Asian Journal of Geographical Research

5(1): 37-46, 2022; Article no.AJGR.85344
ISSN: 2582-2985

The Population Density Map of the Greater Cairo Region Comparison of 2017 Choropleth Map and Dasymetric Map

Asmaa H. Rasslan [a*#] and Abd-Elwahab, Sameh [a≡]

[a] *Department of Geography, Faculty of Arts Cairo University, Egypt.*

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJGR/2022/v5i1123

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/85344

Original Research Article

Received 02 February 2022
Accepted 12 April 2022
Published 18 April 2022

ABSTRACT

Although the choropleth method is considered among the easiest cartographic methods, it lacks accurate representation of the real population density. In this regard, dasymetric maps offer the better alternative, especially for heterogonous spaces and those exhibit intense spatial dynamic, like the Greater Cairo Region, which has the highest population and population density among various Egyptian governorates. The current study aims mainly at comparing the dasymetric mapping technique with the choropleth mapping technique for studying the population density in the Greater Cairo Region. To this end, the satellite image processing and ArcGIS (version 10.6.1) were used. For instance, it was found, in the choropleth map, that the population density category ranged from 161.415 to 270.922 person per km^2 occupied 1% of the total area of 1481 km^2; whereas, in the dasymetric map, the population density category ranged from 139.986 to 761044 person per km^2 concentrated in only 0.4% of the total area of 648 km^2. Thus it is clear that the dasymetric mapping technique is more representative of the realistic population density distribution, because it eliminates all land uses except the residential land use. Conclusively, it is highly recommended to use the dasymetric mapping technique rather than the choropleth method.

[#] *Postgraduate Student;*
[≡] *Professor;*
**Corresponding author: E-mail: asmaahassangis@gmail.com;*

Keywords: The greater cairo region; choropleth map; dasymetric map; satellite image processing; GIS.

1. INTRODUCTION

"Sustainable development requires access to data, information, and knowledge about the study area. The geographical or spatial data are considered an indispensable part of the available knowledge at modern science of Information and Communication Technology" [1]. "Remote sensing and geographic information systems (GIS) will be used in the present study and will be helpful as ancillary data to establish an accurate population density map of the selected area for the study, which is the metropolitan area of Cairo, the political capital, besides a part of Qalyubia (including Shubra Alkhayma I & II), in addition to Giza City that belongs to the Greater Cairo Region (GCR) (Fig. 1). Greater Cairo region is the center of the Egyptian transportation network, and the link between Egypt's economic regions. It is also one of the most seven largest urban conglomerates in Middle East, Africa, and whole world" [2]. "The study area is located at 30°12'N and 31°54'E, in the middle of the Delta Region" [3].

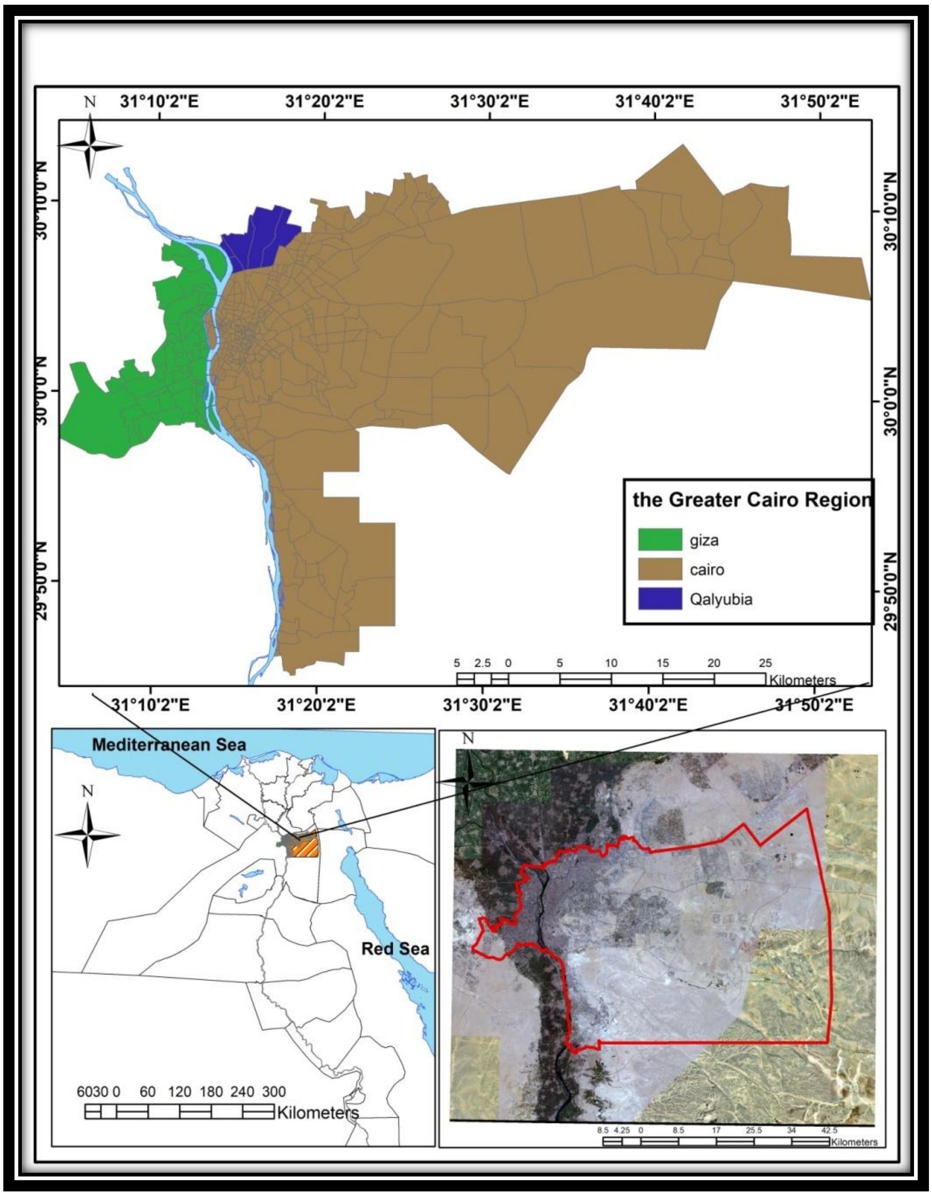

Fig. 1. Study area

The assessment of population density will be done through the establishment and the comparison of both choropleth and dasymetric maps of the Greater Cairo region based on the land use distribution with regards to the results of satellite image processing.

“The dasymetric mapping is a thematic mapping method developed and named in 1911 by Veniamin Petrovich Semenov-Tyan-Shansky and popularised by J.K. Wright” [4]. Since that date, several attempts to implement the method through various spaces whether national, regional or urban with a certain degree of success were done.

The term dasymetric map is a type of thematic map intended to represent a statistical surface of density, that is, a measurement that varies continuously over space and which captures the rate of occurrence of some phenomenon over space. In a dasymetric map, the statistical surface is represented by partitioning the space into a set of spatial units where the unit boundaries occur at the steepest escarpments of the surface, that is, where the density transitions most abruptly from one location to the next. Thus, a dasymetric map has spatial units that maximize within-unit homogeneity while minimizing between-unit homogeneity. Ideally, the density within any given spatial unit of a dasymetric map should be approximately equal. A dasymetric map is often contrasted with a choropleth map, which is also a thematic mapping technique used to represent the spatial distribution of a quantitative variable, density or otherwise. Unlike a choropleth map, however, where the spatial unit boundaries are typically derived from some convenience of enumeration of data collection that has little or nothing to do with the actual spatial variation in the data, a dasymetric map’s spatial units are derived from, and are intended to depict, the nature of the spatial variation in the mapped variable.

Researchers in environmental remote sensing have also focused on modeling population distribution using remotely sensed imagery. This requires the development of a functional model between remotely sensed pixel values and population, which is typically derived using pre-existing population data encoded in a choropleth map. Thus, the use of remotely sensed imagery to derive population estimates is inherently dasymetric in its approach.

“The information generated from a dasymetric population density map could provide useful assistance to district administrations, especially those responsible for regional or city development and land management” [5]. Landsat 7 Enhanced Thematic Mapper Plus satellite image of the Greater Cairo Region was used in the present study and will be classified using interactive supervised classification method. The obtained land use image will be updated through United States Geological Survey (USGS) and then transferred to ArcGIS ESRI GIS software into vector format.

2. MATERIALS AND METHODS

“The methodology for this study included three phases: 1) classification of urban land-cover (impervious surface) from remotely-sensed imagery, 2) dasymetric mapping of the urban areas according to population, and 3) integration of these outputs to compare between the choropleth map and the dasymetric map for 2017” [6]. A flowchart is given for ease of understanding (Fig. 2).

2. 1 Data Description

Firstly, as ancillary basic data, Enhanced thematic mapper plus (ETM+)satellite image was used, dated October 12 2017(path176 and row 39), which was obtained from the U.S. Geological Survey (USGS), Earth Resource Observation Systems Data Center (http://landsat.usgs.gov/index.php). This specific image was chosen for its lowest percentage of cloud cover (2%) and high quality (5), with a 30 meters resolution; it was used for representing the land use and then the real population density.

Secondly, the base map of the Greater Cairo Region was used to determine the districts contours as well as the inner subdivisions limits. These limits may be very useful when calculating densities over effective uninhabited areas and therefore implementing the dasymetric map method.

Thirdly, the statistical population data of different districts of the Greater Cairo Region were taken from the **Central Agency for Public Mobilization and Statistics (Egypt)** based on districts' population numbers (2017).

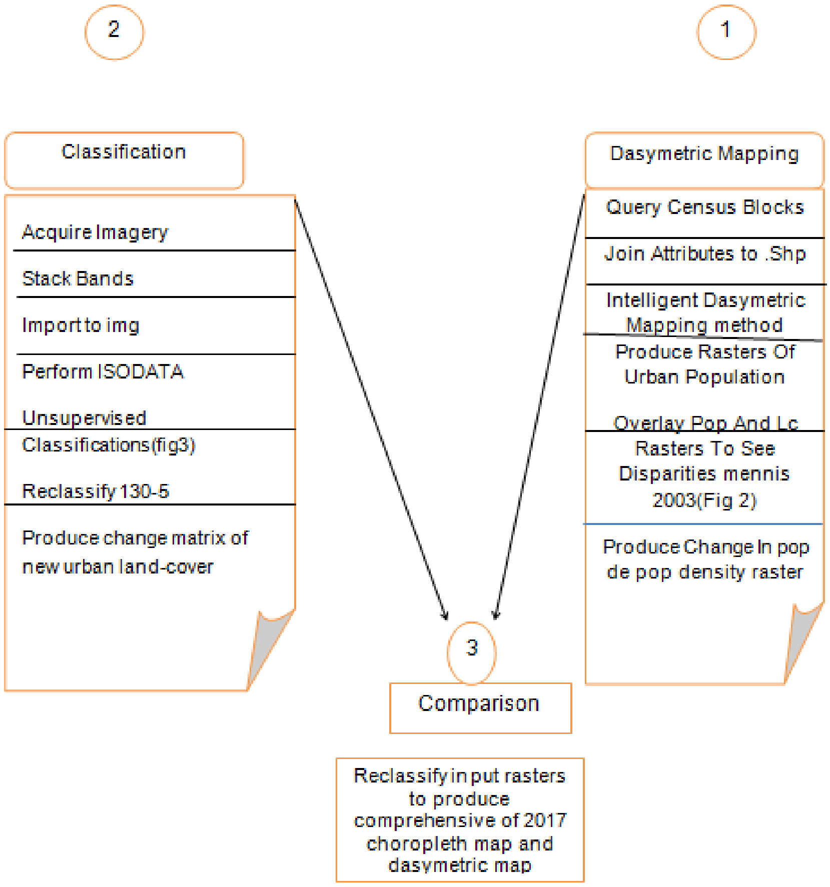

Fig. 2. Flow chart of Methodology

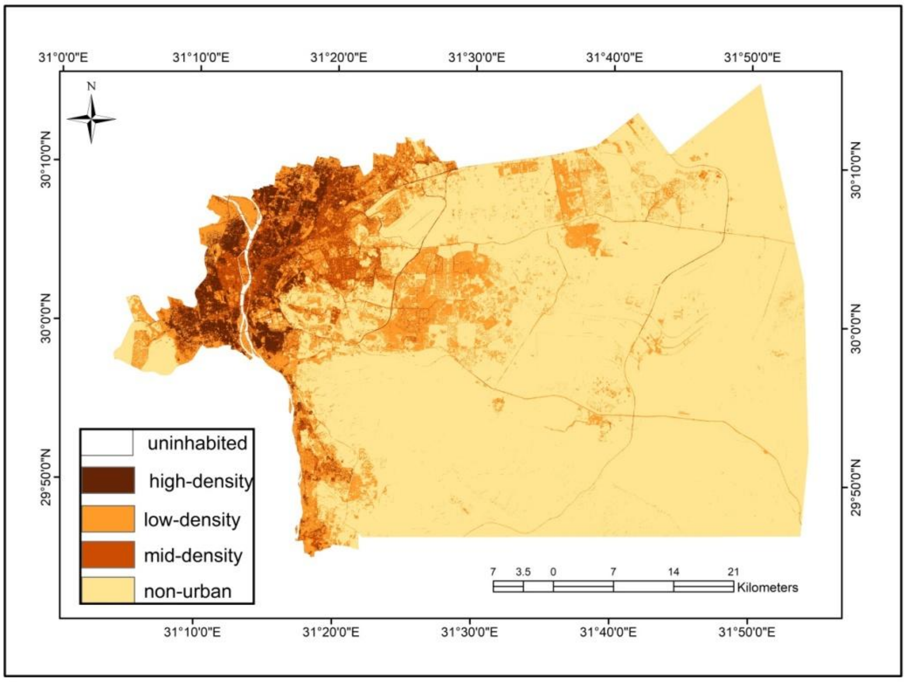

Fig. 3. Classification of 2017 ETM+ imagery

2.2 Classification

The first task was to acquire, import, and stack the ETM+ imagery using INVI.5(30 meters resolution). The USGS had already geometrically corrected the imagery, so there was no need to shift the image to its appropriate coordinates.

Next, the Arc GIS (ersion 10.6) was used to produce an unsupervised classification with 10 classes. These were then manually classified into the five land-cover categories uninhabited , non-urban , low density, mid density and high density.

2.3. Dasymetric Mapping

The second part of the methodology was the dasymetric population mapping, using the classified rasters generated above. A modified version of the equation in Holloway et al. (1999) was used to compute population for each land-cover pixel.

When implementing the dasymetric method, the relative ratios of density values are initially established. Each density ratio was assigned to an associated land class to receive a certain proportion of the total population from each source zone. Then, an area-based locally fitting approach [7] was used to adjust the global density ratio for each source zone and to allow a degree of spatial heterogeneity to exist (see Fig. 4). Using the localised density ratio, the population in each area in a source zone that intersected with a land class can be determined.

The populations at the intersection areas were then aggregated to produce the target areas.

The Intelligent Dasymetric Mapping method was programmed as a Visual Basic for Applications (VBA) script within the ArcGIS (Environmental Systems Research Institute, Inc.) GIS software package. The script prompts the user via a series of dialog boxes to load the source zone and ancillary data layers, set manual preset values for selected ancillary classes, and select a sampling strategy. Alternatively, the user can specify the parameterization of the technique using a header file. The various sampling strategies are implemented using the basic overlay operations offered by ArcGIS. One parameterization option in the spatial selection operation in ArcGIS supports the ability to select only those polygons in one layer that fall completely within polygons in another layer. This option was used to support containment sampling, where the script loops through a series of selection functions that identify those source polygons that are wholly contained within polygons of each ancillary class. Another spatial selection parameterization option supports centroid sampling, using the same looping structure in the script. Here, the script loops through a series of selection functions that identify those source polygons whose centroids fall within each ancillary class, essentially a point-in-polygon search (though the analytical geometry is handled internally by the software).The percent cover method is a bit more complicated as it requires both a polygon overlay operation and a tabular summary operation. An intersect operation between the source zone layer and the ancillary data layer yields a new “intersect” polygon data layer, for which the area is calculated for each polygon. The script then loops through each source zone polygon, retrieves those intersect layer polygons that it contains, sums the area of the source zone polygon occupied by each ancillary class, and divides that area by the area of the entire source zone polygon to yield the percent of the source zone polygon covered by each ancillary class. Those source zone polygons that exceed the user-specified threshold for the percent cover method may be identified using a simple attribute selection operation. When the IDM script finishes a run, it returns a dasymetric vector polygon layer with a data count and density estimates for the target zones. In addition, a summary table is returned that characterizes the map layer output. This table includes information that is intended to assist the user in evaluating the relative quality of the resulting dasymetric map; it is described more fully in the cases study presented below.

Spatial analyses were conducted in ArcGIS.

In order to obtain the dasymetric map, the following steps were followed:

1- Source code for the IDMVBA script, as well as sample data for dasymetric mapping, were downloaded from [1] https://www.epa.gov/enviroatlas/dasymetric-toolbox.

2- Add the dasymetric toolbox to the ArcGIS (version 10.6.1, ESRI) to form the intelligent dasymetric mapping.

3- convert the population features to raster.

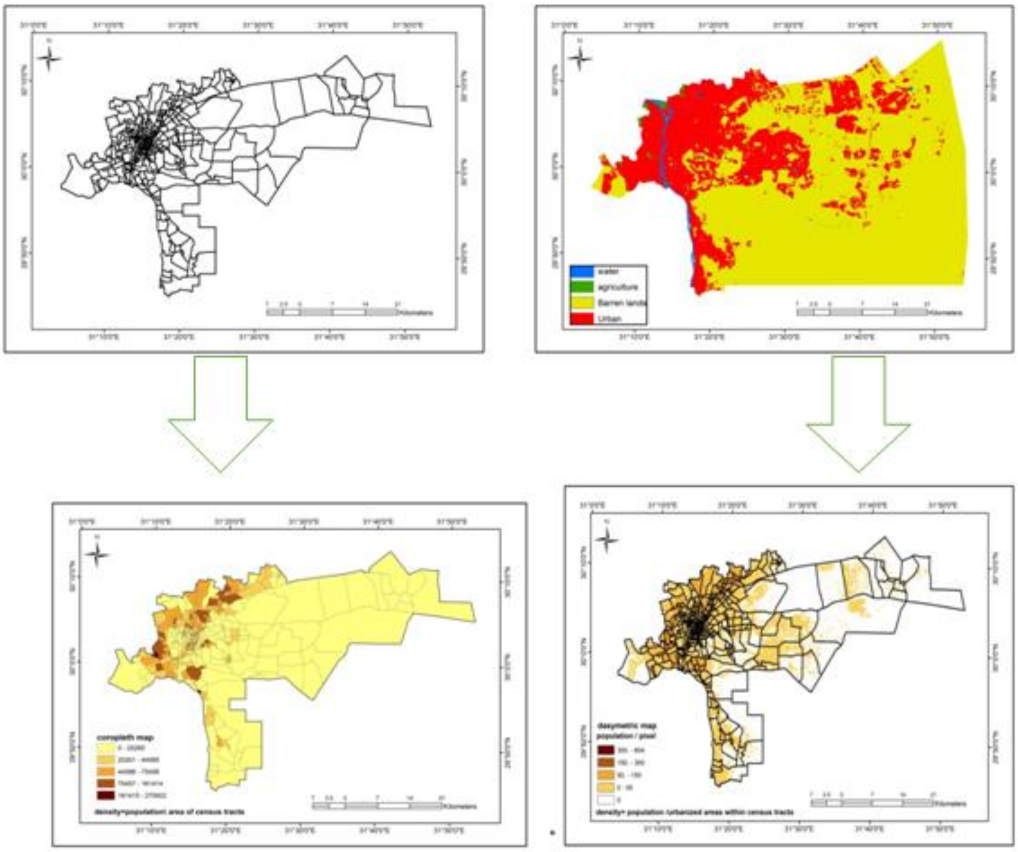

Fig. 4. Choropleth map (left) in contrast with the Dasymetric map (right)

4- combine population and ancillary raster

5- Create ancillary class preset table

6- Perform the dasymetric calculations.

7- Create final dasymetric raster.

2.4 Comparison

The third part of the methodology was comparing both coropleth and dasymetric maps. Both maps were classified into five categories using Natural Breaks, Jenks Classification, as shown in Fig. 4

3. RESULTS AND DISCUSSION

Comparing dasymetric with choropleth maps, it was found that different land uses do not have the same population density; but there is a variation in terms of land use-dependent population density even within the same block group. For example, the regions that recorded low population density in choropleth maping which contain the minimal values of 20260 population/sq.km; on the other hand, in dasymetric maping, certain parts of these areas recorded higher population density. This is because some large districts that extend in the extremities of the Greater Cairo Region, particularly eastern, northern eastern and southern extremities, wherein population is concentrated in some of its parts; thus, it recorded higher densities. So that, when comparing between different block groups located in the Greater Cairo Region, particularly eastern, northern eastern and southern extremities, using dasymetric maping technique, we found that some parts of these block groups are inhabited, while other are uninhabited, and some have high densities, while others have no population. Consequently, it can be concluded that dasymetric maps resolved deficiencies resulted in case of representing the population density using choropleth maping, in which same density value is accounted for all block groups, although the land use-dependent population density is not the same in different block groups. Comparing sectors in different directions, it is noteworthy that dasymetric map calculated the residential uses within the same block group.

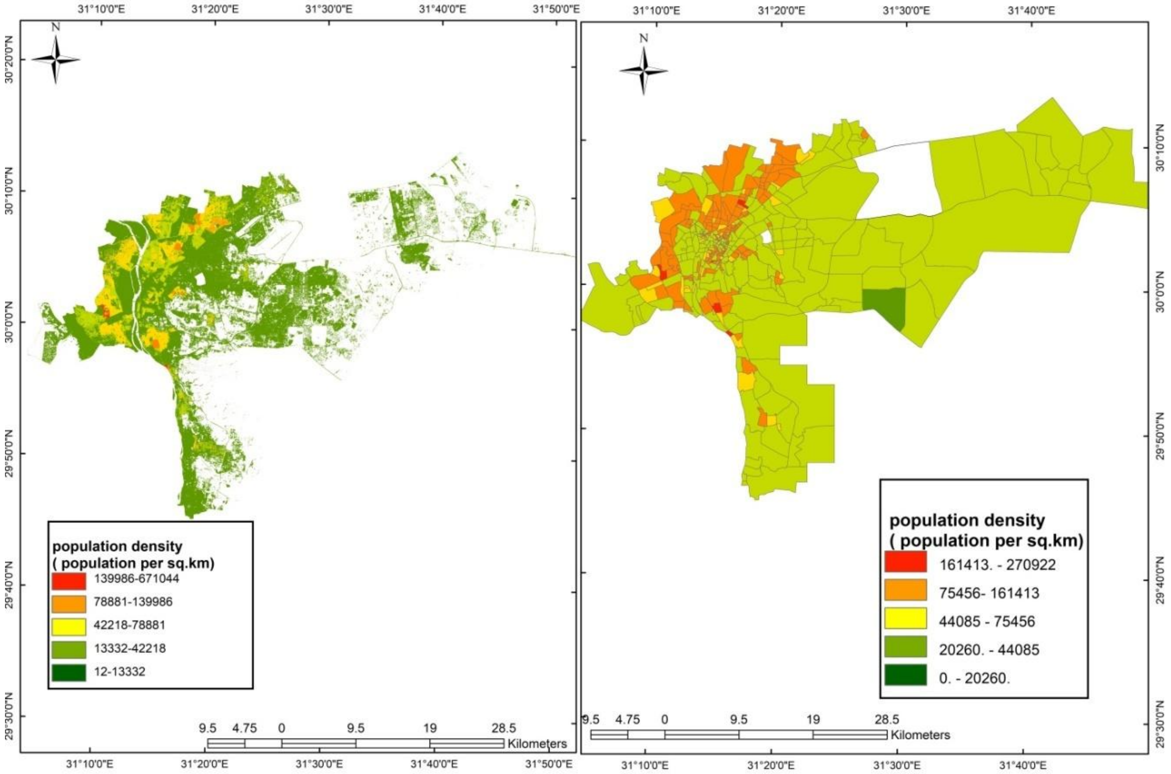

Fig. 5. Comparison of 2017 choropleth and dasymetric population density results for census tract 15203289 [3]. The dasymetric population density that is highlighted represents the northern population of the town of the Greater Cairo Region

Fig. 5 shows the usefulness of dasymetric mapping to more accurately map population density compared to choropleth mapping. Visual comparison clearly shows that dasymetric mapping provides a better representation of the spatial orientation of population density, particularly in outlying census tracts that encompass much uninhabited land. Within urban centers, the population density distribution is relatively homogeneous and coincides well with the choropleth maps. In the outlying census tracts though, it is more apparent that population distribution is not always homogeneous and is often concentrated in smaller areas within census tracts. For example, Fig. 5 displays a relatively dense population concentration within census tract 15203289 [8], that is otherwise indistinguishable in the choropleth map. Visual decadal comparison of this tract using the dasymetric maps reveals that population density has in fact increased, but population distribution has remained in the western part of the census tract primarily because much of the northern and eastern areas of the tract are floodplain, limiting development to the East and northern eastern.

We were able in this study to extract the choropleth map by considering the totality of the area of the Greater Cairo Region, based on the districts, without particular distinction of the built-up areas. The extracted choropleth image was afterward transferred to ArcGIS ESRI GIS software under a shapefile vector format. The data related to the number of persons in the population and those relating to the area of the Greater Cairo Region districts were introduced in the fields of the attribute table of the shapefile. This will subsequently allow to calculate the population density in the study area (Population density = number of people/land area). The choropleth map is covering a total area of 1481.323sq·km; it shows population density values varying between 26841and 270922inhabitants per sq·km; these values were classed into five classes by using the Jenks method (Table 1 and Fig. 4). The dasymetric method gives a better view of population distribution over a given area than conventional choropleth maps [9]. Zones outside of the built areas were excluded from the dasymetric map. As we proceeded for the choropleth map, the dasymetric map was extracted from the landsat 7 (ETM+) image classified unsupervised

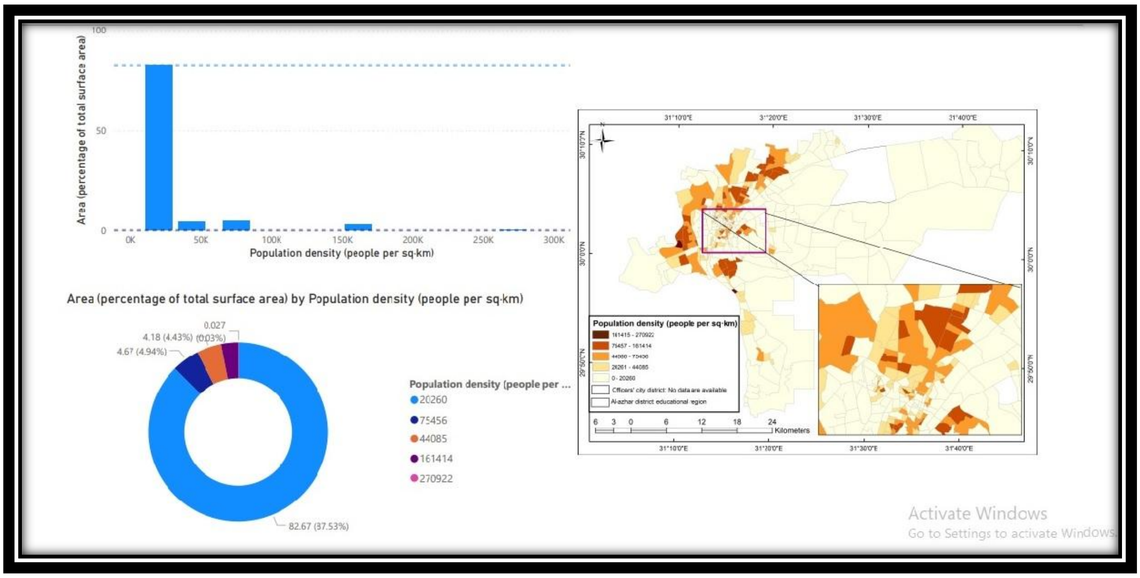

Fig. 6. choropleth map of the Greater Cairo Region (Natural breaks, Jenks classification).and Graph showing areas related to the different classes of population density in the choropleth map (Natural breaks, Jenks classification

Table 1. Area related to the different classes of population density in the choropleth map (Natural breaks, Jenks classification)

Population density (people per sq.km)	area (aq.km)	Area (percentage of total surface area)
0-20,260	1224.678	82.67
20,261 - 44,085	62.040	4.18
44085 - 75456	69.302	4.67
75457 - 161414	43.037	2.90
161415 - 270922	0.406	0.027

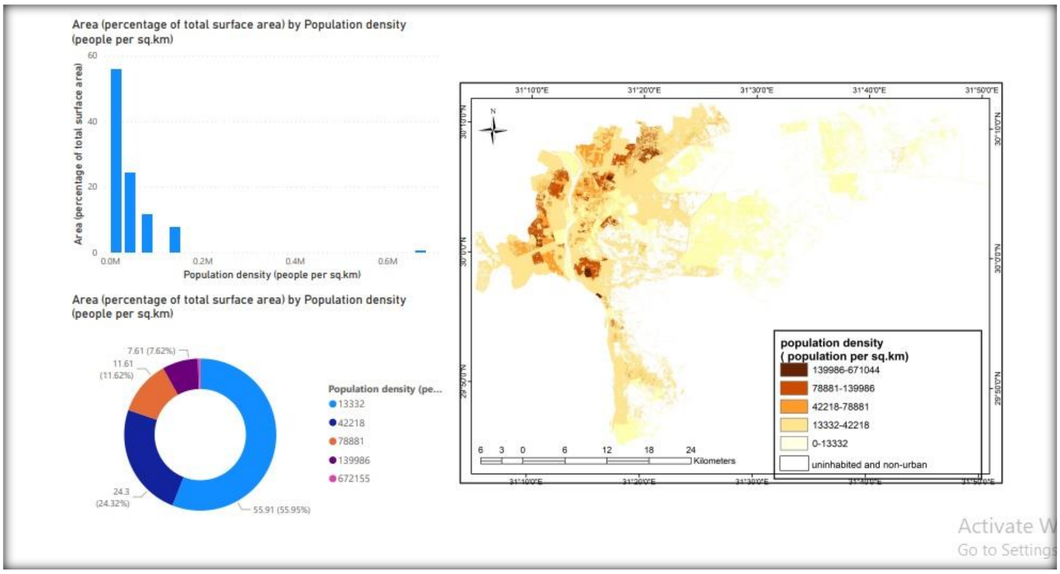

Fig. 7. Dasymetric map of the Greater Cairo Region (Natural breaks, Jenks classification).and Graph showing areas related to the different classes of population density in the Dasymetric map (Natural breaks, Jenks classification

Table 2. Area related to the different classes of population density in the dasymetric map (Natural breaks, Jenks classification)

Population density (people per sq.km)	area (aq.km)	Area (percentage of total surface area)
0- 13332	363.009	55.91
13332- 42218	157.605	24.30
42218- 78881	75.224	11.61
78881- 139986	49.376	7.61
139986-672155	3.234	0.5

classifications. The population density was calculated as same. The extracted dasymetric map has a total area of only 648.450sq·km (1481.323 sq·km in the choropleth map). The population density varies between 13332 and 671044; these values were classed into five classes by using the Jenks method which is more respectful of the groups of densities (Fig. 5). This latter has the advantages of portraying the distribution of small groups of densities with respect to the data physiognomy and profile. Besides this, it may lead to different class limits over 2 statistical series (Table 2 and histograms Fig. 5 and Fig. 6.

4. CONCLUSION

The primary contribution of this research is the comparison of two different methods, i.e. the dasymetric mapping method and choropleth mapping method of the Greater Cairo Region departing from population data, satellite image processing and other ancillary data. The present study concluded that these dasymetric maps are more accurate than the classic choropleth maps usually used when portraying population density because they take into account only the built-up areas. From this study, it was shown that the Greater Cairo Region has numerous unbuilt spaces or even built spaces that are inhabited. In addition, population distributions per enumeration unit can be viewed to understand urban growth in those areas that have experienced the highest population growth rates and contributed most to the region’s growth. This study can be done in the next years for other cities in Egypt. Future research could attempt to solve the aforementioned problem of urban parks, golf courses, and other developed land commonly determined to be rural by remote sensing methods.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

ACKNOWLEDGEMENT

I do greatly acknowledge this paper with the deepest love and respect to my husband, Dr. Mohamed Elwy, for his continuous encouragement, follow-up and moral support for me. Also, I do acknowledge this to my family, especially my lovely children, Ahmed and Malek.

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Peer-review history:
The peer review history for this paper can be accessed here:
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