to (2) *illustrate the impact of these changes on cartographic theory and practice* and to (3) *investigate the special role of digital technology in cartography*. The objectives were achieved by a comprehensive literature review that demonstrated how these three separate issues are closely interrelated. The chapter started with the introduction of the concept of the *anthropocene* in geographic research. The concept stands for a return to a more interdisciplinary way of geographic thinking that include the complex human-environmental relationship as integral elements. Related is a new perception of space of which the physical space is only one dimension in this complex relationship. These changing ways of theoretical thinking find their manifestation in maps, which the overview of map projections as conceptualisation of space and the advances in putting further dimensions of humanity on the map illustrated. Cartograms as a concept for an alternative map projection were outlined in more detail as their advances can be seen as part of the developments that started to change the practices of producing maps as much as the role of the map itself.

The impact of digital technology on geographical visualisation in the last decades was given special consideration in understanding these changes for the further conduct of the research. Information and communication technologies mark the latest change in the globalisation processes that have changed the functioning of the world considerably since the early days of industrialisation. Not only do they correlate to the changing perception of the world (not only for theorists but also in all our minds), but also have they increased the complexity of the relationship between humans and the environment, and the complexity of the social or human space itself. While we try to understand our planet by looking at maps, these maps currently often fail to communicate these complex environments adequately.

FIGURE 8.1: MAPPING NOW AND THEN
The author's contemporary computer workplace (top) and a cartographer at work in the 1940s (below); displayed in the background is a part of Ortelius' *Typvs Orbis Terrarvm* world map from 1570 (own depiction by the author with additional material from Library of Congress 2009, NARA 2008)

The digital turn in cartography that started with the first computer-assisted statistical analyses and in the early days of geographical information systems in the 1960s has changed the way of making maps, but also of analysing geospatial data, and visualising them in novel form. Computers became a standard tool of cartographers in the 1980s, GIS entered the common workflow of geographical sciences in the 1990s, and the internet arrived as a new platform for exchanging and visualising geospatial data. We are now in a new digital age in which the process of making maps looks very different than it did before (Figure 8.1), and the computational capabilities allow us to get a new understanding from the ever-growing amounts of data that are collected. The Worldmapper project to which this research is related was presented as a prime example that stands for the changing nature of cartography by trying to map those new spaces of a globalised world deploying the techniques and possibilities that are part of the digital world.

Chapter 3 addressed the objective of (4) *developing a method for the computer-based creation of density-equalising gridded cartograms*. The objective is successfully met with the elaboration of a procedure that improves on the technique to create cartograms using Gastner/Newman's diffusion-based algorithm. The new technique is based on a considerable improvement of the underlying base data, which involves the creation of a vectorised grid that is used for the actual cartogram transformation. The elaboration of the method involved a comprehensive assessment of suitable data sources with special consideration of population as the key element standing between the different dimensions of space that have been identified in the previous chapter. A review of the Gridded Population of the World (GPWv3) database outlined current concepts of improving gridded demographic datasets, but revealed gaps in the data quality and overall resolution. Therefore the chapter included an examination of ways to generate suitable gridded datasets, which fulfils the complementary objective to (5) *provide ways of generating higher resolution population*. This was demonstrated at two case studies, the Occupied Palestinian Territories (OPT) for a region where highly variable population patterns occur that the existing GPWv3 database cannot show, and the city of London, which was included as an example for an urban level set of gridded population data. The two different approaches to model population on a higher resolution included a manual interpretation of digital maps and aerial imagery for the OPT, and an interpolation of population data from existing census-derived data sets for London.

Population data provided the input material for the initial development of the gridded cartogram approach, which was explained in its technical procedures and then expanded towards a presentation strategy for the new maps. This related to the realisation of the objective to (6) *outline design principles for the maps created with the new technique*.

Following the methodology, chapter 4 introduced the initial results of new gridded population cartograms. The objective to (7) *present a new gridded world population cartogram as an alternative basemap for human space and investigate its value compared to other map projections* was successfully addressed by an examination, how the dimension of population space becomes more accurately depicted in the new map. The reference cartogram of Worldmapper can achieve this only in a crude way at a national level, and in a conventional map projection this topic is restricted to the dimension of physical space that gives most space to the least populated areas. It was demonstrated that the preserved base unit of the equally-distributed grid is transformed in a conformal way that allows every grid cell to be related to its correct geographical reference in the physical space. While in a conventional cartogram the spatial distortion is uniform within a country, and therefore highly dependent on the varying sizes of a country, the grid cell is independent from these artificial reference areas and are based on a neutral map unit that combines the concepts of conventional map projections and cartograms.

The objective to (8) *assess the effects of different resolutions on gridded cartograms using population data* is resolved in two ways. The gridded world population cartogram was generated using two different resolutions of data, which showed that higher resolutions do not always lead to better results. The second aspect of resolution was investigated in relation to scalability. Higher resolutions of the underlying grid are more useful for larger scale gridded population cartograms. The creation of gridded population cartograms for every country in the world, and the two case studies of the OPT and London confirmed a general suitability of the technique at different scales. It was shown that in terms of scale, gridded cartograms have similar characteristics like conventional map projections that add further levels of detail when using larger scale map displays.

Further conceptual questions were examined in chapter 5. The objective to (9) *apply different types of data as overlays on gridded population cartograms and investigate their appearance in comparison to other map projections* was fulfilled with the use of national-, subnational- and grid-level data as well as raster data applied to a gridded population cartogram transformation. The resulting map displays were compared to a normal population cartogram and a conventional map projection that led to the conclusion that the technique produced in no case invalid results, and that the utility of the technique in relation to other kinds and types of data mainly is a question of the purpose for which a map is created. Similar to the problem of scale, it was shown that overlaid data is not restricted to specific types or resolutions of data. Neither was any of the gridded population cartograms superior, nor was it inferior in its visual appearance, although it provided a larger flexibility in its use in comparison to the normal population cartogram. The latter aspect can be seen as another confirmation of the *basemap* aspect raised in objective seven.

The objective to (10) *transform other quantitative data using the gridded cartogram approach to review its flexibility beyond a population projection* is accomplished with the creation of two additional cartogram transformations that depict the population growth and decline. Although the data used here still relates to population, the example moved away from the perspective on total population patterns towards other quantities, which has been used as a first approval of the more general applicability of gridded cartograms in the more diverse way as realised in the original Worldmapper project.

Building on these two overall concepts of using gridded cartograms as basemaps as well as transforming different dimensions, different visualisations of the ecological footprint provided a concluding example that presented the conceptual differences of the different way gridded cartograms can be used in comparison to a conventional map projection.

Chapter 6 builds on the findings of the results to comply with the objective to (11) *provide examples for further applications of gridded cartograms that demonstrate the potential and limitations*. Potential and limitations were already part of the assessments in the two previous chapters, but here a broader range of applications was presented and evaluated with a more geographic rather than technical focus to be able to make these broader statements about potential uses and the current or general limitations. The multifaceted range of mapping examples comprised the themes of elections, national geographies, biodiversity, precipitation, oceans, and global travel times. The diverse nature of data and a representation of the multitude of geographical research stood in the foreground in the selection of these examples.

The implications of the research are discussed in *chapter 7*. The discussion focused on three main issues by first revisiting the successes and problems that occurred in the course of the research to underline the advances that could be made within the scope of the Worldmapper project, and to assess the relevance of the method and its results within contemporary cartographic practice. In the second part of the discussion these considerations were then extended to the theoretical debates about the relevance of space and the contributions that cartographic visualisations such as gridded cartograms can make to overcome some of the gaps that have evolved in geography over the last decades. The third part then identifies future directions of research that result from the findings and outlines concrete measures that are needed to successfully establish gridded cartograms not only within the Worldmapper project, but also within the range of cartographic practice.

The discussion resolves the remaining objectives to (12) *discuss the role of new methods such as the gridded cartograms within the debate about the relevance of space in geography*, to (13) *review the value of the results for the Worldmapper project* and to (14) *identity future directions of research which could facilitate and establish the use of gridded cartograms in a future wider range of cartographic visualisation and geographic practice*.

This summary concludes with a short statement, whether implementation of the objectives as outlined above could contribute to accomplish the aims of this research. The overall aim (a) *to improve capabilities of the cartogram techniques used in the Worldmapper project* was successfully achieved with the development of gridded cartograms as a new mapping technique that builds on and extends the abilities for alternative world maps with additional interpretative value.

The following overview shows the specific cartographic accomplishments that were derived from the overall aim, and points to the corresponding chapters and the specific results that contain the achievements:

(b) *To present a method for the creation of cartograms that meets the requirements of an alternative map projection,* which is included in this thesis as a detailed description of the method and technical procedures (chapter 3);

(c) *The suitability of applying the new technique at different scales, and using different geospatial data for the transformation*, which is documented with the new world map, the country maps, the examples for the Occupied Palestinian Territories and the city of London for the question of scalability (chapter 4), as well as the maps of population growth and decline for the question of other transformations (chapter 5);

(d) *To show the potential of the new cartograms to serve as an alternative basemaps for additional types of data at changing levels of resolution*, which is presented for the Happy Planet Index, infant mortality, economic activity and a night light satellite image (chapter 5);

(e) *To establish a range of potential applications using the new cartogram approach*, which is shown in the case studies for elections, geographies of Germany, biodiversity, precipitation, ocean chlorophyll, and travel times (chapter 6);

(f) *To show the implications of the new maps for geographic theory and practice,* for which the preliminary thoughts are first outlined (chapter 2) and then discussed with regard to the research findings (chapter 7).

8.2 Concluding remarks

This thesis introduced the technique of creating gridded cartograms as a new geographic map projection and presented a wide range of applications illustrating how the new technique can be used to map the geography of the world in an alternative way that has not been shown ever before. It could be demonstrated that the new projection can provide the base for insightful new maps of the world's population at various scales and for virtually every aspect of geography that is related to humanity. Furthermore, an extension of the technique towards other topics than people was successfully implemented, with topics not only from the socio-economic environment, but any quantifiable and geographically locatable aspect of the world being a potential base for the creation of gridded cartograms.

Gridded cartograms were introduced in the context of the historic development of cartographic visualisation (see section 2.3), and stands within the methodological framework of map projections. It was argued that the unprecedented level of geographic detail that can be achieved with the new technique justifies the classification of the gridded cartograms as a real map projection. Humanity has not been mapped in cartogram form like this on a global scale ever before.

By looking at the spatial context, not only of people (as concluded by Dorling 1991: 172), but of the quantifiable dimension of our planet, we can understand the sometimes hard-to grasp dimensions of numbers in a visual way, in a way in which we perceive information. *Visual thinking* remains the most powerful element in more intuitive understandings of a topic (Roam 2009), and allows us to see things that we would have otherwise not noticed in the vast amount of data that is hidden behind the graphics.

Is a map worth two thousand words? I used approximately 2000 words to introduce the gridded world population cartogram in section 4.2.1, and still missed a lot of the details that it shows. We can analyse the hundreds of thousands of individual data values that are contained in the underlying data sets using the most sophisticated statistical analysis, but eventually, the cartogram is worth so much more than these two thousand words. When used wisely, GIS methods conducting geospatial analysis and enabling their visualisation are not the *black box* that turns our data into something we do not understand (Poore 2003), but contribute to our visual capabilities in order to *better* understand the world around us. To describe the new geographies that were presented in this thesis it would probably require many more than the two thousand words that describe the gridded world population cartogram.

Gridded cartograms can not only provide a solution for a different understanding of humanity, but a new understanding of the different social and physical dimensions that determine our livelihoods. The impact of our lifestyles was shown in different views of the ecological footprint (see section 5.4.2). This appeared less malicious from a population perspective, because few people in the *western* world are behaving rather unsustainably, but a visualisation of the real impact demonstrated the power of visualisation when using the grid for showing other quantities than only people. This turned the picture of a little proportion of humanity living quite unsustainable lifestyles into a demonstration of the total impact that this little proportion has on the planet.

The flexibility of the technique can be seen when reversing the concept of a gridded population cartogram, which provided the concluding example of remoteness in this thesis before the final discussion (see section 6.5). While large parts of the planet remain less densely populated, a look at the accessibility of places visualised the empty spaces around us in gridded cartogram form. Very few places are less accessible nowadays, but these spaces of solitude still exist. Morphing the planet by accessibility using a complex set of parameters from the physical and social environment shows a different dimension of the *global village* and visualises the shrinking spaces outside the influence of globalisation.

The gridded cartograms are more than a mere description of the dimension that their transformation is based on (be it people, politics, or precipitation), but allow a comprehensive understanding in all their geographical variations. When mapped with additional geographical layers, they show complex interrelations based on the underlying information rather than the physical space. Unlike in cartograms before, the limits are not set by geographical boundaries, but *only* by the quality and accuracy of the data that is used. Geographical boundaries do no longer determine the emerging picture that we get from the cartogram. This is not limited to land area, or the global surface, but also has the potential to create cartograms of quantitative data from the world's oceans for the first time.

To further improve the methods outlined and discussed in this thesis, and to increase the acceptance of cartograms as a in future not-so-unusual-anymore map projection, several issues need to be addressed: First and foremost, there are still some regions of the world for which very inaccurate population data exist. The approach outlined for the Occupied Palestinian Territories or similar techniques need to be applied to those regions where population data is still less accurate, especially parts of the former Yugoslavia. The population grids for very small countries, such as Andorra and Singapore should also be subject to further refinement to be able to create higher-resolution cartograms similar to that created for London.

As with every new technique, it also is essential to make the workflow of creating gridded cartograms a more straight forward technique that reduces the manual effort necessary to generate the basedata for the cartogram transformation. The gridded population data could be integrated in a tool or GIS script that already contains all underlying basedata and settings that are needed to create a gridded population cartogram, so that users only need to define the additional geographical layers that are transformed accordingly. In a first step, such a tool should be easy to realise for the world population cartogram, or separately for individual countries.

Ideally, a gridded population cartogram generator is optimised in such a way that it contains the underlying population grid in various resolutions, so that a seamless transformation between various scales is possible. However, current technical limitations will set certain boundaries for such a project, and will require further technical progress before such a universal tool is practicable. The amounts of data and corresponding processing times are currently too high, making a similar straight-forward transformation process like switching from Mercator to Peters in a GIS not yet possible. An easier transformation tool that integrates the workflow and data for the gridded world population cartogram, or individual country cartograms of interest should, however, be a viable first step towards an implementation of these techniques in standard mapping procedures.

Gridded cartograms that show other topics than population on the base of a transformed grid (such as rainfall) will certainly continue to require more manual effort, as their utilisation depends highly on the very different kinds of basedata. These will continue to require the examination of suitable procedures to turn the data into adequate datasets that go into a cartogram transformation. But also here, an optimisation of the techniques and the processes in the creation of the cartograms bears a high potential for a more straightforward application. The suitability of gridded cartograms beyond human geography needs to be further evaluated to identify their additional value and suitability for scientific data analysis and visualisation. Compared to the complexity of other geospatial analyses, the creation of gridded cartograms is far easier and may proof useful for a better understanding of some environmental data.

Beyond the very specific needs for technical advances, some of which need to be addressed directly, and some of which will be resolved with improvements of computational capabilities, an obvious need is the promotion of a wider use of cartograms in cartographic practice. The techniques developed in this research aimed to address some of the criticism that has been made related to cartograms in the past. They provide alternative solutions that should allow many geographers to take a second look at cartograms. Cartograms are not perfect, but if one takes a long, hard look at other map projections, one can see that they are not perfect either. There are still many improvements that can be made to cartogram techniques, but rather than keeping this in the domain of methodological cartographic debates, we should start using cartograms in geographic practise and make them a part of the ways how we visually understand the world. I discussed the gaps between theoretical works and empirical practice that we should try to narrow. That does not only require theorists to look towards empirical evidence, but also applies to the quantitative geographer to reflect on his/her practices. The use of cartograms will not solve all these gaps, but more generally spoken, visualising geographical work can help to make the complexity of the world more understandable. Sometimes a map can speak a thousand words.

The maps created in this research (many of which are not included in this thesis, for more examples see Hennig 2011) could also provide the basis for an extension of the Worldmapper project to draw an atlas for the 21st century human planet wherever sufficient data does already exist. Many other national atlases can then be modularly integrated into such a project, drawing the new geographies of the world's population from a very new perspective. It does not have to end there. In similar ways, we could imagine a new atlas the world, using the gridded cartogram technique to rediscover the geographical dimensions of the planet in manifold ways.

Is it too much of an aspiration to take the chance of celebrating Mercator's 500th birthday[91] by changing our mental map of the world from one that guides ships to one that guides our journey into a more sustainable future for humanity?

[91] Mercator was born on 5th March 1512.

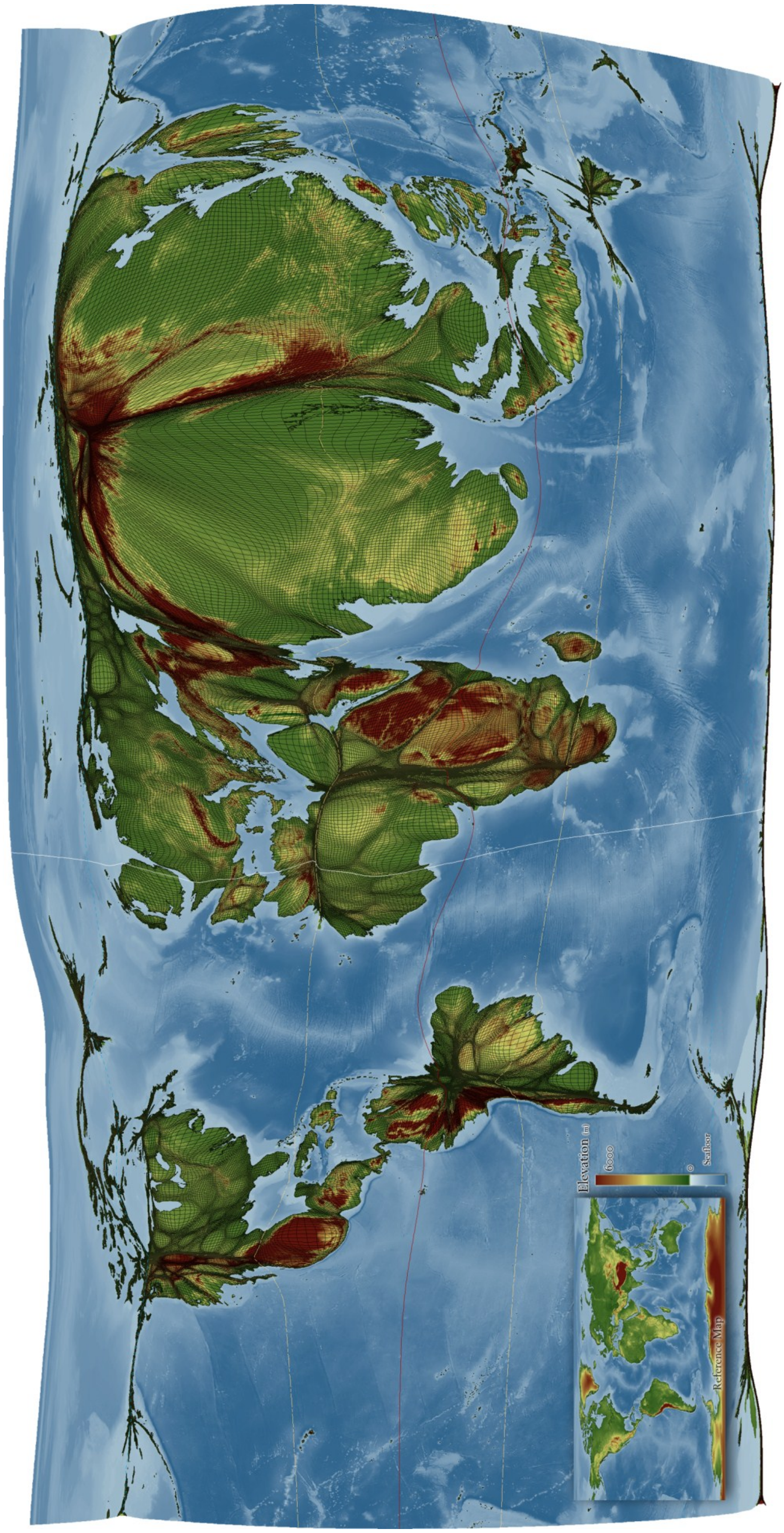


FIGURE 8.2: THE 21ST CENTURY MAP OF THE WORLD
Gridded population cartogram displaying key geographic features
(own depiction by the author using data from CIESIN & CIAT 2005, USGS 2009, NOAA 2009)

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Appendix

Overview

A. Worldmapper basic country data

1_Worldmapper_data.xls obtained from http://www.Worldmapper.org/data/withmap/1_Worldmapper_data.xls (last accessed 2011-06-01) (Sasi Research Group & Newman 2006c)

code	name	region	ISO 3 code	MAP DATA land area (million hectares) 2002
0	World		W	13056
i	Central Africa	1	AC	556
ii	Southeastern Africa	2	AS	790
iii	Northern Africa	3	AN	1616
iv	Southern Asia	4	SA	413
v	Asia Pacific	5	PA	1281
vi	Middle East	6	ME	2712
vii	Eastern Asia	7	EA	1115
viii	South America	8	SO	1816
ix	Eastern Europe	9	EE	291
x	North America	10	NO	2071
xi	Western Europe	11	WE	358
xii	Japan	12	JP	36
166	Angola	1	AGO	125
173	Burundi	1	BDI	3
169	Central African Republic	1	CAF	62
144	Congo	1	COG	34
168	Democratic Republic of Congo	1	COD	227
109	Equatorial Guinea	1	GNQ	3
122	Gabon	1	GAB	26
159	Rwanda	1	RWA	2
123	Sao Tome & Principe	1	STP	0
164	Zambia	1	ZMB	74
128	Botswana	2	BWA	57
136	Comoros	2	COM	0
154	Djibouti	2	DJI	2
156	Eritrea	2	ERI	10
170	Ethiopia	2	ETH	100
148	Kenya	2	KEN	57
145	Lesotho	2	LSO	3
150	Madagascar	2	MDG	58
165	Malawi	2	MWI	9
64	Mauritius	2	MUS	0
171	Mozambique	2	MOZ	78
126	Namibia	2	NAM	82
35	Seychelles	2	SYC	0
197	Somalia	2	SOM	63
119	South Africa	2	ZAF	121
137	Swaziland	2	SWZ	2
146	Uganda	2	UGA	20

162	United Republic of Tanzania	2	TZA	88
147	Zimbabwe	2	ZWE	39
108	Algeria	3	DZA	238
161	Benin	3	BEN	11
175	Burkina Faso	3	BFA	27
141	Cameroon	3	CMR	47
105	Cape Verde	3	CPV	0
167	Chad	3	TCD	126
163	Cote d'Ivoire	3	CIV	32
120	Egypt	3	EGY	100
155	Gambia	3	GMB	1
131	Ghana	3	GHA	23
160	Guinea	3	GIN	25
172	Guinea-Bissau	3	GNB	3
186	Liberia	3	LBR	10
58	Libyan Arab Jamahiriya	3	LBY	176
174	Mali	3	MLI	122
152	Mauritania	3	MRT	103
125	Morocco	3	MAR	45
176	Niger	3	NER	127
151	Nigeria	3	NGA	91
157	Senegal	3	SEN	19
177	Sierra Leone	3	SLE	7
139	Sudan	3	SDN	238
143	Togo	3	TGO	5
92	Tunisia	3	TUN	16
200	Western Sahara	3	ESH	27
138	Bangladesh	4	BGD	13
134	Bhutan	4	BTN	5
127	India	4	IND	297
84	Maldives	4	MDV	0
140	Nepal	4	NPL	14
142	Pakistan	4	PAK	77
96	Sri Lanka	4	LKA	6
3	Australia	5	AUS	768
33	Brunei Darussalam	5	BRN	1
130	Cambodia	5	KHM	18
180	Cook Islands	5	COK	0
189	Fed States of Micronesia	5	FSM	0
81	Fiji	5	FJI	2
111	Indonesia	5	IDN	180
185	Kiribati	5	KIR	0
135	Lao People's Dem Republic	5	LAO	23
59	Malaysia	5	MYS	33
188	Marshall Islands	5	MHL	0
132	Myanmar	5	MMR	66
191	Nauru	5	NRU	0
18	New Zealand	5	NZL	27
192	Niue	5	NIU	0
193	Palau	5	PLW	0
133	Papua New Guinea	5	PNG	45

83	Philippines	5	PHL	30
75	Samoa	5	WSM	0
25	Singapore	5	SGP	0
124	Solomon Islands	5	SLB	3
76	Thailand	5	THA	51
158	Timor-Leste	5	TLS	1
63	Tonga	5	TON	0
199	Tuvalu	5	TUV	0
129	Vanuatu	5	VUT	1
112	Viet Nam	5	VNM	33
178	Afghanistan	6	AFG	65
82	Armenia	6	ARM	3
91	Azerbaijan	6	AZE	8
40	Bahrain	6	BHR	0
102	Gaza Strip & West Bank	6	PSE	1
97	Georgia	6	GEO	7
184	Iraq	6	IRQ	44
101	Islamic Republic of Iran	6	IRN	164
22	Israel	6	ISR	2
90	Jordan	6	JOR	9
78	Kazakhstan	6	KAZ	270
44	Kuwait	6	KWT	2
110	Kyrgyzstan	6	KGZ	19
80	Lebanon	6	LBN	1
74	Oman	6	OMN	31
47	Qatar	6	QAT	1
57	Russian Federation	6	RUS	1689
77	Saudi Arabia	6	SAU	215
106	Syrian Arab Republic	6	SYR	18
116	Tajikistan	6	TJK	14
86	Turkmenistan	6	TKM	47
49	United Arab Emirates	6	ARE	8
107	Uzbekistan	6	UZB	41
149	Yemen	6	YEM	53
94	China	7	CHN	933
181	DPR Korea	7	PRK	12
23	Hong Kong (China)	7	HGK	0
117	Mongolia	7	MNG	157
28	Republic of Korea	7	KOR	10
198	Taiwan	7	TWN	4
55	Antigua & Barbuda	8	ATG	0
34	Argentina	8	ARG	274
29	Barbados	8	BRB	0
99	Belize	8	BLZ	2
114	Bolivia	8	BOL	108
72	Brazil	8	BRA	846
43	Chile	8	CHL	75
73	Colombia	8	COL	104
45	Costa Rica	8	CRI	5
52	Cuba	8	CUB	11
95	Dominica	8	DMA	0

98	Dominican Republic	8	DOM	5
100	Ecuador	8	ECU	28
103	El Salvador	8	SLV	2
93	Grenada	8	GRD	0
121	Guatemala	8	GTM	11
104	Guyana	8	GUY	20
153	Haiti	8	HTI	3
115	Honduras	8	HND	11
79	Jamaica	8	JAM	1
118	Nicaragua	8	NIC	12
61	Panama	8	PAN	7
89	Paraguay	8	PRY	40
85	Peru	8	PER	128
194	Puerto Rico	8	PRI	1
39	Saint Kitts & Nevis	8	KNA	0
71	Saint Lucia	8	LCA	0
87	St Vincent & The Grenadines	8	VCT	0
67	Suriname	8	SUR	16
54	Trinidad & Tobago	8	TTO	1
46	Uruguay	8	URY	18
68	Venezuela	8	VEN	88
65	Albania	9	ALB	3
62	Belarus	9	BLR	21
66	Bosnia Herzegovina	9	BIH	5
56	Bulgaria	9	BGR	11
48	Croatia	9	HRV	6
30	Cyprus	9	CYP	1
32	Czech Republic	9	CZE	8
36	Estonia	9	EST	4
38	Hungary	9	HUN	9
50	Latvia	9	LVA	6
41	Lithuania	9	LTU	6
60	Macedonia FYR	9	MKD	3
37	Poland	9	POL	31
113	Republic of Moldova	9	MDA	3
69	Romania	9	ROM	23
196	Serbia & Montenegro	9	YUG	10
42	Slovakia	9	SVK	5
27	Slovenia	9	SVN	2
88	Turkey	9	TUR	77
70	Ukraine	9	UKR	58
51	Bahamas	10	BHS	1
4	Canada	10	CAN	922
182	Greenland	10	GRL	41
53	Mexico	10	MEX	191
8	United States	10	USA	916
179	Andorra	11	AND	0
14	Austria	11	AUT	8
6	Belgium	11	BEL	3
17	Denmark	11	DNK	4
13	Finland	11	FIN	30

16	France	11	FRA	55
19	Germany	11	DEU	35
24	Greece	11	GRC	13
183	Holy See	11	VAT	0
7	Iceland	11	ISL	10
10	Ireland	11	IRL	7
21	Italy	11	ITA	29
187	Liechtenstein	11	LIE	0
15	Luxembourg	11	LUX	0
31	Malta	11	MLT	0
190	Monaco	11	MCO	0
5	Netherlands	11	NLD	3
1	Norway	11	NOR	31
26	Portugal	11	PRT	9
195	San Marino	11	SMR	0
20	Spain	11	ESP	50
2	Sweden	11	SWE	41
11	Switzerland	11	CHE	4
12	United Kingdom	11	GBR	24
9	Japan	12	JPN	36

B. SEDAC GPWv3 documentation

GPWv3 country summaries obtained from http://sedac.ciesin.columbia.edu/gpw/global.jsp#summary (last accessed 2011-06-01) (SEDAC 2011a)

Country Summaries

Country or Area	ISO3v10 Code	Population 2000 (UN '000)	Area (km²)	Resolution (km)	Number of Administrative Units	Population Per Administrative Unit ('000)	Number of Urban Extents	Number of Settlement Points	Continent
1. Afghanistan	AFG	21,765	634,908	44	329	65	35	50	Asia
2. Albania	ALB	3,134	28,346	33	26	119	39	47	Europe
3. Algeria	DZA	30,291	2,302,498	219	48	634	116	151	Africa
4. American Samoa	ASM	68	198	6	5	11	1	15	Oceania
5. Andorra	AND	86	464	8	7	9	1	7	Europe
6. Angola	AGO	13,134	1,251,924	264	18	1	6	8	Africa
7. Anguilla	AIA	11	83	9	1	11	1	3	North America
8. Antigua and Barbuda	ATG	65	444	15	2	32	1	12	North America
9. Argentina	ARG	37,032	2,736,391	74	499	72	465	1,091	South America
10. Armenia	ARM	3,787	28,277	51	11	293	33	42	Asia
11. Aruba	ABW	101	189	14	1	101	1	2	North America
12. Australia	AUS	19,138	7,634,648	76	1,329	14	148	224	Oceania
13. Austria	AUT	8,080	83,145	29	99	81	93	289	Europe
14. Azerbaijan	AZE	8,041	85,355	34	74	108	27	29	Asia
15. Bahamas	BHS	304	13,162	28	17	18	4	12	North America
16. Bahrain	BHR	640	623	8	11	0	3	7	Asia
17. Bangladesh	BGD	137,439	136,305	17	486	251	130	157	Asia
18. Barbados	BRB	267	441	21	1	267	1	3	North America
19. Belarus	BLR	10,187	207,013	42	119	84	33	35	Europe
20. Belgium	BEL	10,249	30,553	7	589	17	74	574	Europe
21. Belize	BLZ	226	22,290	61	6	40	6	9	North America
22. Benin	BEN	6,272	115,828	39	78	80	36	38	Africa
23. Bermuda	BMU	63	63	8	1	63	2	1	North America
24. Bhutan	BTN	2,085	38,040	45	19	110	5	18	Asia
25. Bolivia	BOL	8,329	1,069,350	103	100	80	67	95	South America
26. Bosnia-Herzegovina	BIH	3,977	51,295	131	3	1,301	22	22	Europe
27. Botswana	BWA	1,541	559,502	156	23	71	28	67	Africa
28. Brazil	BRA	170,406	8,480,395	29	9,847	17	2,133	4,243	South America
29. British Virgin Islands	VGB	24	166	6	4	5	1	1	North America

30. Brunei Darussalam	BRN	328	5,901	38	4	81	1	5	Asia
31. Bulgaria	BGR	7,949	111,307	21	261	30	36	41	Europe
32. Burkina Faso	BFA	11,535	275,747	28	353	33	93	205	Africa
33. Burundi	BDI	6,356	25,227	15	114	58	15	15	Africa
34. Cambodia	KHM	13,104	179,492	11	1,604	8	22	27	Asia
35. Cameroon	CMR	14,876	465,765	97	49	255	101	166	Africa
36. Canada	CAN	30,757	9,458,886	40	5,984	5	324	884	North America
37. Cape Verde	CPV	427	4,072	21	9	48	8	16	Africa
38. Cayman Islands	CYM	38	279	10	3	14	1	3	North America
39. Central African Republic	CAF	3,717	622,868	111	51	69	31	37	Africa
40. Chad	TCD	7,885	1,243,139	298	14	527	38	52	Africa
41. Chile	CHL	15,211	721,229	50	292	50	40	62	South America
42. China	CHN	1,275,133	9,198,103	62	2,370	523	3,803	4,707	Asia
43. Colombia	COL	42,105	1,141,569	33	1,059	34	353	783	South America
44. Commonwealth of Dominica	DMA	71	769	9	10	7	3	17	North America
45. Comoros	COM	706	2,046	23	4	140	5	93	Africa
46. Congo	COG	3,018	343,235	86	46	60	21	22	Africa
47. Congo, Democratic Republic	COD	50,948	2,313,414	124	150	347	148	182	Africa
48. Cook Islands	COK	20	688	7	15	1	1	1	Oceania
49. Costa Rica	CRI	4,024	51,015	25	82	46	9	32	North America
50. Croatia	HRV	4,654	56,406	10	544	8	46	121	Europe
51. Cuba	CUB	11,199	111,199	26	169	66	114	140	North America
52. Cyprus	CYP	784	9,273	5	414	2	4	73	Asia
53. Czech Republic	CZE	10,272	78,616	4	6,258	2	93	131	Europe
54. Denmark	DNK	5,320	42,484	12	276	19	87	429	Europe
55. Djibouti	DJI	632	20,903	65	5	128	5	5	Africa
56. Dominican Republic	DOM	8,373	48,092	40	30	267	30	42	North America
57. East Timor	TLS	737	14,923	29	18	46	2	3	Asia
58. Ecuador	ECU	12,646	246,700	16	931	13	40	55	South America
59. Egypt	EGY	67,884	968,071	65	230	281	60	151	Africa
60. El Salvador	SLV	6,278	20,279	9	263	23	18	44	North America
61. Equatorial Guinea	GNQ	457	27,104	62	7	127	9	15	Africa
62. Eritrea	ERI	3,659	121,863	57	38	94	9	9	Africa
63. Estonia	EST	1,393	43,179	13	251	5	21	42	Europe
64. Ethiopia	ETH	62,908	1,123,714	46	523	119	207	407	Africa
65. Faeroe Islands	FRO	46	1,408	10	15	3	2	11	Europe
66. Falkland Islands	FLK	2	11,988	77	2	1	--	1	South America

67. Federated State of Micronesia	FSM	123	675	13	4	27	--	17	Oceania
68. Fiji	FJI	814	18,254	35	15	54	7	15	Oceania
69. Finland	FIN	5,172	317,001	27	448	12	43	101	Europe
70. France	FRA	59,238	547,120	4	36,585	2	261	348	Europe
71. French Guiana	GUF	165	83,634	63	21	7	4	16	South America
72. French Polynesia	PYF	233	3,745	10	39	6	2	35	Oceania
73. Gabon	GAB	1,230	265,146	76	46	27	29	35	Africa
74. Gambia	GMB	1,303	10,838	17	37	32	19	96	Africa
75. Georgia	GEO	5,262	69,236	29	80	59	48	61	Asia
76. Germany	DEU	82,017	356,027	28	446	184	584	1,132	Europe
77. Ghana	GHA	19,306	231,730	46	110	172	113	175	Africa
78. Gibraltar	GIB	27	5	2	1	27	1	1	Europe
79. Greece	GRC	10,610	131,891	11	1,034	10	113	1,103	Europe
80. Greenland	GRL	56	377,972	149	17	3	2	14	North America
81. Grenada	GRD	94	325	18	1	94	4	6	North America
82. Guadeloupe	GLP	428	1,751	8	31	14	4	33	North America
83. Guam	GUM	155	546	2	203	1	1	27	Oceania
84. Guatemala	GTM	11,385	108,523	18	329	32	26	46	North America
85. Guernsey	GGY	--	85	9	1	56	1	5	Europe
86. Guinea	GIN	8,154	245,860	86	33	257	36	44	Africa
87. Guinea-Bissau	GNB	1,199	34,106	30	37	33	11	19	Africa
88. Guyana	GUY	761	211,156	145	10	79	6	11	South America
89. Haiti	HTI	8,142	26,876	14	135	57	9	15	North America
90. Holy See	VAT	1	1	1	1	1	--	--	Europe
91. Honduras	HND	6,417	112,079	6	3,696	2	34	53	North America
92. Hong Kong	HKG	6,860	1,054	8	18	367	3	13	Asia
93. Hungary	HUN	9,968	92,046	5	3,158	3	136	1,426	Europe
94. Iceland	ISL	279	91,116	27	123	2	4	29	Europe
95. India	IND	1,008,937	3,209,716	25	5,209	194	2,736	3,570	Asia
96. Indonesia	IDN	212,092	1,898,776	5	69,349	3	238	443	Asia
97. Iran	IRN	70,330	1,590,351	80	250	260	137	193	Asia
98. Iraq	IRQ	22,946	430,575	151	19	1,258	21	24	Asia
99. Ireland	IRL	3,803	69,474	4	3,440	1	57	189	Europe
100. Isle of Man	IMN	75	572	5	24	3	1	8	Europe
101. Israel	ISR	6,040	21,878	38	15	411	6	91	Asia
102. Italy	ITA	57,530	299,287	6	8,105	7	341	1,349	Europe
103. Ivory Coast	CIV	16,013	320,329	42	185	89	67	76	Africa
104. Jamaica	JAM	2,576	11,060	28	14	185	11	18	North America
105. Japan	JPN	127,096	371,705	10	3,373	38	143	995	Asia
106. Jersey	JEY	--	119	11	1	87	1	12	Europe

107. Jordan	JOR	4,913	88,362	48	39	141	12	26	Asia
108. Kazakhstan	KAZ	16,172	2,619,352	101	256	62	31	34	Asia
109. Kenya	KEN	30,669	579,617	9	6,624	4	72	77	Africa
110. Kiribati	KIR	83	1,073	6	28	3	2	17	Oceania
111. Korea	KOR	46,740	98,977	21	227	204	55	129	Asia
112. Korea, Dem. People's Rep. of	PRK	22,268	122,440	30	136	169	21	24	Asia
113. Kuwait	KWT	1,914	17,259	59	5	445	1	27	Asia
114. Kyrgyz Republic	KGZ	4,921	184,763	58	55	89	17	97	Asia
115. Lao People's Democratic Republic	LAO	5,279	230,230	42	133	39	17	17	Asia
116. Latvia	LVA	2,421	64,196	10	585	4	33	76	Europe
117. Lebanon	LBN	3,496	10,328	20	26	128	11	17	Asia
118. Lesotho	LSO	2,035	30,582	55	10	209	13	15	Africa
119. Liberia	LBR	2,913	96,166	42	54	70	16	27	Africa
120. Libyan Arab Jamahiriya	LBY	5,290	1,611,363	254	25	223	30	39	Africa
121. Liechtenstein	LIE	33	160	4	11	3	1	9	Europe
122. Lithuania	LTU	3,696	64,995	36	51	69	52	98	Europe
123. Luxembourg	LUX	437	2,587	5	118	4	3	82	Europe
124. Macao	MAC	444	19	3	3	142	1	1	Asia
125. Macedonia	MKD	2,034	24,702	14	123	16	21	30	Europe
126. Madagascar	MDG	15,970	592,965	22	1,242	12	70	98	Africa
127. Malawi	MWI	11,308	94,958	3	9,219	1	31	35	Africa
128. Malaysia	MYS	22,218	329,941	19	920	24	69	125	Asia
129. Maldives	MDV	291	189	3	21	13	1	58	Asia
130. Mali	MLI	11,351	1,248,137	68	272	39	103	155	Africa
131. Malta	MLT	390	315	2	67	6	2	60	Europe
132. Marshall Islands	MHL	51	219	3	33	2	1	2	Oceania
133. Martinique	MTQ	383	1,146	34	1	383	1	32	North America
134. Mauritania	MRT	2,665	1,036,905	140	53	48	13	28	Africa
135. Mauritius	MUS	1,161	1,993	3	186	6	4	94	Africa
136. Mayotte	MYT	153	372	19	1	155	2	3	Africa
137. Mexico	MEX	98,872	1,943,018	28	2,414	40	465	787	North America
138. Monaco	MCO	33	10	3	1	34	1	4	Europe
139. Mongolia	MNG	2,533	1,546,294	265	22	108	23	24	Asia
140. Montserrat	MSR	4	103	10	1	4	--	1	North America
141. Morocco (includes Western Sahara)	MAR	29,878	669,159	107	58	508	69	78	Africa
142. Mozambique	MOZ	18,292	777,123	44	402	42	69	78	Africa
143. Myanmar	MMR	47,749	669,310	49	284	165	58	64	Asia
144. Namibia	NAM	1,757	819,964	90	102	18	15	34	Africa
145. Nauru	NRU	12	18	4	1	12	1	1	Oceania
146. Nepal	NPL	23,043	139,087	43	75	302	37	45	Asia
147. Netherland Antilles	ANT	215	818	3	71	2	1	1	North America

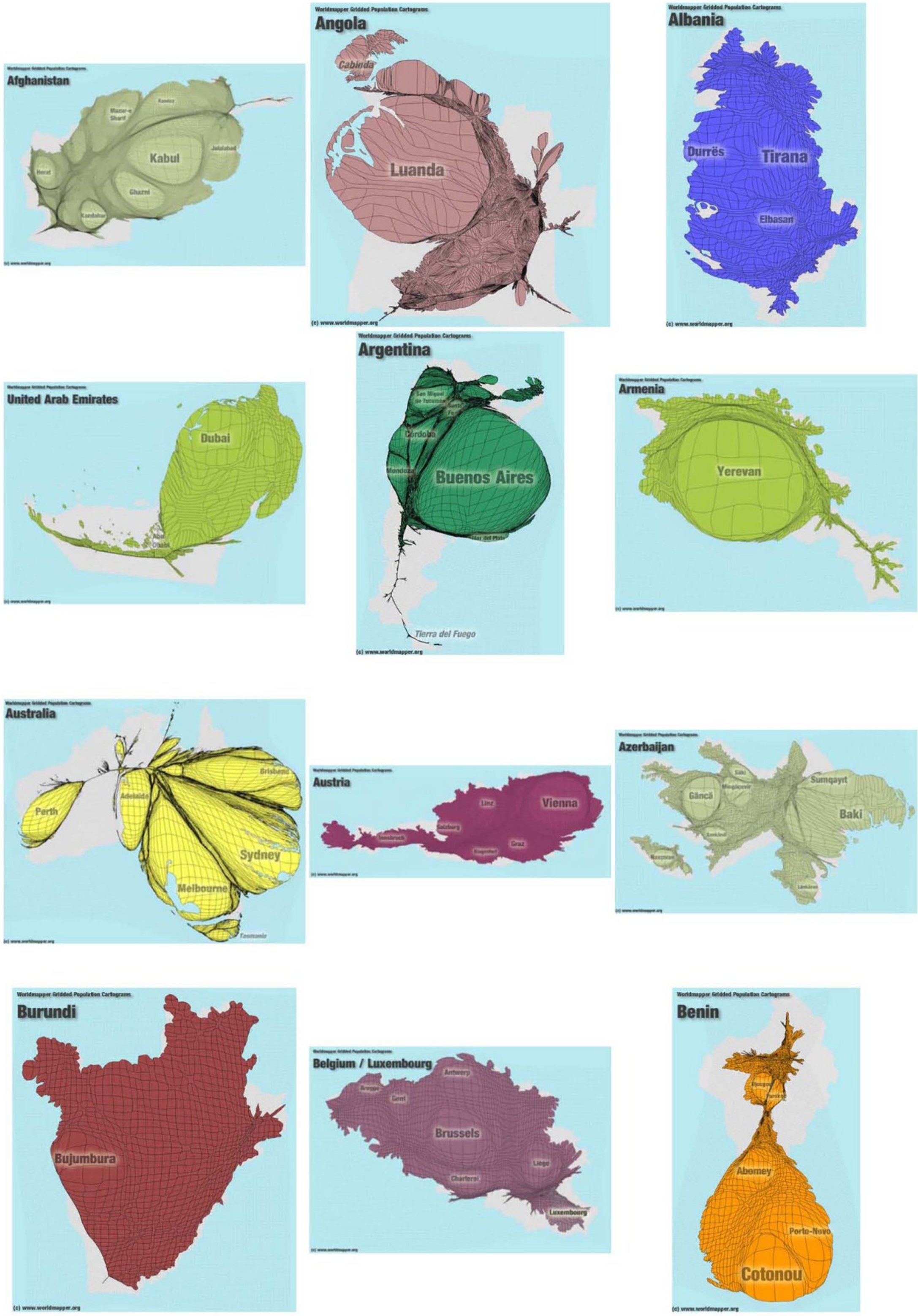
148. Netherlands	NLD	15,864	41,364	9	469	33	67	229	Europe
149. New Caledonia	NCL	215	18,837	52	7	31	1	10	Oceania
150. New Zealand	NZL	3,778	265,334	27	371	10	46	113	Oceania
151. Nicaragua	NIC	5,071	118,279	29	144	37	28	40	North America
152. Niger	NER	10,832	1,157,232	95	129	76	42	50	Africa
153. Nigeria	NGA	113,862	904,235	41	538	231	126	138	Africa
154. Niue	NIU	2	267	16	1	2	--	--	Oceania
155. Norfolk Island	NFK	--	40	4	3	1	--	--	Oceania
156. Northern Mariana Islands	MNP	73	466	3	72	1	1	14	Oceania
157. Norway	NOR	4,469	318,524	27	434	10	56	304	Europe
158. Occupied Palestinian Territory	PSE	3,191	6,006	19	16	199	30	226	Asia
159. Oman	OMN	2,538	304,190	134	60	37	11	25	Asia
160. Pakistan	PAK	141,256	785,320	87	104	1,309	174	202	Asia
161. Palau	PLW	19	463	8	7	3	1	2	Oceania
162. Panama	PAN	2,856	74,515	33	67	41	18	40	North America
163. Papua New Guinea	PNG	4,809	464,043	152	20	241	20	35	Oceania
164. Paraguay	PRY	5,496	395,886	41	236	21	18	36	South America
165. Peru	PER	25,662	1,289,475	27	1,800	13	108	704	South America
166. Philippines	PHL	75,653	295,408	14	1,541	49	73	132	Asia
167. Pitcairn	PCN	0	41	6	1	0	--	--	Oceania
168. Poland	POL	38,605	311,195	11	2,489	16	167	226	Europe
169. Portugal	PRT	10,016	91,421	5	4,228	2	83	460	Europe
170. Puerto Rico	PRI	3,915	8,985	11	78	51	3	217	North America
171. Qatar	QAT	565	10,973	35	9	70	2	10	Asia
172. Republic of Moldova	MDA	4,295	34,012	26	49	88	20	26	Europe
173. Reunion	REU	721	2,548	50	1	719	13	24	Africa
174. Romania	ROU	22,438	237,057	9	2,935	7	237	865	Europe
175. Russia	RUS	145,491	16,679,998	82	2,486	55	523	704	Europe
176. Rwanda	RWA	7,609	24,349	13	142	55	5	6	Africa
177. Saint Helena	SHN	6	127	7	3	2	--	--	Africa
178. Saint Kitts and Nevis	KNA	38	277	12	2	19	2	4	North America
179. Saint Lucia	LCA	148	620	25	1	148	3	9	North America
180. Saint Pierre and Miquelon	SPM	7	227	9	3	2	1	1	North America
181. Saint Vincent	VCT	113	453	21	1	113	2	6	North America
182. San Marino	SMR	27	62	8	1	26	--	4	Europe
183. Sao Tome and Principe	STP	138	1,008	22	2	72	1	11	Africa
184. Saudi Arabia	SAU	20,346	1,938,837	386	13	1,604	28	47	Asia

185. Senegal	SEN	9,421	196,151	46	93	107	42	71	Africa
186. Serbia and Montenegro	SCG	10,552	101,561	159	4	2,658	58	66	Europe
187. Seychelles	SYC	80	196	10	2	40	1	4	Africa
188. Sierra Leone	SLE	4,405	72,616	22	147	31	36	77	Africa
189. Singapore	SGP	4,018	597	9	8	488	1	1	Asia
190. Slovakia	SVK	5,399	48,875	4	2,919	2	87	137	Europe
191. Slovenia	SVN	1,988	20,224	2	5,989	0	38	156	Europe
192. Solomon Islands	SLB	447	28,707	54	10	42	1	4	Oceania
193. Somalia	SOM	8,778	634,315	93	74	110	7	8	Africa
194. South Africa	ZAF	43,309	1,217,645	0	83,125	1	199	310	Africa
195. Spain	ESP	39,910	505,275	8	8,186	5	208	737	Europe
196. Sri Lanka	LKA	18,924	65,830	16	242	75	25	55	Asia
197. Sudan	SDN	31,095	2,492,385	171	85	358	60	72	Africa
198. Suriname	SUR	417	141,133	119	10	45	2	15	South America
199. Svalbard	SJM	--	60,543	246	1	2	--	1	Europe
200. Swaziland	SWZ	925	17,410	66	4	247	6	12	Africa
201. Sweden	SWE	8,842	431,704	39	288	31	153	574	Europe
202. Switzerland	CHE	7,170	38,975	4	2,912	2	59	341	Europe
203. Syrian Arab Republic	SYR	16,189	184,366	119	13	1,241	26	36	Asia
204. Taiwan	TWN	--	36,223	42	21	1,030	8	89	Asia
205. Tajikistan	TJK	6,087	130,295	47	60	99	12	26	Asia
206. Thailand	THA	62,806	513,618	26	792	77	116	167	Asia
207. Togo	TGO	4,527	57,277	52	21	216	32	45	Africa
208. Tokelau	TKL	1	15	0	3	0	--	--	Oceania
209. Tonga	TON	99	664	13	4	25	1	8	Oceania
210. Trinidad and Tobago	TTO	1,294	5,202	13	30	41	3	21	North America
211. Tunisia	TUN	9,459	147,882	80	23	416	58	113	Africa
212. Turkey	TUR	66,668	768,690	98	80	848	359	441	Asia
213. Turkmenistan	TKM	4,737	460,254	98	48	86	12	14	Asia
214. Turks and Caicos Islands	TCA	17	548	23	1	17	--	2	North America
215. Tuvalu	TUV	10	32	2	9	1	--	--	Oceania
216. Uganda	UGA	23,300	206,968	7	4,122	5	47	68	Africa
217. Ukraine	UKR	49,568	588,417	31	622	77	82	102	Europe
218. United Arab Emirates	ARE	2,606	74,777	97	8	399	4	9	Asia
219. United Kingdom	GBR	59,415	247,193	11	2,143	27	107	447	Europe
220. United Rep. of Tanzania	TZA	35,119	891,021	99	90	362	55	56	Africa
221. United States Virgin Islands	VIR	121	374	3	32	3	2	8	North America
222. United States of America	USA	283,230	9,210,755	12	60,884	5	1,634	14,462	North America
223. Uruguay	URY	3,337	173,985	96	19	171	62	106	South America
224. Uzbekistan	UZB	24,881	412,914	45	208	118	58	83	Asia

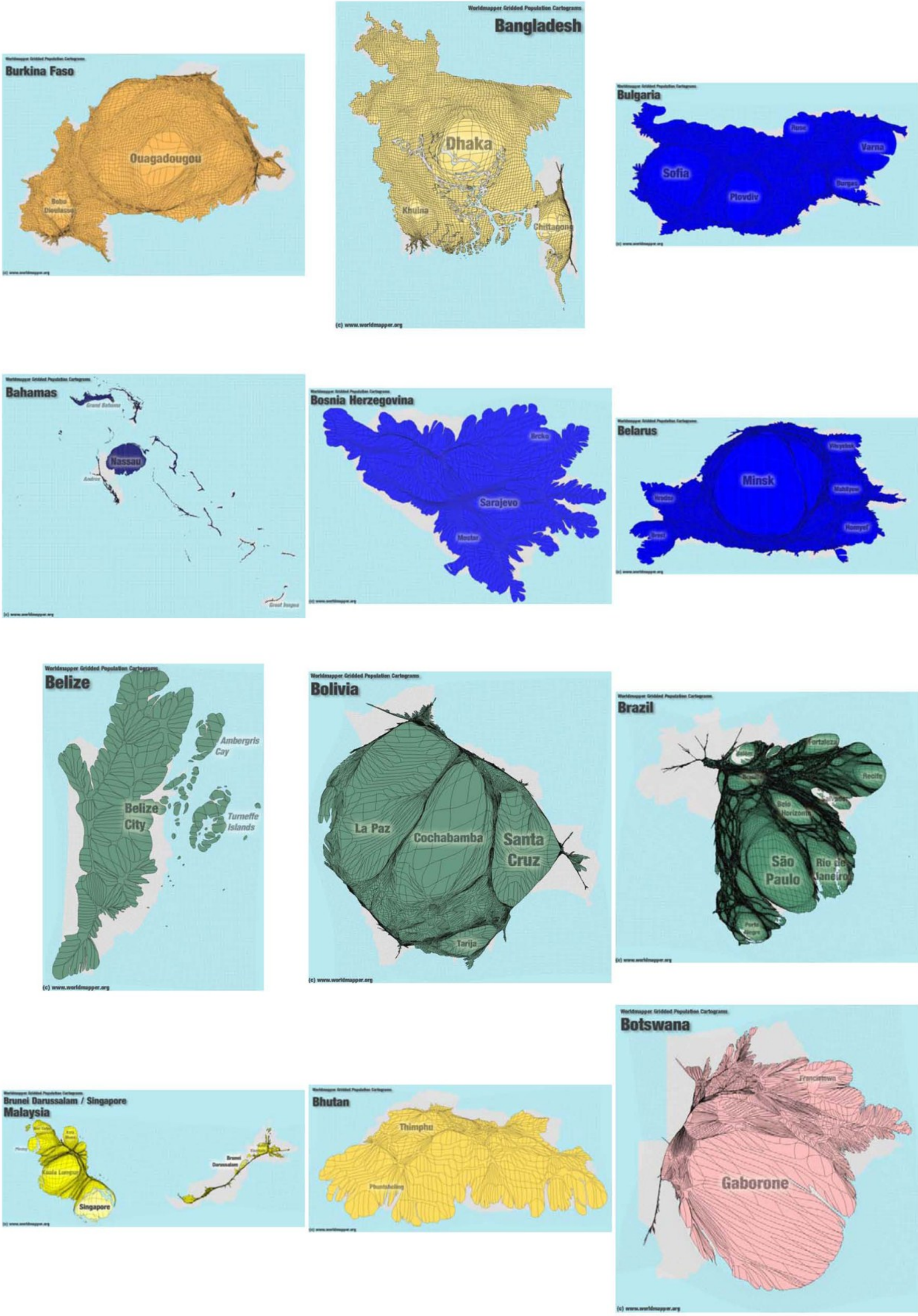
225. Vanuatu	VUT	197	12,274	45	6	27	2	2	Oceania
226. Venezuela	VEN	24,170	911,559	53	324	70	177	591	South America
227. Viet Nam	VNM	78,137	328,535	6	10,476	7	52	55	Asia
228. Wallis and Futuna	WLF	14	176	9	2	7	--	2	Oceania
229. Western Samoa	WSM	159	2,888	31	3	58	1	20	Oceania
230. Yemen	YEM	18,349	415,196	43	227	77	27	33	Asia
231. Zambia	ZMB	10,421	745,317	114	57	173	35	44	Africa
232. Zimbabwe	ZWE	12,627	389,055	82	58	196	23	27	Africa

C. World population atlas

Gridded population cartograms of the countries of the world (Hennig 2009); sorted in alphabetical order using ISO country codes; (own depictions by the author using data from Wick 2010, CIESIN & CIAT 2005).



Series of gridded population cartograms of the countries of the world – Part I of XV; (own depictions by the author using data from Wick 2010, CIESIN & CIAT 2005).



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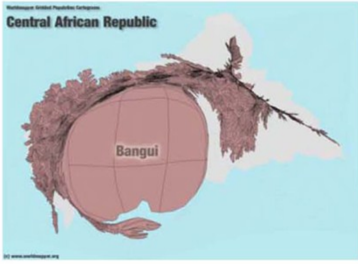
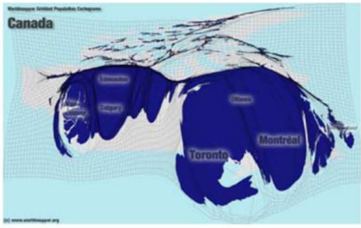
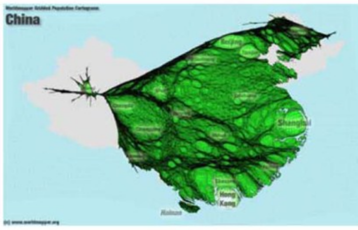
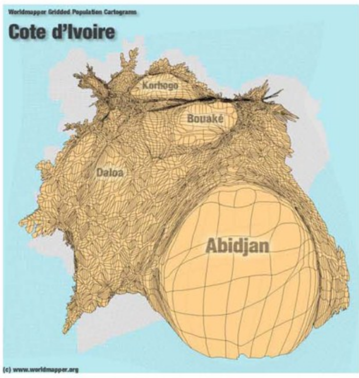
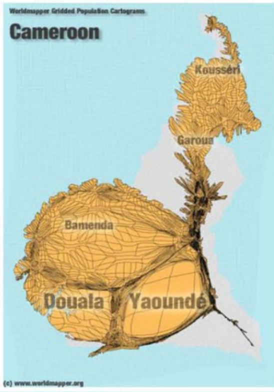
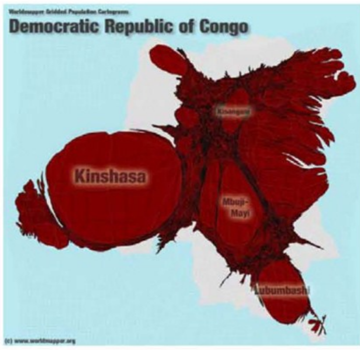


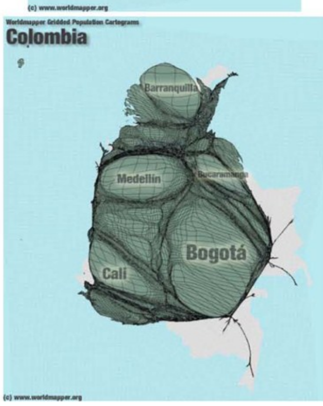


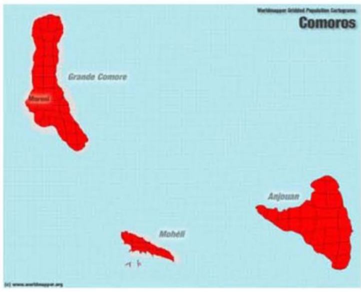




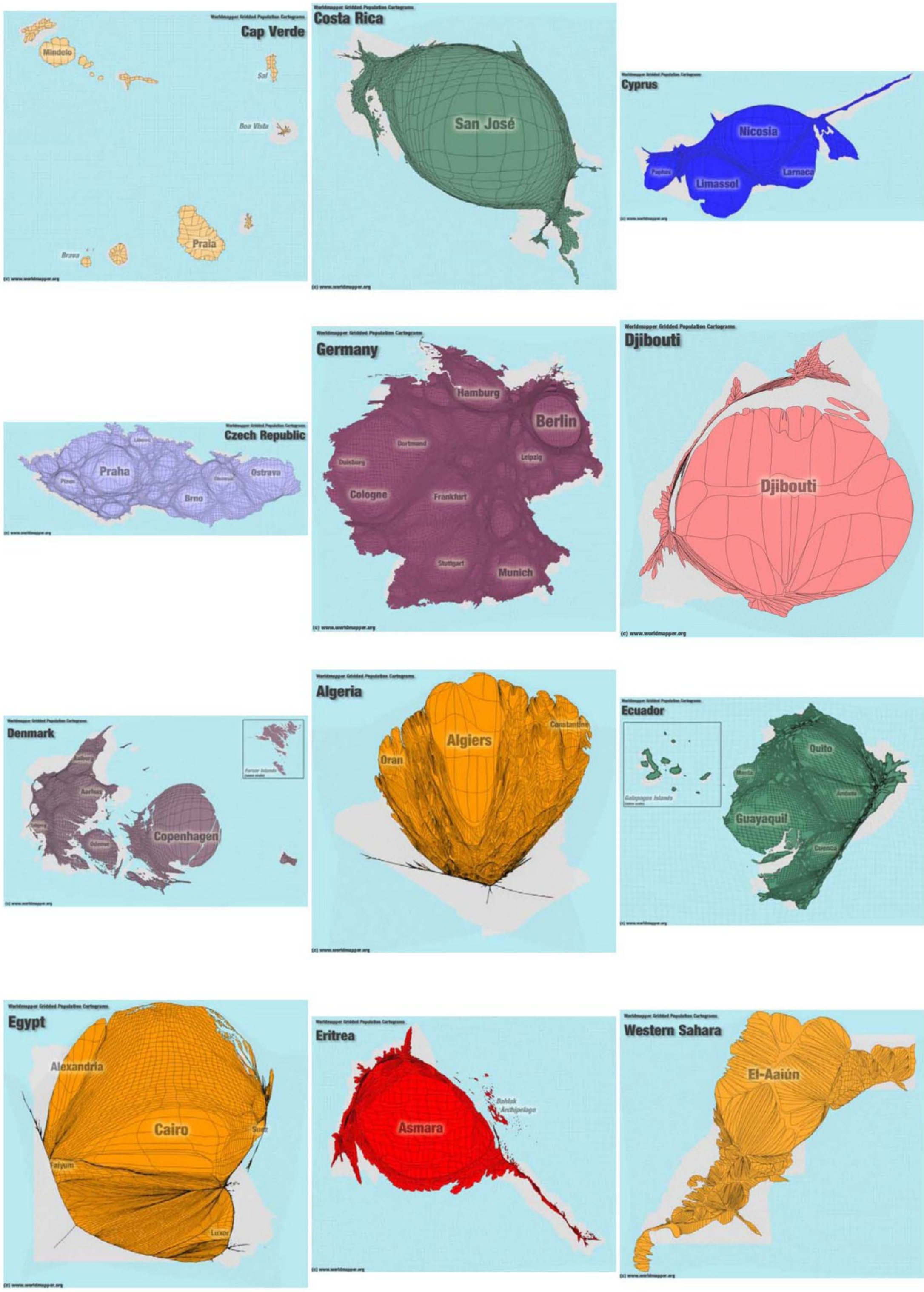




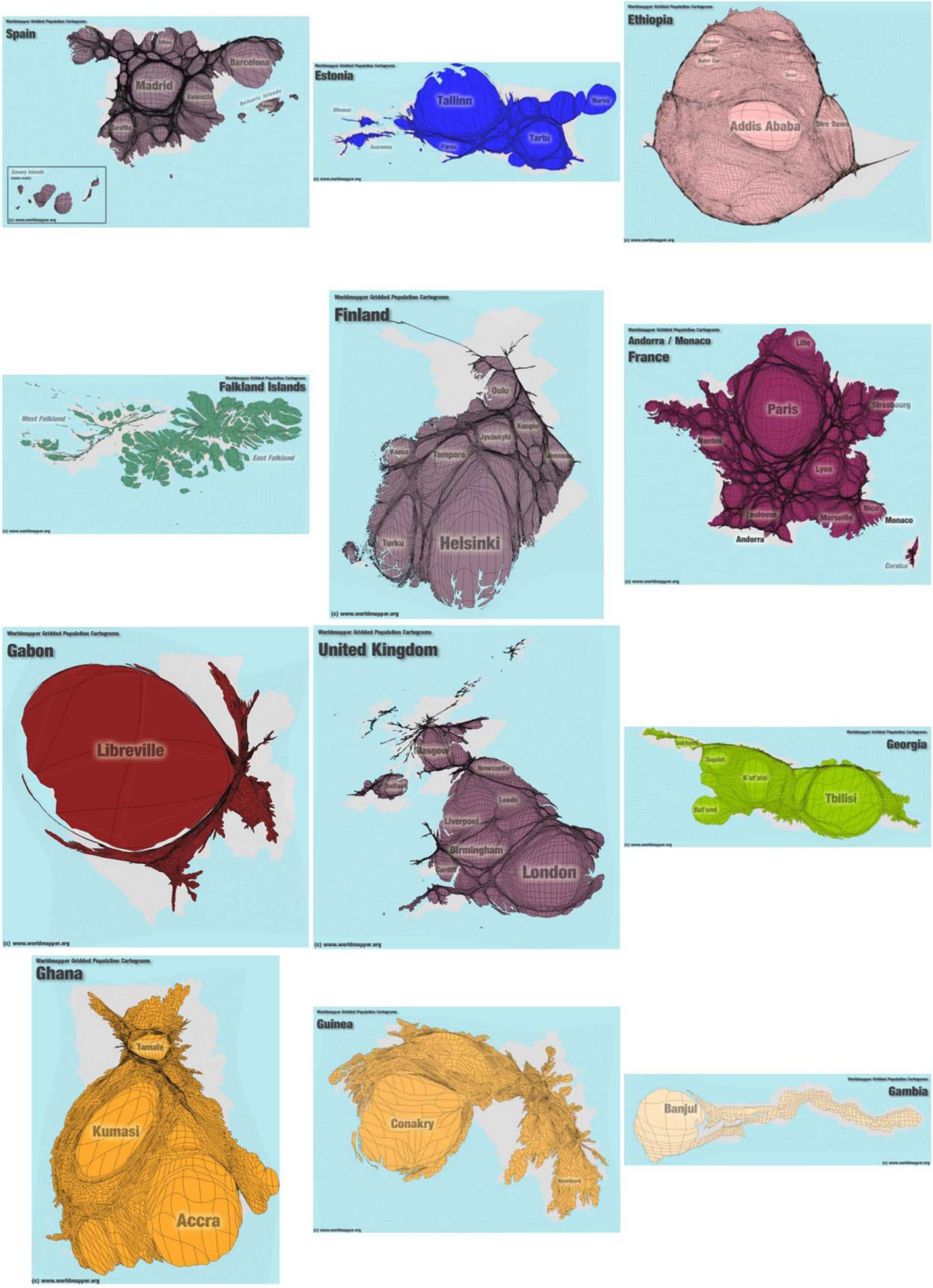




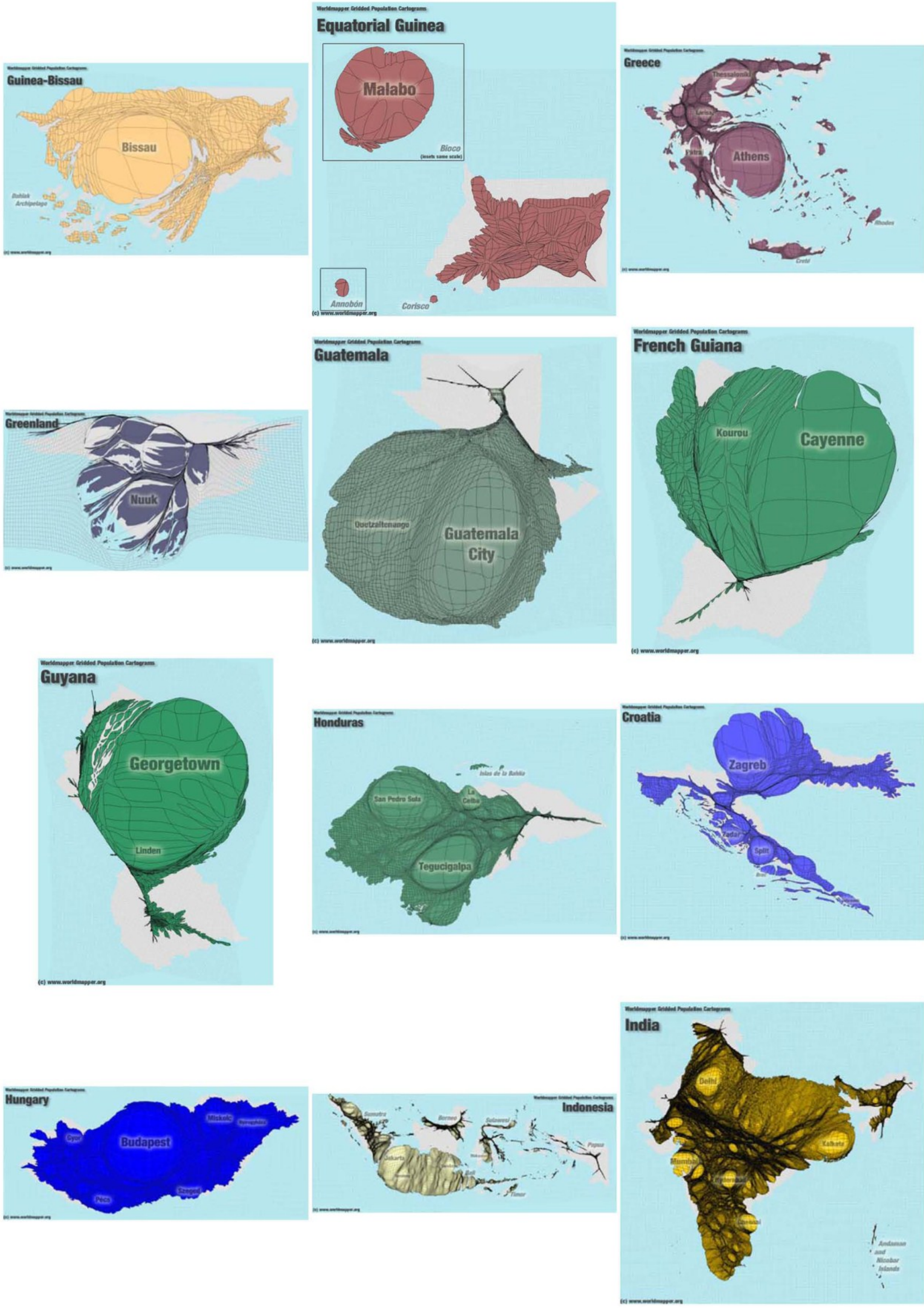
Series of gridded population cartograms of the countries of the world – Part III of XV; (own depictions by the author using data from Wick 2010, CIESIN & CIAT 2005).



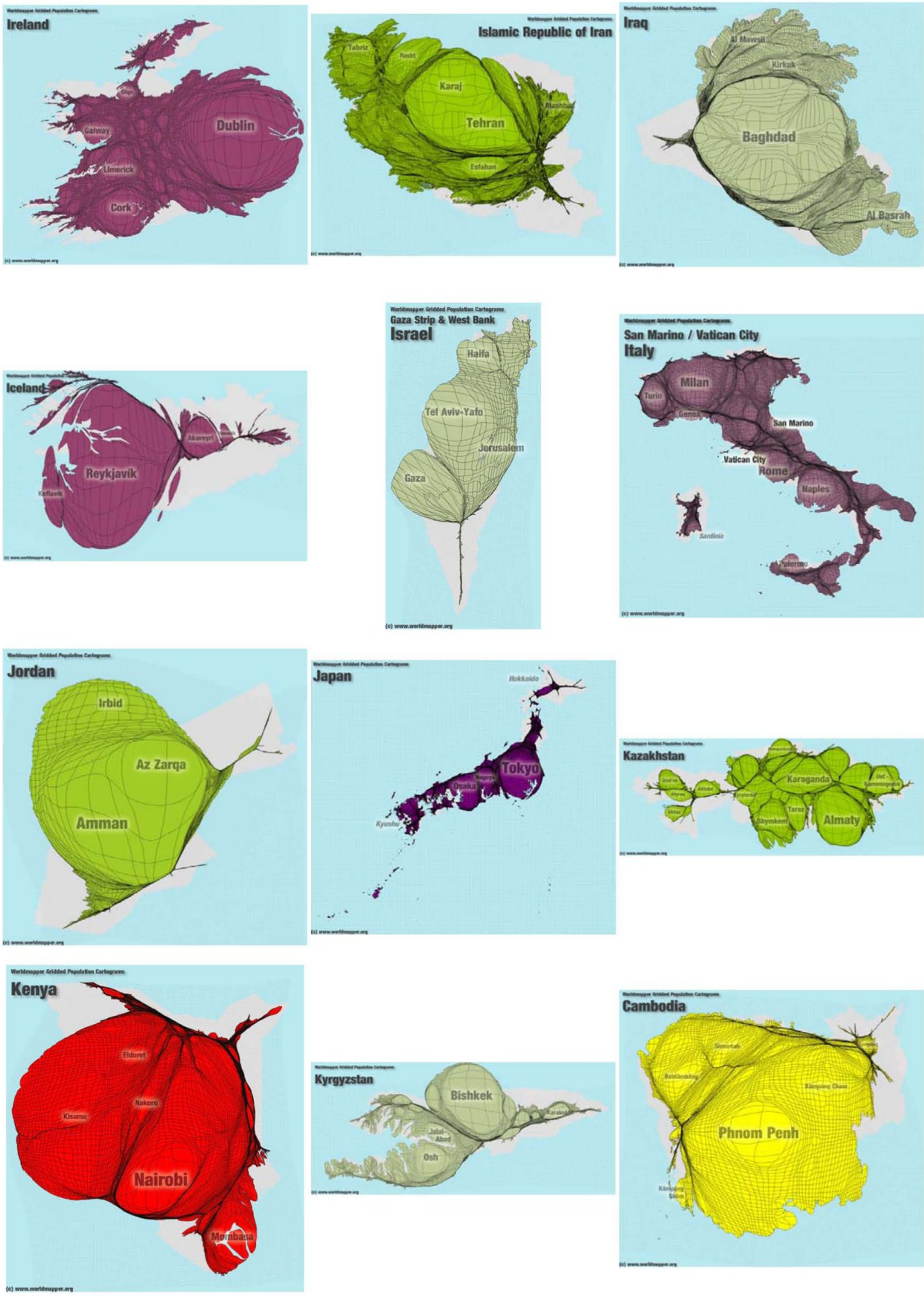
Series of gridded population cartograms of the countries of the world – Part IV of XV; (own depictions by the author using data from Wick 2010, CIESIN & CIAT 2005).



Series of gridded population cartograms of the countries of the world – Part V of XV; (own depictions by the author using data from Wick 2010, CIESIN & CIAT 2005).



Series of gridded population cartograms of the countries of the world – Part VI of XV; (own depictions by the author using data from Wick 2010, CIESIN & CIAT 2005).



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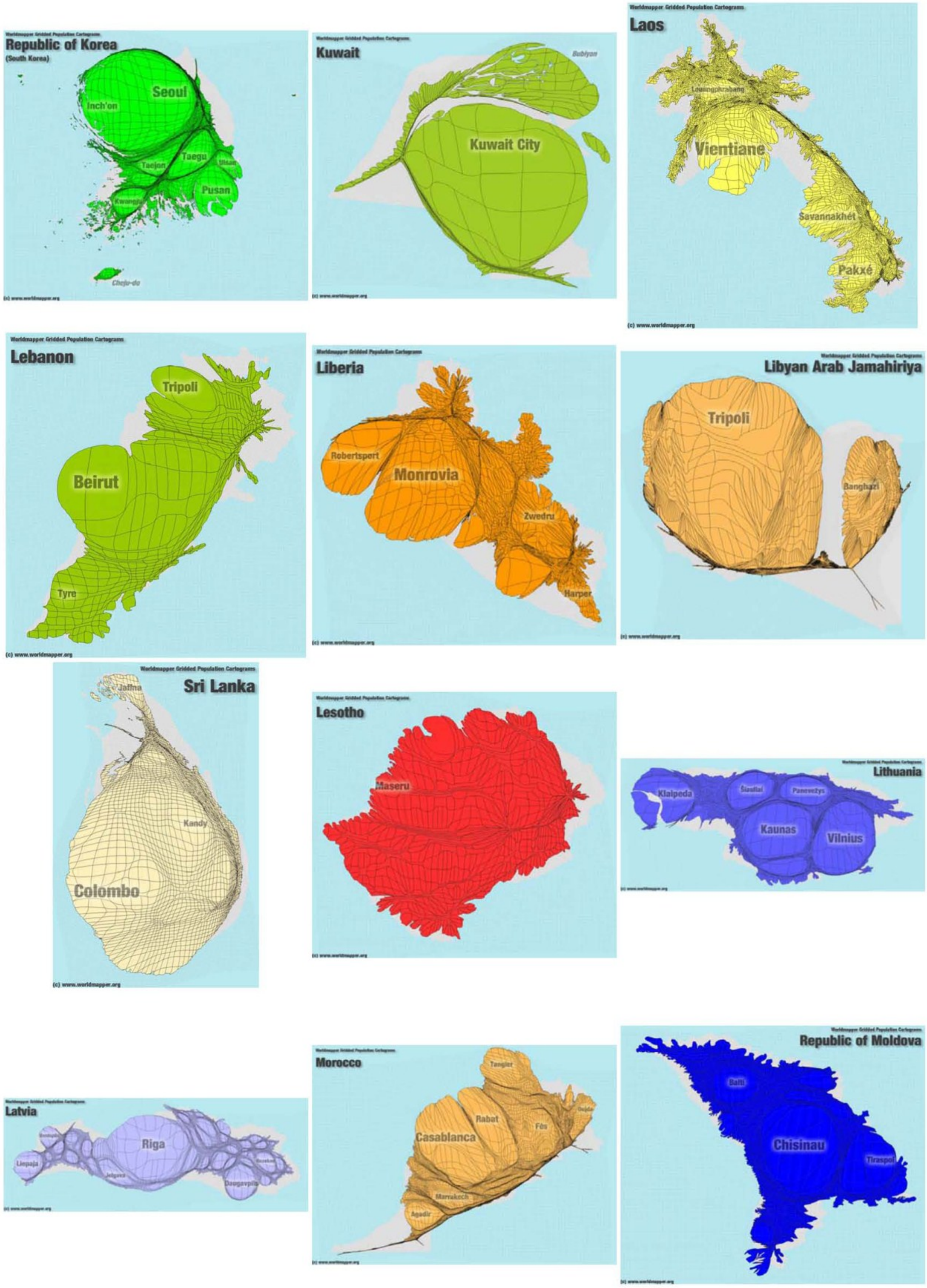

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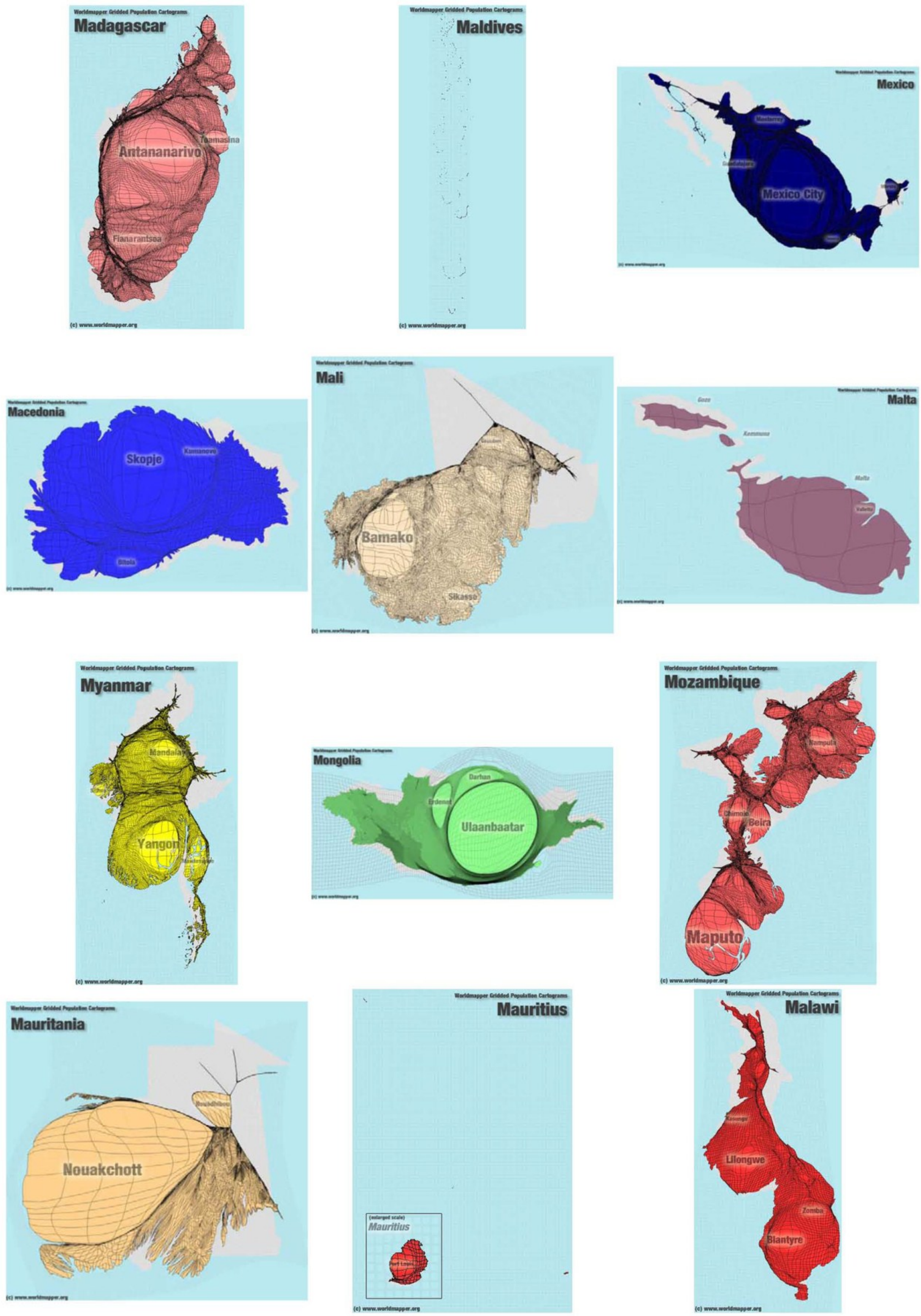

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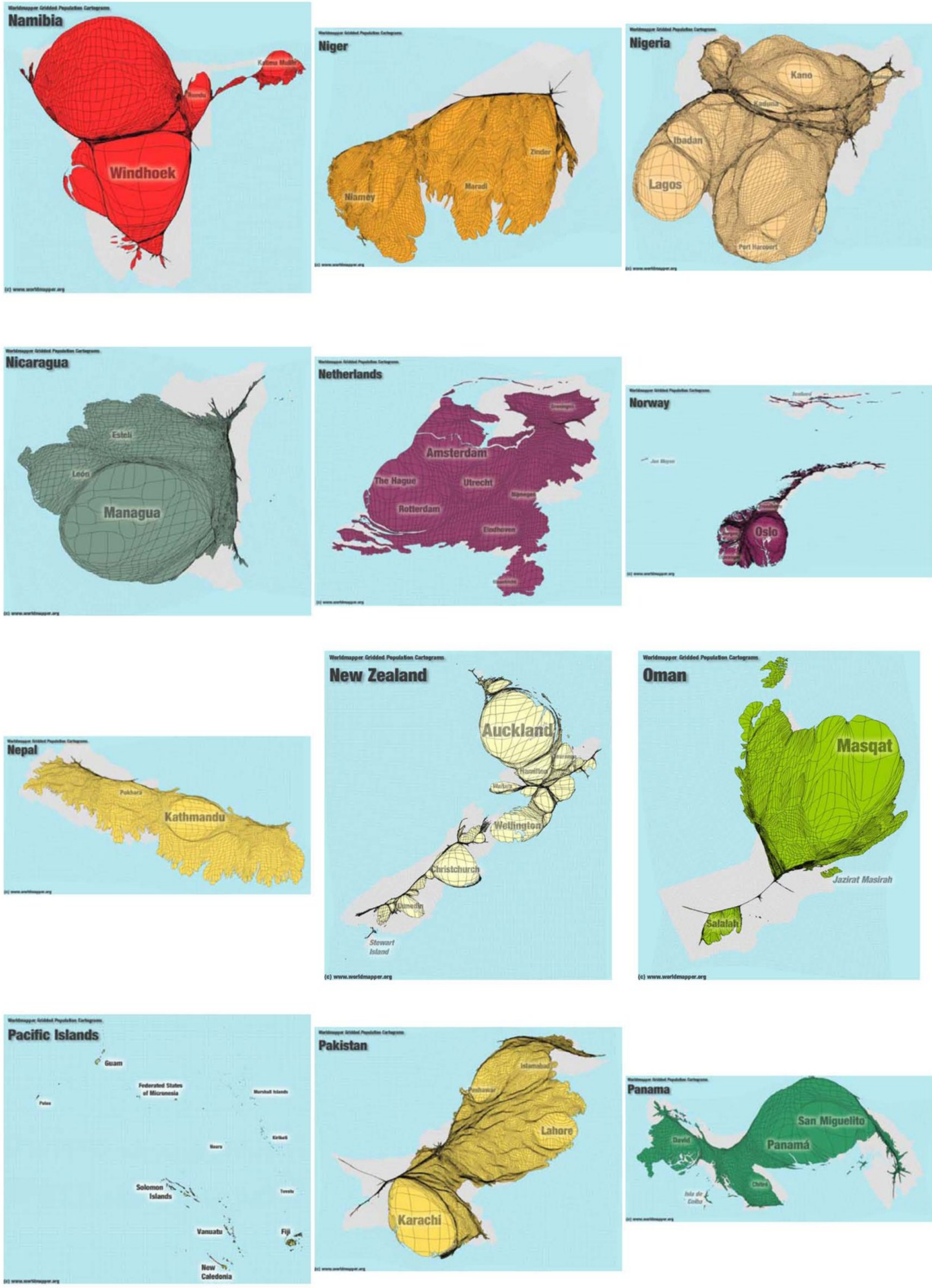

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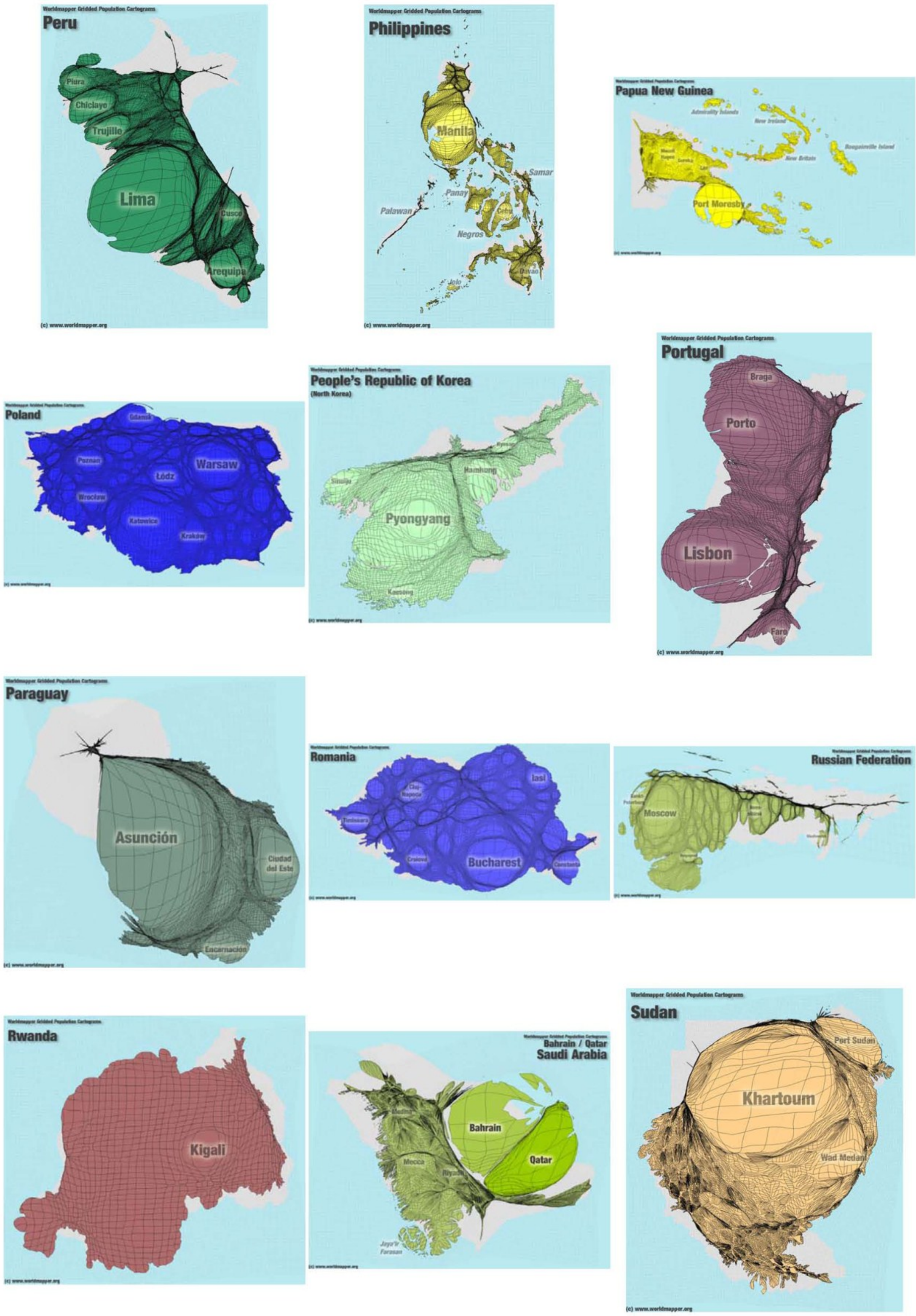
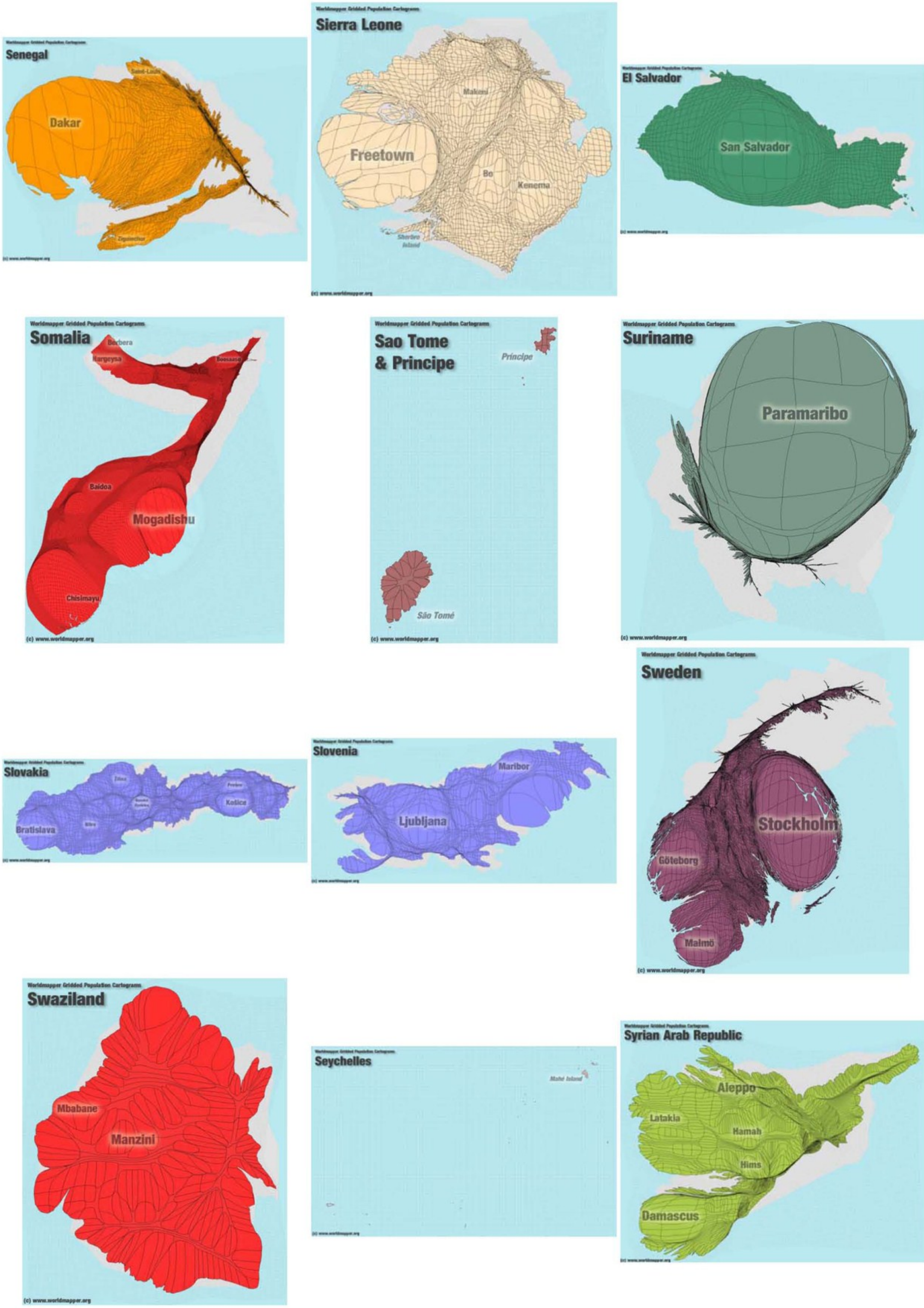


Series of gridded population cartograms of the countries of the world – Part XI of XV; (own depictions by the author using data from Wick 2010, CIESIN & CIAT 2005).



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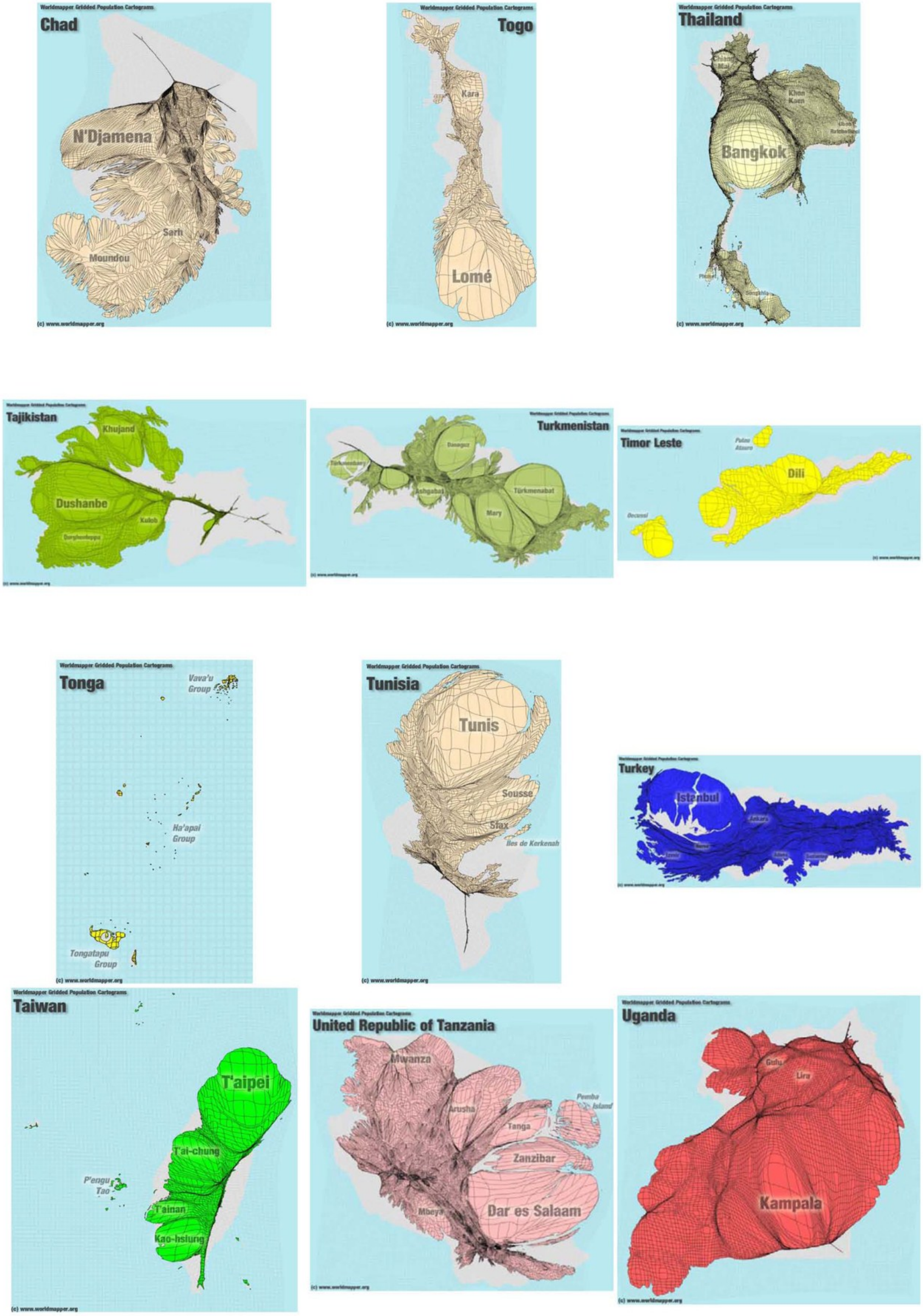

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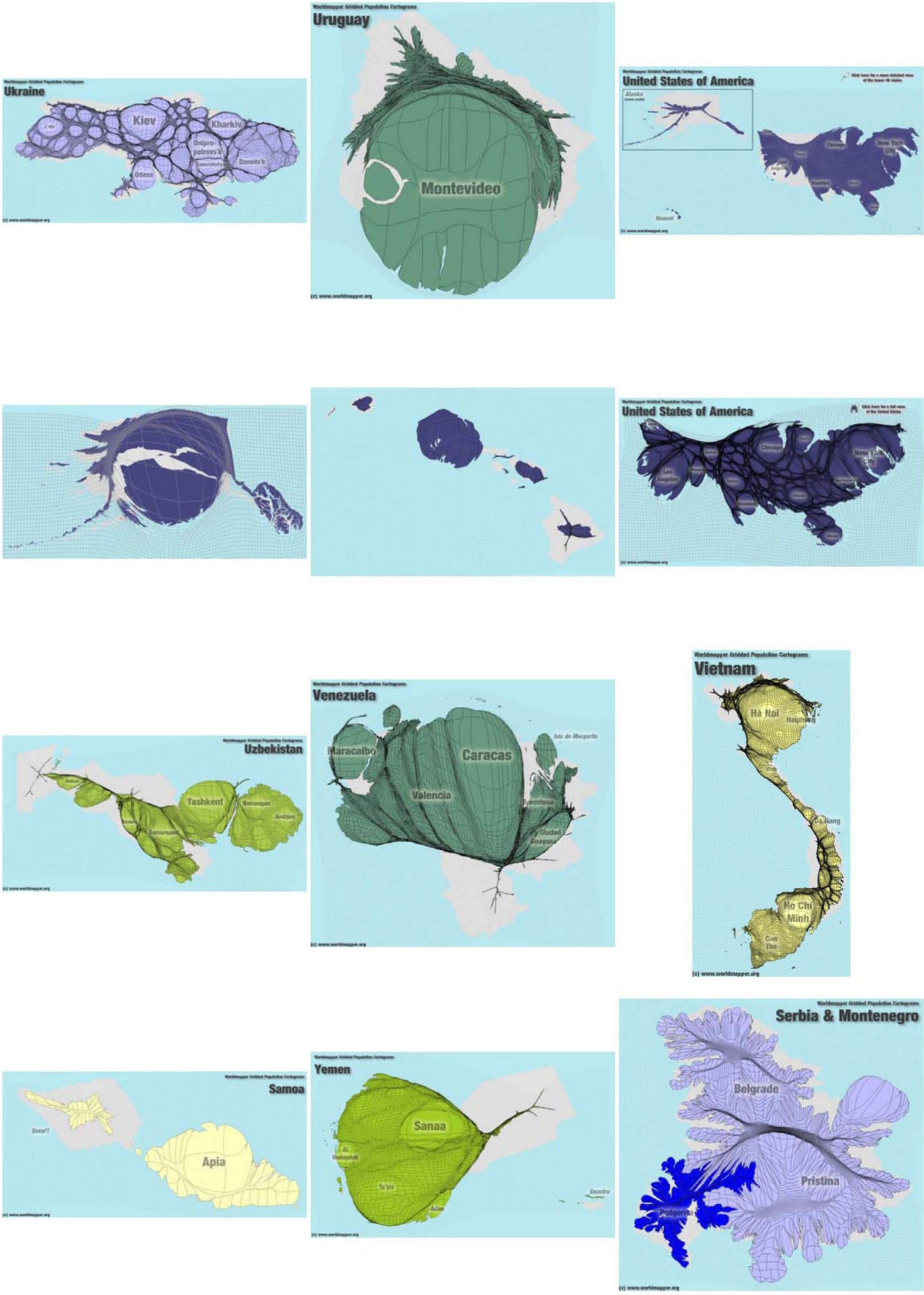

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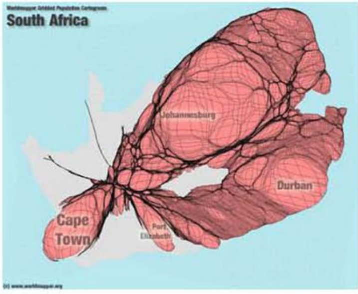

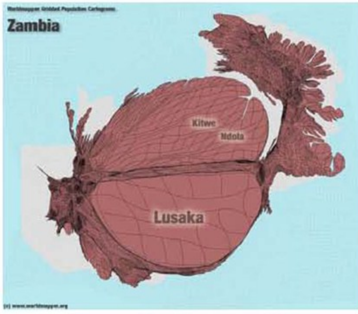

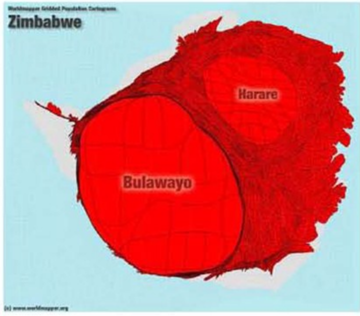

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