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Steel Stock Estimation for Building and Civil Construction by Satellite Image

Feng-Chi Hsu [1,*], Christopher. D. Elvidge [2], Yasunari Matsuno [1],

1 Graduate School of Materials Engineering, The University of Tokyo
2 National Oceanic and Atmospheric Administration

E-Mails: david@mfa.t.u-tokyo.ac.jp; Chris.Elvidge@noaa.gov ; matsuno@material.t.u-tokyo.ac.jp;

* Corresponding author. Graduate School of Engineering, Department of Materials Engineering, the University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-8656, Japan; Tel.: +81-3-5841-8652; Fax: +81-3-5841-1282

Abstract: Steel is the most widely used metal in the world. Many studies analyzing the flow and stock of steels have been conducted for Japan, Asian countries and the world. While top-down and bottom-up approaches have been used in these material flow and stock analyses, the applicability of these approaches is dependent on data availability. To overcome this problem, we proposed a methodology to estimate steel stock based on satellite images. Previous studies have shown that satellite images of nighttime lights are closely correlated with human activities, such as electricity consumption, CO_2 emissions, and GDP, which can also be linked to the amount of steel stock. In this study, images of nighttime lights were used in conjunction with land cover data to estimate the building and civil construction steel stock in Japan and other Asian countries. Analysis was first performed for each prefecture in Japan, and then the results were applied to China, South Korea and Taiwan. Building steel stock was highly correlated with urban nighttime lights, while the steel stock used for civil construction structures correlated more closely with total nighttime lights. This work is considered as revised version of the authors' previous study by updating some of the nighttime light data.

Keywords: Building, Construction, Material flow analysis, Nighttime light, Steel stock

1. Introduction

From the viewpoint of controlling global warming and preserving natural resources, it is necessary to recycle materials from products used in human society and utilize them as secondary resources. To this end, analyses of flows and stocks of materials on a global scale are essential, and extensive material flow analyses (MFA) have been conducted since around 2000 [1)].

Annual crude steel production had exceeded 1.3 billion ton in 2008, and steel stock was estimated to be around 30 billion ton [2)]. This made steel the most consumed metal of all kinds. Especially, the steel used in buildings and civil constructions comprises the largest stock due to their long life spans of the structure [3)]. Moreover, previous study showed that the need for steel shows signs of leveling off in developed countries [4)]. On the other hand, developing countries such as China and India are still growing rapidly and will continue to consume large amount of steel. Therefore, in order to establish a society with an environmentally sound material cycle, it is necessary to investigate the consumption, flow and stock of steels used in building and civil construction on a global scale.

Material flow analysis (MFA) has been used to characterize flow and stock of materials within national and continental boundaries. The method used for estimating material stocks in a society can be divided into two types: 1) the top-down approach, and 2) the bottom-up approach. The top-down approach is a method used to calculate material stocks by using annual time series statistical data for material production and lifetime distributions of end-use products in a society. On the other hand, in the bottom-up approach, the number of products within a specified boundary is quantified. Then, the material intensities of the products are multiplied by the number of products so as to give an estimate of material stocks[5)]. Both methods require reliable data for the target region and are dependent on data availability, which can be conducted for some developed countries. Consequently, in MFA on a global scale, most studies have only been able to show material flows for a single year. Therefore, the objective of this study is to develop a methodology for estimating steel stocks based on satellite images in order to overcome data accessibility restrictions.

2. Methods

This study used nighttime light image to estimate the steel stock in buildings and civil engineering. Previous study showed that there is strong correlation between nighttime lights and power consumption and economical activities (GDP) [6]. Recent study by Takahashi et al. also showed that there is strong correlation between nighttime light and copper stock [7]. Based on these results, this study uses nighttime lights as a proxy to steel stock estimation. In addition, this study uses nighttime light images in conjunction with land cover images to correlate nighttime light radiance with the amount of steel stock in each land cover category. This method is based on the hypothesis that the radiance of nighttime lights in urban areas represents the urbanization of those regions, which is correlated with the amount of steel stock used in buildings.

In this study, we focused on countries in Asia where statistical data and results for with statistical data and results for in-use stock of steel by previous studies are available, i.e. Japan, China, South Korea and Taiwan [4]. We first analyzed the steel stocks in buildings and civil engineering structures in each prefecture in Japan, where many detailed statistical data are available. The correlation between the steel stocks and the radiance of nighttime lights obtained by satellite images was analyzed. Then, the results were applied to China, South Korea and Taiwan to estimate the steel stock by nighttime lights, the results of which were compared with those obtained by previous studies with statistical data.

This article is an extended study of the authors' previous work [8] by updating the nighttime light image to the latest version. Moreover, the data of previous work for the four Asian countries were also updated by the data obtained from Hatayama et al [9]. These updates are crucial for future studies, their details are elucidated in the following sections.

2.1. Nighttime light data preparation

The nighttime light images produced by NOAA (The National Oceanic and Atmospheric Administration) [10] were used for this study. Traditional nighttime light images had the problem of being saturated in the urban centers, where the brightness overwhelmed the detection limit of the gain setting. To solve this problem, this study used new series of images in which images taken under three different gain settings were merged based on the method proposed by Elvidge et al. [11]. The image used in this study is the latest version released by June, 2010, which was

made from the data collected within 28/11/2005 to 24/12/2006. Its coverage is from 75º N to 65º S with resolution of 30 arc seconds. This version of nighttime light image geo-registered with LandScan 2008, and is considered to be the most precise product in present. Nighttime light used in this study was processed by latest algorithm with profound improvement on merging images taken under different gain settings compared to the one utilized by previous study. Thus resolution in city centers, which we care the most, is enhanced.

2.2. Global Land Cover by National Mapping Organizations (GLCNMO)

The land cover data used in this study were Global Land Cover by National Mapping Organizations (GLCNMO) distributed by International Steering Committee for Global Mapping (ISCGM) [12)]. They cover the globe with the same resolution with the nighttime light data explained in 2.1. They were produced based on 16 days MODIS images collected in year 2003, and categorized the land cover into 20 categories.

2.3. Steel stock data

In this study, the data about building and civil engineering steel stock for each prefecture in Japan were obtained from Kakiuchi et al [4)]. Whereas, these data for the four Asian countries, i.e. Japan, China, Korea, Taiwan were updated by using the results from Hatayama et al. [8)]. Hatayama et al. includes steel stock data for 42 countries, thus this update is taken as a preliminary test of adaptively for the methodology, which will lead to future global scale analysis.

3. Results

3.1. Building steel stock and nighttime light

The total nighttime light was calculated by integrating the nighttime light radiance within each Japanese prefecture. Then, the building steel stocks in each Japanese prefecture were compared with the total nighttime light. The result showed positive correlation between building steel stock and total nighttime light as illustrated in Figure 1. However, it also shows a tendency of larger variance toward axial direction. Moreover, the steel stock is relatively smaller in Hokkaido than expected from the sum of nighttime lights, while it is relatively larger in Tokyo,

Kanagawa and Osaka. Hokkaido is a typical agricultural area while the other three are some of the most populated areas in Japan. This gives us a clue of introducing parameters of urbanization to describe this difference.

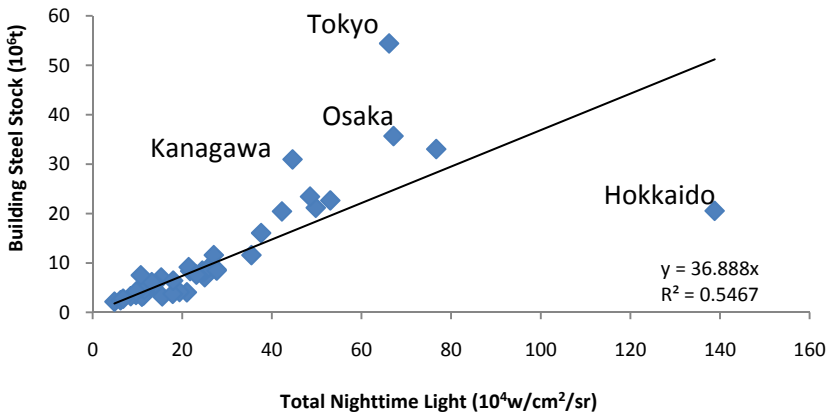

Figure 1. Linear Regression of building steel stock and total Nighttime light for each Japan prefecture

Next, the land cover image was used in conjunction with the nighttime light image to identify the land coverage of those areas where the nighttime lights were observed. The comparison of nighttime lights and land cover in Nagoya area is shown in Figure 2 as an example.

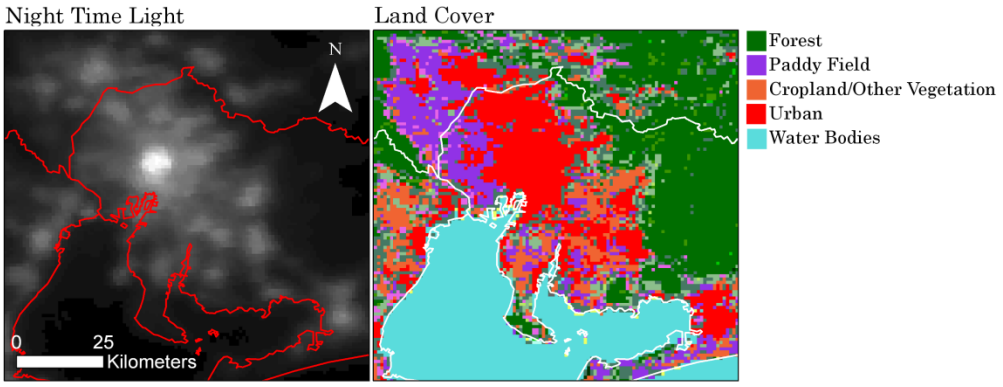

Figure 2. Example of Nighttime light and land cover for Nagoya

In order to quantify the results, we analyzed the proportion of the nighttime lights for each land cover category in Hokkaido, Tokyo, Kanagawa, Osaka, and determined the average

proportion of all the other prefectures as shown in Figure 3. The result indicated that the proportion of nighttime light emitted from croplands was 20% higher than the average in Hokkaido. Conversely, the proportions of nighttime lights in urban areas were 45% to 65% higher than the average for Tokyo, Kanagawa and Osaka. It was assumed that the steel stock in buildings is likely to be larger in urban areas than in agricultural areas, which means the steel stock might only be correlated to nighttime lights in urban areas and not to light in agricultural areas.

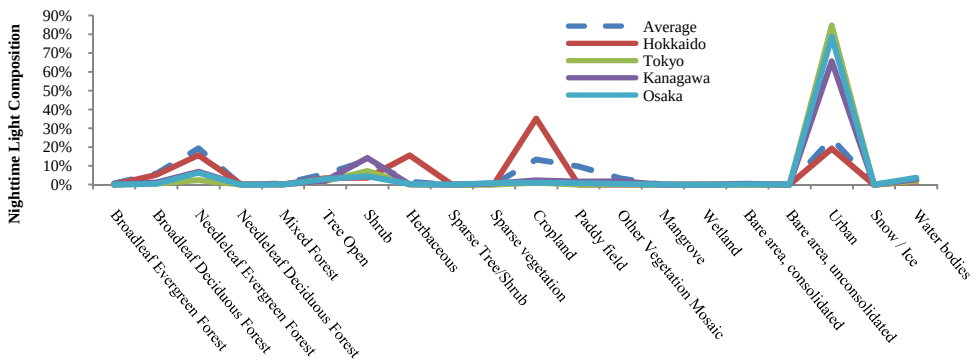

Figure 3. Comparison of Nighttime light composition for Hokkaido, Tokyo, Kanagawa and Osaka

Therefore, using land cover data, the radiance of nighttime light data in urban areas were extracted for each prefecture in Japan and summed. Figure 4 shows the result of building steel stock regressed with urban nighttime lights. As a result, the R^2 value shows a significant improvement compared to the one from regressing total nighttime light with building steel stock.

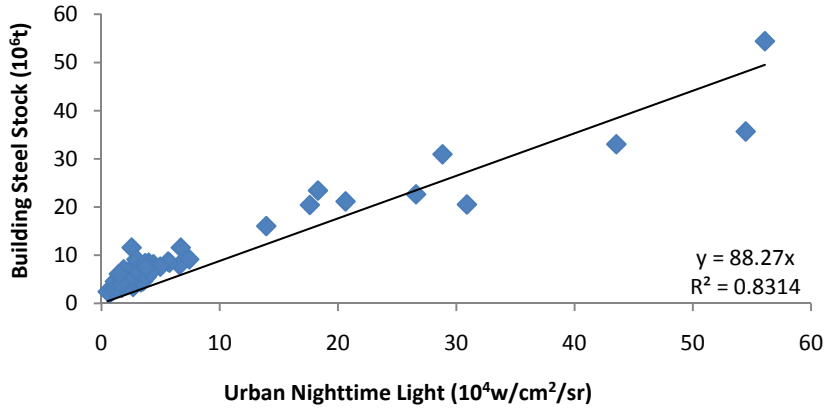

Figure 4. Linear regression of building steel stock and urban Nighttime light for each Japan prefecture.

3.2. Civil engineering Steel Stock and Nighttime light

The correlation of civil engineering steel stock and total nighttime light was also investigated for each prefecture in Japan. Its result is shown in Figure 5, which shows that, similar to the results obtained for building steel stock, the dispersion increases in the axial direction. However, when the civil engineering steel stock was regressed with urban nighttime light, the R^2 value got even worse to 0.4405. Same as the regression result for building steel stock, the result seems to be slightly improved for civil engineering steel stock by updating nighttime light image.

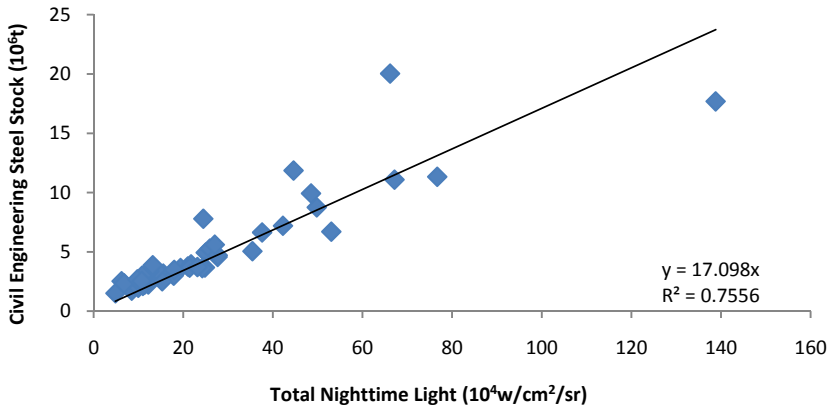

Figure 5. Linear regression of civil engineering steel stock and total Nighttime light for each Japan prefecture.

3.3. The Building Steel Stock of Japan, China, South Korea and Taiwan

The regression results were then applied to four chosen Asian countries to estimate their steel stock. The estimated results were compared with values calculated using statistical data, which were obtained from previous works by Kakiuchi et al [4)] and Hatayama et al. [9)]. The results are displayed in Table 1. From both tables, we can see that there are some discrepancies between the values derived from nighttime images and statistical data (i.e. previous work). Further work is required to analyze the source of the differences in detail. One of the reasons for these differences may be attributable to the cultural variance between countries, which, for instance, can be the form of building styles, etc.

Table 1

The result of estimated value compared with previous work. (Discrepancies are calculated with previous work by Hatayama et al. [9] as the base.)

	Taiwan	S. Korea	China	Japan	Unit
Buildings Steel Stock					
Estimated	52.88	122.23	759.50	371.53	10^6 ton
Previous Work (Hatayama et al.)	131.26	187.60	675.15	454.25	10^6 ton
Discrepancy	57%	35%	12%	18%	
Civil engineering Steel Stock					
Estimated	28.11	89.76	549.52	211.75	10^6 ton
Previous Work (Hatayama et al.)	42.75	82.42	542.23	295.52	10^6 ton
Discrepancy	34%	9%	1%	28%	

4. Conclusions

This study attempted to establish a methodology to estimate steel stock in building and civil engineering in four Asian countries based on linear regressions of steel stock against nighttime lights in the different prefectures in Japan. Since building steel stock was more closely correlated with urban nighttime lights than with total nighttime lights, including land cover data is effective in improving the estimation. Conversely, the civil engineering steel stock showed higher correlation with total nighttime lights. Taken together, these findings indicate that the building steel stock mostly exists in urban area, where most of the inhabitants reside, while civil engineering steel stocks are spread throughout the land cover categories.

Nevertheless, the values obtained when the results of linear regression analysis for nighttime light and steel stock in Japan were applied to four Asian countries differed markedly from the results obtained in previous studies. The examples of the reasons for these differences may be attributable to the cultural variance, or different level of development between countries, which requires further study.

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