



Dasymetric Mapping for Estimating Population in Small Areas

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Abstract

A dasymetric map depicts a statistical surface, most commonly population density, as a set of simply connected regions, such that variation within each region is minimized and the region boundaries approximate the steepest escarpments of the surface. Dasymetric mapping has its roots in early thematic mapping of population, but has recently been taken up by researchers focusing on areal interpolation and population estimation using remote sensing. The process of dasymetric mapping typically involves the disaggregation of population data encoded in choropleth map form using an ancillary spatial data set, most commonly either an area-class map or satellite image. The functional relationship between the ancillary data and the statistical surface being mapped may be specified a priori by the researcher or estimated using a variety of statistical techniques. Challenges facing dasymetric mapping research include handling spatio-temporal data and the development of standardized and accessible methods.

Introduction

Dasymetric mapping is a cartographic technique for the display of statistical surface data, a type of cartographic variable that can be conceptualized and represented as varying continuously over space, as with elevation or temperature (Dent 1999; Robinson 1961). Cartographic representation of statistical surfaces includes isoplethic mapping as well as enumeration by zones. A dasymetric map depicts a statistical surface as a set of simply connected regions, such that variation within each region is minimized and the region boundaries approximate the steepest escarpments of the surface. Thus, the dasymetric map may be considered a means of representing the continuous, but irregular, variation that occurs in the natural world as a set of discrete areal observations for encoding and visualization purposes. This process of discretization from a representation of continuous variation to a set of simply connected regions exploits the property of spatial dependency that statistical surfaces of geographic phenomena typically possess (Goodchild 1992) – locations nearby one another tend to have more similar values than locations farther apart.

A dasymetric map is typically described in contrast to a choropleth map, which also depicts a statistical surface. In a choropleth map, however, the boundaries of the regions are derived from convenience of enumeration, typically from administrative or jurisdictional divisions, and not from the pattern of the surface itself. For example, a map of population density in the USA by county is considered a choropleth map, as the county boundaries may not necessarily reflect abrupt changes in population density, but rather represent the boundaries of political jurisdiction. A dasymetric map of population density in the USA would be composed of regions of relatively uniform population density. The region boundaries would not occur at jurisdictional or political demarcations, but rather at the places where population density changes abruptly, as, for instance, at the transition between urban and rural areas.

Though dasymetric mapping has been an established cartographic technique for over 150 years, its popularity as a topic of research has grown substantially over the past two decades because of its use in developing estimates of population over small areas. Although dasymetric mapping can be applied to the representation of any statistical surface data, such as earth surface elevation or air pressure, research in dasymetric mapping has focused almost exclusively on population, and particularly in disaggregating choropleth population maps to make estimates over small areas for which observational population data are not available.

Obtaining high-resolution population data is difficult in many parts of the world, particularly in less developed countries where the lack of transportation infrastructure and/or characteristics of the terrain make travel more challenging and funds may not be available to support a regular census. Accurate population estimates over small areas are necessary, however, to support a variety of administrative and management functions, including urban and regional planning, economic development, and disaster relief operations (Dobson et al. 2000; NRC 2007). Even in developed nations with well-funded censuses, access to high resolution population data may be restricted due to privacy concerns. For these reasons, dasymetric mapping has been used to estimate population distribution to facilitate a variety of types of analyses, including criminal justice (Poulsen and Kennedy 2004), environmental risk (Maantay et al. 2007; Mennis 2002), public health (Hay et al. 2005), accessibility to social services (Langford and Higgs 2006, Langford et al. 2008), and historical analysis (Gregory and Ell, 2005).

The objective of this article is to provide an overview of dasymetric mapping, including its history and principal methods and techniques. An example dasymetric mapping application is provided using population data for Delaware County, Pennsylvania, USA. Finally, the article offers a summary of the challenges and future developments of dasymetric mapping.

History of Dasymetric Mapping

There has been a great deal of confusion in the recent literature concerning the origins of dasymetric mapping. This is likely due to the diversity of academic backgrounds of those pursuing dasymetric mapping, the long period of relative research inactivity following its invention until the development of technologies that facilitated its application, and the fact that some of its earliest examples, and the term 'dasymetric mapping' itself, were published in Russian geography journals and reports. Thus, the academic roots of dasymetric mapping may be inaccessible to many of its English speaking practitioners. Additionally, the dasymetric approach is perhaps intuitive to anyone seeking to model and map population distribution. Thus, it has been 'reinvented' many times over by researchers who are unaware of its previous incarnations.

Dasymetric mapping is closely associated with mapping human population, and two of the earliest dasymetric maps are congruent with the earliest efforts in population mapping more generally (MacEachren 1979). The 1833 map of world population density created by English geologist George Julius Poulett Scrope is commonly thought to be the earliest example of a dasymetric map (Maantay et al. 2007), though the term 'dasymetric map' had not yet been invented. Just a few years later, in 1837, Henry Drury Harness produced a dasymetric map of the population density of Ireland for the Second Report of the Railway Commissioners (Robinson 1955). While these authors did not claim to use a dasymetric technique specifically, as the term itself had not yet been invented, both of these maps used shading to represent the magnitude of population density, where the regional boundaries of a constant shade do not correspond consistently with administrative boundaries. Thus, they can be considered dasymetric maps.

Many authors have also noted the Russian foundations of dasymetric mapping (Bielecka 2005; Fabrikant 2003; Mennis and Hultgren 2006; Wright 1936). The Russian geographer Benjamin Semenov-Tian-Shansky is credited for coining the term 'dasymetric,' which is intended as a Greek translation of 'density measurement', in a 1911 report to the Russian Geographic Society (Kamenetskiy 1930, as cited in Petrov 2008). The dasymetric mapping approach became widely known in Russia following the population density mapping project of European Russia started in 1923 by Semenov-Tian-Shansky (Petrov 2008). This map, and the dasymetric mapping approach, was introduced to English speakers in a review by Sten de Greer (1926) appearing in the *Geographical Review*, and then 2 years later in the same journal by Semenov-Tian-Shansky himself (1928). In summarizing the recommendations of the US federal government's Science Advisory Board report for managing the nation's natural resources, Joerg (1935) note that dasymetric mapping is preferred over isoplethic mapping for population data. The dasymetric mapping

approach, and its Russian origins, is also described in an influential Russian and German-language edition textbook of the mid-twentieth century (Preobrazenskiy 1954, 1956, as cited in Bielecka 2005; Fabrikant 2003).

Many current dasymeric mapping researchers cite the 1936 *Geographical Review* article by J. K. Wright as a seminal publication in the development of dasymeric mapping. In fact, Wright has occasionally been credited with inventing dasymeric mapping, though he acknowledged the Russian origin of the term 'dasymeric' (Wright, 1936, p. 104). Following Wright's (1936) publication, dasymeric mapping and related topics were given occasional treatment by English-speaking cartographers through the 1980s (Alexander and Zahorchak 1945; Monmonier and Schnell 1984), and was the subject of an influential PhD dissertation by George McCleary (1969). However, the technical difficulty of dasymeric mapping in the pen-and-ink map production environment that predominated prior to the 1980s hindered its widespread use. Consequently, in most cartography textbooks from the 1950s to the present dasymeric mapping is relegated to just a few paragraphs, and typically only as an alternative to the more prominent choropleth map approach (e.g. Dent 1999; Slocum et al. 2003).

Two related technologies helped to transform dasymeric mapping from a somewhat obscure cartographic technique to a much more prominent topic of recent investigation: geographic information systems (GIS) and satellite remote sensing. GIS provides the computational tools to overlay data layers, a necessary procedure for the dasymeric mapping process. Satellite remote sensing provides a large resource of ancillary data necessary to perform dasymeric mapping of population, particularly in the form of classified land cover maps.

Recent scholars in GIS, spatial analysis, and remote sensing are often only partially aware of the cartographic roots of the technique, and this has led to some confusion in terminology. The term 'areal interpolation' is related to dasymeric mapping and has been used by some researchers in place of the term dasymeric mapping. Areal interpolation refers to the transformation of data from one set of zones to another (Goodchild and Lam 1980). Dasymeric mapping research also appears regularly in remote sensing journals, though in many cases it is presented as a remote sensing application and not as a cartographic technique. Confusingly, a number of GIS and remote sensing scholars have used the term 'dasymeric mapping' to describe a particular dasymeric mapping technique referred to as the 'binary' method (described below).

Principles and Definitions

Data encoding a statistical surface may be derived from the measurement of a single thematic variable, where the data values vary continuously over

space, as, for example, with earth surface air temperature. Statistical surface data can also be derived from punctiform data using area-weighted summary statistics of point distributions, as derived from, say, kernel density estimation. For example, the spatial distribution of population may be represented as a statistical surface of population density, where the value at a given point on the surface of the earth represents the population over an area that is centred at that location.

While a dasymetric map depicts a statistical surface by partitioning the surface into a tessellation of non-overlapping regions, the term 'dasymetric mapping' has come to refer to a particular cartographic process by which data in choropleth map form are transformed to a form that better approaches a dasymetric map. The phrase 'better approaches' is used here because the result of dasymetric mapping is typically a disaggregation of the choropleth data to sub-choropleth units. Thus, such a map is not truly dasymetric in the traditional cartographic use of the term, where ideally the region boundaries would be derived solely from the nature of the statistical surface itself. The process of dasymetric mapping assumes that the actual variation of the statistical surface is unknown, but may be estimated from its encoding in a choropleth map.

The process of dasymetric mapping involves the application of ancillary data – additional data distinct from, but related to, the statistical surface. These ancillary data are typically in the form of an area-class map, where the data are nominal and boundaries divide homogeneous areas of categorical membership (Mark and Csillig 1989). The process of dasymetric mapping quantifies the functional relationship between the area-class map data categories and values of the statistical surface as encoded in the choropleth map. The area-class map and choropleth map are typically combined using a polygon overlay operation that yields a set of sub-choropleth, or dasymetric, zones. Note that these dasymetric zones are derived from the intersection among the area-class map and choropleth map zone boundaries, such that each dasymetric zone is perfectly nested within both a choropleth zone and an area-class map zone. Data are redistributed to the dasymetric zones from the choropleth zones based on the functional relationship among the area-class map categories and the statistical surface. The challenge of dasymetric mapping is to accurately quantify this functional relationship.

An important related property of dasymetric maps worth noting is the pycnophylactic property (Tobler 1979). A dasymetric map preserves the pycnophylactic property if the total population of each choropleth zone is preserved in the transformation to a dasymetric map. In other words, the sum of the estimated population of the dasymetric zones that compose a single original choropleth zone should equal the original encoded population of that choropleth zone.

By far the most common form of ancillary data for dasymetric mapping population is land cover data. Many of the early dasymetric mapping

efforts used area-class land cover maps (Wright 1936) or the locations of cities as a proxy for urban versus rural land cover (de Greer 1926). More recent dasymeric mapping and related efforts have followed the same approach, in some cases utilising vector GIS data (Eicher and Brewer 2001). However, the most prominent source of land cover data in most contemporary dasymeric mapping research is satellite imagery, often used as post-processed categorical land cover data in raster format (Langford and Unwin 1994; Wu et al. 2005). Researchers have also used satellite image properties such as image texture for estimating population (Chen 2002; Liu et al. 2006), where the type of residential development, and thus population density, may be captured by a texture metric. For example, the texture of the urban core of a city in the USA, with multi-family housing structures and high population density, may differ markedly from that of the suburbs, with single family homes sitting surrounded by lawns and other vegetation. Other researchers have utilised the spectral values of individual pixels to estimate population (Harvey 2002; Holt et al. 2004; Lo 1995).

Besides land cover data, street network data also have a demonstrated relationship to population and so have been used as an ancillary data set in dasymeric mapping (Mrozinski and Cromley 1999; Xie 1995). For example, the density, or length of street segments per unit area, can be used in place of an area-class map such as land cover, to redistribute population to dasymeric zones (Reibel and Bufalino 2005). Likewise, zoning and other parcel-based information, which typically contain very precise land use information that may be richer in information content than space-based observations, offer ancillary information that is strongly related to population (Maantay et al. 2007). Recently, Langford (2007) suggested the use of easily accessible scanned reference maps as a source of ancillary data for dasymeric mapping, noting that the use of remotely sensed data typically require substantial expertise for pre-processing.

Traditional Cartographic Techniques

Eicher and Brewer (2001) identify three traditional dasymeric mapping techniques rooted in cartography: binary, three-class, and limiting variable. Each of these three techniques quantifies the functional relationship between the ancillary data classes and the statistical surface subjectively using a priori knowledge. The simplest, and perhaps most widely used, dasymeric mapping technique is referred to as the binary method, and was incorporated into J. K. Wright's and Semenov-Tian-Shansky's approaches (de Greer 1926; Wright 1936). Here, an area-class map delineating inhabited and uninhabited regions is used to redistribute data from choropleth map zones, such that the data in the choropleth zones are concentrated solely in the inhabited regions of each zone. In the resulting dasymeric map, the uninhabited portions of the map are assigned zero

data, and the density in the inhabited portion is increased as compared to the data density encoded for the parent choropleth zone. For example, if one assumes that people do not live in areas classified as water, wetlands, or bare ground, population may be excluded from these areas and concentrated in the other land covers.

In the three-class method the functional relationship between the area-class map categories and the statistical surface is quantified on a percentage basis. Each area-class map category is assigned a percentage so that all the category percentages sum to 100%. Data are redistributed within each choropleth zone to the different dasymetric zones that lie within it by simply assigning a percentage of the data in the choropleth zone to each dasymetric zone based on its associated area-class category. For example, in dasymetric mapping population using land cover data, one may assign percentages to each land cover class, where say urban regions are assigned a value of 70%, forests a value of 25% and agriculture a value of 5%. In the dasymetric mapping process, each choropleth zone would redistribute a proportion of its population to the dasymetric zones that lie within it according to the specified percentages. Though the name of the method implies the presence of three area-class categories, the technique can be applied to any number of categories.

The 'limiting variable' method assigns maximum density limits to the area-class map categories. The method was developed by McCleary (1969), though its basic form was used by Harness (Robinson 1955) and Wright (1936), both of whom thought to redistribute population to urbanised areas by limiting population density in rural areas. Through a process of iterative refinement, data are redistributed among the dasymetric zones to meet the maximum density thresholds set for each area-class category. The process begins by distributing the data of a choropleth zone among its component dasymetric zones using areal weighting, a method that distributes data among a set of units in proportion to the area of each unit. If a dasymetric zone exceeds the maximum density set for its associated area-class category, a small amount of the data is redistributed to the adjacent dasymetric zones, provided that such zones do not then exceed their own maximum density thresholds. The process continues iteratively in this manner until each dasymetric zone is below its maximum density threshold.

Statistical Techniques

Researchers in areal interpolation have brought a statistical perspective to dasymetric mapping that seeks to quantify the functional relationship between the ancillary data and choropleth map in a more sophisticated manner than the traditional cartographic approaches. Instead of using a priori knowledge to quantify this relationship, statistical techniques seek to extract this relationship from patterns embedded in the data.

One common approach is to use regression to quantify the relationship between the statistical surface and the area-class map categories (Flowerdew and Green 1989; Flowerdew et al. 1991; Goodchild et al. 1993). The basic form of this approach has been described in the context of areal interpolation, where the transformation of data from one set of choropleth map zones to another set of target zones is facilitated using a third set of 'control' zones, equivalent to the role of the area-class map in conventional dasymeric mapping. Unlike in conventional dasymeric mapping, the target zones for which density are estimated are not necessarily the area of overlap of the choropleth map and area-class map, but an independent zonal scheme. Here, the contributing area of each area-class map category to a choropleth map zone is used to calibrate a regression model whose parameters may then be used to redistribute data from the choropleth map zones to the target zones.

The regression-based approach has been used with remotely sensed land cover data serving as the area-class map, where the contributing pixel counts of different land covers to choropleth zones are used as explanatory variables (Langford et al. 1991; Reibel and Agrawal 2007). The basic regression-based approach has the disadvantage of not meeting the pycnophylactic property, and it is possible for the regression equation to predict a negative population density if the slope intercept is negative. A solution to this problem can be had by simply shifting the intercept to the origin and scaling the estimated density values to fit with the sum of the original choropleth map zone counts so that the pycnophylactic property is preserved (Reibel and Agrawal 2007; Yuan et al. 1997). Further improvements to this approach are suggested by Liu et al. (2008), who improve the accuracy of regression-based population estimates by exploiting spatial dependency in regression residuals of population estimation using area-to-point residual kriging (Kyriakidis, 2004).

Another dasymeric mapping approach is to sample those choropleth map zones associated with a given area-class map category to derive the area-class map category density estimates (Mennis 2003; Mennis and Hultgren 2006; Sleeter and Gould 2007). Here, samples for a particular area-class map category may be drawn from those choropleth zones that fall completely within that category. Or, one may relax the criteria for association by finding those choropleth map zones whose centroid falls within that category. Once a set of samples is acquired, a mean density measure for each area-class map category may be calculated and used to reapportion data within the original choropleth map zones according to the ratio of the area-class map category densities, as with the traditional cartographic three-class technique.

The expectation maximization algorithm (Dempster et al. 1977) has also been employed for dasymeric mapping (Flowerdew and Green 1994; Gregory 2002). This approach is an iterative one which begins by using simple areal weighting to apportion data from the choropleth map zones

to the dasymetric map zones. The next step in the technique estimates the data density for each area-class map category using maximum likelihood. The population of each dasymetric zone is then re-estimated using the new information about the estimated density of each area-class category, maximum likelihood is employed again to estimate the data density for each area-class map category, and so on until the algorithm converges.

A related approach is presented by Mrozinski and Cromley (1999), who propose a dasymetric mapping approach based on a spatial interaction model where dasymetric map zones are represented as cells within a spatial relation matrix. As with the expectation maximization approach described above, an iterative procedure is used to estimate the densities for the dasymetric map zones. Here, however, the density of each dasymetric zone is refined at each iteration as a function of the densities of neighboring dasymetric zones. Another related iterative refinement approach based on satellite imagery is described by Harvey (2002). This technique calibrates a regression model of spectral values on population density using areal weighting to distribute population to inhabited image pixels. The regression model is then refined over a series of iterations by using the parameter estimates to adjust the population assigned to each pixel, recalibrating the regression equation on the new population estimates for each pixel, and so on until convergence. Researchers have also combined iterative approaches with more traditional techniques. For instance, Gregory (2002) and Harvey (2002) used the binary dasymetric mapping technique and areal weighting as the basis for initial calibration of their iterative refinement models.

An Example Application

An example of dasymetric mapping is provided for illustration. Here, population density data from the US Bureau of the Census is disaggregated using pre-processed remotely sensed land cover data. The example focuses on 2000 census tract level population data for Delaware County, Pennsylvania, USA. Delaware County serves as a good case study region for dasymetric mapping because it lies on the urban-rural fringe of the city of Philadelphia, Pennsylvania, USA, a metropolitan area encompassing approximately 5 million people. Delaware County thus contains a wide range of population density values.

Figure 1 shows a conventional choropleth map of population density by tract for Delaware County. Note that higher population densities in the county tend to occur in the east, where the county contains many inner-ring suburbs that lie adjacent to the city of Philadelphia. In the western part of the county, the landscape has more of a rural character, and the population densities tend to be lower. However, even in these more rural areas, there are many small towns within tracts where population

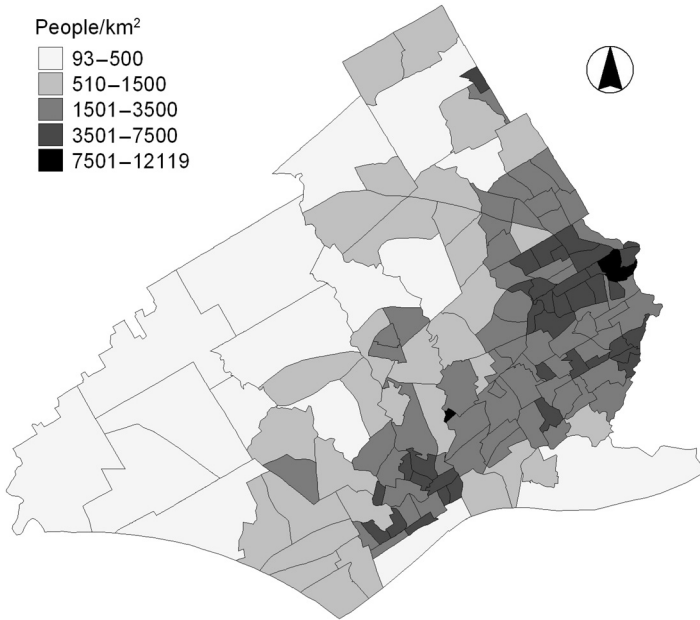


Fig. 1. Choropleth Map of Population density by tract for Delaware County, PA, USA.

densities are relatively high. The dasymetric mapping process will use an area-class map ancillary data set to disaggregate the tract-level choropleth map and generate a dasymetric map that displays the distribution of population more accurately.

The dasymetric mapping algorithm used in this example is described by Mennis (2003) and Mennis and Hultgren (2006). Population data are redistributed to dasymetric map zones based on a combination of areal weighting and the estimated population density of each ancillary class. Consider a choropleth map composed of zones s ; an area-class map composed of zones m , where m is associated with a class c ; and a dasymetric map composed of zones t , where t is an area of overlap of m and s . The basic premise of the dasymetric technique used here can be expressed as

$$\hat{y}_t = y_s \left(\frac{A_t \hat{D}_c}{\sum_{t \in s} (A_t \hat{D}_c)} \right) \quad (1)$$

where \hat{y}_t is the estimated population of dasymetric zone t , y_s is the observed population of choropleth zone s , A is the area, and \hat{D}_c is the estimated population density of class c . The value of \hat{D}_c may be assigned manually by the analyst or it can be derived by sampling those zones s

that can be spatially associated with each class c . This association may be defined by noting which zone s centroids fall within class c . Once a sample of choropleth map zones has been selected as representative of a particular class, the population density of an ancillary class can be calculated as

$$\hat{D}_c = \sum_{s=1}^n y_s / \sum_{s=1}^n A_s \quad (2)$$

where n is the number of sampled choropleth map zones associated with class c .

Research has suggested that substantial non-stationarity may occur in the relationship of the statistical surface to ancillary data, introducing inaccuracy in dasymetric mapping (Langford, 2006). This dasymetric mapping technique also has the ability to account for such non-stationarity, the fact that population density of class c may vary from one location to another. To account for this variation, a third spatial data layer that partitions the area under investigation into regions may be introduced so that \hat{D}_c is calculated individually for each class c within each region. If \hat{D}_c is not set manually nor can an adequate sample be obtained, \hat{D}_c is estimated by using information about the other ancillary classes for which population densities can be determined to make an estimate. Note that this dasymetric mapping method seeks to preserve Tobler's (1979) pycnophylactic property which specifies that the total population contained within an original choropleth map zone remains within the boundaries of that zone following the dasymetric mapping.

The dasymetric mapping technique was implemented as a VBA script that can be run within the GIS software package ArcGIS (Environmental Systems Research Institute, Inc.). The script ingests a header file that specifies path and file names for the input choropleth and area-class maps, as well as user-defined parameters such as the manually set values of \hat{D}_c and preferred sampling strategy. For more information on the details of the technique the reader is referred to Mennis and Hultgren (2006).

The choropleth map ingested into the dasymetric mapping script is the population density by tract map displayed in Figure 1. The area-class map used in the dasymetric mapping is a land cover data set extracted from the National Land Cover Data program administered by the US Geological Survey. The data are derived from 2001 Landsat Enhanced Thematic Mapper Plus (ETM+) imagery and made available as classified 30 meter resolution raster data. These land cover data were preprocessed by passing a focal majority filter over the raster and then transforming the subsequent grid to vector format. The resulting polygon boundary lines were then smoothed (Figure 2).

The dasymetric mapping script was parameterized so that values of zero population density were assigned a priori for agriculture, bare, water, and wetland land covers. While this parameterization may be open to a certain

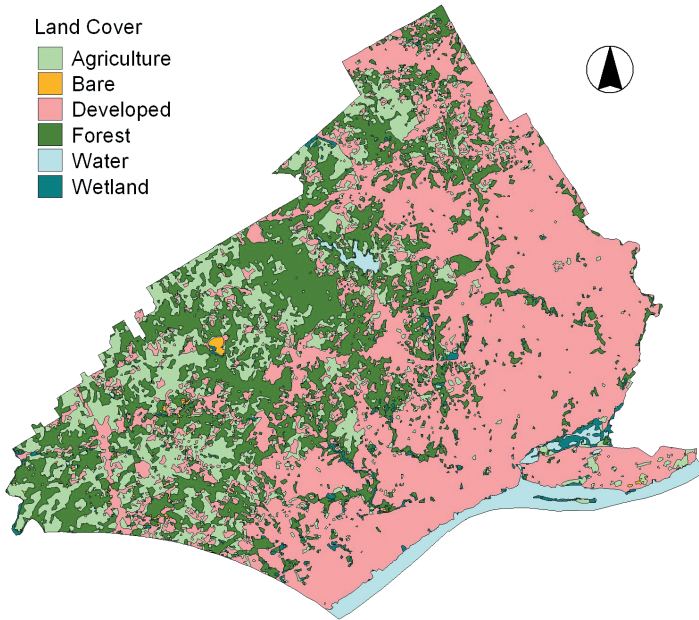


Fig. 2. Land cover for Delaware County, PA, USA.

degree of error – people do in fact live on houseboats and farms, it seeks to capture subjective knowledge about the land cover types within which the vast majority of the population likely reside. The population density for the developed and forest land covers were estimated according to Equations 1 and 2. A regions layer was introduced to account for the fact that the population density of certain classes may vary across the county. For instance, developed areas in the eastern, urban areas adjacent to the city of Philadelphia may have generally higher population densities than developed areas in the west, which may capture small towns or residential subdivisions. The regions layer partitions the county into three regions: urban, suburban, and exurban (Figure 3). These regions were generated by manually categorizing tracts into one of these three regions. The dasymetric script executes Equations 1 and 2 separately for each region.

Figure 4 shows the resulting dasymetric map. Note that the dasymetric map contains significant within-tract variation in population density, particularly in the western part of the county where intermixed forest and agricultural land covers dominate. The distribution of population density for much of the more densely populated far eastern part of the county appears similar to the original choropleth map (Figure 1), as many of these tracts are occupied nearly completely by developed land cover. Note also that a number of tracts in the southeastern part of the county extend into the Delaware River (Figure 2). The dasymetric mapping script takes this

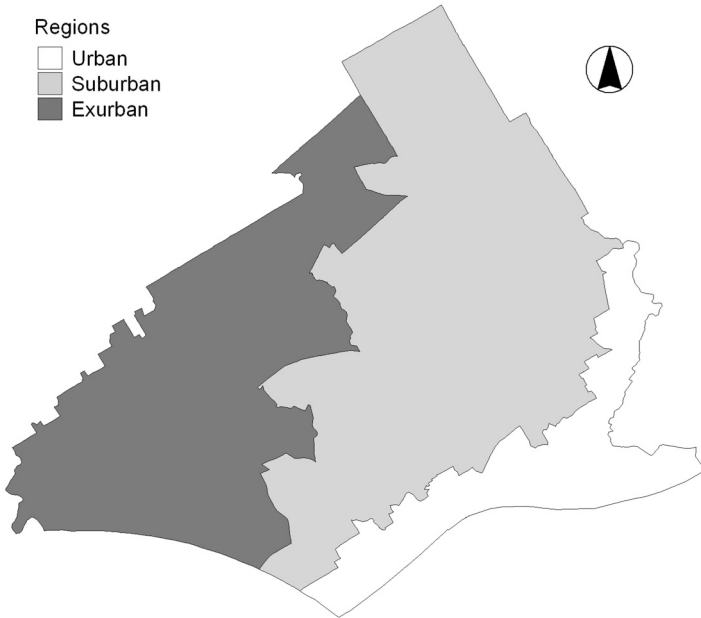


Fig. 3. Region boundaries used in the dasymetric mapping.

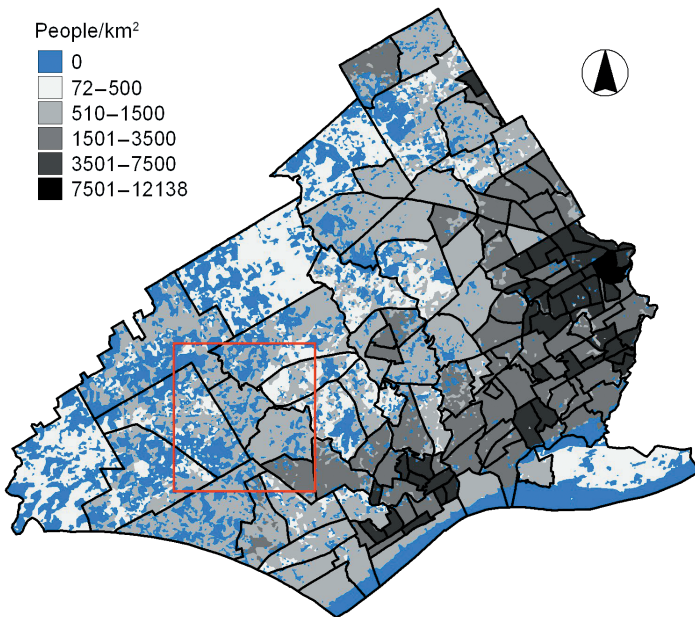


Fig. 4. Results of dasymetric mapping using a preset value of zero population density for agriculture, bare, water, and wetlands land covers. Box outlined in red shows area depicted in Figure 5. Tract boundaries are overlain in bold.

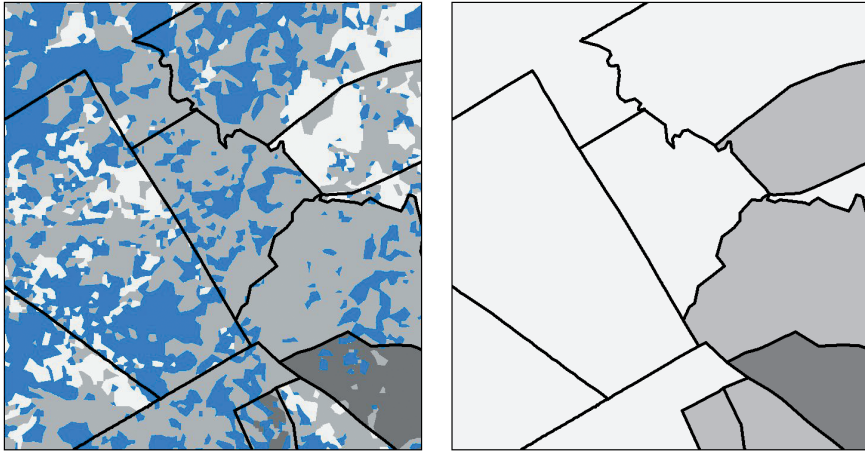


Fig. 5. Close-up of area shown red box in Figure 4: the dasymetric map of population density depicted in Figure 4 (left) and the choropleth map of population density by tract depicted in Figure 1 (right).

into account and redistributes the population into the non-water cover portion of the tract.

A close-up view of the area delineated by the red box in Figure 4 is shown in Figure 5, alongside a comparative view of the same area from the choropleth map of tract-level population density shown in Figure 1. One can clearly see the within-tract variability that the dasymetric map captures in the suburban and exurban regions as compared to the choropleth map. For example, the choropleth map encodes a population density of 287 people/km² for the southwestern-most tract shown in Figure 5, whereas the dasymetric map encodes population densities ranging from 0 people/km²–582 people/km² over the same area.

Conclusion

Several challenges to the continued development of dasymetric mapping can be identified. First, research on the dasymetric mapping of population has focused almost exclusively on modeling residential population. This is because the base source of population data for disaggregation from a choropleth map, or for use in calibrating a model of population distribution using remote sensing, is typically derived from census counts of residential population. However, effective use of dasymetric mapping for applications such as emergency response necessitate modelling population not only at night (when people are typically at home) but also during the day, when people may be at work or leisure. The Landscan project is notable for providing nighttime and daytime dasymetric population map products (Bhaduri et al. 2007), however, these researchers have also noted the

challenge associated with acquiring accurate daytime base population data for parameterizing dasymetric models (Patterson et al. 2007).

The concept of dasymetric mapping is not necessarily limited to the disaggregation of spatial data. The same general idea may be applied to data that are encoded over durations of time, and there are many situations in which it is desirable to disaggregate data not only spatially but also temporally. For example, crime data are often collected such that while the location of a crime may be known, the specific time of the crime's occurrence is not. Consider the case of an automobile theft – while the location of where precisely the car was stolen from may be known, it may only be established that the car was stolen at some time during the night. In situations such as this, it would be advantageous to disaggregate the temporal reference for a crime event from a period of time (i.e. overnight) to a specific time or at least shorter duration (e.g. 2 a.m.–4 a.m.) (Ratcliffe 2000). While dasymetric mapping techniques have been applied almost exclusively to spatial data, the principles of spatial data disaggregation may just as easily be applied to temporal data. For example, the simple division of a 24 hour day into periods of morning, afternoon, evening, and night can provide ancillary information that may be useful in disaggregating temporal crime data, assuming that certain types of crimes tend to occur at certain times of day.

Another challenge concerns the representation of uncertainty in dasymetric maps. The process of dasymetric mapping is one of discretization as well as estimation – a geographic phenomenon that is conceptualized as continuous in nature is represented as a set of discrete entities whose boundaries are estimated according to patterns extracted from observational data. Thus, dasymetric maps always have a certain degree of uncertainty associated with them. While many researchers have used root mean square error and maps of count or percentage errors as a means to assess the relative accuracy of dasymetric mapping techniques they have implemented (e.g. Eicher and Brewer 2001; Gregory 2002; Mennis 2003), this assumes that one has reference data available at a finer spatial resolution than the dasymetric map. Since the purpose of dasymetric mapping is typically to disaggregate data in situations where finer resolution data are not available, alternative representations of data uncertainty must be identified. Mennis and Hultgren (2006) describe a dasymetric mapping technique that produces not only a map but also data that express the nature of the sampling and variance associated with the quantification of the relationship between the ancillary data classes and continuous surface data. Dasymetric mapping using kriging (Kyriakidis et al. 2005) offers similar information, where maps of standard errors may accompany the dasymetric map itself. Field-based methods for validating dasymetric mapping results have been described by Dobson (2007).

Perhaps the biggest challenge to dasymetric mapping research, however, is to develop standardized dasymetric mapping techniques that are accessible

to the general public. Most advances in dasymeric mapping have focused on improvements to statistical approaches or ancillary data products, typically derived from satellite imagery. While these advances have resulted in improved accuracy of dasymeric mapping, the statistical sophistication of the techniques and the expertise required to manipulate and use remotely sensed data have put such methods out of reach for most casual GIS users. Dasymeric mapping algorithms must be made accessible with user-friendly interfaces, either as stand-alone software or as extensions to commercial off-the-shelf GIS software packages, in order to exploit the widely recognized utility of dasymeric mapping for social, health, and policy applications that rely on fine-resolution population estimates.

Short Biography

Jeremy Mennis is an Associate Professor in the Department of Geography and Urban Studies at Temple University. He received a Ph.D. in Geography from Pennsylvania State University in 2001. His research interests are in spatio-temporal data modeling and spatial analysis applications in the social sciences.

Note

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