Original Research Article

The Population Density Map of the Greater Cairo Region
Comparison of 2017 choropleth map and dasymetric map

ABSTRACT

It is well-known that, when dealing with density of population, most of the proposed maps choose the easiest and probably the most understandable cartographic method, i.e. the choropleth method. Nevertheless, for heterogonous spaces and those observing intense spatial dynamic, it is proven that this method has many defects and shortcomings. This is the case of the Greater Cairo Region; the region has the highest population and population density among the Egyptian governorates and is considered one of the most populous regions worldwide. Yet, most of the planning decisions are often taken on those types of maps and may mislead the urban planners. In this context, the dasymetric maps is considered of utmost importance because they may give the real distribution of population. Therefore, we think that establishing a dasymetric map at a convenient scale with regards to the results of satellite image processing may help the planners and the geographers as well as the common users. Indeed, this method may be an interesting alternative to the classic choropleth map. It may improve our estimations towards the density within the various areas of the districts. The current study aims mainly at comparing dasymetric mapping technique with choropleth mapping technique for studying the population density in the Greater Cairo Region. To this end, the satellite image processing and Arc GIS (version 10.6.1) were used as tools.

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) (Figure 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].

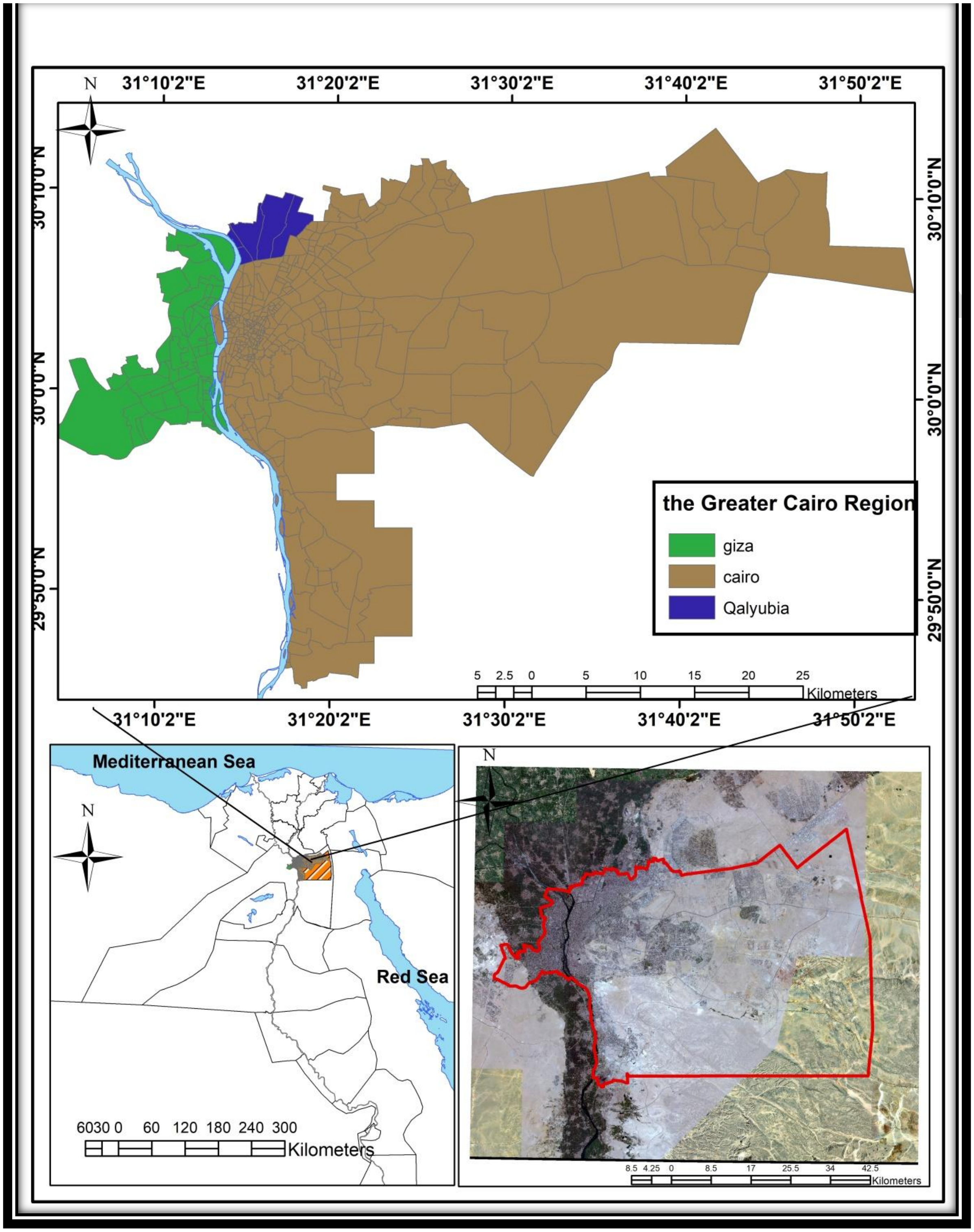

Fig 1.: study area

The 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. In this study assessment of the population density will be done through the establishment and 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 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. MATERIAL AND METHODS

2.1 Data Description

Different data types were used in this study. First, the statistical population data in the different districts of Greater Cairo Region were taken from the services of the Greater Cairo Region department of statistics and information based on districts population numbers (2017)

Second, the base map of Greater Cairo Region uses 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.

Third, as ancillary basic data, the use of the satellite image and USGS images allowed the extraction of the updated inhabited zones from the study area to calculate the real densities of population.

The purpose is to distribute the population only on the populated zones. In order to match with the 2017 census data, a Landsat 7 Enhanced Thematic Mapper Plus (ETM+) image (path 176 row 39) for March 7, 2017 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.

Therefore, instead of using administrative units portraying the densities through various choropleth maps, the dasymetric maps are based on effective homogeneous likelihood zones [6]. These new subdivisions may be portrayed with or without referring to the original limits. In our case, in population data, collected by census block-groups, were then reallocated to a 30-meter surface grid based on the relative difference in population densities among the urbanization classes and the percentage of total area of each census-block-group occupied by the three inhabited zones. The GCR was chosen to test the proposed predictive model. The 2017 official census puts the population of the region at more than 15 million. [7]

3. RESULTS AND DISCUSSION

Dasymetric mapping was performed in order to capture the spatial variation in population density and population density change. As previously discussed, this technique involves a real interpolation of census data into urban land-cover classes. The Dasymetric Mapping Extension (DME) for ArcGIS 10. was developed for EnviroAtlas was used for this task[8].The objective of the DME is to "automate the process of taking population homogeneous zones while (1) maintaining volume preserving properties and (2) using an empirical sampling method for determining relative densities for each homogeneous zone" [9]. The underlying mathematics of the software is based on the methods developed by **Torrin Hultgren**. presents an overview of the difference between choropleth and dasymetric mapping. In addition, we present in Figure 2.

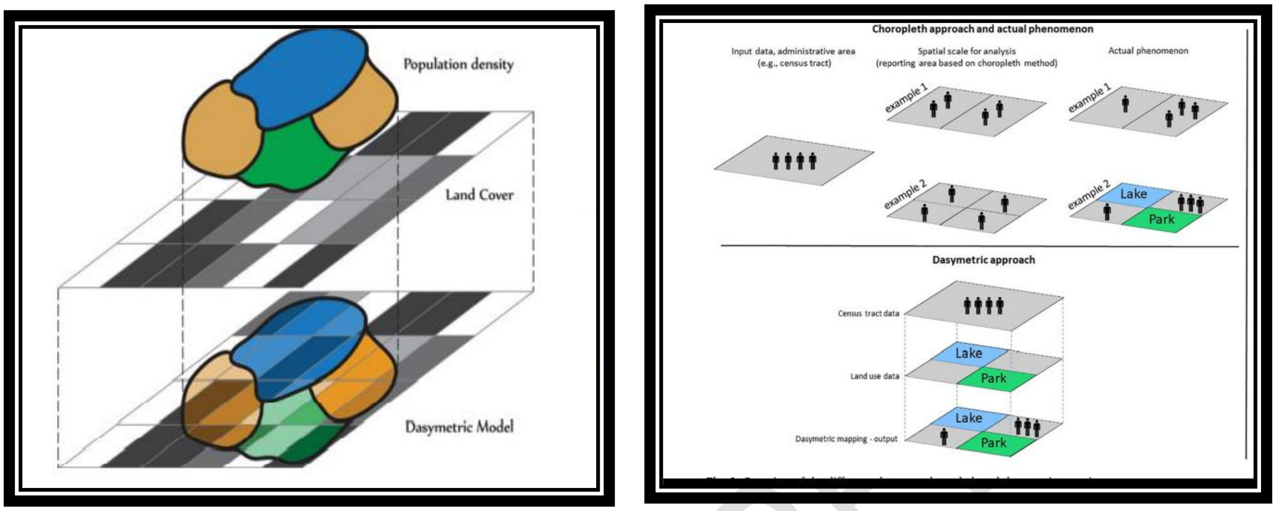

Fig2 .two satellite images with the boundaries of a specific census tract to show that the real population density is not evenly distributed within the census area.

Dasymetric mapping has been indicate as an alternative approach to provide a more accurate and detailed distribution of population at any scale, including high-resolution scales. Dasymetric has been widely applied method in many scientific areas, which includes social science [11], criminal studies [10], historical analysis [12], and public health research, as mentioned above. In contrast to choropleth mapping, which accounts only for the linear ratio between population and area, dasymetric maps account for geographic properties by incorporating ancillary dataset (usually, land use data) and extensively partitioning space into zones to increase the spatial resolution of population [13]. The zone boundaries here reflect the underlying statistical surface variation or information. Specifically, the dasymetric mapping process will use an area class map ancillary dataset to disaggregate the tract-level choropleth map and produce a dasymetric map showing the distribution of population more accurately [14]. As result, unpopulated spaces are removed and the population is redistributed to the remaining areas based on areal weighting [15]. Fig. 2 shows the interaction between the two geographical layers (census tract and land use data) used in the dasymetric mapping.

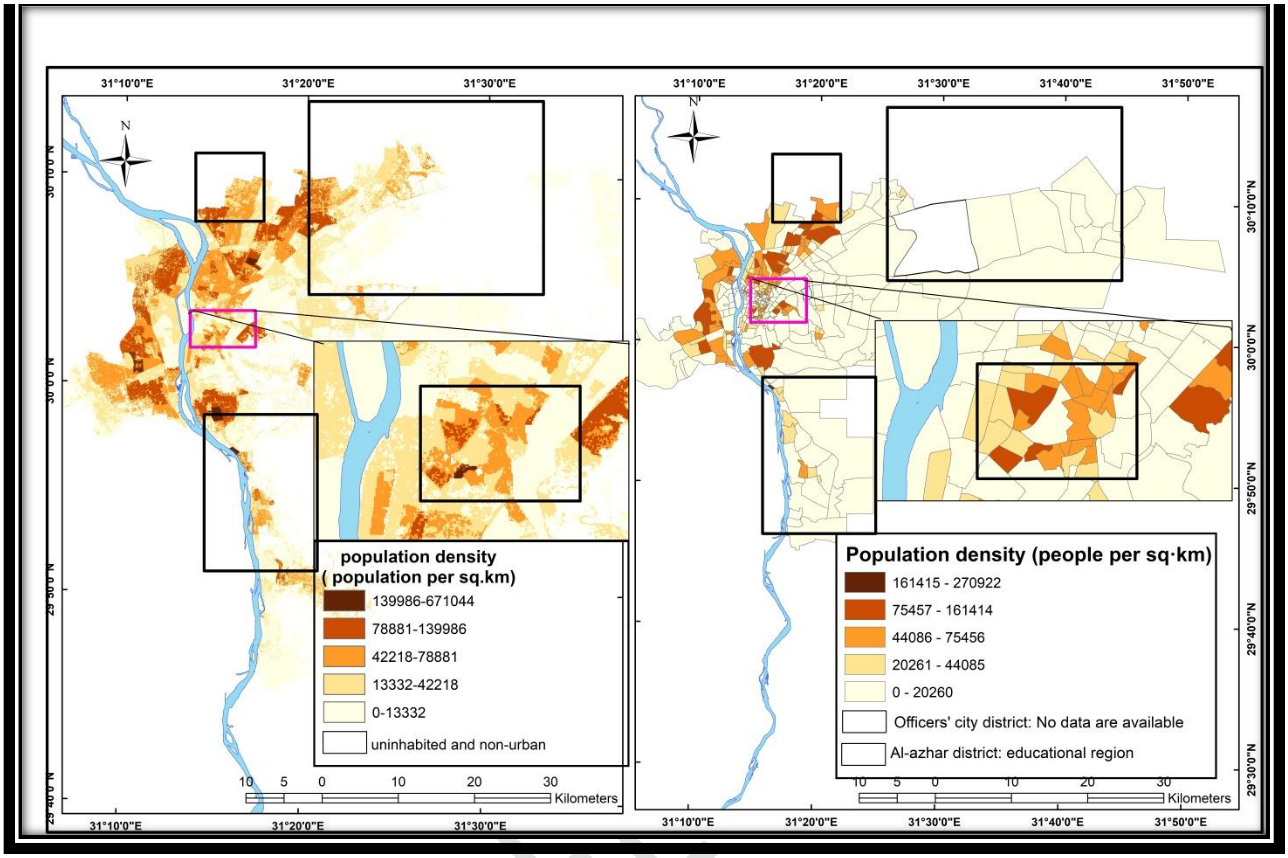

Fig3. Comparison of 2017 choropleth and dasymetric population density results for census tract 15203289[3]. The dasymetric population density that is highlighted represents the northern population of the town of the Greater Cairo Region

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 mapping which contain the minimal values of 20260 population/sq. km.p on the other hand, in dasymetric mapping, 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 mapping 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 mapping, 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.

Figure 3 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, Figure 3 displays a relatively dense population concentration within census tract 15203289[3] 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 .

. A prerequisite to the multi-class dasymetric mapping technique used for this study was the creation of a three-class raster representing high, medium, and low-density urban landcovers, as well as an uninhabited class. All classification tasks were performed in ArcMap using the Spatial Analyst Image Classification toolbar. Following work done by Hammann (2012)[16], a 5-class interactive supervised classification was run for each year to define a set of spectral signatures for subsequent supervised classifications. The resulting supervised classifications were evaluated to identify areas of rural land that may spectrally resemble urban land-covers. the goal of the classification techniques is to determine to which class is belonging each of the pixels in the image, following an approach where the accuracy of the results can be analyzed statistically [17]. High density urban land-cover was defined as downtown areas and central business/commercial districts. Medium density urban land-cover included residential areas (i.e., subdivisions) in close proximity to downtown areas and within their respective city limits. Low density urban land-cover included residential development outside of city limits that generally exhibited isolated development patterns. Unsupervised classification rasters were also used to verify urban training samples as well as to help identify uninhabited land-covers that may be confused for urban land-cover. Additional training samples were collected to identify uninhabited land-cover signatures for agriculture, water, natural areas, and cleared/vacant land.

Table1Supervised classification training samples for each urban density type

Urban Land-Cover Class	**Number of Training Samples**	**Pixel Count**
uninhabited	7	15917
Non-urban	9	2495326

High Density	12	123391
Medium Density	10	170116
Low Density	16	486787

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 1481.323 sq·km; it shows population density values varying between 26841and 270922 inhabitants per sq·km; these values were classed into five classes by using the Jenks method (Table 2 and Figure 4). The dasymetric method gives a better view of population distribution over a given area than conventional choropleth maps [18]. 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 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 (Figure 4). 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 Table 3 and histograms Figure 4 and Figure 5.

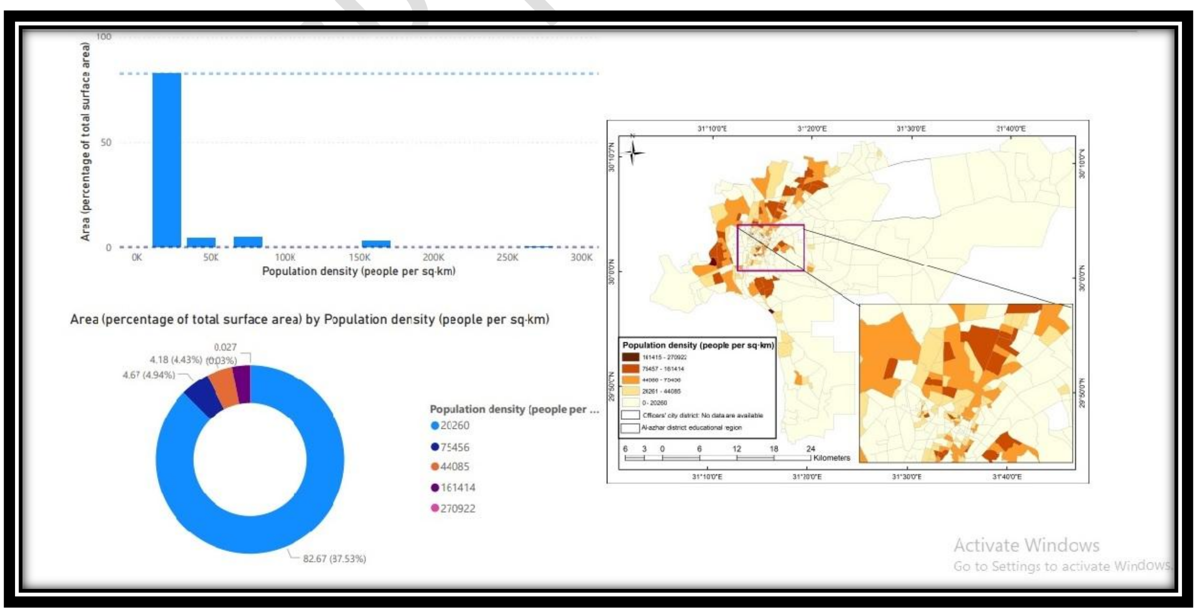

Fig4. choropleth map of the Greater Cairo Region (Natural breaks, Jenks classification).and Graph showing areas related to the different classes of population density in the choropleth map (Natural breaks, Jenks classification

Table 2. 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

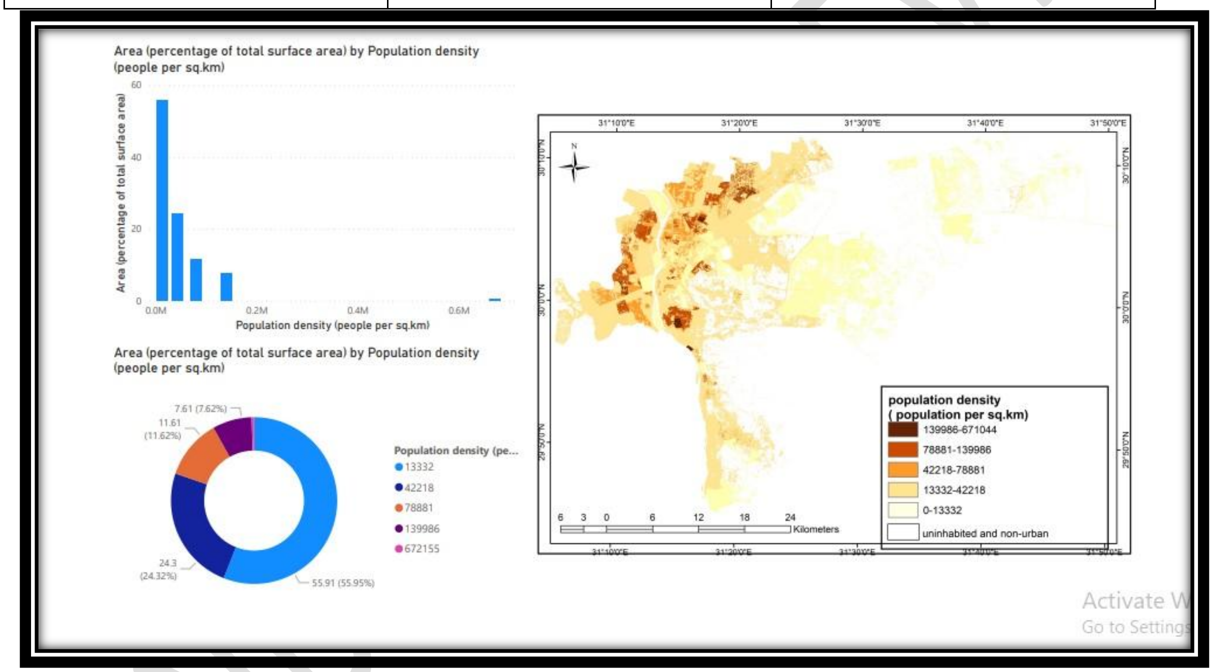

Fig5. Dasymetric map of the Greater Cairo Region (Natural breaks, Jenks classification).and Graph showing areas related to the different classes of population density in the Dasymetric map (Natural breaks, Jenks classification

Table 3. 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

4. CONCLUSION

The primary contribution of this research is the presentation of two different method dasymetric maps and choropleth maps of the Greater Cairo Region departing from population data, satellite image processing and other ancillary data. 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. For that, the method was used: the Natural breaks methods. Now, we know that the Greater Cairo Region has numerous unbuilt spaces or even built spaces that are inhabited. These spaces were deduced from processing the satellite image landsat7 Enhanced Thematic Mapper Plus (30 meters resolution) of the Greater Cairo Region. These images were used to extract the land use types by classifying the image using tools image classification processing in GIS software. The used classification method was interactive supervised classification. The classified images were transferred to the GIS software ESRI ArcGIS under a shapefile vector format. This was essential to add the data related to the number of individuals in the population and those relating to the area of Greater Cairo Region in the fields of the attribute tables. Dasymetric mapping provides a method of combining census data and urban land-cover data to more accurately map population density through aerial interpolation. Comparison of dasymetric population density maps across census years provides a more accurate view than choropleth maps of population density change. 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.

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