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Estimating in-use steel stock of civil engineering and building in China by nighttime light image

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

1 Graduate School of Materials Engineering, The University of Tokyo
2 National Geophysical Data Center, 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: China is dramatically changing due to rapid development in recent years. This can be observed from the change in landscapes, which most resulted from new or replaced constructions. The floor area of residential and commercial construction had increased fourfold from 1990 to 2005, and its speed does not show any sign of slowing down. The construction will also drive the demand of steel, which comprises half of the total national consumption. However, there were not many studies aiming to quantify the construction steel stock in China, which was mainly due to lack of statistical data. In order to overcome this obstacle, we proposed a methodology to estimate sub-national steel stock using nighttime light image. As a result, we found out that the Beijing municipality possesses the most construction steel stock. Most construction steel stock exists on the eastern coast, and is most concentrated in the Beijing municipality, the Tianjin municipality, the Shanghai municipality, and the Guangdong province.

Keywords: Building, Civil engineering, Steel stock, Nighttime light

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1. Introduction

Steel is the most used metal in the world, large proportion of which was input into civil engineering and building sector. China had become one of the world's largest steel producers as well as consumers due to the rapid development since late 1990s. Residential and non-residential buildings have been constructed to meet the increase in demand of floor area, which is largely driven by the population growth and urbanization. Modernization also triggers the building types in China to transform from old-fashioned brick-cement to modern designs with much higher steel intensity. On the other hand, civil engineering, which is mainly comprised by infrastructures, has also increased dramatically to support the basic functions of urban areas. Hu et al. pointed out that the apparent consumption of steel for China was about 35.75 Mt in civil engineering, and 110 Mt in building in 2004, which were about half of the total annual consumption of China [1]. High flow rate of steel input into China also caused large change in steel stocks. Hatayama and others estimated that the in-use steel stock in China had grown from 680 Mt to 2,334 Mt in the period of 1990 to 2005, whereas civil engineering/building sector grew from 455 Mt to 1,456 Mt. This indicates that civil engineering/building contributed about 65% of the steel stock through these years, and was the main cause for the growth of in-use steel stock [2]. Therefore, the in-use steel stock of civil engineering/building of China needs to be investigated in more detail.

Material flow analysis (MFA) is often used to account for the material flow and stock. There are basically two approaches to quantify the stock of materials, which are top-down and 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 system. On the other hand, in the bottom-up approach, the number of products within a system 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 [3].

The buildings and their material contents in China had been estimated by MFA in previous studies. Hu et al. tried to estimate the housing stocks using dynamic material flow analysis modeling for the period of 1900-2100 by top-down approach [4]. This work was then extended to estimate the iron and steel stock of the buildings [1]. Similar work was carried out by Yang et al. [5], which used a combined top-down and bottom-up approach to account the material and energy flows in construction sector. Other researchers included China as a part of their work, tried to estimate the stock for multiple countries [2,6]. However, these studies had been restricted either at country level or in few cities. Due to the restriction of data availability, the comprehensive estimation for all provinces in China had not yet been achieved.

In order to estimate the civil engineering/building steel stock in each province in China under such situation, it is necessary to develop a methodology which is applicable regardless of the statistical data. The authors have proposed that the data with global coverage can be used as a proxy to estimate unknown steel stock in our previous study [7]. In this study, the correlation between steel stock and nighttime light was examined for Asia. The result was then used to estimate the construction steel stock in China with higher spatial resolution, e.g. for each province.

2. Methodology

2.1 Outline of the methodology

Lights emitted by human activities can be observed from the space. Nighttime light was known to have positive correlation regarding anthropogenic activity parameters, such as population, power consumption, GDP, etc [8]. Takahashi et al. further examined its correlation with copper stocks [9]. The authors also proved the linear correlation between nighttime light and civil engineering/building steel stock in Japan [7] In this study, the relationship between nighttime light and civil engineering/building steel stock was investigated for Asian countries, and then applied to sub-national level in China. Flow chart of this methodology is shown in Fig. 1.

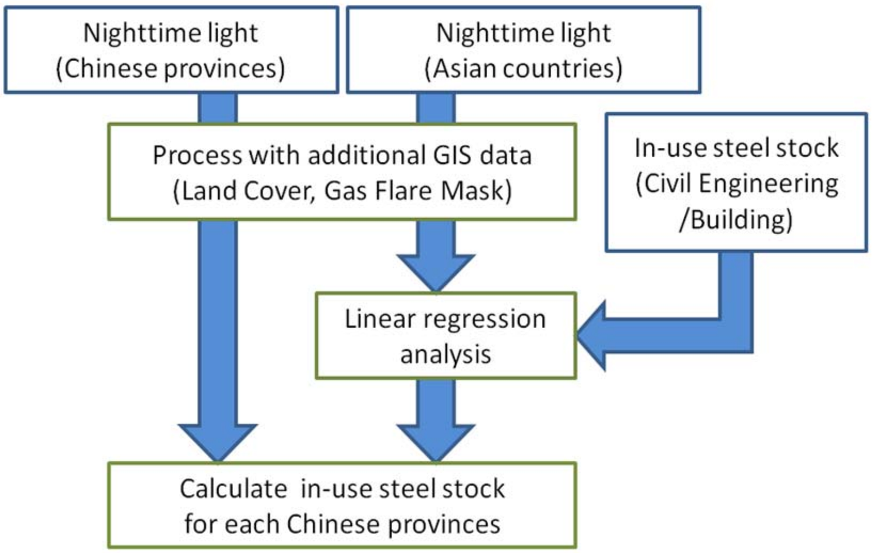

Fig. 1 Flow chart of the methodology

2.2 Data preparation

The data used in this study were prepared as follows:

2.2.1 Nighttime light

The Defense Metrological Satellite Program – Operational Linescan System (DMSP-OLS) was able to record nighttime light with highly sensitive sensors. In 1997, Elvidge et al. proposed a methodology to merge those images and thus produced a global nighttime light map [10]. These data were stored in map with 30 second mesh. However, these images were recorded by sensors under high gain settings, thus sensors were overwhelmed by bright urban centers. This problem was referred as “saturation”. In order to avoid this problem, Elvidge et al. tried to merge images taken under 3 different gain settings, which covered a wider range of radiance. This is called “Radiance Calibrated” images [11]. It is reasonable to guess that most of the steel stock exist in urban areas, therefore, the incomplete recording of radiance resulted by saturation in urban centers is intolerable. Therefore, the radiance calibrated image taken from 2005/11/28 to 2006/12/24 was used in this study. The nighttime light was extracted based on the administrative boundary of countries and provinces.

2.2.2 Land Cover

In previous study, the authors discovered that the building steel stock had better correlation with urban nighttime light, while civil engineering steel stock was more likely to be correlated with the total nighttime light[7)]. Therefore, in this study, the urban nighttime light was also extracted as another dataset using land cover data which was produced and distributed by ISCGM (International Steering Committee for Global Mapping) [12]. The data classified land cover into 20 categories, and these values were stored in 30 second mesh map. The land cover data has the same resolution with nighttime light, which enables pixel to pixel analysis.

2.2.3 Gas Flare Mask

Gas flares are originated mainly from oil wells, refineries, and etc. They are designed to burn excess gases which are not feasible for storing and transporting. Although these flames only occupy small areas on the surface, they are extreme bright. We suspect that its brightness might not be necessary correlated to the steel stock on site, thus may largely influence the correlation between construction steels tock and nighttime light. In this study, the gas flares were excluded to produce another version of nighttime light to further look into this problem. Elvidge et al. had tried to trace the change of gas flares and their global warming potential [13]. In this study, their results were used to exclude the gas flare lights from the nighttime lights.

2.2.4 Construction Steel Stock

In this study, the data about the civil engineering/building steel stock in 16 Asian countries were obtained from Hatayama et al. [2]. These countries and their civil engineering/building steel stock are listed in Table 1.

Table 1 Sample countries and their steel stock data (10^6 t)

	Country	Civil Eng. Steel Stock	Bld. Steel Stock
1	Russia	614	422
2	China	661	796
3	India	79.0	163
4	Japan	302	468
5	Korea	94.0	215
6	Pakistan	4.20	5.60

7	Turkey	65.7	64.3
8	Indonesia	27.6	28.9
9	Australia	47.3	29.4
10	Thailand	42.5	48.1
11	Malaysia	37.6	33.8
12	Taiwan	47.1	146
13	Philippine	15.2	25.0
14	New Zealand	9.10	6.00
15	Bangladesh	1.10	4.20
16	Singapore	7.80	32.0

*Countries are listed according to their total nighttime light.

2.3 Investigation of the correlation between nighttime lights and steel stocks

Correlation between civil engineering/building steel stock and each type of nighttime light (i.e., total nighttime light, urban nighttime light, gas flare excluded nighttime light) were analyzed by linear regression. The intercept of the linear model was set to zero. The type of nighttime light that gives highest R^2 value was selected to be the model for estimating civil engineering/building steel stock in each province of China.

3. Results

The correlation between civil engineering/building steel stock and three types of nighttime light are shown in the scatter plot matrix (Fig. 2). For civil engineering steel stock, Russia shows dramatic horizontal shift between nighttime light data. This is due to the enormous amount of gas flares in the middle Russia. They were not accounted for in urban nighttime light and gas flare excluded nighttime light. Gas flare was not considered in the previous study by the authors, because there was none in Japan [7]. However, the result shows that gas flare significantly influence the correlation and need to be taken into account. As to the building steel stock, most of the countries agree with the relationship with urban nighttime light.

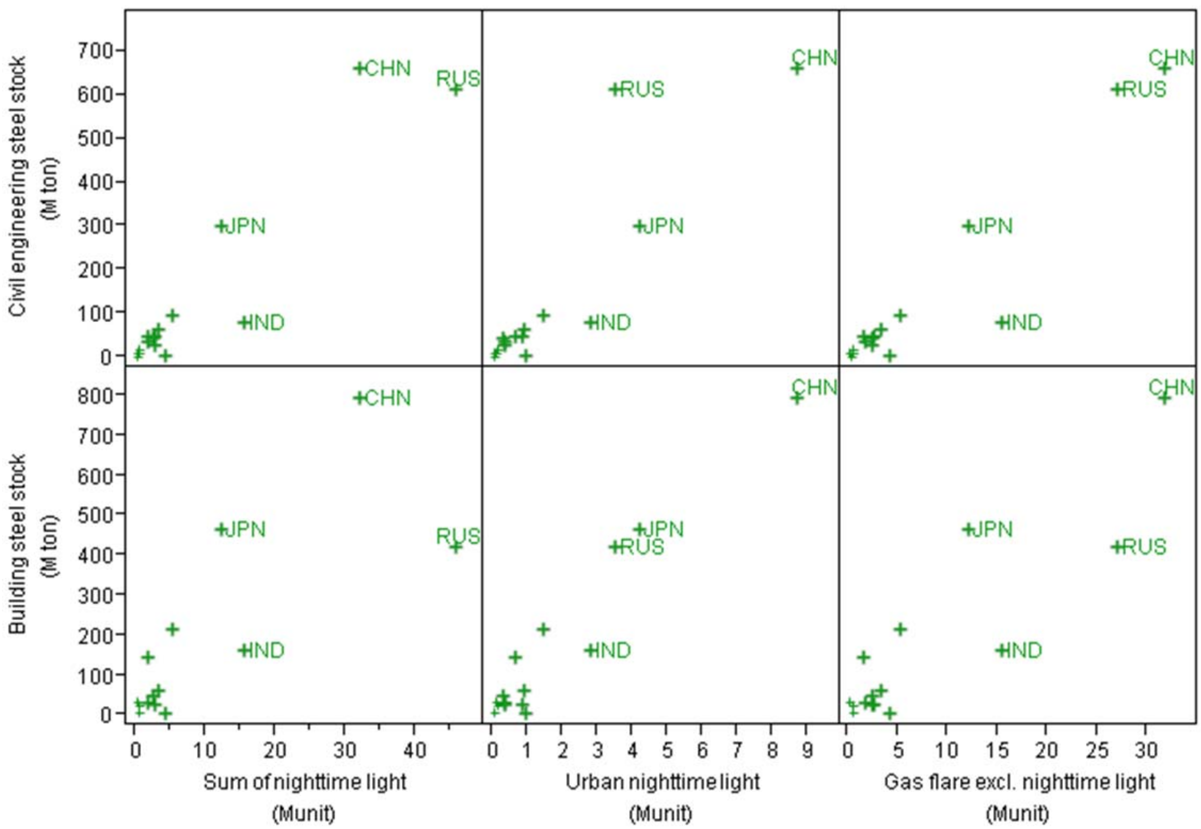

Fig. 2 Scatter plot matrix of 2 types of steel stocks against 3 types of nighttime light.

Table 2 Result of linear regression for each element in scatter plot matrix

NTL type (unit)	Civil Con. Steel Stock (10^3 t)		Comment	Building Steel Stock (10^3 t)		Comment
	Slope	R^2		Slope	R^2	
Sum NTL	15.5	0.91		15.7	0.73	
Urban NTL	82.5	0.85		99.3	0.96	Best Result
Flare excl. NTL	19.9	0.92	Best Result	21.9	0.87	

The regression result of each element in the matrix is listed in Table 2. The estimated steel stock is listed in Table 3, and the values are plotted on the map shown in Fig. 3. Since the nighttime light used here was taken in 2006, the estimated result is regarded as for 2006. It is shown that the steel stock is mostly concentrated in large cities or relatively more developed areas, e.g. the Beijing municipality, the Tianjin municipality, the Shanghai municipality, and the

Guangdong province. The density of civil engineering/building steel stock also appears to be higher toward the direction to the coastline.

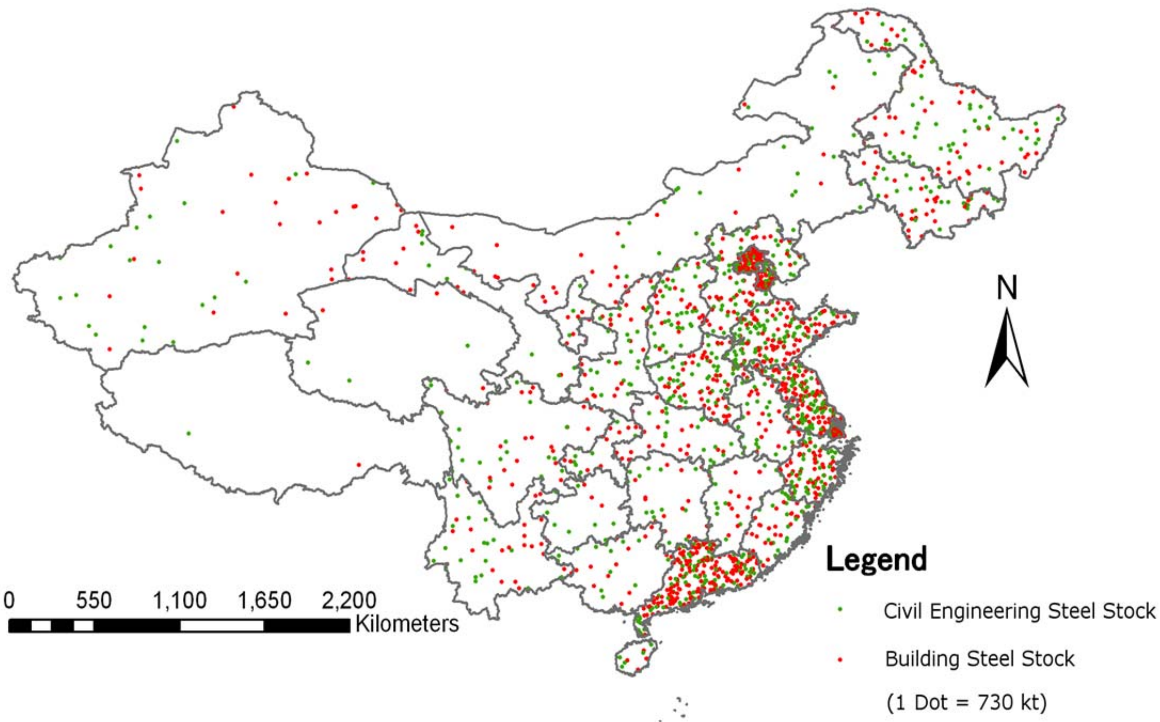

Fig. 3 Density map of for civil engineering and building steel stock in China, 2006. Data are calculated separately for each province.

Table 3 Estimated civil engineering / building steel stock for each province in China, 2006 (Unit: 10^6 t)

	Province	Civ. Eng.	Bld.		Province	Civ. Eng.	Bld.
1	Anhui	15.7	15.5	17	Jilin	16.4	21.6
2	Beijing	21.4	63.4	18	Lianoning	28.8	47.1
3	Chongqing	5.60	7.00	19	Nei Mongol	19.7	20.0
4	Fujian	15.4	19.3	20	Ningxia Hui	4.60	3.80
5	Gansu	8.70	9.80	21	Qinghai	2.40	2.70
6	Guangdong	65.7	126	22	Shaanxi	18.4	17.7
7	Guangxi	11.2	10.0	23	Shandong	57.9	61.8
8	Guizhou	5.20	2.20	24	Shanghai	21.4	61.6

9	Hainan	3.80	3.20	25	Shanxi	25.0	19.3
10	Hebei	35.8	30.0	26	Sichuan	15.7	15.2
11	Heilongjiang	32.6	41.0	27	Tianjin	13.5	26.7
12	Henan	35.9	36.9	28	Xinjiang Uygur	15.0	17.6
13	Hubei	14.0	144	29	Xizang	800	1.10
14	Hunan	10.6	10.1	30	Yunnan	15.8	16.4
15	Jiangsu	53.5	67.5	31	Zhejiang	33.0	38.4
16	Jiangxi	8.70	9.10				

In the study by Rauch et al., the total steel stock for the Beijing municipality was reported to be 29.4 Mt for 2000 [14)]. Nevertheless, the total of estimated civil engineering/building steel stock in the Beijing municipality was estimated to be 84.8 Mt for 2006 in this study. Considered the ratio of civil engineering/building steel stock against the total steel stock, the estimated result in this study is almost 4 times higher than that from Rauch et al. There are two possible reasons for this outcome. One is the year that data represents. If the growth speed of China in recent years is accounted for, it might not be surprising that the total steel stock in 2006 is several times more than in 2000. Another reason is the tremendous transition in building styles China is experiencing. Typical Chinese dwellings at early 20th century were low-story buildings built from local materials like brick and wood. But with recent promotion of steel structures, the average steel intensity in China's residential construction was expected to show a 13% increase by 2010 compared to 2004 [1)]. Therefore, it is possible that nighttime light is also emitting from constructions with low steel intensity, thus substantially resulted in over estimation of construction steel stock.

4. Conclusions

This study attempted to estimate the civil engineering/building steel stock for each province in China via nighttime light. Correlations between civil engineering/building steel stocks and nighttime light of Asia countries were investigated. The result confirms that there exists linear correlation between civil engineering/building steel stocks and nighttime lights, and can be further improved using ancillary datasets such as land cover and gas flare locations. The result of linear regression with highest R^2 value was then used to estimate the civil engineering/building steel stock for each Chinese province. The estimated result indicates that the most of the civil engineering/building steel stocks are kept in few highly-developed provinces along the coastline. The methodology proposed in this study shows the ability of estimating civil engineering/building steel stocks for areas with no data availability, and points out a new possibility for MFA studies.

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