A 2010 Mapping of the Constructed Surface Area Density for S.E. Asia - Preliminary Results

Paul C. Sutton 1*, Christopher D. Elvidge 2, Benjamin T. Tuttle 3, Daniel Ziskin 3, Kimberly Baugh 3 and Tilottama Ghosh 3

1 Department of Geography, University of Denver, Denver, CO 80208.
2 National Geophysical Data Center (NGDC), National Oceanic and Atmospheric Administration (NOAA), 325 Broadway, Boulder CO 80305, USA.
3 Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, 216 UCB, Boulder CO 80309, USA.

E-Mails: Paul.Sutton@du.edu; Tilottama.ghosh@noaa.gov; Chris.elvidge@noaa.gov; Kim.baugh@noaa.gov; Daniel.ziskin@noaa.gov

* Author to whom correspondence should be addressed; Tel.: +1-303-871-2399; Fax: +1-303-871-2201

Abstract: Human beings around the world build, use and maintain constructed impervious surfaces for shelter, transportation and commerce. It is a universal phenomenon – akin to clothing – and represents one of the primary anthropogenic modifications of the environment. Expansion in population numbers and economies combined with the popular use of automobiles has led to the sprawl of development and a wide proliferation of constructed impervious surfaces. Constructed impervious surfaces are both hydrological and ecological disturbances. However, constructed surfaces are different from most other types of disturbances in that recovery is arrested through the use of materials that are resistant to decay and are actively maintained. The same characteristics that make impervious surfaces ideal for use in construction produce a series of effects on the environment. We present a new map of the density of constructed surface in S.E. Asia derived from Defense Meteorological Satellite Program’s Operational Linescan System (DMSP OLS) nighttime lights and LandScan population count data.

Keywords: Impervious Surface Area, Constructed Surface Density, DMSP-OLS Nighttime satellite imagery, LandScan population grid
1. Introduction

A significant fraction of the earth’s surface has been made impermeable by human actions; and, this land conversion has significant agricultural, environmental, and ecological impacts (Frazer, 2005). Impervious surfaces alter sensible and latent heat fluxes, causing urban heat islands (Chagnon, 1992). In heavily vegetated areas the proliferation of Impervious Surface Area (ISA) reduces the sequestration of carbon from the atmosphere (Milesi et al., 2003). ISA alters the character of watersheds by increasing the frequency and magnitude of surface runoff pulses (Booth, 1991). This increased overland flow alters the shape of stream channels, raising water temperatures, and sweeping urban pollutants into aquatic environments (Beach, 2002). Hydrologic consequences of ISA include increased flooding, reductions in ground water recharge, and reductions in surface water quality. A widely accepted scale for the impacts of ISA on watersheds holds that watershed areas are stressed if they contain 1-10% ISA, impacted if they contain 10%-25% ISA and are degraded if they contain more than 25% ISA.

We have used nighttime satellite imagery in conjunction with population distribution datasets to estimate the impervious surface area of the world to be 579,703 km² (Elvidge et al., 2007). This is nearly the same size as the country of Kenya (584,659 km²) and larger than Spain (505,735 km²) or France (546,962 km²). The country found to have the most ISA was China (87,182 km²) followed closely by the United States (83,881 km²), and India (81,221 km²). Recent analyses have demonstrated that ISA per person is highly correlated with resource consumption and national ecological footprints (Sutton et al, 2010), suggesting that it may be possible to construct resource (food, wood, fuel, water) consumption maps based on the ISA per person index. Data products such as percent impervious surface that are derived substantially from nighttime satellite imagery serve as good proxy measures of myriad human activities including environmental impact, economic activity, energy consumption, and CO₂ emissions (Doll et al. 2000; Ghosh et. al.; 2010; Ghosh et. al. 2010; Sutton, 2003).

The aforementioned studies of ISA were accomplished using global parameters for all regions of the world. In this investigation we focused on a particular region of the world, Southeast Asia, and developed regionally specific parameters in the hope that the skill of our model would be improved. Ultimately, we believe the best approach to developing global datasets of percent constructed area will use global datasets such as the Landscan and DMSP-OLS products in tandem with regionally specific parameterizations to maximize accuracy. This is a preliminary investigation of the potential of this approach.
2. Methods

2.1. Data: Nighttime Lights, Landscan, and Google Earth

The basic methodological approach we used was to predict the fraction or percentage constructed area of a given pixel using a simple two variable multi-variate regression model. A pixel in both the Landscan and the DMSP OLS dataset is a 30 arcsecond grid cell (roughly 1 km²). The predictor variables (independent variables) used were the nighttime lights DN and a population count from Landscan.

We used a radiance calibrated image of the world derived from scores of orbits of the DMSP OLS in 2010. This was a cloud-free composite derived from data collected by the F16 satellite at low, medium, and high gain settings. In addition we used the 2008 Landscan population grid developed at, and provided by, the Oak Ridge National Laboratory (Bhaduri et. al., 2002). The predicted (dependent) variable was ‘percent constructed surface area density’. Constructed surface area density is a variable we have defined that we believe captures the idea of anthropogenic impervious surface. Essentially constructed areas density measures what fraction of a given area has been converted to rooftop, sidewalk, street, or parking lot (a surface built by humans that does not allow water to seep into the ground). We obtained actual values for 35 pixels using a web application we refer to as the Impervious Surface Mapper (also affectionately know as ‘the light picker’). The impervious surface mapper uses the high resolution imagery available in Google Earth to enable the users to classify 225 points within each of these pixels.

2.2. Impervious Surface Mapper [http://www.ngdc.noaa.gov/dmsp/imaps/isamapper ]

The impervious surface mapper is a web application that uses a google earth plug-in to allow users to zoom to any area of the world and choose a DMSP ‘pixel’ to collect gridded point count data to estimate the density of constructed surfaces and other land cover types listed in table 1.

Table 1: Classification Scheme for the Impervious Surface Mapper

<table>
<thead>
<tr>
<th>Developed</th>
<th>Street/road</th>
<th>Tree/Shrub</th>
<th>Open Area</th>
<th>Flat Roof</th>
<th>Other Roof</th>
<th>Other Constructed</th>
<th>Lawn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other</td>
<td>Unpaved Road</td>
<td>Tree/Bush</td>
<td>Open Area</td>
<td>Ag. Field</td>
<td>Water</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Typically, we would selected grid cells along transects that traversed through the center of a cities and extending across suburban, rural, and undeveloped areas. These ‘transects’ would almost invariably also traverse through the brightest pixels in the nighttime imagery (Figure 1). Once the user identifies a pixel he or she wishes to classify they initiate a command that draws a grid of 225 red squares inside the pixel. The very center point of each of these squares is classified via a radio button check box using the scheme outlined in Table 1 (Figure 2).
The Town of Nakhon Ratchasima, Thailand (pop ~150,000) seen through the Impervious Surface Mapper

High Resolution Satellite Imagery from Google Earth is used to Classify a sample of pixels from SE Asia

DMSP OLS imagery overlaid as a KML file via the Google Earth Plug-in

**Figure 1:** Impervious Surface Mapper representation of Nakhon Ratchasima, Thailand

Each Pixel is a bit of work...

Each of the red boxes is classified. As each of the 256 points are classified they turn green. The ‘% Constructed Area’ is determined by the fraction of the 256 (16 x16 red squares in each DMSP OLS pixel) that are classified as one of the following ‘Developed’ categories: ‘Street/Road’, ‘Flat Roof’, ‘Other Roof’ or ‘Other Constructed’

**Figure 2:** The 225 point per pixel sampling scheme of the impervious surface mapper
2.3. Regression model

The analytical approach we took is quite simple. The Impervious Surface Mapper web application generates a simple flat file table with the following columns: Pixel ID, Latitude, Longitude, Username, Time of Classification, DMSP OLS DN value, and Landscan Population Count. We collapse the table on pixel ID summing the number of occurrences of the ‘developed’ category of ‘Street/Road’ or ‘Flat Roof’ or ‘Other Roof’ or ‘Other Constructed’. This resulted in a table with 33 records in which each record represented a pixel (recall this table was derived from 33 x 256 = 8,448 ‘point’ classifications of the imagery in google earth). The three values for each pixel we used were: ‘% Constructed area’, ‘DMSP OLS DN’, and ‘Landscan Population count’. Using this table we conducted a simple multi-variate regression in which we used the light intensity measured by the DMSP OLS DN and the population density measured by Landscan Population count to predict the percent constructed area. The regression was significant ($R^2 = 0.87$ with significant values for both the DMSP OLS DN and the Landscan Population count parameters) (Figure 3). We did force the regression to pass through a (0,0) intercept. This is justified in a theoretical sense in that we do not want negative values of % constructed area.

3. Results

Implementation of the model was accomplished by simply applying these regression parameters to the DMSP OLS and Landscan datasets for the areas of Southeast Asia (Figure 4). A more detailed picture of this estimate of percent constructed area is shown for Hanoi and Ho Chi Minh City (HCMC) (Figure 5). It is interesting to note that even in the very heart of these large cities the fraction of land cover that is impervious is often much less than 50%.
Figure 4: Regression model parameters applied to DMSP OLS and Landscan for SE Asia

Figure 5: Estimation of Impervious Surface Area for Hanoi and HCMC, Viet Nam
Table 2: Summary Statistics for Nations of Southeast Asia (GDP figures from World Bank)

<table>
<thead>
<tr>
<th>Countries</th>
<th>Population (millions)</th>
<th>Total Area (km²)</th>
<th>Total ISA (km²)</th>
<th>%ISA</th>
<th>GDP 2008 - (millions) US$</th>
<th>ISA (m²)/person</th>
<th>GDP (millions)/ISA (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brunei</td>
<td>318,930</td>
<td>5,804</td>
<td>114</td>
<td>1.97</td>
<td>19,559</td>
<td>359</td>
<td>171</td>
</tr>
<tr>
<td>Cambodia</td>
<td>14,282,900</td>
<td>182,857</td>
<td>117</td>
<td>0.06</td>
<td>28,408</td>
<td>8</td>
<td>242</td>
</tr>
<tr>
<td>East Timor</td>
<td>1,024,330</td>
<td>15,154</td>
<td>13</td>
<td>0.09</td>
<td>880</td>
<td>13</td>
<td>67</td>
</tr>
<tr>
<td>Indonesia</td>
<td>229,554,000</td>
<td>1,896,490</td>
<td>5,516</td>
<td>0.29</td>
<td>907,955</td>
<td>24</td>
<td>165</td>
</tr>
<tr>
<td>Laos</td>
<td>6,696,710</td>
<td>230,940</td>
<td>99</td>
<td>0.04</td>
<td>13,181</td>
<td>15</td>
<td>133</td>
</tr>
<tr>
<td>Malaysia</td>
<td>24,087,200</td>
<td>330,669</td>
<td>2,797</td>
<td>0.85</td>
<td>384,002</td>
<td>116</td>
<td>137</td>
</tr>
<tr>
<td>Myanmar (Burma)</td>
<td>46,965,100</td>
<td>670,705</td>
<td>392</td>
<td>0.06</td>
<td>?</td>
<td>8</td>
<td>?</td>
</tr>
<tr>
<td>Papua New Guinea</td>
<td>5,424,430</td>
<td>466,753</td>
<td>98</td>
<td>0.02</td>
<td>14,337</td>
<td>18</td>
<td>146</td>
</tr>
<tr>
<td>Philippines</td>
<td>90,491,600</td>
<td>296,755</td>
<td>1,452</td>
<td>0.49</td>
<td>317,352</td>
<td>16</td>
<td>219</td>
</tr>
<tr>
<td>Singapore</td>
<td>4,314,760</td>
<td>552</td>
<td>314</td>
<td>56.89</td>
<td>238,685</td>
<td>73</td>
<td>760</td>
</tr>
<tr>
<td>Thailand</td>
<td>64,857,000</td>
<td>515,058</td>
<td>3,511</td>
<td>0.68</td>
<td>544,913</td>
<td>54</td>
<td>155</td>
</tr>
<tr>
<td>Vietnam</td>
<td>84,658,300</td>
<td>326,884</td>
<td>2,295</td>
<td>0.7</td>
<td>240,292</td>
<td>27</td>
<td>105</td>
</tr>
</tbody>
</table>

The values of ‘% constructed area’ pixels were summed for each nation of Southeast Asia (Table 2). Indonesia was by far the most populous nation and not surprisingly the nation with the most anthropogenic impervious surface. Not surprisingly, the city state of Singapore had the highest percentage of impervious surface at roughly 57%. We find it interesting that our estimates of the ISA per person seems to correlate so strongly with income. We estimate wealthy state of Brunei to have 359 square meters of ISA per person whereas the nations of Cambodia, Myanmar, and East Timor have only 8, 8, and 13 square meters of ISA per person.

4. Discussion and Conclusion

In this paper we used a web-based tool for the collection of reference data on the density of constructed surfaces with gridded point counts made on high spatial resolution imagery available in Google Earth. Originally, much of the base imagery present in Google Earth was from Landsat (30-meter resolution). However, an increasing number of areas – especially urban areas – have high-resolution imagery from the Digital Globe Corporation. While there are some compression related distortions present in the Digital Globe imagery as rendered by Google Earth, our assessment is that the images are suitable for extraction of gridded point counts of surface cover types. For our project, using Google Earth vastly reduces the cost that would be associated with selecting, purchasing and managing the high spatial resolution imagery required to measure constructed area densities. We believe that the web-based tool we have developed could be useful for other projects which require surface cover data that can be visually identified in high spatial resolution satellite imagery. This development opens up new possibilities for widely dispersed collaborations.
The preliminary ISA density grid of S.E. Asia for the year 2010 is available at: http://www.ngdc.noaa.gov/dmsp/download.html. We believe the development of regionally specific regression parameters for estimating the fraction of impervious surface from global data products such as the DMSP OLS and Landscan has great potential for dramatically improving the accuracy of estimation of the fraction of ISA regionally and globally. We are still exploring how the relative relationships of nighttime lights and population density contribute to the variation of the percentage of impervious surface around the world. Nonetheless, even if identifying this relationship remains elusive we believe the identification of a simple set of regionally varying parameters for the globe would be useful in its own right for the improvements in the accuracy of estimation alone. We are convinced that global representations of ISA that can be updated on an annual basis would be widely used as a spatially explicit proxy measure of myriad human activities and impacts on the environment.

References


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