

A Bivariate Dasymetric Population Map of Saudi Arabia

Mohsen Dhieb

Department of Geography and GIS, Faculty of Arts and Humanities, King Abdulaziz University, Jeddah, Saudi Arabia Email: mohsendhieb2003@yahoo.fr

How to cite this paper: Dhieb, M. (2022). A Bivariate Dasymetric Population Map of Saudi Arabia. *Current Urban Studies, 10,* 673-696.

https://doi.org/10.4236/cus.2022.104040

Received: November 4, 2022 Accepted: December 20, 2022 Published: December 23, 2022

Copyright © 2022 by author(s) and Scientific Research Publishing Inc. This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

http://creativecommons.org/licenses/by/4.0/

Open Access

Abstract

The dasymetric method is used to portray accurately phenomena such as densities of population over one space. In general, this method is preferred to the classical choropleth one since it yields more accurate results, especially when the mapped space is characterized by its inner heterogeneity and therefore reflects what Langford called "spatial specialization". Now, many topics dealing with space such as planning, site selection, or spatial risk and hazard studies require accurate and real population location since most issued spatial choices or decisions may impact the population, and the dasymetric method may help. Since KSA is a huge country characterized by a high percentage of a few inhabited population entities crowded in small areas as opposed to wide empty or almost empty deserts or rural spaces, and to embrace its overall territory in a glance, we used the bivariate method on the scale of 1 to 2 million. Scarce highly populated urban poles appear opposed to very large portions of the remaining territory characterized by scarce or null densities. Besides a classical choropleth map, a dasymetric map was drawn to portray the highly contrasted distribution of population in the Kingdom of Saudi Arabia (KSA). It distinguishes two highly contrasted classes of densities. The overall objective is to achieve small-scale vector population maps (1 to 2 million) departing from the smallest administrative count unities, *i.e.*, the governorates (locally called mouhafadhat). Besides population data, the Saudi Topographic map, Open Street map and Saudi Basemap were utilized to delimitate the land use classes, according to the scale. Population data was integrated in a dedicated GIS which allows calculations of areas and densities of the issued spatial units. The resulting bivariate dasymetric maps may constitute useful tools to help geographers and planners in understanding the population distributions forms and factors. This way, decision-makers may implement further spatial measures and various projects particularly when taking into consideration their effects on population.

Keywords

Dasymetric Map, Bivariate Method, GIS, Saudi Arabia, Population Distribution, Land Use Classification

1. Introduction

Choosing a convenient cartographic method is not a straightforward procedure. When population density is mapped, many methods are offered to cartographers. The cartographer's choice depends at least on 3 components: the final goal of the map; the nature and accuracy of the available data, *i.e.*, the base map and the population counts; and the scale or the level of details to reach. Besides, many other defining factors intervene: We can cite the overall efficiency of the method; its ability to portray or reproduce the geographic reality; its capacity to reach the set goals which can be resumed in Presenting, Representing, Analyzing and Deciding (PRAD). It also should convince its users with regards to its Semiology.

In the case of the Kingdom of Saudi Arabia (KSA), the author aims to design a single small-scale population map (1 to 2 million) that may give a first approach of the highly contrasted population distribution. This approach highlights the two major tendencies of the population settlement and movements instead of the widespread choropleth one, namely, the intense urbanization and the *spatial specialization* (Langford, 2007). It may be useful to support the ambitious territorial program KSA is featuring: *Saudi Vision of* 2030.

The main purpose of the study is to design a convenient small scale population map that fits the overall Saudi geographic characteristics. After stating the problem, presenting the case study, the data, and presenting a selected literature review, the author found that the bivariate variant of the dasymetric method already experimented by Bielecka (2005), may portray Saudi distribution population at a convenient scale. The specific methodology is adopted, and the results are deduced. These later show to what extent this convenient population map can help in country's planning and territorial development. Future studies should go beyond the set overall main goal and related sub-objectives, by refining the discretization and classification methods with regards to larger scales.

2. The Statement Problem

When talking about the dasymetric cartographic methods, many cartographers evoke the difficulties of its implementation, the methods used to classify and obtain homogeneous densities classes, and the quality and the refinement of ancillary data in use. All things being equal, available, updated, and detailed data influence to some extent the results.

Some cartographers may focus mostly on methodological aspects (Holt et al., 2004; Hwahwan et al., 2010) while others consider case studies as more pertaining (Goodchild & Lam, 1980; Fisher & Langford, 1995; Maantay & Maroko;

2009). A third category combines the method used as well as the results of its implementation and application on given case studies. Whatever the approach, most of the cartographers agree that the dasymetric method has by far better results than the choropleth, isopleth and/or graded circles map methods for example, even when used in urban spaces. We refer here to the research conducted on Jeddah City (Hamza et al., 2016) or on Riyadh (Alahmadi et al., 2012, 2013, 2015, 2016; Alahmadi, 2018).

Traditionally, geographic variables are classified as continuous or discontinuous within geographical space, depending on their location, nature, characteristics, and relationships to the environment. But sometimes grey areas do exist in between, and it is not obvious to set rigorously such strict dichotomy today for all case studies (Dhieb et al., 2021). Accordingly, cartographers use various methods to describe unequal population distribution over space (McCleary Jr., 1969). In many cases, the choropleth method is adopted, mostly because of its ease of use and the inherited tradition to represent data by administrative subdivisions. However, in the last decades, many studies revealed serious pitfalls in relation with the choropleth method, ranging from biases in data conformity to reality to the erroneous picture yielded. Besides, the sharpness of data subdivisions of the method may infer unreal discontinuity in population densities whereas other relevant borders are not mapped (Olson, 1975; Cauvin et al., 2007). The dasymetric method is often given as an alternative solution to better portray the distribution and gives more accurate knowledge of population that help in domains such as planning issues or locating spatial decisions (Sleeter & Gould, 2007).

The dasymetric method application is especially useful when serious contrasted distribution of geographic phenomena is engaged. It is the case of the population of the Kingdom of Saudi Arabia (KSA), a very wide country compared to its population, *i.e.*, almost 2,149,690 km² for 35.8 million inhabitants (https://www.unfpa.org/fr/data/world-population/SA), with an average density of 16.65 h/sq.km in 2022. Besides this, KSA is conducting an ambitious program of spatial and economic planning and future territorial projects called *Saudi vision* 2030, which implies a solid and accurate knowledge of population location (https://www.globalmediainsight.com/blog/saudi-arabia-population-statistics/).

Our hypothesis is that, for countries like Saudi Arabia, where population settlements are much contrasted, and since 85 % of the population reside in urban areas, the dasymetric population method may apply rather in fields such as planning, health, risk studies, agriculture, tourism, management systems or sustainable development instead of common choropleth maps (Dhieb et al., 2021). The issue is to determine enough homogeneous density areas in a systematic way, *i.e.*, to find the best solution to draw a dasymetric map that fits Saudi Arabia territorial characteristics on a small scale.

3. Selected Literature Review

Classical textbooks (Dent, 1999; Slocum et al., 2003) define the dasymetric maps,

as irrespective of any administrative boundaries, requiring the use of ancillary date to create new limits of various density areas, instead of the traditional ones used by cartographers; and the fulfillment of the pycnophylactic Tobler's principle (1979). This principle states that the sum of the estimated population in the new spatial units created by the dasymetric must equate the originally encoded zones of the whole population in the original choropleth map, whatever the ancillary data used to identify and set homogeneous density areas (Tobler, 1979; Hwahwan et al., 2010). Practically, the procedure is not easy to use and may lead to tedious and cumbersome processes. But development of several kinds of ancillary data, topographic maps, Remote Sensing images on the one hand, and GIS and Spatial Analysis on the other hand, played a central role in collecting, combining, synthetizing, and restituting accurate data and helped in refining the method.

Wide literature reviews were achieved in previous research on the subject (Petrov, 2012; Buttenfield et al., 2015; Dmowska, 2019). Obviously, it is too hard to cite all literature works on the issue. The author refers here only to some selected works and focuses on the recent ones dedicated to the Arab world. Cartographers agree that the roots of the dasymetric map method were engrained in Scrope and Harness works (Scrope, 1833; Harness, 1838 cited in Robinson, 1955). But, as these precursors did not state explicitly the dasymetric method in their work, cartographic textbooks tell that the method was rather created in the beginning of the twentieth century by Veniamin Petrovich Semenov-Tyan-Shansky (Dent, 1999; Slocum et al., 2003). For the first time, this Russian geographer and statistician talked about "measuring density" to signify the dasymetric method (Petrov, 2012). Later, the method was applied to Cape Code area by the American cartographer J. K. Wright (Wright, 1936). But a long time ago after Wright's work, until the end of the twentieth century, and if we exclude a few works such as McLeary PhD on "the Dasymetric method in Thematic Cartography" (1969), the method was neglected, probably because of increasing difficulties in its implementation.

The term "dasymetric" signifies a cartographic technique replacing the administrative limits delineated by the choropleth method by new ones that fit the real distribution of geographic phenomena, by means of ancillary data, especially Remote Sensing images. Besides, Goodchild and Lam (1980) state that there was an abuse in using it. They think that what was presented and referred as a particular "dasymetric mapping technique method" is confusing and that this expression also appears regularly in Remote Sensing (Goodchild & Lam, 1980).

Fisher and Langford (1995) stated that the new densities of the New Spatial Units (NSU) must be calculated carefully to be conformal to Tobler's pycnophylactic principle (Tobler, 1979). But as many applications of the dasymetric method are derived from RS images, some applications were exclusively concerned by the raster model or tried to link it with areal data. For instance, Eicher and Brewer (2001) integrate the use of GIS to produce more accurate dasymetric

maps. Chen (2002) tries to set a value density for each pixel to linking remotely sensed data and areal census data. But Eicher and Brewer (2001) went further by demonstrating how GISs reveal powerful tools to manage and process data calculations. After a series of tests on five dasymetric mapping methods, including ones derived from work on areal interpolation, resulting dasymetric maps of the six socio-economic variables were produced for 159 counties (2001). In this research, both polygonal (vector) and grid (raster) dasymetric methods were tested; map accuracy was evaluated using both statistical analyses and visual presentations of error (2001) and a repeated-measures analysis of variance showed that the traditional limiting variable method had a significantly lower error than the other four methods (2001).

Mennis wrote thoroughly on the technique. He studied how to generate Surface Models of Population Mapping using the dasymetric method (Mennis, 2003). He also investigated how to estimate population in small areas (Mennis, 2009). Together with Hultgren, they wrote on "Intelligent dasymetric mapping and its application to areal interpolation" (Mennis & Hultgren, 2006).

An interesting application of the dasymetric method was realized in Poland after Bielecka (2005). It combines the bipolar and the multivariate variants of the technique. Departing from the Corine Land Cover database, the author excluded first the unpopulated areas from the calculations of the densities of Poland. Second, she attributed fixed coefficients to determine population ratios for the remaining land cover classes, based on homogeneous estimates on the "communes".

The author may also cite many authors such as Zandbergen and Ignizio (2010) for alternative sources of ancillary data, including imperviousness, road networks, and nighttime lights; Tapp (2010) who focused on new algorithms to determine accurate calculation of density to render more automatic implementing the dasymetric method.

More recently, the issue of dasymetric modeling was studied with links to the uncertainty issue and attempts to unify the methods more accurately (Nagle et al., 2014). Others try to explore the impact of dasymetric refinement on spatiotemporal small area estimates, proving that refinements effects are prominent in areas observing fast changes in their population (Buttenfield et al., 2015). The dasymetric technique was also suggested to enhance spatial analysis by "Increasing the Accuracy of Urban Population Analysis with Dasymetric Mapping" (Mennis, 2015). Even though it is difficult to implement the dasymetric method using an automated and straightforward way, attempts to help implementing the method were achieved by ArcGIS (DASMAP). An example was applied to the city of Lisbon in Portugal and produced. It was based on relative density according to land classification derived from Corine Land Cover

(https://www.arcgis.com/apps/Cascade/index.html?appid=fde9d5cc2716490faf1e 861d171a6fdd).

Mostly, European, or North American countries were concerned by research

works on the dasymetric method, whether addressing methodological or/and technical aspects, or case studies. In Arab countries, a few attempts were conducted (Jaullt & Serradj, 2011; Alahmadi et al., 2012, 2015, 2016, 2018; Hamza et al., 2016; Dhieb et al., 2021).

Jaullt and Serraj used Remote Sensing and 2004 Tunisian Census to replace the biased choropleth data of Kairouan region (Tunisia) by a more realistic dasymetric map focusing on really populated data (Jaullt & Serradj, 2011).

Alahmadi et al. (2012) presented the case study of Riyadh, Saudi Arabia. The authors used various ancillary data satellite images. They attempted to estimate population of Riyadh by using remotely sensed built land cover and height data (2013). In another research, they refined the residential classes to make accurate estimations of dwellings areas or height, and population distribution estimates were obtained by downscaling detailed residential land-use classes (2015). In a third research, three statistical regression models were combined with two dasymetric areal interpolation models leading to six-classes proving that multivariate dasymetric mapping (2016). In a recent study, Alahmady used a spatial non-stationarity analysis to estimate dwelling units in Riyadh (Alahmadi, 2018).

The work conducted by Hamza and al. was also an application concerned by the urban space of Jeddah in KSA (Hamza et al., 2016). Based on a high-resolution satellite image classification, it shows first the big contrast between the highly populated central part of Jeddah, and the northern and southern districts less populated; second, it shows the interstitial empty parts of the populated buildings and quarters (Hamza et al., 2016).

In a recent work, Dhieb and al. presented a case study of the whole Tunisian country (Dhieb et al., 2021). The authors suggested a multivariate dasymetric approach to this heterogeneous land use of Tunisia. They affected a specific weigh to each land use class issued from an adapted version of a land use classification issued from Corine Land Cover to this North African country. Then the dasymetric population map was drawn; it was based on calculation of the probable density of population for land use classes determined by affecting an empirical weigh ratio to each class.

In conclusion, at least 3 main ideas can be retained. First, it is proven that the dasymetric method has by far better results than choropleth, isopleth, or graded circles method maps even when used in urban spaces. Second, many variants of the method should be applied depending on the case studies characteristics, whether leading to raster or vector map, or a combination of both; so, cartographers should look after the best model depending on the spatial characteristics of population distribution of the studied spaces; the available ancillary data; and the reached goal. Third, Remote Sensing provides today accurate data to draw dasymetric maps, whereas GIS and Spatial analysis can enhance densities calculations and treatment.

4. The Study Area

We know that the quality of results depends on the study case specificity. The interest of the present study of KSA population distribution resides first in the tremendous spatial contrast of its distribution. KSA is constituting the greater part and the heart of the Arabic Peninsula. From North to South, it borders Jordan, Iraq, Kuwait, Qatar, the United Arab Emirates, Oman, and Yemen; it is also bordered by the Red Sea in the west side and the Arab Gulf in the east side. Moreover, its north-western coasts are not far from the Suez Canal and the Mediterranean Sea.

A first look at the 1 to 2 million Saudi Topographic Map (Figure 1) shows large, inhabited areas versus very small urbanized or cultivated areas. In reason of severe climatic conditions, Saudi Arabia is containing important desertic spaces and inhabited areas. As ancillary basic data, the use of the satellite images and Google Earth images allows the extraction of the updated inhabited zones from the study area to calculate the real densities of population. Unless conducting



Figure 1. The Saudi topographic map originally at 1:2.000.000 was chosen as the scale of work. It shows the greatest desertic part of Saudi territory against spread red points corresponding to main cities and localities (Source of base map: Saudi Topographic Map; cartography: M. NASR and M. DHIEB).

a study on greater scales, distinguishing between diverse rural densities, this work turns out to be a difficult task.

With almost 2.15 million km², KSA is the thirteenth country considering its surface area in the world, and the second one in the Arab world; but is only the sixth rank in population with 35,436,627 million inhabitants in 2021, including 37.8% of non-Saudis (https://www.stats.gov.sa/en/5680). Only, a few spaces of this huge country are populated, particularly the urban areas with approximately 85 per cent of the entire population residing in the urban *Mouhafadhats*. The 5 major cities, *i.e.*, Riyadh, Jeddah, Makkah, Dammam, and Medina, which are less than 10 per cent of the country area, house more than 50 per cent of the population. The other 50 per cent of urbans are sparsely distributed in the remaining 90 per cent of the Saudi territory

(https://worldpopulationreview.com/countries/cities/saudi-arabia). This may explain the choice of the bivariate model of the dasymetric map (Figure 2).

KSA is divided into 6 main regions (Eastern, Central, Northern, Northwest, Midwest, and Southwest) subdivided into 13 provinces (locally called *Imarats* or



Figure 2. A Google map of Saudi Arabia confirms that the greatest part of Saudi territory is desertic or mountainous (Source: <u>https://goleaddog.com/gis-data-products/satellite-maps/satellite-maps-index/saudi-arabia-satellite-maps/</u>).

Manatiq) containing the 136 governorates (locally named *Mouhafadhat*). At the lower level, KSA counts 1374 centers or (*Markaz*). It is worth to say that the most useful administrative level for the present study is constituted by the governorates, since one could not draw accurate limits for the centers and does not have accurate population data. To simplify this point, **Figure 3** shows the different administrative levels of KSA (Source: Central Department of Statistics and Information) (**Figure 3**).

The country's population is tremendously unequally populated and the average density of inhabitants, almost 16 per km² in 2020 does not have much meaning since the greatest part of the Saudis and almost the totality of Residents (*Mouquimoun*) live in greater cities. A great part of the country is composed of arid and hostile deserts such Rub Al Khali, semi-arid lands (Nefoud, Dahna), chains of mountains (Asir, Hijaz), coastal plains (Tihama), and narrow cultivated areas (oasis), with high daily temperatures and limited rainfall and scarce natural vegetation. Because of severe natural and climatic conditions, a few areas of KSA are populated: towns, oasis, cultivated areas, or artificial communities built



Figure 3. The map shows the various administrative levels of Saudi Arabia (Source: Central Department of Statistics and Information).

for petroleum industry or at crossing points on the main roads. When portraying the distribution of population by cartographic means, and whatever the method used, one should consider these essential points.

5. Methodology and Available Data

Before implementing the method in the present case study, the author should prevent readers about the common confusion between the cities and the governorates or *Mouhafadhat* which, in Saudi Arabia, mostly have the same name but do not necessarily have the same territorial boundaries. Whereas Saudi cities are the urban features that, reasonably, do not obey strict spatial limits because of constant changes, the governorates or *Mouhafadhat* are recognized as administrative units and their stable boundaries are identified accurately. These latter may contain one or several urban entities or parts of them. This remark implies that we consequently obtain slightly different results when applying the dasymetric method on recognized cities or on the *Mouhafadhat* as count units. The use of cities gives better results since limits of urban poles are approximately boundaries of densities thresholds, whereas limits of the *Mouhafadhat* are not necessarily.

The official detailed population data for the Saudi governorates or the cities date from 2010 (Saudi Census, <u>https://www.stats.gov.sa/en/73</u>, achieved by the General Authority of Statistics). The census of 2010 gave a population of 27,236,156 million inhabitants, and the 2020 preliminary results of the population census gave 34,813,871 million inhabitants, whether Saudis and foreigners. Today, the total population of Saudi Arabia is about 36 million inhabitants and about 35 in 2020 (Estimations of provinces and governorates tables population of Saudi Arabia in 2020). It is worth noting that the governorates limits do not fit totally with the built areas' limits identified on Open Street maps. These latter seem more significant to calculate urban densities.

Departing from the literature review, the case study, the available population data on governorates that can be handled, the assessment of population density in Saudi Arabia was realized through a two steps methodology to design the dasymetric maps.

We departed first from the resulting chorpopleth density maps, based on fixed enumeration units which are the 13 regions or *Imarat* (Figure 4, Nasr and Dhieb, 2022) and the 136 governorates or *Mouhafadhat* (Figure 5, Nasr and Dhieb, 2022). At a first look, these maps emphasize the principle of cartographic generalization of a tedious reality of population's distribution. Therefore, they cannot describe accurately the real Saudi densities of population inside the administrative units. For instance, Figure 4 does not tell us that the region of Charguiyya is constituted by a few littoral cities and Al Ahsa oasis, whereas the biggest part is desert and almost empty (Rab AlKhali). We can apply such statement for governorates in Figure 5, but at a lower and finer level.

In the design of choropleth maps, the author retains the Jenks discretization



Figure 4. The *natural breaks method* used to map *Imarats* density of population shows high contrasts in average population densities, yet these contrasts do not fit the boundaries of the administrative units.

method based on the notion of thresholds as well as the dasymetric method established on marked thresholds considering the land use classification inspired from Corine Land Cover nomenclature

(https://www.statistiques.developpement-durable.gouv.fr/sites/default/files/2018 -12/clc-guide-d-utilisation-02_0.pdf).

Another focal point deals with the choice of a convenient map scale depending not only on the real users' needs, but also on data accuracy and its availability. All things being equal, the question of scale plays a crucial role in the choice of one variant of dasymetric method (Dhieb et al., 2021). The establishment of such map for the whole country of KSA cannot afford a too big scale. The author chose 1 to 2 million since it corresponds to the recent Topographic map of KSA. Since it is the first approach of real population densities, an intermediate map scale was chosen: 1 to 2 million. This choice is also sustained by the existing topographic map at the same scale and the first use (**Figure 1**). Choosing greater



Figure 5. The choropleth map of population density of Saudi Arabia yields similar aspects of abruptness of change in boundaries even though when changing the geographic scale *(The Mouhafadhats instead of Imarats)* and the statistical quantile method instead of natural breaks method used in **Figure 4**.

cartographic scales to fit the implementation of regional or local concerns overwhelms the scope of this study conducted on the national level.

But it is noticeable to observe that, all things being equal, these limits are more significant and realistic towards densities of urban population. The calculation of the areas of each land use piece was achieved automatically in ArcGIS by defining the appropriate cartographic projection system (Ain El Abd UTM, zone 38). The land use classification was inspired from Corine Land Cover Nomenclature hierarchized to levels considering the specificities of this desertic region.

To extract the urban areas polygons and calculate their density of population first, the author used Open Street map and Very High Spatial Resolution satellite images of Basemap in Arc GIS 10.8 at the maximum zoom, and residential or built areas were delimited and extracted. Extraction of specific areas was achieved on a precise digitization according to a digitization protocol, and delimitation of homogeneous zones of land use was delineated. So, more than 1900 polygons for urban space in this work were identified.

The author used a map scale of 1:100,000 to delimitate the urban areas and 1 to 2 million to the others land use classes. The relative densities were calculated departing from population cities and governorates data. Very small built portions which seem to be isolated buildings, villages and recreation areas along roads were not considered, since the task of extracting them practically is very tedious and goes beyond the work goal, besides the fact that they do not contain numerous population et could not distort final calculations. The distribution of these polygons (in red on **Figure 5**) gives us a more global and spatial vision.

The dasymetric bivariate maps were produced according to an adapted common methodology, because of the profound dichotomy between a few crowded places and huge empty spaces. It is the result of the visual interpretation (photointerpretation) of Open Street map and Very High Spatial Resolution satellite images based on ESRI's "ArcGIS 10.8 Basemap". This was achieved by the identification and digitization of defined areas, urban vs remaining space in the bivariate dasymetric map. Urban areas of polygons of at least 1 ha and homogeneous from the point of view of land use were delimited. This area is considered as the area of the smallest mapped unit (description threshold). This choice was made to facilitate the digitization of the author documents and the printing of readable maps.

6. Results

The distribution of Saudi population is very contrasted in space, but it is also changing over time since the rate of urbanization grew meanwhile from 82.1% to 84.3%. This statement is first shown on both choropleth maps. The present average density of population is very contrasted between approximately 0.4 in the Northern Borders to 134 in Jazan if we consider the *Imarat*, and from less than 1 to 1312 inhabitants per sq.km if we consider the *Mouhafadhat*. Both Saudi *Imarats* and *Mouhafadhats* choropleth maps showed noteworthy distances between high and low densities on the choropleth maps, whatever the discretiza-

¹KSA is subdivided into 13 first level regional subdivisions, called *Imarat* (plural of *Imara* which means literally in Arabic principality or *Emirate*); at the second hierarchical level, we find lower subdivisions called *Mouhafadhat* (plural of *Mouhafadha*) (or governorate). The number of the *mouhafadhat* is growing continuously. From 118 in 1412 h [1991], their number is 138 in 2020. (https://en.wikipedia.org/wiki/Subdivisions of Saudi Arabia#Governorates).

²KSA is subdivided into 13 first level regional subdivisions, called *Imarat* (plural of *Imara* which means literally in Arabic principality or *Emirate*); at the second hierarchical level, we find lower subdivisions called *Mouhafadhat* (plural of *Mouhafadha*) (or governorate). The number of the *mouhafadhat* is growing continuously. From 118 in 1412 h [1991], their number is 138 in 2020. (https://en.wikipedia.org/wiki/Subdivisions of Saudi Arabia#Governorates).

tion method used.

The bivariate variant dasymetric map is a two-class map composed of urban areas on the one hand, and all other classes on the second hand. It reveals very small and dispersed spots opposed to a big empty portion, *i.e.*, a very contrasted map The remaining population was divided on the remaining territory which was calculated and considered as a one single class of population in the first bivariate variant. The average density was calculated and gave us 2.71 inhabitants per sq.km. The author estimates the issued map as acceptable at this scale of 1 to 2 million. **Figure 6** is a reduced prototype of what would be the dasymetric map (**Figure 6**, Nasr and Dhieb, 2022), but four selected portions of Saudi Arabia were enlarged evenly (**Figures 7-10**, Nasr and Dhieb, 2022) to show more details, and another figure has the scale of 1 to 2 million to reproduce what would be the final dasymetric map of Saudi Arabia at its real scale (**Figure 11**, Nasr and Dhieb, 2022).

In an overall synthesis of the resulting maps, the bivariate map shows major urban Saudi poles as the main inhabited areas in Saudi Arabia: Riyadh, the trio



Figure 6. The Saudi governorates (*The Mouhafadhats*) do not fit necessarily the changing urban limits of Saudi cities and localities over space and time. The original dasymetric bivariate map was drawn at 1 to 2 million and reduced to embrace the overall Saudi territory. It was processed by combining Google Earth and Open Street Map combination with Corin Land Cover classification level 2. The original design of urban areas was processed at a scale of 1/100.00 and then reduced.



Figure 7. An extracted and inset bivariate map of Tabuk region enlarged to show to users more details that may show useful information. It is worth to say that this region will witness many huge projects of Saudi vision 2030.

Jeddah-Makkah-Al Taief, Dammam and its suburbs, and Al Madinah. At a lower level, we may observe other smaller poles with intermediate or smaller cities.

It is worth to delineate 3 main north-south axes in this distribution: a full western axis redoubled on littoral and in the western chains of mountains Asir and Hijaz; an obturated central axis starting from the south of Riyadh towards the north-west; and a smaller axis starting in the eastern coast of Saudi Arabia.

It is also noticeable that incomplete transversal axes merely East-west are added to the first ones; the most important by far is the one starting at Jeddah-Makkah-Al Taïf and finishing at the Eastern coast at Dammam Al-Khobar, passing by Riyadh and Al Ahsa. It is worth noting that this axis gathers 2/3 of the whole Saudi population. Another axis starts at Yanbu, goes through Al Madina than Hail and Buraidah and goes south to Riyadh; the northern transversal axis



Figure 8. An extracted and inset bivariate map of the southern region enlarged to show more details that may show useful information. Al Assir mountainous region is the most densely populated area of Saudi Arabia.

will probably have more importance in the future since it links the future Nayoum city to the northern poles of Saudi Arabia and to the eastern region and probably will join the eastern axis at Arabic Gulf (Dhieb, 2020).

Many elements shown on the 1 to 2 million Topographic Map of KSA may give useful insights and explain the overall distribution, *i.e.*, topography, wadis, roads... (Figure 11).

The cartographic production of land use by photointerpretation combining Corine Land Cover and extraction of homogeneous density classes remains a very popular method. It is increasingly becoming an approach that has shown its relevance in several works and research projects on the mapping of land use, especially in European and North-African countries such Tunisia (Dhieb et al., 2021). This method was used to map land use on a large scale and particularly to



Figure 9. An extracted and inset bivariate dasymetric population map of Al Hijaz region enlarged to show more details that may show useful information. This region includes at least 4 main Saudi cities. Jeddah, the second Saudi city, Makkah, the Islamic Holy city, Al Taef and Al Baha, two recreative cities.

map urban fabrics and large infrastructures on a larger scale than what Corine Land Cover nomenclature proposes for example.

When we add some natural and cultural features (fere rivers, water bodies and roads) at the same scales, gains in use for planning may be greatly enhanced.

7. Discussion and Comments

When mapping population density, it is obvious that the most used cartographic method is the choropleth method. The reason is that it consists in attributing on a scale of graded colors or shades, one that fits its mean density calculated on its whole territory, whatever the chosen count unit. But the choropleth method leads to big errors towards the reality of population distribution even when small



Figure 10. An extracted inset bivariate dasymetric map of Riadh region, the capital of Saudi Arabia, enlarged to show to users more details that may be show useful information.

areas units are considered (Olson, 1975). Therefore, the author think that many planning or strategic decisions made on the mean population density of the administrative units, whatever the level, should profit of the dasymetric method. This may apply to future planning projects requiring an accurate portray of the distribution of population considering the fact that the real population distribution should precede the act of taking planning decisions.

The dasymetric method could be the alternative solution though the issue of map scale is crucial. Thus, the choice of the scale of 1 to 2 million was decided to give more chance to Saudi cities to be well represented and classify the other land use on an overall level. At this scale, apart from the urban spaces, Remote Sensing Image or Open Street Maps provide useful data. The map scale factor remains as the most important factor to determine to what extent cartographers may distinguish between land use categories, such as the multiple Corine Land Cover nomenclature delineated in multiple levels. In this case, a question that



Figure 11. Finally, Figure 11 shows an example of Saudi Arabia map at the real 1:2.000.000 scale.

leads our level choices is to what extent one may show details of density that are useful to the theme to study.

The dasymetric map drawn here constitutes the alternative solution to replace the choropleth maps, even though, as far as we know, this method was not applied for Saudi Arabia before, neither in the Arab world, at least for a whole country, except for Tunisia (Dhieb et al., 2021), as far as the author knows. Using the dasymetric method reveals very useful when compared to the classical methods used in similar cases such as the choropleth method, the isopleth method, the dot map method, the cartograms, and other cartographic methods describing distributions. In various fields of science, and when appropriately applied, the dasymetric method is far superior to these methods in substituting average statistical data by areas of interest.

8. Conclusion

Mapping the population distribution for the whole Saudi country was a challenging issue and may be controversial whatever cartographic method chosen. On the one hand, 85 per cent of the population resides in a smallest part of the huge territory, and consequently, the main part of the remaining territory is empty or almost empty. Therefore, the bivariate dasymetric method seems a priori to be enough sufficient to give a first idea on the population distribution.

Studying the Human Environment subtract of Saudi territory needs a convenient choice of an optimal cartographic method that conveys the real description of reality of population distribution. Yet, as shown in the dedicated literature, the common cartographic method, *i.e.*, the choropleth method often leads to big biases towards reality (Dhieb et al., 2021).

The dasymetric method is seen as one alternative solution. Depending on the map scale retained and the study scope, the author examined the various available ancillary data available to produce, at a given scale, the optimal maps portraying the real human occupation of one territory. The study proves that the bivariate dasymetric map at a small scale for the whole country is sufficient, though regional, or local investigations need more classes, in addition to an accurate and detailed population data.

9. Prospects and Recommendations

The author thinks that dasymetric mapping will be increasingly used in the future not only in academic milieu but also in applied studies. Accurate spatial population distribution using the dasymetric methods constitutes a crucial issue in all spatial studies despite difficulties of its implementation. Moreover, all topics requiring knowledge about accurate population settlement may be concerned: planning, environment, transportation, agriculture, risk studies, sustainable development, or other topics.

In addition, difficulties of implementation of the dasymetric method will be reduced and automation of the method will be assessed. Considering the case of KSA which is preparing *Saudi vision* 2030, establishing a dasymetric map is a challenging tool for planners and political decision makers interested in regional development. It would help them to link their options and decisions of the preferred locations of their projects, with regards to the human resources location, the areas' natural resources, spatial organization, and land use.

The last goal of *Saudi vision* 2030 was set "to increase household spending on cultural and entertainment activities inside the Kingdom from the current level of 2.9 per cent to 6 per cent"

(https://www.vision2030.gov.sa/media/rc0b5oy1/saudi_vision203.pdf). Such equipment should not be implemented rationally if one does not consider the spatial distribution of Saudi population and the trends of future settlements. It may provide useful and accurate tools to portray population distribution and to plan space evolution. The thematic maps that can be established for planning should be based on dasymetric method rather than the mostly biased choropleth method in use, or many other cartographic methods.

It is worth to establish vector dasymetric population maps for Saudi Arabia at convenient scales based on the land use distribution. Many territorial decisions in KSA which may impact the regional development of the regions, could benefit from such maps. The search of best sites location gains when using accurate data population locations much more than the average population density of corresponding administrative units. The author recommends changing this approach.

The author also suggests adapting semiological principles to the yielded cartographic data (Denègre, 2005). For instance, small areas should be enhanced by optimal color visualization; supplementary elements should be set to explain for readers the factors of one human settlement and so on, or linking population distribution with other themes by using GIS.

Further studies should be conducted on bigger scales or on parts of Saudi Arabia to refine classification of density categories and to fit planning decisions needs. Moreover, all present and future projects implying spatial dimension should consider both real current population distribution and its contrasts, and so its future trends, in terms of moves and growth. Geographical, strategical, and planning studies may help this issue. Overlays of topographic data on the background of the dasymetric map should give useful insights.

Acknowledgements

This paper was funded by the Deanship of Scientific Research (DSR) at King Abdulaziz University, Jeddah, under grant no. (G-831-125-1441). The authors, therefore, acknowledge with thanks DSR for technical and financial support.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

- Alahmadi, M. (2018). Spatial Non-Stationarity Analysis to Estimate Dwelling Units in Riyadh, Saudi Arabia, *European Journal of Remote Sensing*, *51*, 558-571. https://doi.org/10.1080/22797254.2018.1459209
- Alahmadi, M. S. et al. (2012). Estimation of the Spatial Distribution of Urban Population Using Remotely Sensed Satellite Data in Riyadh Saudi Arabia. <u>https://www.geos.ed.ac.uk/~gisteac/proceedingsonline/GISRUK2012/Papers/presentation-31.pdf</u>
- Alahmadi, M., Atkinson, P. M., & Martin, D. (2016). A Comparison of Small-Area Population Estimation Techniques Using Built-Area and Height Data, Riyadh, Saudi Arabia. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 9*, 1959-1969. <u>https://doi.org/10.1109/ISTARS.2014.2374175</u>
- Alahmadi, M., Atkinson, P., & Martin, D. (2013). Estimating the Spatial Distribution of

the Population of Riyadh, Saudi Arabia Using Remotely Sensed Built Land Cover and Height Data. *Computers, Environment and Urban Systems, 41*, 167-176. https://doi.org/10.1016/j.compenvurbsys.2013.06.002

- Alahmadi, M., Atkinson, P., & Martin, D. (2015). Fine Spatial Resolution Residential Land-Use Data for Small Area Population Mapping: A Case Study in Riyadh, Saudi Arabia. *International Journal of Remote Sensing*, 36, 4315-4331. <u>https://doi.org/10.1080/01431161.2015.1079666</u>
- Bielecka, E. (2005). A Dasymetric Population Density Map of Poland. In *ICC2005— International Cartographic Conference*. <u>https://icaci.org/files/documents/ICC_proceedings/ICC2005/htm/pdf/oral/TEMA5/Ses</u> <u>sion%209/ELZBIETA%20BIELECKA.pdf</u>
- Buttenfield, B. P. et al. (2015). Exploring the Impact of Dasymetric Refinement on Spatiotemporal Small Area Estimates. *Cartography and Geographic Information Science*, 42, 449-459. <u>https://www.tandfonline.com/toc/tcag20/42/5</u> <u>https://doi.org/10.1080/15230406.2015.1065206</u>
- Cauvin, C., Escobar, F., & Serradj, A. (2007). *Cartographie thématique volume 2: Des transformations incontournables.* Elsevier.
- Chen, K. (2002). An Approach to Linking Remotely Sensed Data and Areal Census Data. *International Journal of Remote Sensing, 23,* 37-48. https://doi.org/10.1080/01431160010014297
- Denègre, J. (2005). *Sémiologie et conception cartographique* (274 p.). Hermes Science, Lavoisier.
- Dent, B. D. (1999). *Cartography: Thematic Map Design* (5th ed.). WCB/McGraw-Hill. <u>https://www.geos.ed.ac.uk/~gisteac/proceedingsonline/GISRUK2012/Papers/presentation-31.pdf</u>
- Dhieb, M. (2020). Using Chorems in Graphical Modeling: The Case of the Kingdom of Saudi Arabia. *Current Urban Studies*, *8*, 265-283. <u>https://doi.org/10.4236/cus.2020.82015</u>
 <u>https://www.scirp.org/journal/paperinformation.aspx?paperid=100690</u>
- Dhieb, M. et al. (2021). Approaching the Tunisian Human Environment by Using RS and the Dasymetric Method. In F. K. Allouche, & A. M. Negm (Eds.), *Environmental Remote Sensing and GIS in Tunisia* (pp. 17-35). Springer International Publishing. https://doi.org/10.1007/978-3-030-63668-5_2
- Dmowska, A. (2019). Dasymetric Modelling of Population Distribution—Large Data Approach. *Quaestiones Geographicae, 38,* 15-27. https://doi.org/10.2478/quageo-2019-0008
- Eicher, C. L., & Brewer, C. A. (2001). Dasymetric Mapping and Areal Interpolation: Implementation and Evaluation. *Cartography and Geographic Information Science*, 28, 125-138. <u>https://doi.org/10.1559/152304001782173727</u>
- Fisher, P. F., & Langford, M. (1995). Modeling the Errors in Areal Interpolation between Zonal Systems Using Monte Carlo Simulation. *Environment & Planning A*, 27, 211-224. <u>https://doi.org/10.1068/a270211</u>
- Goodchild, M. F., & Lam, N. (1980). Areal Interpolation: A Variant of the Traditional Spatial Problem. *Geo-Processing*, *1*, 297-312. http://www.geog.ucsb.edu/~good/papers/46.pdf
- Hamza, M. H., Thubaiti, A., Dhieb, M. et al. (2016). Dasymetric Mapping as a Tool to Assess the Spatial Distribution of Population in Jeddah City (Kingdom of Saudi Arabia). Urban Studies, 4, 329-342. <u>https://doi.org/10.4236/cus.2016.43022</u>

https://www.scirp.org/Journal/PaperInformation.aspx?PaperID=70931

- Harness, H. D. (1838). Atlas to Accompany the Second Report of the Railway Commissioners, Ireland. H.M.S.O.
- Holt, J. B. et al. (2004). Dasymetric Estimation of Population Density and Areal Interpolation of Census Data. *Cartography and Geographic Information Science*, *31*, 103-121. https://doi.org/10.1559/1523040041649407
- Hwahwan, K. et al. (2010). Pycnophylactic Interpolation Revisited: Integration with the Dasymetric-Mapping Method. *International Journal of Remote Sensing*, *31*, 5657-5671. https://doi.org/10.1080/01431161.2010.496805
- Jaullt, R., & Serradj, A. (2011). Les cartes dasymétriques et l'apport des images satellitaires dans la représentation de la densité de la population dans le gouvernorat élargi de Kairouan en Tunisie. SIG 2011. In *Conférence Francophone ESRI*.
- Langford, M. (2007). Rapid Facilitation of Dasymetric-Based Population Interpolation by Means of Raster Pixel Maps. *Computers, Environment and Urban, 31*, 19-32. <u>https://doi.org/10.1016/j.compenvurbsys.2005.07.005</u>
- Maantay, J. A., & Maroko, A. R. (2009). Mapping Urban Risk: Flood Hazards, Race and Environmental Justice in New York. *Applied Geography (Sevenoaks, England), 29,* 111-124. <u>https://doi.org/10.1016/j.apgeog.2008.08.002</u>
- McCleary Jr., G. F. (1969). *The Dasymetric Method in the Thematic Cartography*. Unpublished Ph.D. Dissertation, University of Wisconsin.
- Mennis, J. (2003). Generating Surface Models of Population Using Dasymetric Mapping. *Professional Geographer*, *55*, 31-42.
- Mennis, J. (2009). Dasymetric Mapping for Estimating Population in Small Areas. *Geographic Compass, 3,* 727-745. <u>https://doi.org/10.1111/j.1749-8198.2009.00220.x</u>
 <u>https://www.researchgate.net/publication/229649191</u> Dasymetric Apping for Estimating Population in Small Areas/citation/download
- Mennis, J. (2015). Increasing the Accuracy of Urban Population Analysis with Dasymetric Mapping. *Cityscape*, *17*, 115-126. https://doi.org/10.1559/152304010792194985
- Mennis, J., & Hultgren, T. (2006). Intelligent Dasymetric Mapping and Its Application to Areal Interpolation. *Cartography and Geographic Information Science, 33*, 179-194. https://www.researchgate.net/publication/228653393 Intelligent Dasymetric Mapping and Its Application to Areal Interpolation https://doi.org/10.1559/152304006779077309
- Nagle, N. et al. (2014). Dasymetric Modeling and Uncertainty. *Annals of the American Association of Geographers, 104,* 80-95. https://doi.org/10.1080%2F00045608.2013.843439
- Olson, J. (1975). Autocorrelation and Visual Map Complexity. *Annals of the American Association of Geographers, 75,* 189-204. https://doi.org/10.1111/j.1467-8306.1975.tb01030.x
- Petrov, A. (2012). One Hundred Years of Dasymetric Mapping: Back to the Origin. *The Cartographic Journal, 49*, 256-264. <u>https://doi.org/10.1179/1743277412Y.0000000001</u>
- Robinson, A. H. (1955). The 1837 Maps of Henry Drury Harness. *Geographic Journal*, *121*, 440-450. <u>https://doi.org/10.2307/1791753</u>
- Scrope, G. J. P. (1833). *Principles of Political Economy, Deduced from the Natural Laws of Social Welfare, and Applied to the Present State of Britain*. Longman.
- Sleeter, R., & Gould, M. (2007). Geographic Information System Software to Remodel

Population Data Using Dasymetric Mapping Methods (15 p.). US Geological Survey Techniques and Methods 11-C2. <u>https://pubs.usgs.gov/tm/tm11c2/tm11c2.pdf</u>

- Slocum, T. et al. (2003). *Thematic Cartography and Geographic Visualization* (2nd ed.). Prentice Hall.
- Tapp, A. (2010). Areal Interpolation and Dasymetric Mapping Methods Using Local Ancillary Data Sources. *Cartography and Geographic Information Science*, *37*, 215-228.
- Tobler, W. R. (1979). Smooth Pycnophylactic Interpolation for Geographical Regions. *Journal of the American Statistical Association*, 74, 519-530. <u>https://www.jstor.org/stable/2286968?seq=1#page_scan_tab_contents</u> <u>https://doi.org/10.1080/01621459.1979.10481647</u>
- Wright, J. K. (1936). A Method of Mapping Densities of Population with Cape Cod as an Example. *Geographical Review, 26*, 103-110. <u>https://doi.org/10.2307/209467</u>
- Zandbergen, P. A., & Ignizio, D. A. (2010). Comparison of Dasymetric Mapping Techniques for Small-Area Population Estimates. *Cartography and Geographic Information Science*, *37*, No. 3. <u>https://doi.org/10.1559/152304010792194985</u>