Correlation of Human Activities with Population and GDP in Chinese Cities

—Based on the Data of DMSP-OLS

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Abstract- **Intensive activities occur in urban areas with economic factors and population agglomerating near cities. This paper sets up the connection between the light brightness with DMSP-OLS images and the combined factors of population and gross domestic product (GDP) with an allometric model at the scale of prefecture-level cities in China. LS regression results show that economic factors predict human activities more than population factors do. It implies that mega cities with compact urban areas are most effective for human urban activities.**

Keywords- Human Activities; GDP; Population; DMSP; Allometric Model; Correlation

I. INTRODUCTION

Human being's activities are the result of social and economic development especially those intensive activities occur in urban areas with economic factors and population agglomerating near cities. However, there is no valid indicator to describe the intensiveness of human activities. Night light measured by Remote Sensing has been an important data source for urban context studies because it is objective, available in real time, low in cost and may be easily integrated with spatial data. Particularly, the brightness data of nocturnal light from the Defence Meteorological Satellite Program (DMSP) Operational Line-Scan System (OLS) (DMSP-OLS) provide the possibility for evaluating the density of human activities. Nevertheless, previous studies have analysed the relationships of nocturnal light with size and density of population as well as with that of GDP separately. Though the results of them have shown significant relationships, it is still difficult to define the accurate effects of population and GDP combined upon human activities. In fact, the size and density of population and GDP together determine the growth of cities. Further, the combination of the factors indicates the properties of urban areas. China represents about one-fifth of the world's population and its economy has been growing at staggering rates for over three decades. Chinese cities have higher population densities than many other countries. Therefore, the analysis on the relationships between population plus GDP and nocturnal light in Chinese cities will present an innovative application of Remote Sensing technique.

II. LITERATURE REVIEW

Since nightlight remote sensing images were adopted to estimate human settlement in the 1970s, there have been two major categories for this application. One was to estimate the population density and size, especially explicit population spatial distribution with relationship between population factors and the light brightness, especially explicit population spatial distribution, and the other one was to analyse the industrial structure with the relationship between Gross Domestic Products (GDP) and the light brightness values.

The studies of population estimation approach mainly discussed the possibility to estimate population distribution with remote sensing images. Night light images from the DMSP had also been used to map human settlements (Elvidge Baugh, Kihn, Kroehl and Davis, 1997) and urban extent (Imhoff, Lawrence, Stutzer and Elvidge, 1997), and to estimate population nationwide and worldwide (Welch, 1980; Sutton, 1997 and 2001; Lo, 2001) since the late 1990s. The former studies concluded that lighted areas presented a linear relationship between light brightness and population size values at the level of R^2 = 0.85, where the outliers were countries with poor economies. This approach just separated the population settlement areas from non-human areas and the lit areas from non-lit areas. Even the results showed a good relation between the night time light values and population areas, it is difficult to display the relation between these two factors from intensity perspective.

The use of sub-national data allowed for the analysis of within-country differences of the radiance-GDP relationship (Doll, Peter Muller and Morley, 2006). Sutton and Costanza (2002) looked for a possible correlation between a DMSP-OLS dataset and a modified form of GDP values and achieved an R^2 value of 0.86. Elvidge, Baugh, Kihn, Kroehl and Davis (1997) also concluded that lighted areas were linearly correlated with GDP at the level of R^2 = 0.97. Their results suggested a strong relation between economic activities and the night-light imagery. This indicates that GDP is also one significant factor to determine human activities. However, the studies above failed to further display the influence of GDP size and density of human activities from the viewpoint of intensity respectively.

Most results of the previous studies showed the estimation approach at global, provincial and county levels, which covered both lit and non-lit areas. Doll, Peter Muller and Morley (2006) mapped regional economic activities from the DMSP-OLS dataset within the United States and Western Europe at various scales. Strong correlations at aggregate scales were also found to exist in the relation between the DMSP-OLS night-time satellite imagery and human population density in the United States (Sutton, Robert, Elvidge and Baugh, 2001), China (Zhuo et al., 2009) and Australia (Townsend, 2010). However, the differences between lit areas and non-lit areas had been hidden in these studies. The approaches above often omitted the areas with small proportional settlements such as towns and villages and overestimated urban extents. This resulted in information loss of spatial patterns. Though the previous studies also indicate that extremely high or low population density is difficult to be estimated using remotely sensed data (Lo, 1995; Harvey, 2008) due to the errors with too bright or dark areas, there is still a problem to resolve: the blooming. The reality is that the brightest areas are located at the centre of a city, and the dark areas imply rural areas around the city. Hence, if the scale is larger than the urban area, the result will be over estimated; or if the scale is smaller than the urban area, the result will be underestimated. Lo (2001) compared the results among province, county and city levels, and concluded that at city level the allometric growth model had been successfully applied to estimate urban population.

Consequently, areas with administrative boundary of cities have the medium scale, and within the area of a city, there is relatively similar light brightness, as well as similar properties of population and economic elements. Therefore, size of a city area is suitable for defining brightness area.

The work of this paper will try to indicate the night time light brightness as human activities and set up the connection between the light brightness and the combination of population and GDP with an allometric model in order to find the intensities of the population and economic factors impacting on human activities at the scale of prefecture-level cities in China. Finally, the author will compare the effects of population and GDP on human activities with their size and density identities.

III. METHODOLOGY

A. Modelling

A city is a comprehensive region with integrated features. Many scholars have provided enough evidences that there is an allometric relation between the integrated features and each individual feature during urban evolution (Nordbeck, 1971; Lee, 1989). According to the allometric model, the function with a single dependent variable has been set up. However, there are various factors that determine the agglomeration, which result in the intensive human activities. Among the factors, population and economic ones are the most important with the identities of size and density. Alternatively, the essence of human activities lies in the agglomeration of population and economic factors together. Hence, the relation function between the human activities and city's factors with the allometric model will be set up as the following:

$$Humanactivity = \eta Population^{\alpha} GDP^{\beta} \quad (1)$$

Where η is the coefficient, α and β are the power coefficients of allometric growth respectively. The effects of size and density are different for the city: the former indicates urban scale identity and the latter denotes the urbanization quality property. Since human activity intensity will be presented by night time light brightness, the functions of size and density of the two factors will be set up respectively.

$$Brightness = \eta Populationsize^{\alpha} GDPsize^{\beta} \quad (2)$$

$$Brightness = \eta Populationdensity^{\alpha} GDPdensity^{\beta} \quad (3)$$

The power coefficients between the values of night-time brightness and population size and density, economy size and density will be calculated with the functions above. The results can also be used to explain the relations between human activities and city factors.

B. Technique

DMSP-OLS method will be adopted to acquire the images of night time light. The DMSP-OLS acquires broadband visible-near infrared image data with a nominal spatial resolution of 1.0 km. Two wavebands of the sensor can be used to detect lights by using the visible/ near infrared waveband (0.4–1.1mm) for the lights and the thermal infrared (10.5–12.6 mm) band to filter out clouds (which are colder than the land surface). Making a night-time pass typically between 20:30 and 21:30 each night, night-time light emissions have been recorded and composted over time to create an annual composite image of average intensity (digital number recorded at the sensor).

Owing to that lit areas present urban lands, it is necessary to define the boundary of each city. In China, one city has its administrative boundary with attributes and census category. In order to match city attributes with the spatial data set, light brightness is also needed to be defined at the same boundaries as city administrative ones. The OLS sensor is at least 4 orders of magnitude more sensitive to VNIR than other satellite systems. Due to this sensitivity, the smallest light source can saturate a pixel. In order to offset the blooming effect, average value of brightness within the area of administrative boundary of each city will be adopted to be the indicator of brightness instead of the light volume value in urban areas which is indicated by mean value of digital number (DN).

C. Data Set

The data of night light brightness values are plotted into 30 arc second grids, spanning -180 to 180 degrees longitude and -65 to 75 degrees latitude. A number of constraints are used to select the highest quality data for entry into the composites. Sunlight data, as well as glare data are excluded based on the solar elevation angles while moonlight data are excluded based on solar elevation angles. Moonlight data are excluded based on a calculation of lunar luminance. Observations with clouds are excluded based on the clouds identified with the OLS thermal band data and NCEP surface temperature grids. Lighting features from the aurora have been excluded in the northern hemisphere on an orbit-by-orbit manner using visual inspection.

The DMSP-OLS data of China for this study are average intensity lights which are composite of cloud-free radiance-calibrated low-light data obtained in 2009 by DMSP with F16 satellite. The pixel is a digital number in byte format with a series of saturated values of 0 to 63. There are 225 cities with valid values of DMSP-OLS imagery data. Nightlight distribution of the whole of China is shown in Fig. 1.

Fig. 1 Nightlight distribution of China in 2009

Fig. 1 shows that cities in eastern China have lighter brightness that the inner cities. Along the coast areas of China, areas of north-eastern cities group, Bohai rim cities group, Yangtze River Delta cities group, as well as Pearl River Delta cities group occupied are the most lit areas. The other parts of China are much darker due to the many rural areas locating over there. It indicates that the lit areas and the cities distributions are matching each other.

The vector data of urban areas are obtained from China Administrative Regions GIS Data Centre with a scale of 1:4000000. And the projection of the vector data is Lambert. With support of ArcGIS software, urban areas from administrative boundaries will be extracted. Population and GDP data of the 255 cities at the year of 2009 are obtained from China City Statistical Yearbook (2010). Distributions of population and GDP density values with an equal area classification method of ArcView software are shown in Figs. 2, 3.

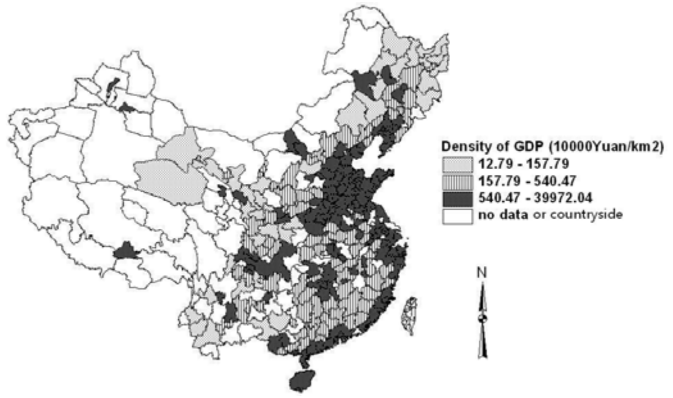

Fig. 2 Population density distribution of Chinese cities in 2009

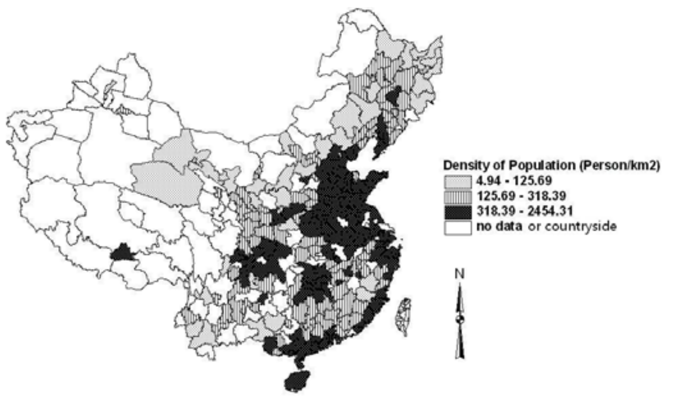

Fig. 3 GDP density distribution of Chinese cities in 2009

The three figures above show that the highest values of lightness are all distributed along coast areas, the medium and the lowest values are next to the highest ones orderly and, most western areas are countryside or have no data. The three figures display a good match in spatial locations thereby reflecting the spatial distribution relations among the three elements. It indicates that there are relations among the brightness of night time light, population and GDP. Based on the reality logistics that human being made light, GDP is produced by human beings, it is easy to have the conclusion that population and GDP which are conducted by human beings affect the brightness of light.

D. Data Processing

Geographic coordinating projection of DMSP-OLS data is Geo-graphic (Lat/lon) with spheroid WSG-84. While projection of the vector data of urban areas is Lambert. In order to capture the DMSP-OLS data of urban boundaries with the vector data, it is necessary to convert the projections of the two kinds of data to be a consistent mapping system. With the Zonal Statistics tool of ArcGIS 9.3, statistic calculations for each city area have been defined by a city dataset based on values from the dataset (a value raster) of cities boundary. The mean values of light brightness for each city will be calculated by Zone Fill tool of the software.

IV. REGRESSION ANALYSIS

According to the Functions (2) and (3), the relations between the variables can be described as the functions as follows:

$$\ln DN = \ln \eta + \partial \ln P_s + \beta \ln GDP_s + u \quad (4)$$

$$\ln DN = \ln \eta + \partial \ln P_d + \beta \ln GDP_d + u \quad (5)$$

Functions (4) and (5) indicate that there are relations between light values and population as well as GDP with size and density criteria respectively. The criteria of GDP and population, which are independent variables, impact light brightness, which is the dependent variable. With the data shown above, descriptions about the variables with logarithmic values are shown in Table Ⅰ.

Among relations studies, regression analysis is a popular method to be used for estimating the relation extent. It is valid for finding the statistic low by observing amount of atmosphere about the variables. Least Squares (LS) method has been involved for calculating the coefficients popularly for long time. With Least Squares (LS) calculation, the regression results are shown in Table Ⅱ.

TABLE I DESCRIPTION ABOUT THE VARIABLES FOR REGRESSION

Variable	Observation Number	Mean Value	S.D. Value	Minimum Value	Maximum Value
DN	255	1.064	1.414	-4.605	3.898
GDP Size	255	15.817	0.911	13.538	18.735
Population Size	255	5.859	0.707	2.923	8.089
GDP Density	255	6.532	1.245	2.548	10.596
Population Density	255	5.784	0.857	1.597	7.806

Data source: China City Statistic Yearbook (2010); unit of GDP size is 10000 Yuan (RMB); Unit of population size is 10000 people; Unit of GDP density is 10000 Yuan (RMB)/km^2; unit of population density is Person/km^2.

TABLE II RESULTS OF REGRESSION WITH LS

	Variable	Coefficient	T-Value	P-Value
Function (4)	Constant	-5.7818***	-3.8172	0.0002
	Ps	-0.1159	-0.7489	0.4546
	GDPs	0.4758***	0.1201	0.0001
	R^2	0.0752		
Function (5)	Constant	-2.3696***	-4.2266	0.0000
	Pd	0.3050*	1.8115	0.0713
	GDPd	0.2556**	2.2056	0.0283
	R^2	0.1535		

Note: *** means significant at 1% level; ** means significant at 5% level; * means significant at 10% level.

Table II shows that between size variables at Function (4), the coefficient for GDP size is 0.4758 at the significant level of 1%. It indicates that every 1% growth of GDP size results in 0.4758% increase of light brightness. The coefficient for population size is -0.1159 but has no significance. It indicates that population size growth has no significant effects on light brightness at 10% level. Between density variables at Function (5), the coefficient for population density is 0.3050 at the significant level of 10%. It indicates that every 1% growth of population density results in 0.3050% increase of light brightness. The coefficient for GDP density is 0.2556 at the significant level of 5%. It indicates that every 1% growth of GDP density results in 0.2556% increase of light brightness. Values of R^2 are low due to the spatial data with different economic structures of the cities instead of temporary data. But it still indicates the strong effects of GDP size and density and, population density factors on human activities.

Table II also indicates that night time light brightness is significantly impacted by size of GDP, densities of GDP and population. Alternatively, human activities are determined by the combination of population and economy densities or economy size other than population size.

V. CONCLUSIONS AND IMPLICATIONS

Results above show that night light measured by Remote Sensing can also indicate the intensity of human activities with values of brightness besides defining the lit areas from the non-lit areas. Particularly, the brightness value is valid to indicate the distribution of human activities in urban areas.

The effects of the two combined factors on human activities can be described simultaneously by an allometric model. Between size variables, economic one has a more significant impact on human activities than population one; between density variables, both population and economic ones have significant effects. It is displayed that economic factors affect human activities more than population factors do. When the lit areas are denoted to estimate urban areas, it is disturbed by economic factors.

The significant effects from population density and GDP size also imply that mega cities with compact urban areas have more effects for human activities than smaller cities. Therefore, city sprawl with less density of human activities might reduce the service growth. Furthermore, it might be negative for service sector agglomeration near central parts of the cities.

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