COMPARISON BETWEEN NIGHTTIME LIGHT AND SOCIOECONOMIC INDICATORS ON AN INTERNATIONAL SCALE USING VIIRS DAY-NIGHT BAND

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ABSTRACT: Observation of nighttime light is the representative method for monitoring human activities using satellite remote sensing. The Visible Infrared Imaging Radiometer Suite (VIIRS) sensor on the Suomi National Polar-orbiting Partnership (NPP) Satellite observes nighttime light at higher spatial resolution and with higher radiometric accuracy than the Defense Meteorological Satellite Program's Operational Linescan System (DMSP-OLS), and it increased the potential to utilize nighttime light data for urban monitoring. This study aims to evaluate the ability of the VIIRS nighttime light data to estimate socioeconomic indicators on an international scale. Firstly, the VIIRS nighttime light data is corrected by combining with the DMSP data for removing lights attributed to ephemeral events, and the total nighttime light (TNL) is calculated for each country. Then the TNL is compared with six indicators; GDP, population, electric power consumption, energy use, total road network and motor vehicles. As a result, the determinant coefficient (R^2) value between the TNL and GDP is 0.88 and this is almost the same value as that of the previous study in provincial units in China. The R^2 value between the TNL and electric power consumption is 0.81, which is smaller than that in provincial unit of China. This result shows the electricity use efficiency differed from country to country. The R^2 value of the TNL and population is 0.61, and the TNL values in developing regions are overall small for their population and those in developed regions are overall large for their population. This result is considered to show that as the economy grows, the lights emitted per person become bright. The R^2 value between the TNL and total road network is 0.69, and the R^2 value between the TNL and motor vehicles is 0.91. It is found that the TNL has a very good performance in estimating the number of motor vehicles.

1. INTRODUCTION

Socioeconomic data is important to understand the countries in the world, and performing an economic census is a representative method to collect such data. However, an economic census is difficult to perform especially in developing countries, and even in some countries where economic census data is available, the data reliability is considered to be poor. Therefore, it is desired to establish a method to estimate economic data that is independent from an economic census.

Traditionally, the observation of nighttime light is the representative method for estimate socioeconomic indicators using satellite remote sensing (Doll *et al.*, 2006) (Elvidge *et al.*, 1997). The Defense Meteorological Satellite Program's Operational Linescan System (DMSP-OLS) had been the only sensor to observe nighttime light until the advent of the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor on the Suomi National Polar-orbiting Partnership (NPP) Satellite launched in 2011.

There has been several studies using the VIIRS DNB for estimating socioeconomic indicators. Li *et al.* performed an evaluation on the VIIRS nighttime light imagery in modeling gross regional product (GRP) through analyzing 31 provincial regions and 393 county regions in China. They found that the VIIRS data is more predictable for the GRP than those of the DMSP data (Li *et al.*, 2013). Shi *et al.* improved the method by Li *et al.*, and modeled GDP and electric power consumption at multiple scales through a case study of China. Their study revealed the VIIRS data could be a powerful tool for modeling socioeconomic indicators. These two studies are the same in that they are targeting in China, and there has still not been reported the potential of the VIIRS nighttime light for modeling socioeconomic indicators in an international scale.

The objective of this study is comparing the VIIRS nighttime light and socioeconomic indicators in an international scale and evaluating the ability of the VIIRS nighttime light imagery to modeling human activities.

2. DATA AND METHODOLOGY

2.1 The flowchart of this study

Figure 1 shows the flowchart of this study. Two types of nighttime light data and statistical data from World Bank are used. VIIRS DNB data is corrected by combining with DMSP-OLS data, and generated corrected nighttime light data is summed up for each country. The total nighttime light (TNL) is compared various data.

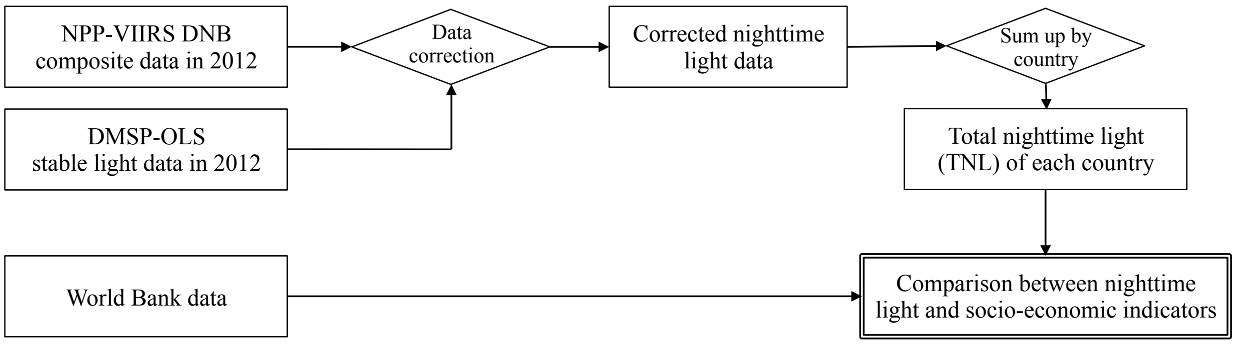


Figure 1. The flowchart of this study. Two types of nighttime light data and statistical data from World Bank are used.

2.2 Data sources

2.2.1 VIIRS nighttime light data: The composite VIIRS nighttime light data of the year 2012 were obtained from website of NOAA/NGDC (http://ngdc.noaa.gov/eog/viirs/download_viirs_ntl.html) (Baugh *et al.*, 2013). In this data, the original radiance values have been multiplied by a billion and thus the units are nano-Watts/(cm2*sr). This product has not been filtered to remove light detections associated with fires, gas flares, volcanoes or aurora. Also, the background noise has not been subtracted (NOAA, 2013).

2.2.2 DMSP nighttime light data: Three types of the DMSP data are available: the stable light data, the cloud-free coverage, and the data with no further filtering. Among these data, the stable light data contain lights from cities, towns and other sites with persistent lighting, and have removed ephemeral events (e.g., fires, gas flares, volcanoes and background noise) (Shi *et al.*, 2014). The DMSP stable light data of the year 2012 (Baugh *et al.*, 2010) (NOAA, 2012) is used in this study.

2.2.3 World Bank data: The World Bank Open Data (World Bank, 2014) provides many kinds of data about development in countries around the world and they can be accessed freely through the Web. Among these data, GDP, population, electric power consumption, energy use, total road network and motor vehicles (including cars, buses, and freight vehicles, and not including two-wheelers) are used in this study.

2.3 Correction of the VIIRS nighttime light data

As already mentioned, the original VIIRS nighttime light data contains lights from ephemeral events and background noise. There are some methods of removing those confounding factors in previous studies.

Li *et al.* used a hypothesis that the lit areas in 2010 and 2012 are the same, and generated a mask with all positive value pixels from the DMSP imagery in 2010 and multiplied the VIIRS imagery by the mask to derive a denoised nighttime light imagery (Li *et al.*, 2013). Based on this method by Li *et al.*, Shi *et al.* used the more up-to-date DMSP data of the year 2012, and they preserved the values of the extracted pixels in 2012 VIIRS data while Li *et al.* multiplied them by the extracted pixels from the DMSP data image (Shi *et al.*, 2014).

In this study, the method by Shi *et al.* is adopted and the correction method is applied on a global scale while the studies by Li *et al.* and Shi *et al.* are targeted at China.

3. RESULTS AND DISCUSSION

3.1 Result of noise reduction

As a result of noise reduction, the background noise was almost completely reduced. Figure 1 shows the original data of VIIRS DNB, and Figure 2 shows an image after noise reduction.

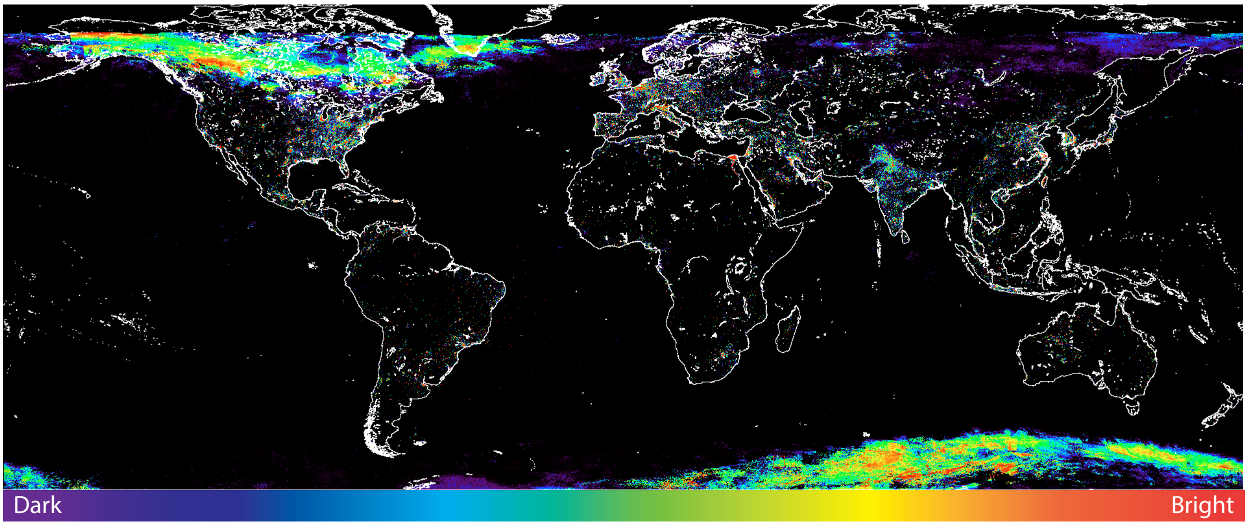


Figure 2. The original imagery of the VIIRS day-night band. The widespread high value in North America and Russia is attributed to aurora.

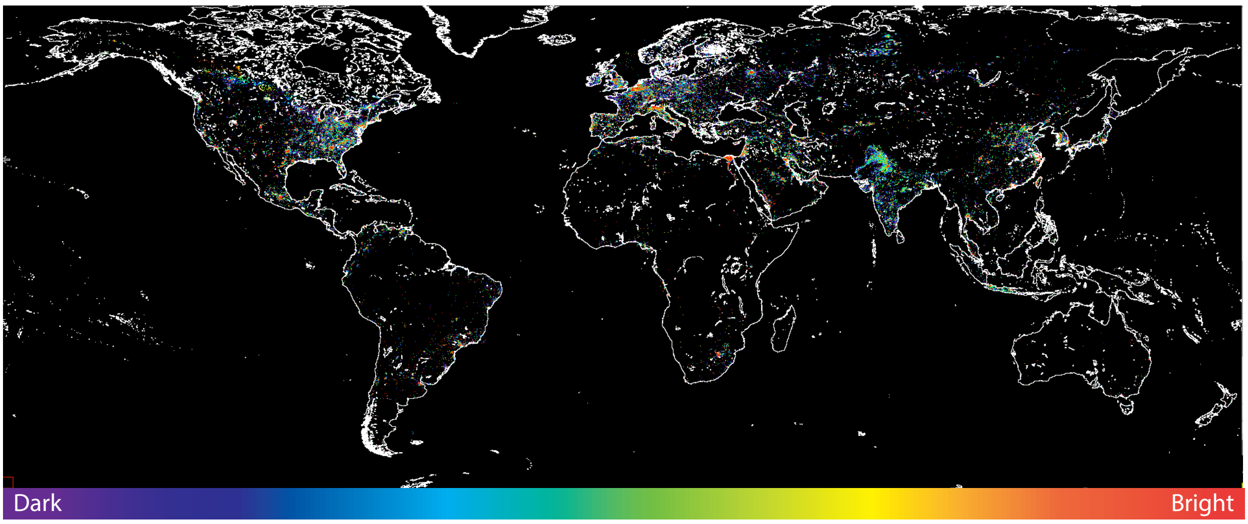


Figure 3. The corrected imagery of the VIIRS day-night band with the method by Shi *et al*. The high value attributed to aurora is almost completely removed.

3.2 Total nighttime light for each country

By using the corrected nighttime light data and country boundary data, the total nighttime light (TNL) for each country was calculated. Table 1 showed countries with high TNL value. United States has the largest TNL in the world, followed by populous countries including China and India or countries with large area including Russia and Brazil.

Table 1. Countries with high total nighttime light (TNL) value.

Country	TNL	Country	TNL	Country	TNL
United States	107207	France	12066	Japan	6711
China	40135	Mexico	11569	Poland	6107
Russian Federation	39414	Spain	10833	Kazakhstan	5476
Brazil	22383	Venezuela, RB	9214	Netherlands	5375
India	20844	Argentina	9206	South Africa	4235
Canada	16127	Egypt, Arab Rep.	8937	Korea, Rep.	4207
Saudi Arabia	15692	United Kingdom	8039	Libya	3995
Iran, Islamic Rep.	14713	Algeria	7579	Pakistan	3469
Italy	12687	Germany	7317	Indonesia	3361
Iraq	12255	Turkey	7314	Finland	3360

[$kW \cdot Sr^{-1}$]

3.3 Comparison between TNL and socioeconomic indicators

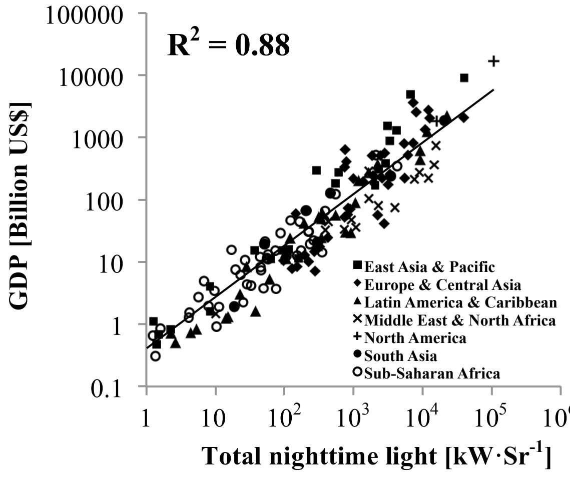
The TNL for each country was compared with six kinds of socioeconomic indicators: GDP, population, electric power consumption, energy use, total road network and motor vehicles (including cars, buses, and freight vehicles, and not including two-wheelers). Figure 4 showed the regional scatter plot and linear regression analysis for the six data.

The R^2 value of the TNL and GDP was 0.88 (Figure 4a). Shi *et al.* reported that in provincial units in China, the R^2 value of the TNL of the corrected VIIRS data was 0.8702 (Shi *et al.*, 2014), and it was found that the R^2 value of the TNL and GDP was almost the same in the cases between in China and on an international scale.

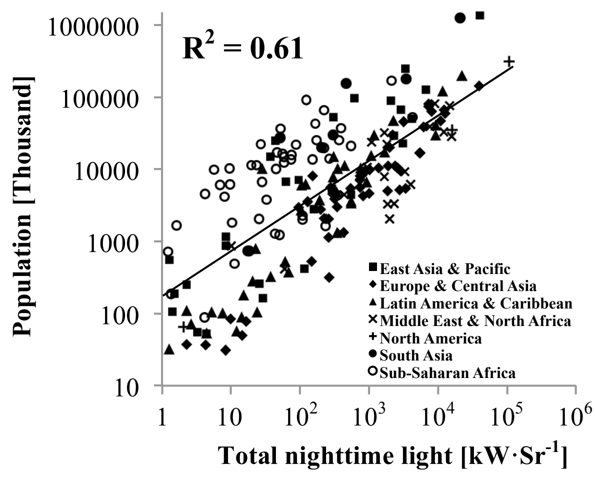
The R^2 value of the TNL and population was 0.61 (Figure 4b), and this is the smallest value among the six indicators. This result showed the number of people was not always proportional to the brightness and the proportion differed from country to country. Figure 4b showed the TNL values in South Asia and Sub-Saharan Africa, which were developing regions, were overall small for their population. On the other hand, those of Europe & Central Asia and Middle East & North Africa, which were developed regions, were overall large for their population. This was considered to show that as the economy grew, the lights emitted per person became bright.

The R^2 value of the TNL and electric power consumption was 0.81 (Figure 4c). Shi *et al.* reported that in provincial units in China, the R^2 value of the TNL of the corrected VIIRS data was 0.8961 (Shi *et al.*, 2014), and it was found that the R^2 value of the TNL and GDP on an international scale was smaller than that in provincial unit of China. This result showed the electricity efficiency differed from country to country. The R^2 value of the TNL and energy use was 0.77 (Figure 4d).

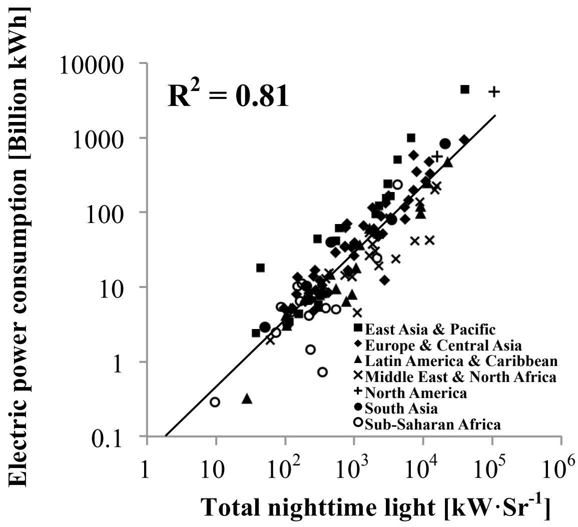
On the hypothesis that the nighttime light is mainly emitted from roads, the indicators related with road were also compared with the TNL. In the result, the R^2 value of the TNL and total road network was 0.69 (Figure 4e), and the R^2 value of the TNL and motor vehicles was 0.91 (Figure 4f). It was found that the TNL had a very good performance in estimating the number of motor vehicles. It was unclear that the lights from motor vehicles were directly observed from the satellite, and therefore an additional inspection would be necessary to confirm this.



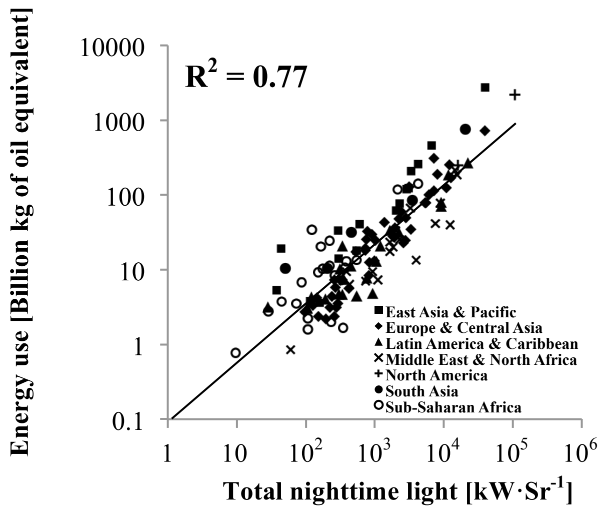
(**a**) TNL and GDP



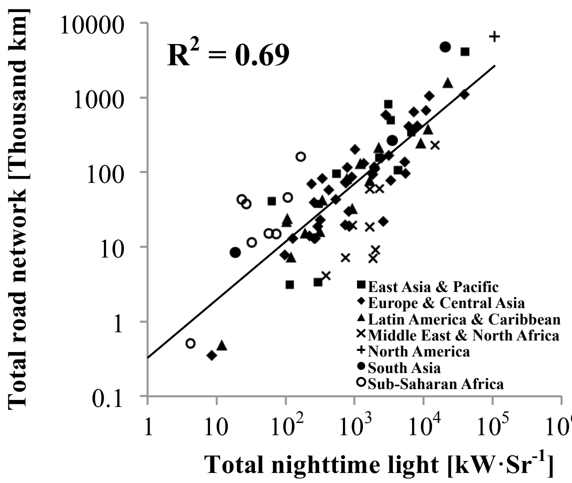
(**b**) TNL and population



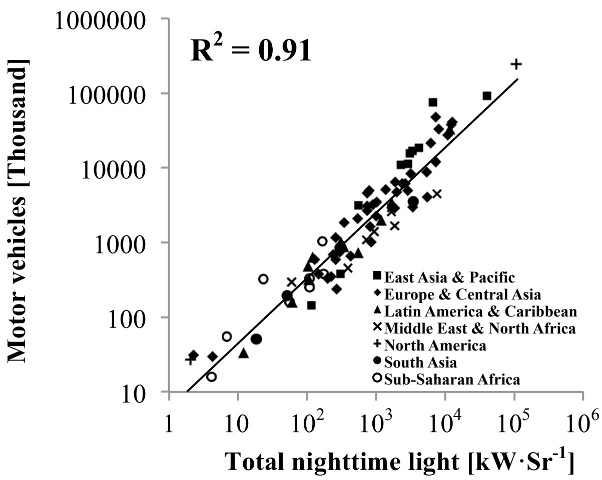
(**c**) TNL and electric power consumption



(**d**) TNL and energy use



(**e**) TNL and total road network



(**f**) TNL and motor vehicles

Figure 4. The regional scatter plot between TNL and each socioeconomic data: (**a**) the total nighttime light (TNL) and the GDP; (**b**) the TNL and the population; (**c**) the TNL and the electric power consumption; (**d**) the TNL and the energy use; (**e**) the TNL and the total road network; (**f**) the TNL and the motor vehicles.

4. CONCLUSION AND FUTURE WORKS

The VIIRS day-night band has a higher spatial resolution and a wider radiometric detection range compared with the DMSP, and it increases the potential to utilize the nighttime light data for estimating socioeconomic indicators. However, the VIIRS nighttime light data includes lights from ephemeral events and background noise, which are unnecessary to estimate socioeconomic indicators. To remove those confounding factors, the DMSP data is combined with the VIIRS data for masking in this study. As a result the unnecessary light, especially the light attributed to aurora in North America and Russia, is removed on a global scale.

Based on the corrected nighttime light data, the total nighttime light (TNL) is calculated by each country and it is compared with following six indicators; GDP, population, electric power consumption, energy use, total road network and motor vehicles. As a result, the R^2 value of the TNL and GDP was 0.88413 and this is almost same value as that of the previous study in provincial units in China. The R^2 value of the TNL and electric power consumption was 0.81182, which is smaller than that in provincial unit of China. This result shows the electricity efficiency differed from country to country.

The R^2 value of the TNL and population is 0.61, and this result shows the number of people is not always proportional to the brightness and the proportion differs from country to country. The TNL values in developing regions are overall small for their population and those in developed regions are overall large for their population, and this result is considered to show that as the economy grows, the lights emitted per person become bright.

In addition, on the hypothesis that the nighttime light is mainly emitted from roads, the indicators related with road are also compared with the TNL. In the result, the R^2 value of the TNL and total road network was 0.68517, and the R^2 value of the TNL and motor vehicles was 0.91035. It was found that the TNL had a very good performance in estimating the number of motor vehicles. However, since it was still unclear that the lights from motor vehicles were directly observed from the satellite, an additional inspection would be necessary to confirm this.

Our next step will be a dynamic monitoring of socioeconomic indicators with nighttime light. Using the VIIRS data obtained every day, a yearly transition of nighttime light can be observed at some areas. By analyzing the transition, population flows in the event of disasters, trips or homecoming visits could be detected from nighttime light. In addition, by observing how nighttime light changes in the event of floods and forest fires, the possibility of disaster detection by nighttime light will be investigated in the future.

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