Analyzing urban population density gradient of Dhaka Metropolitan Area using Geographic Information Systems (GIS) and Census Data

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Abstract

Worldwide increase in urban population draws special attention to urban population density related research. Based on *Thana* level census data for the years 2001 and 2011, this study attempts to analyze the density gradient of urban population in Dhaka Metropolitan Area using Geographic Information Systems (GIS). Four mathematical functions have been considered to examine the change in population density with distance from CBD, after the classical work of Colin Clark in 1951. The density gradient appears to be following the negative exponential function. Result reveals that the density curve flattens over time, indicating greater increase of population density in the areas located further from the CBD than areas adjacent to it. GIS-based surface modeling using density contours shows the spatial pattern of population density has changed substantially. The study further corroborates that historical as well as economic factors are influencing the pattern and change of population density in Dhaka Metropolitan Area (DMA).

Keywords: CBD, density curve, density gradient, Dhaka Metropolitan Area (DMA), Geographic Information Systems (GIS), population density

Introduction

More than fifty percent of global population is now urban and the rate of urbanization has been increasing over time (World Bank and BCAS, 1998; Zaman et al., 2010). However, the rate of urbanization is higher in developing countries than developed ones. On the hand, some developed countries are experiencing disurbanization meaning that people are moving away from the urban core and settling in the periphery (Angeles et al., 2009; Pacione, 2009). As a result, population research in urban areas has been subject of academic research for long. Following Clark's seminal work in 1950s, many researchers across the world have concentrated on urban population density research to demonstrate urbanization, employment structure of city and so on.

The density function approach examines how population density varies with distance from the city centre and what function best characterizes the density pattern (Griffith, 1980). Although major cities and urban places are experiencing rapid population growth since independence, Dhaka being the primate city ranks ninth in the world (World Bank, 2010). Estimation shows that this trend will continue which may result in the rapid conversion of natural land use/cover (Islam, 2005). Unless this spread of urbanization is effectively managed, the existing chaotic conditions and associated problems like environmental degradation, unemployment and rise of criminal activities are likely to multiply (Huda, 2001).

The morphology of Dhaka City, population dynamics, and slum population have been studied by many scholars which can be traced back to 1950. The commercial structure and the central business district (CBD) have also been a focus of urban studies (Nilufar, 2010). However, study on urban population density gradient has been less studied. The study of population density needs more attention as it is related to health, sanitation, housing, social and economic development of a particular city.

This research attempts to model urban population density gradient of Dhaka City using GIS and census data as it might be useful for planners and policy makers for effective management and distribution of resources and facilities.

Objectives of the study

This study attempts to study the density of population in relation to the distance from the Central Business District (CBD). Motijheel has been considered as the central business district of Dhaka City in this context. The major objectives of this study are:

(a) To analyze the population density gradient of Dhaka Metropolitan Area; and
(b) To understand how this density gradient has been changed over time and the factors driving the population change in the Dhaka.

Concept of urban population density

By the term population density gradient, academics mean the change in the density of urban population with distance from Central Business District (CBD). This relationship is normally portrayed in a graph, in which X-axis represents the distance from CBD while Y-axis represents the population density.

Colin Clarke was the first to introduce the concept of population density gradient in 1950s. He found out that the density of population declines exponentially with distance from the CBD. According to his model, urban population density conforms to the empirically derived equation: $d_x= d_o e^{-bx}$*(1)*. Here, d_x is the population density at distance X from the city centre and d_o is the central density, as extrapolated, and b is the density gradient (Clark, 1951).

Tanner (1961) and Sherratt (1960) developed two models independently and reached the same conclusion that the population declines exponentially some distance away from the centre (Northam, 1979).

Newling (1969) proposed another model which adds another significant feature to earlier models i.e the *Density Crater*. He found out that the area immediately adjacent to the CBD has lower density of population which rises some distance away creating a crater in the density gradient curve.

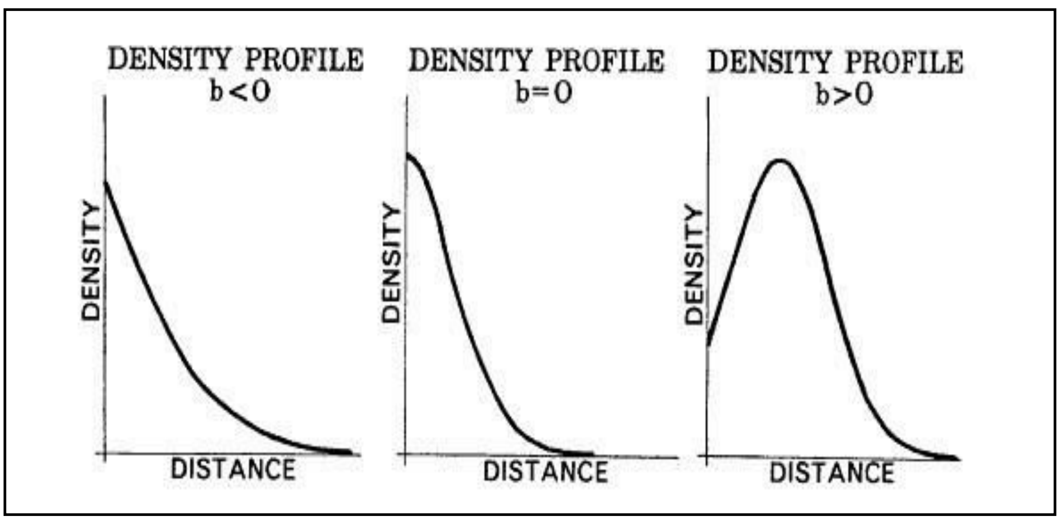

Figure 2. *Density profile at various "b" values (Newling, 1969)*

Figure 2 shows the three types of models. The first one represents Clark's density gradient model. The second one show that the density declines some distance away from the center which is in accordance with Tanner and Sherratt's conclusion and the third one shows Newling's density crater model.

Population density gradient study around the world

A number of researches have been carried out after the pioneering work of Colin Clarke. Winsborough (1961) found out the weakest correlation between density and distance in Chicago, USA during 1860 to 1950. Kramer (1958) shows that the model fits better for net residential densities rather than gross residential densities. Sherratt (1960) fitted a similar model to data for Sydney, Australia. Newling (1969) fitted the Clarke's model satisfactorily for Jamaica. Even in Asia this model was tested in the late 19^{th} century to mid 20^{th} century. The model was fitted for Colombo, Hyderabad, Manila, Rangoon, Singapore, Jakarta, and Tokyo and Calcutta by Tennant (1961).

Griffith (1980) has modeled the population density gradient for Toronto, Canada using volcano model]. His approach was quite different as he assumed a polycentric urban area instead of monocentric city. Small and Song (1994) studied the population density distribution pattern of Los Angeles. They showed that the density gradient declines with time; regression line becomes flatter, indicating greater dispersion with time. They also pointed out that monocentric density function fit better in earlier temporal dimension than recent years. This indicates that density gradients show exponentially at their youth stage, but with time, the exponential nature gradually flattens such as in Los Angeles Quite opposite to the pattern found in westerns capitalist countries, the density functions are found to be positive in socialist countries.

For example, in the absence of efficient land market and misallocation of land occurs in Russia, which results in positive density function (Wang & Meng, 1999) which is opposite to China. McMillan and McDonald (1997) described urban density pattern, resembling a circus tent model of land use with ridges along the major radial arteries and peaks at the key intersections. They found the city of Chicago being bi-centric with multiple additional strong clusters.

For Paris in 2000, the gradient of the density curve was *-0.103*; that is, the density declined by 10.3 percent, on average, as distance from the center increased by one kilometer (Angel et al., 2011). Apart from these works, Corner et al. (2011) used lowest census-tracts data to demonstrate the density gradient change and spatio-temporal distribution of population in Dhaka Megacity. This study also confirms earlier findings carried out in western and socialist countries.

Description of the study area

Dhaka Metropolitan Area (DMA) is located at the central area of Bangladesh. It is bounded by Gazipur to the North, Savar to the West, Keraniganj to the South and Rupganj to the East. It is located between 23.40º North to 23.54º North latitude and 90.20º East to 90.30ºEast longitude. DMA is a police jurisdiction area that comprises of forty one "*Thanas*" (the lowest administrative unit among four administrative tiers of Bangladesh) of DMA with an area of about 300 km^2 (Figure 1). The total population of the study area was 64, 82,875 in 2001 and 89,06,039 in 2011 with an annual growth rate of 3.74 percent (computed from BBS data).

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Figure 1. *Location of study area*

These Thanas have an average area of 7.33 $km^2$with the lowest being only 0.46 $km^2$and the largest being 41.32 km^2. Table 1 shows some basic statistics of the study area and its demographic characteristics. It may be noted that the total number of *thanas* were not the same as it in 2011. However, for simplicity, an aerial distribution function (Mennis, 1999) was used to derive the figures shown in Table 1.

Table 1. Basic statistics of Thanas of Dhaka City

	Area (Km^2)	Population 2001	Density 2001	Population 2011	Density 2011
Minimum	0.458142	5079	899	10626	1881
Maximum	41.33	326201	125943	596835	340826
Total	300.36	6482875	1789198	8906039	2343838
Mean	7.33	158119	43639	217220	57167
Standard Deviation	8.50	83116	33616	137072	5591

Estimated from BBS population censuses (BBS 2003, 2012)

Data and methods

The study is based on secondary data. The population data were collected from BBS population census report of 2001 and BBS population and housing census of 2011. The GIS map was created from the Thana map of Dhaka City available on the internet. Upon heads-up digitizing of *thana* boundaries, a table having unique ID for each *thana* was created in a spreadsheet. Population data for each *thana* was then encoded and finally joined with the *thana* boundary shape files.

For the purpose of distance measurement, centroid of each polygon was derived with “feature to point” option in ArcGIS. Straight line distance from each point (centroids of Thanas) was measured from the point representing Motijheel which has been used taken as CBD of study area. Using field calculator in ArcMap, distance from Motijheel to other *thanas* was estimated.

An attribute table containing total population of each *thana*, density of 2011, 2001 and distance from CBD was exported to a spreadsheet so that mathematical modelling can be formulated. In order to figure out the density gradient of a DMA, a scatter plot was constructed in which the X-axis represented the distance from the CBD and the Y-axis represented the population density. The density gradient has been expressed with mathematical functions. In order to carry out this, the trend line was added for four functions and the Goodness-of-fit test was done to determine the most ideal function representing the density gradient.

Population density gradient in Dhaka Metropolitan Area

A density function can be generalized as: $D_r = f(r)$; where, D_r is the population density at distance r (usually air distance) from the city centre, and f is a function of r. Specifically, four functions were tested: (1) Linear (2) Exponential (3) Logarithmic (4) Polynomial. The results of the tests are presented in Table 2 and Table 3. Table 2 shows the equation and R^2 value by function type for the year 2001. Similarly, Table 3 shows the R^2 values of each function in 2011. Examining the R^2 values of the functions for the year 2001 and 2011 the highest R^2 values are represented by the exponential function (Figure 3 and Figure 4).

Table 2. The fit of various functions for the density gradient in 2001

	Type of Function	Equation	R² value
1	Exponential	y = 93166e-0.18x	R² = 0.477
2	Linear	y = -4789.x + 73793	R² = 0.335
3	Logarithmic	y = -2410ln(x) + 46650	R² = 0.036
4	Second Order Polynomial	$y = 117.1x^2 - 6631.x + 78806$	R² = 0.339

Table 3. Fit of various functions for the density gradient in 2011

Type of Function	Equation	R² value
Exponential	$y = 64416e^{-0.08x}$	R² = 0.113
Linear	y = -2306.x + 71687	R² = 0.028
Logarithmic	y = -2640ln(x) + 60465	R² = 0.015
Second Order Polynomial	$y = -379.2x^2 + 3653.x + 55465$	R² = 0.041

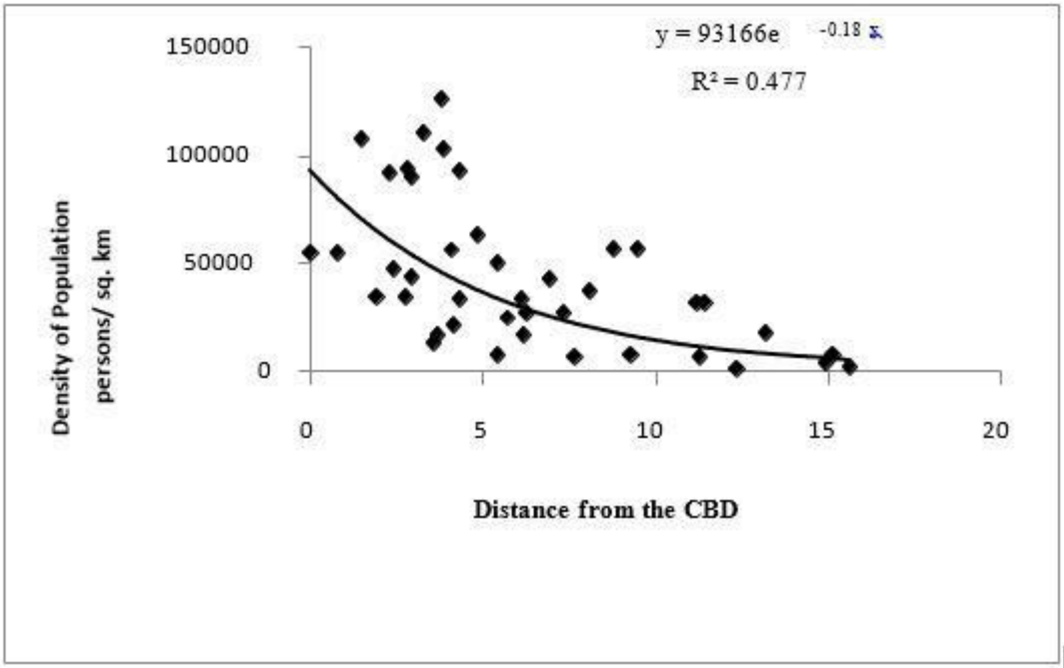

Figure 3. *Exponential functions for population density gradient of Dhaka Metropolitan Area 2001*

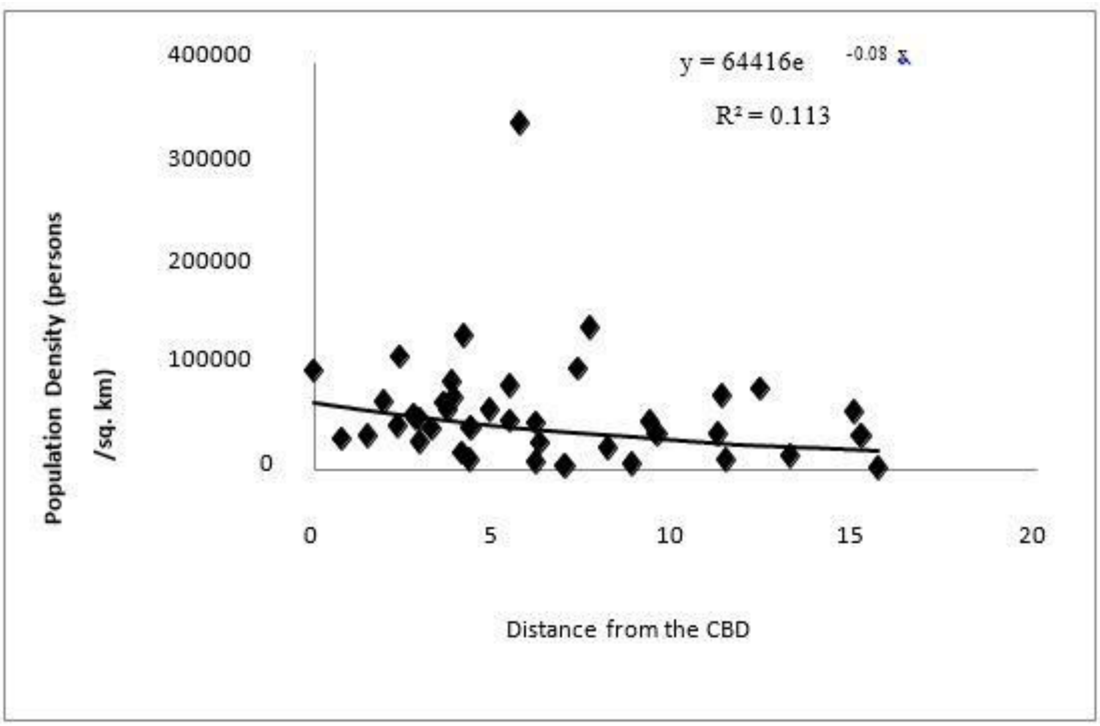

Figure 4. *Exponential functions for population density gradient of Dhaka Metropolitan Area 2011*

The exponential function explains 47.7 percent of the density variation in 2001 while in 2011 it only explains only 11.3 percent. The gradient in terms of b has declined in all four functions, and the city centre intercept has also dropped from 2001 to 2011. In more general terms, it can be said that population density gradient have flattened over time which is in agreement with the previous work in elsewhere(McDonald, 1989, Fonseca and Wong, 2000).From the monocentric model, even the best among the four functions only explains only 47.7 percent of variation of densities in 2001 and 11 percent in 2011. This indicates that the population distribution pattern in DMA is far more complicated than concentric (Nilufar 2010, Siddiqui 2010).

Density surface modeling

Population density can be represented as a three dimensional surface model, thus, eliminating the effect of Modifiable Areal Unit Problem (MAUP) (Openshaw, 1983) and provides a more accurate cartographic representation of population distribution (Openshaw, 1983; Menis, 2008). A population density surface is expressed as $D= f(x, y, z)$; Where, x= longitude, y= latitude and z = population density.

At first, a raster model of population density has been produced using the Inverse Distance Weighting (IDW) interpolation algorithm in GIS. Later the raster model is converted into contours where the population density has been used as z value (Wang & Zhou, 1999).

In 2001, the highest density peaks were found in the older parts of the city, i.e. in Sabujbagh, Gendaria and Tejgaon. The importance of Mirpur, Uttara etc. is not that prominent (Figure 5). But in 2011, Mirpur shows a true peak which can be interpreted as the characteristics of secondary centers (Figure 6).

Figure 5. *Contour Map Representing Population Density of DMA in 2001*

In 2001, the contour line 20,000 passes through Gulshan, but in 2011, the contour dissecting Gulshan stands for 40,000 population per km^2 which indicates population density has been doubled. Mirpur, Pallabi has emerged as distinguishable centers with moderate population densities. Density peaks have steepened and moderate density areas have also been expanded.

Figure 6. *Contour Map showing Population Density of DMA in 2011*

Discussion

Examining the population density gradient of 2001 and 2011 in DMA, several trends have emerged. The mean population density has increased from the year 2001 to 2011. The minimum density value has more than doubled while maximum density value has nearly tripled. Among the four functions tested, the exponential model fits better than the others although the fitting power has dropped over time which is in agreement with previous work (Wang & Meng, 1999).The density gradient curve has flattened over time. Population density contour map reveals several peaks (New Market, Mirpur etc.) which have steepened over time. The presence of these peaks indicates the multi-centered nature of DMA (Islam & Adnan, 2011). A number of factors is considered to act behind the pattern of density gradient and its change over time. These include, improvements in transportation and communication (Fonseca & Wong, 2000), land market dynamics, historical footprint etc. Transport and communication lines provide opportunity to people to live far away from city center, thus flattening the density curve. Land market influences the intensity of land use. Higher land value near the city center encourages smaller areas to accommodate huge number of people and functions (Khan, 1972; Akter, 2007) while further from the center, decreasing land value allows larger parcels of land being owned by single owners, and thus, decreasing the density of people and functions (Berry et al., 1963).

Another factor could be the new emerging commercial centers of DMA. Developers have been intensifying land use by building high rise buildings in the peripheral areas. The provision of better roads, planned structure and housing facilities have been attracting people and function and creating other important centers in Dhaka City such as Uttara (Wang & Meng, 1999; Nilufar, 2010; Siddiqui et al., 2010). People are attracted to city center simply because of its accessibility. According to a popular saying in China,*"Prefer a bed in the central city than a house in suburbia"* (Wang & Guldmann, 1996). Dhaka gravitates people from all over the country due to its metropolitan characteristics, employment opportunities, education and health facilities.

One study conducted by Begum (1999) revealed economic reasons contribute 46 percent behind rural to urban migration, these migrants prefer to stay close to their workplace which is the commercial center. Thus, high density but low class residential structures are found around the commercial core areas of Dhaka City (Begum, 1999). Another important factor of Dhaka's population density pattern is the historical development of Dhaka. The older part of Dhaka is located in the Southern part which developed long before the Northern part, and it is still developing vertically rather than horizontally due to lack of residential spaces (Khatun, 2003). These densely populated *Thanas* of old Dhaka lie close to the CBD and contributes to the steep density profile near the city center.

Conclusions

The study is aimed at analyzing the population density gradient in DMA. Its population density pattern reflects the influence of its history, culture, land-market and commercial values of certain areas. Although it is a city of third world country, it has certain similarities with developed countries cities as far as the population density concerns. Density gradually decreases with distance from the CBD meaning that it conforms to the negative exponential model. However, with time, the change of population density per unit distance, i.e., the gradient has declined. From this trend, it can be inferred that the gradient will be flatter with time with more or less uniform density throughout DMA. Otherwise, a more complex population density pattern may arise which requires further study.

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