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Chapter 2

Consistent Measures of Urbanization with Remote Sensing Data

Souknilanh Keola

Abstract

This article pulls together economic metrics of urbanness suggested in existing literature, and demonstrates a method to derive measurements of urbanization, given a particular set of thresholds, that are comparable across countries and sub-national regions, using only remote sensing data that is available with none or little cost. Three sets of remote sensing data, LandScan, DMSP-OLS, and Openrouteservice are combined to quantify the stock and flow in urban areas. I have found results that both agree with, but also those that are not obvious from observations on the ground. The results confirm the benefit of applying remote sensing data to generate consistent, and objective, data for economic studies.

Keywords: Urbanization, Remote Sensing

1. Introduction

Theoretically, cities are understood to generate higher growth, but the optimal degree of urbanization exists, beyond which the gain slows down (Henderson, 2003; Duranton, 2009). The optimal degree of urban concentration in terms of maximizing productivity varies with the level of development and country size (Henderson, 2003). Many studies find that rapid urbanization and rapid growth do not always temporally coincide (Henderson, 2003; Bloom et al., 2008). Nonetheless, international development financiers have, in practice, been promoting urbanization as a means to achieve growth in recent years (World Bank, 2009). However, similar to many measures in economics, quantification is often based on data collected with varied definitions, relies heavily on figures provided by rarely impartial responders, whose knowledge of the requested information is hardly verifiable. It is unrealistic to expect quantities in the social sciences, including economics, to be perfectly objective and without measurement errors, but it would not be right to make no effort to advance towards that direction. I contend that subjective quantitative data is mostly responsible for contradicting and unrepeatable findings in economics. As such, increasing the objectivity of data would not only refine research findings, but also improve their applicability. Sophisticated statistical econometric technics to deal with poor quality data can improve research findings, but so does better quality data.

Current metrics of urbanness vary greatly. Different measures and thresholds are adopted by different authorities, the results from which are used by subsequent studies. The most common metric is population density, which is widely used to identify urban areas across many disciplines (Finley, 1977). Authorities in many countries use population density as an important criterion of urbanness. However, the official thresholds vary greatly from several hundreds to several tens of thousands (UN[1]). The urbanization rate is mostly computed based on such official data, the result of which is then used in studies of the relationship between urbanization and, for example, growth. Quantitative comparative analyses among countries in such circumstances can be misleading, inconclusive, or even irrelevant.

Fujita et al. 1999, a standard text book of spatial economics, added concentration of non-agricultural, or more precisely increasing return type of economic activities. It should be noted that some modern agricultural activity is actually of the increasing return type. The percentage of non-increasing return economic activity is then used to identify urbanness, but the thresholds remain different. The percentage cannot be computed without first defining the geographic boundary. Such an approach has to rely on the assumption that urban areas coincide with predefined boundaries, mostly administrative ones. Although less often, infrastructure is also used as an indicator of an urban area in academic studies (UN, Dahly and Adair, 2007). The amount of infrastructure is certainly less obvious than the number of people. Developing countries are also more likely than developed countries, to use some kind of infrastructure, such as access to electricity, tap water, etc. to identify an urban area. This is probably due to the different dynamism between the location of people and the infrastructure in developed and developing countries. In developed countries, it is easier for people to relocate to where there is better infrastructure, whereas the authorities also have more capacity to install additional infrastructure to cope with the increasing population. The ratio of the self-employed is relative low in developed countries, so it is mostly safe to assume people usually co-locate with firms. In developed countries, it is then

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1 https://esa.un.org/unpd/wup/DataSources/

sufficient to focus on the population density.

Another economic aspect of urbanness is connectivity. Most urban positive externalities of urban areas assume firm-firm, firm-people, and people-people interaction (Van der Panne, 2004). Consequently, infrastructure, transport in particular, that facilitates face to face communication is dispensable. Amindarbari and Sevtsuk (2012) excellently summarize the urban metrics that identify flows as one important indicator. Flow data is even more difficult to obtain. Therefore, identification of an urban area using flow data is largely limited to a case study in certain countries or regions. In summary, urban areas are identified by (i) an accumulation of factors, both human and non-human, and (ii) the connectivity between these factors. The aim of this article is to identify an urban area in such a way that can be comparable across countries and sub-national regions. So firstly, it can only use data that is available for all countries, from the poorest to the richest. Developed countries have more data for financial and capacity reasons, and making use of such data would certainly refine the findings. But this would not help if there is a need for a comparison with countries which do not have such sophisticated data in the first place. Following seminal work by Henderson et al. in 2012, my strategy is to rely solely on remote sensing data to overcome the lack of data in developing countries. The rest of this article is structured as follows. Section 1, groups urban metrics in existing studies into three categories, and describes the remote sensing data that could be used to capture each of them. Section 2, shows descriptively and visually how urban areas vary with different thresholds and different indicators. Section 3, demonstrates how any selected criteria would generate urban areas, and therefore urbanization measures that are consistent and comparable across countries and sub-national regions. Section 4, discusses the results and compares them with conventional urbanization statistics. Section 5 concludes.

2. Capturing the Stocks and Flows in a City with Remote Sensing Data

Definitions of urbanness center around the accumulation of factors and their interaction. The former can be divided further into human and non-human factors. Non-human factors include infrastructure and the facilities installed or acquired by firms and individual persons. Whereas most infrastructure is immobile, some do move around. Trains, subways, buses are examples of mobile infrastructure. The interaction of factors happens through the movement of people and goods by public and private transport means. So, in this paper, I need to quantify the number of people, the infrastructure, and the movability using only remote sensing data. The use of remote sensing data to overcome data limitations in developing countries, in main stream economics, started with seminal work by Henderson et al. in 2012, that made use of Nighttime light (NTL). Although NTL is still the most used remote sensing data in economics, some studies began using other data sets, such as land cover (Keola et al., 2016; Tanaka and Keola, 2017). In this article LandScan and NTL are used to quantify stocks and factors by uniform geographical unit, approximately 1 km by 1 km at the equator. Online Routing API is then used to quantify connectivity. The rest of this section describes this data and discusses the justification of their usage.

2.1 LandScan (Population)

LandScan is an annual global population data set produced and provided with some cost by Oak Ridge National Laboratory. Annual data is available from 2000 onwards. The spatial resolution of LandScan is 30", or approximately 1 km at the equator. It represents the ambient, or daytime, average population. LandScan uses a multi-variable dissymmetric modeling approach to disaggregate census counts within an administrative boundary (Bhaduri et al. 2007). This approach, also known as smart interpolation, uses high definition satellite images, including those with sub-meter resolution, to distribute official population figures across national boundaries. National population figures aggregated from LandScan often agree with the official data, because the latter is, whenever possible, used to construct the former. Superiority in terms of consistency of LandScan is obvious. Conventional population density data is provided by administrative boundaries, which are different both in shape and size. On the contrary, the spatial unit of LandScan is uniform globally. Population density based on LandScan means the same for any country anywhere on the globe.

2.2 DMSP-OLS (Infrastructure)

The United States Air Force has operated the Defense Meteorological Satellite Program (DMSP) for more than 40 years. The program is based on a series of orbiting satellites whose primary function is to monitor the weather. The daytime records of the sensors are exclusively sunlight reflected from clouds or the Earth’s surface and thus of limited use other than for weather forecasting. When the Earth’s surface is at night, the electromagnetic energy sensed by the system is mostly a product of human light emitting activity. Croft (1978) was, to the best of my knowledge, the first to acknowledge that nighttime light data could be used to measure economic activity. The

DMSP Operational Line Scan (OLS) sensors operate at an altitude of 830km with a sun synchronous near polar orbit and a revisit time of 101mins. The OLS is an oscillating scan radiometer generating images with a swathe width of approximately 3,000kms. With fourteen orbits per day, each OLS is capable of generating global daytime and nighttime coverage of the Earth every 24 hours.

So far, NTL is mostly used to estimate the level or change of economic activity on the ground. But in this article, I propose using it to capture the level of installed infrastructure. However, I am not the first to suggest this application. Jensen and Cowen (1999) demonstrated how to use remotely sensed urban and suburban infrastructure and socio-economic attributes. Good infrastructure needs to be lit up at night for operational and security reasons. The spatial extent of the infrastructure can often be captured with a certain precision according to the NTL. The concentration of more infrastructure, and therefore more NTL, and an increase intensity of NTL can be observed from space. So, in this article I use the illuminated area to identify the spatial extent, and the intensity of NTL to capture the infrastructure's density.

2.3 Online Routing API

Online Routing API allows a user to query the time needed to move between, virtually, any two points within or among adjacent countries. The quality varies among providers and areas of interest. Major commercial providers utilize live traffic data collected from the location information of mobile devices, and this data generates relatively accurate results. Queries among places in developed countries usually generate more accurate results because of the better quality of the real-time data that is available. For demonstration purposes, I make use of the Openrouteservice, a university-based open source API based on the OpenStreetMap. As OpenStreetMap data coverage in Asia does not include live traffic in general, the result generated by this API does not take into account traffic density.

3. Different Findings According to Different Thresholds

Consistent measurement does not mean universal measurement. The unit of length of one meter in the Internal System of Units (SI) is an example of the latter, with which everyone would agree, although measurement errors remain. On the other hand, a measurement is consistent if the result is the same for any given set of criteria. The rest of this section shows how different results are generated from different thresholds. For demonstration purposes, data is analyzed for each of 10 members of ASEAN (Association of Southeast Asia Nations). The methodology is applicable to any country and sub-national region, given the availability of the required data sets.

3.1 Population

Traditionally, urban areas have been identified by population density. The urban density is computed over different spatial units, usually administrative boundaries. As is well discussed in the literature of Modifiable Arial Unit Problems (MAUP), one can never be sure what number better reflects reality (Gehlke and Biehl). Figure 1, illustrates the changes of aggregated urban area identified by different thresholds of population density, and aggregated by country for each member of ASEAN. The threshold densities are 100, 1,000, 2,000 and 10,000 persons per grid. When only population density is considered, the general trend is a country with a larger population would have a larger urban area. For example, when the threshold is 100, Indonesia would have an aggregated urban area of about 200,000 km^2, which decreased a little between 2001 and 2013. The Philippines, Vietnam, Thailand, Myanmar etc. follow the same pattern regarding the size of the total population. When the threshold is increased to 1,000 persons per grid, the results and also the trend changes. The aggregated urban area in Indonesia decreased to between 30,000 and 40,000, from about 200,000 per km2. On the other hand, the urban area in Indonesia follows increasing trend with the threshold of 1,000 persons per grid. This means that more areas with population from 1,000 persons per grid have emerged in Indonesia between 2001 and 2013. The aggregated urban areas in each country become smaller as the thresholds are increased to 2,000 and then 10,000 persons per grid. The dynamics of the movement of people between places are also different between each threshold. For the threshold up to 2,000 persons per grid, the general trend is urban areas having expanded between 2001 and 2013. However, if 10,000 persons per grid is selected, many members of ASEAN would find that the urban area has shrunk significantly between 2003 and 2005.

Figure 1. Aggregated Urban Area by Different Levels of Population Density in ASEAN

3.2 Infrastructure

Figure 2. Depicts the change of aggregated urban areas in ASEAN by different levels of NTL. Note, that in this article, the higher NTL is interpreted as the greater concentration of infrastructure. When only infrastructure is considered, the first impression is that the size of the population becomes almost irrelevant. When the threshold is set to 1, meaning urban areas are defined by any places with an observed positive amount of NTL, the aggregated urban area in Thailand becomes about 200,000 km2, comparable to that of Indonesia. This is despite the fact that Thailand's population and land area (approx. 60 million persons, 0.51 million km2 in 2013) are both less than a third that of Indonesia (approx. 255 million persons, 1.81 million km2 in 2013).

Figure 2. Aggregated Urban Area by Different Levels of NTL in ASEAN

The order by size or aggregated urban area for the rest of ASEAN does not follow that by size of population, nor land area. Malaysia (approx. 30 million persons, 0.32 million km2 in 2013), has an urban area a little less than Vietnam's (approx. 90 million persons, 0.32 million km2 in 2013), and more than the Philippines (approx. 100 million persons, 0.3 million km2 in 2013). Urban areas in higher income ASEAN countries become relatively larger when the threshold of NTL is raised to 10, 40 and then 60. With NTL from 10 and above, Thailand has the largest aggregated urban area in ASEAN, followed by Indonesia, the largest and most populous country in ASEAN. In addition, the aggregated urban area in Malaysia becomes larger than Vietnam from NTL 10 and above. With NTL from 40 and above Malaysia has the second largest urban area in ASEAN, followed by Indonesia. The Philippines lags behind Vietnam. When the threshold is raised to 60 and above, the gap between Malaysia and Thailand shrinks, while Vietnam and the Philippines become comparable by size of urban area. The urban area in Singapore becomes larger than in Cambodia, Laos and Myanmar. In short, even when the indicators are obvious, objectively measurable with less measurement errors, the results from different thresholds can look very different. Problems in social sciences are generally complex. Different aspects are more critical concerning different problems. Remote sensing data allows greater freedom to choose different thresholds for different research questions after the data is collected.

3.3 Infrastructure and Population

With remote sensing data, one has the option to combine many different thresholds to generate consistent results that are comparable across countries and sub-national regions. For example, Figure 3, illustrates the aggregated urban area for each member of ASEAN based on both population and NTL density per grid. The threshold for the population per grid is fixed at 300 persons. The population thresholds in ASEAN varies, and 300 is based on the EUROSTAT definition. To define the urban areas by EUROSTAT would group grids according to continuity. Grids with a population of 300 persons or more, or a group of grids with a minimum combined population of 5,000 persons are considered urban areas. EUROSTAT regards the 1 km² grid as the most likely future standard of a spatial boundary to compute population density. In the EU, the 1 km² grid is already available for Denmark, Sweden, Finland, Austria and the Netherlands. The 1 km² population grid for the rest of the EU members is based on the population disaggregation grid (Version 5) prepared by the Joint Research Center based on the LAU2 population and CORINE land cover. In other words, although this article uses the LandScan grid population data, the EU compiles and uses its own data, and the accuracy of this data is likely to be superior given the proximity and access to ground based data, but the limitation of such data is the partial spatial coverage. Nevertheless, the increasing availability of 1 km² grid population data at the regional level would certainly improve the quality of the existing and the new global grid population data sets.

Figure 3. Aggregated Urban Area by a Combination of Thresholds in ASEAN

NTL, a proxy of infrastructure density can change from 10, 20, 40 and 60. Similar to the previous section, Indonesia has the largest aggregated urban area when less emphasis is put on infrastructure, i.e. NTL from 10, 20, 40 and above. However, as more emphasis is put on infrastructure, i.e. NTL from 60 and above, Thailand has the largest aggregated urban area, followed closely by Malaysia and Indonesia. Vietnam has a larger aggregated urban area when more emphasis is placed on the infrastructure. Although the results are not shown, the threshold of NTL whereby Thailand would surpass Indonesia as the country with the largest aggregated urban area in ASEAN would be lower if less emphasis is placed on population. For example, if the threshold of population is 150 persons, instead of 300 persons per grid as in Figure 3, the NTL threshold at which Thailand surpasses Indonesia would be 20. This fits with my observations on the ground. Indonesia is the largest country by population and population density in ASEAN, especially the island of Java is relatively high when compared to the ASEAN standard. Thus, aggregated urban areas defined with more emphasis on population density would generate a higher figure for Indonesia. On the other hand, urban areas and metropolitan areas in Thailand and Malaysia are better equipped with infrastructure. Hence, aggregated urban areas with more emphasis on infrastructure yield a larger result for Thailand and Indonesia. It should be noted that when infrastructure is considered sufficiently, the aggregated urban area of Singapore is larger than in Cambodia, Laos and Myanmar. Unless stated otherwise, the threshold for identify urban areas from the next section onward is a population of 300 persons and NTL from 40 and above per grid.

3.4 Urban Connectivity

Figure 4. Isochrones by Time Intervals in Thailand’s Largest Urban Area

This section discusses what an online routing API can do to measure urban connectivity. Besides providing the routing, i.e. the route between two points based on road shape, with additional information such as speed, traffic condition, expected arrival time, etc., isochrones, or reachable places by time or distance is one of the interesting by-products of the online routing API. Not all APIs provide isochrones due to the computing resources required, especially when aquery concerns longer distances. The Opensourcerouting API used in this article allows up to 60 minutes for isochrones' query by reachable time. Figure 4, shows isochrones which are reachable places by time interval, i.e. 1-10, 11-20, 21-30, 31-40, 41-50, 51-60 minutes from the center, determined by the center of mass computed by the amount of NTL within the largest urban area, identified by grids with a population from 300 and NTL from 40 and above. The result in Figure 4 obviously considers road shape, but not live traffic conditions.

4. Results

Since the focus of this article is individual urban areas, the analyses from here focus on the largest urban areas in each country. Figure 5-1 and 5-2, show the boundary of the largest urban areas in ASEAN, and the places reachable by time interval. Figure 5-1, includes 6 countries with the same map scale (0 to 60 km). Figure 5-2, includes three other countries with a map scale from 0 to 40 km, except Brunei which has a slightly smaller scale. The grouping is for convenient visual comparison. The red line represents the urban area defined by grids with from 300 persons, and NTL from 40 and above per grid. The blue area represents the places reachable by time interval from the center of the urban area.

Several observations can be made from Figures 5-1 and 5-2. Firstly, except for the city state of Singapore, and the less populated Brunei, the size of the largest city in the largest urban areas in the other relatively industrialized members of ASEAN are not much different from each another. The largest urban area in Thailand is the largest in ASEAN, followed by the second in Indonesia, Malaysia and Vietnam. Singapore comes next with the largest urban area larger than that in Cambodia, Laos and Myanmar. This is despite the fact that these countries are several times larger and more populated than Singapore. In fact, the largest urban area in Singapore is only a little smaller than that in other larger ASEAN countries.

Figure 5-1. Aggregated Urban Area by Combinations of Thresholds in ASEAN

Figure 5-2. Aggregated Urban Area by Combinations of Thresholds in ASEAN

The size of an urban area would change if one considers also urban mobility. In Singapore, the whole urban area, as defined by aforementioned criteria, is accessible from the center within about 20 minutes, assuming traffic. Malaysia follows closely, although some places within the red lined boundaries need about 30 minutes to reach, without traffic. In Thailand, Vietnam, the Philippines, 30 minutes are needed to reach the outer edge part within the red lined boundaries, without traffic. It should be noted that heavy traffic is a fact of daily life in ASEAN metropolitan areas such as Bangkok, Jakarta, and Manila. Public transport in these cities also lags behind Singapore. Consequently, if mobility is considered in more detail, Singapore easily becomes the largest urban area in the whole of ASEAN.

In the smaller ASEAN countries, urban areas with the same definition in Brunei can be reached within ten minutes from the center, without traffic. The same is valid for Cambodia and Laos, although this is largely due to the smaller size of the urban areas. The size of the urban areas in these countries extend for roughly 10km from end to end. The size of the largest urban area, and also reachable area within 60 minutes, in Myanmar is very small given its relative land area and population size. Nonetheless, if the mobility required to identify an urban area is set to 1 hour without traffic, the largest urban area in ASEAN coincides with definition based on population and NTL.

5. Discussion

Figure 6: Urbanization Rate in ASEAN based on Remote Sensing Data

I have shown in this article how consistent measurements of urbanization can be generated from remote sensing data. In this section, I would like to generate the urbanization rate, one of the most important statistics regarding urbanization. The process of doing so is straightforward. The urban area is first identified by both the population density (300 persons or above per grid) and NTL (40 and above). These urban boundaries are overlaid on the LandScan to summarize the number of persons within the boundaries. The result is show in Figure 6. The urbanization of Singapore is approximately 1 (or 100%) regardless of the NTL threshold, although Figure 6 only shows one of the results. The urbanization rate in Brunei is also consistently high. Urbanization in Malaysia is also often high, though to a lesser extent, regardless of the NTL threshold. The urbanization rate in the other countries varies largely according to the NTL threshold selected. I cannot say that this result is better than capturing the reality on the ground, but as far as a comparison among countries and sub-national regions is concerned, it must be superior to conventional urbanization measures often based on completely different criteria and threshold parameters.

6. Conclusions

Quantitative research is composed of two major parts, the methodology and the data. Improvement in the latter is marginal when compared to the achievement of the former since the birth of econometrics, or quantitative analyses of economics in general. This article is a contribution in this direction. I demonstrate, in this article, how to generate consistent measures of urbanization, given particular thresholds, from remote sensing data, which is available with nil or a small cost. I found results that both agree with, but also those that are not obvious from observations on the ground. The results confirm the benefit of remote sensing data to generate consistent, and objective, data for economic studies.

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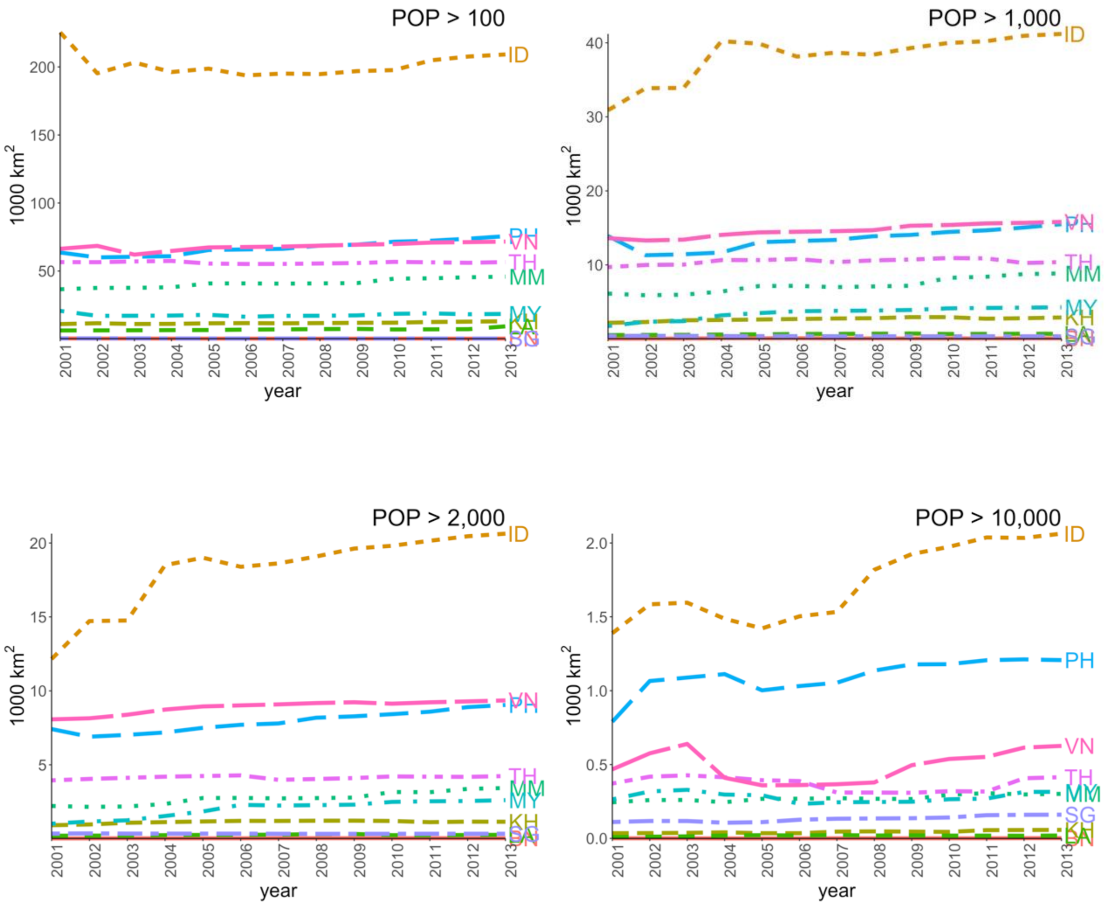
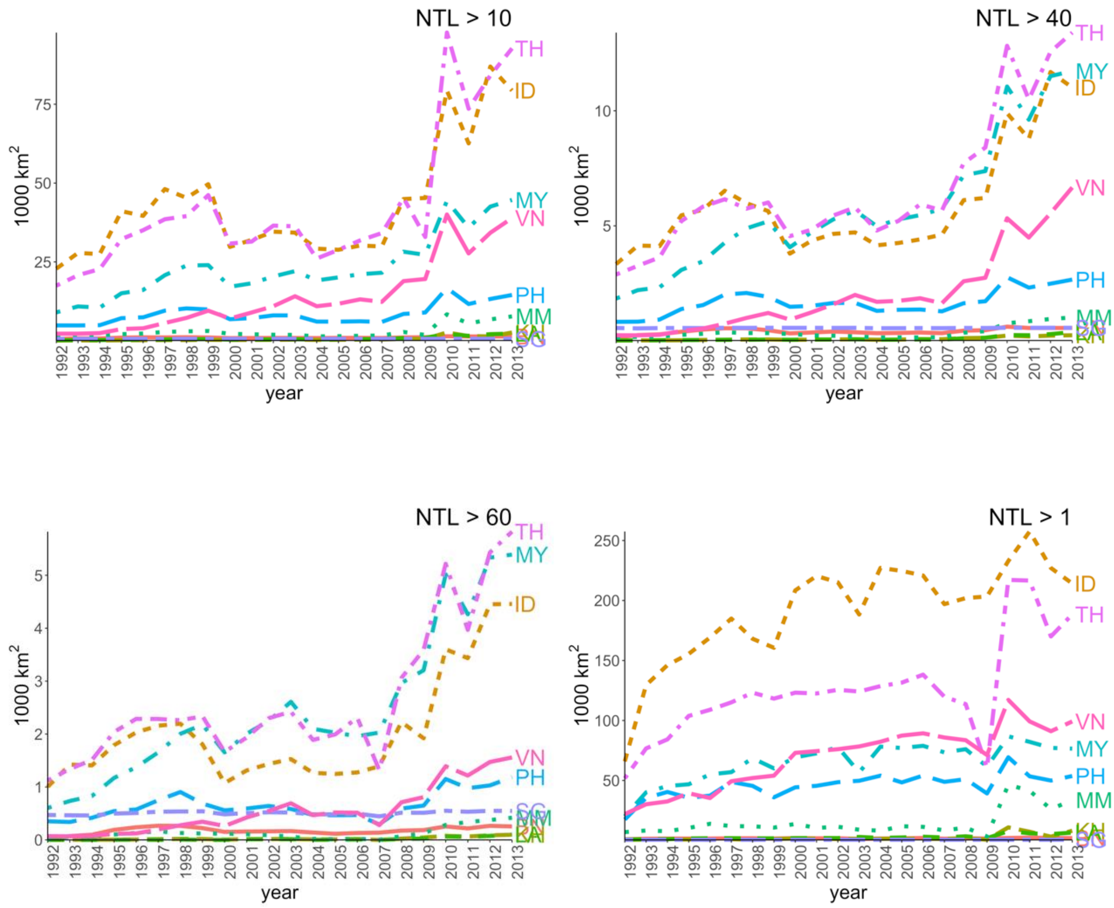
Figure 1. Aggregated Urban Area by Different Levels of Population Density in ASEAN



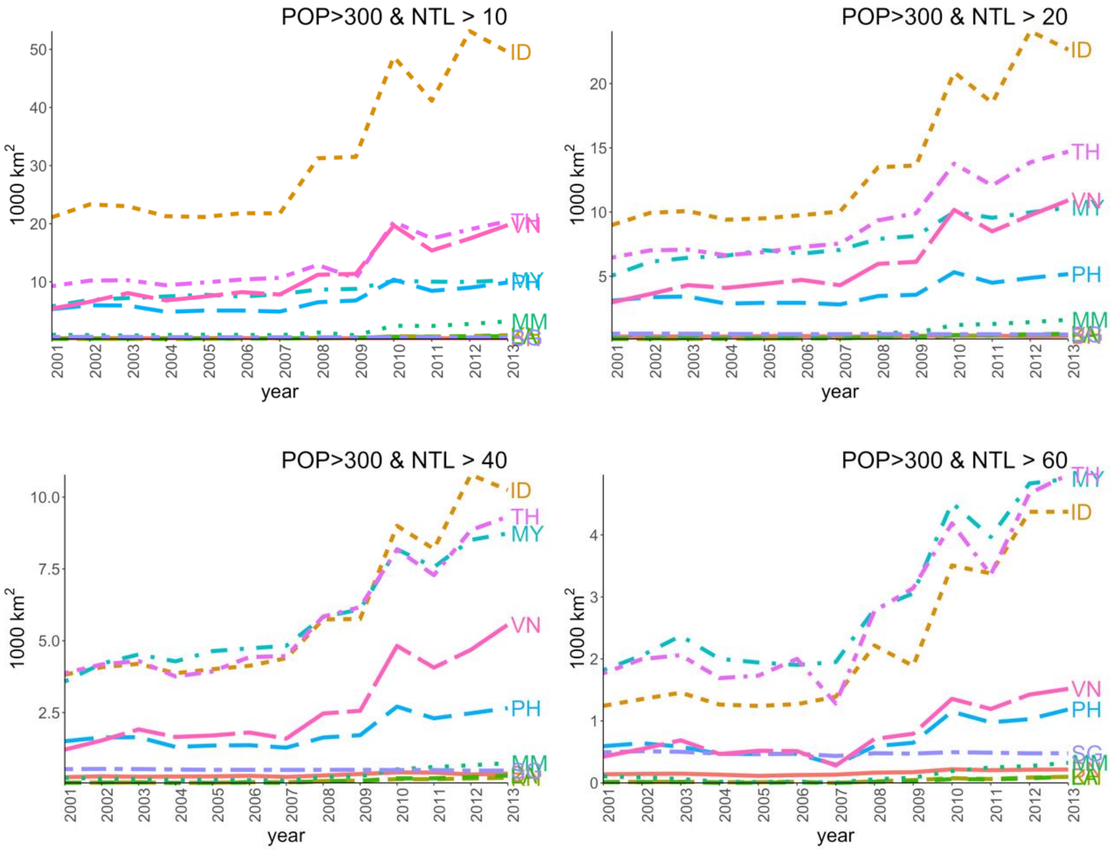
Notes: Computed by author based on LandScan and GAUL. BN: Brunei, KH: Cambodia, ID: Indonesia, LA: Laos, MY: Malaysia, MM: Myanmar, PH: Philippines, SG: Singapore, TH: Thailand, VN: Vietnam.

Figure 2. Aggregated Urban Area by Different Levels of NTL in ASEAN



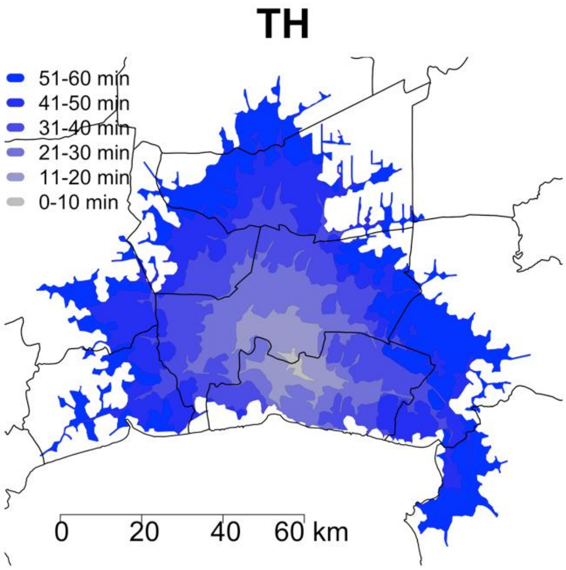
Notes: Computed by the author based on DMSP-OLS and GAUL. BN: Brunei, KH: Cambodia, ID: Indonesia, LA: Laos, MY: Malaysia, MM: Myanmar, PH: Philippines, SG: Singapore, TH: Thailand, VN: Vietnam.

Figure 3. Aggregated Urban Area by a Combination of Thresholds in ASEAN



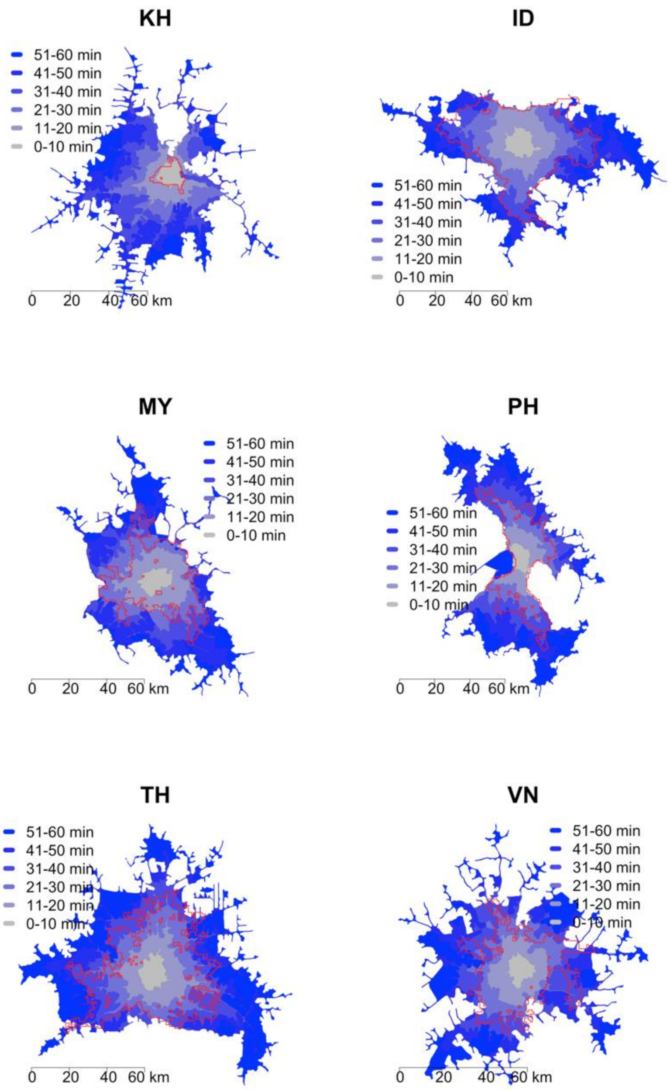
Notes: Computed by author based on DMSP-OLS, LandScan and GAUL. BN: Brunei, KH: Cambodia, ID: Indonesia, LA: Laos, MY: Malaysia, MM: Myanmar, PH: Philippines, SG: Singapore, TH: Thailand, VN: Vietnam.

Figure 4. Isochrones by Time Intervals in Thailand’s Largest Urban Area



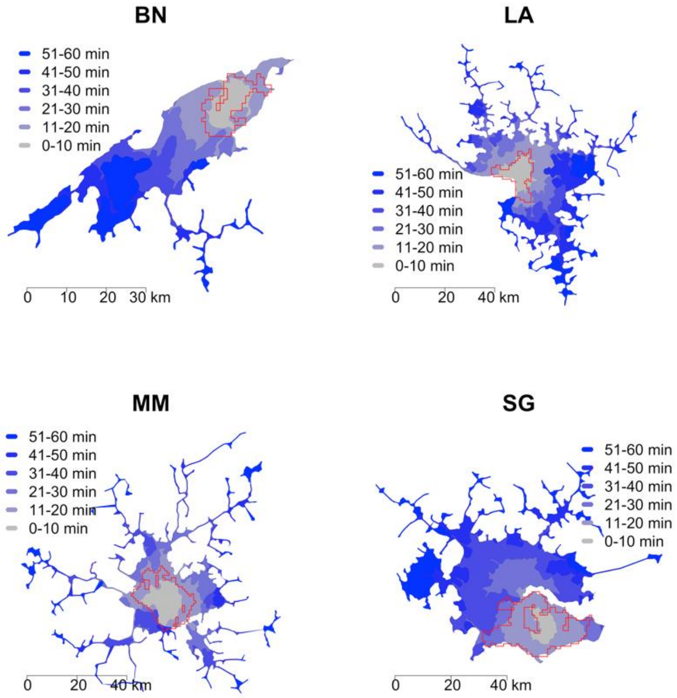
Note: Opensourcerouting. TH: Thailand.

Figure 5-1. Aggregated Urban Area by Combinations of Thresholds in ASEAN



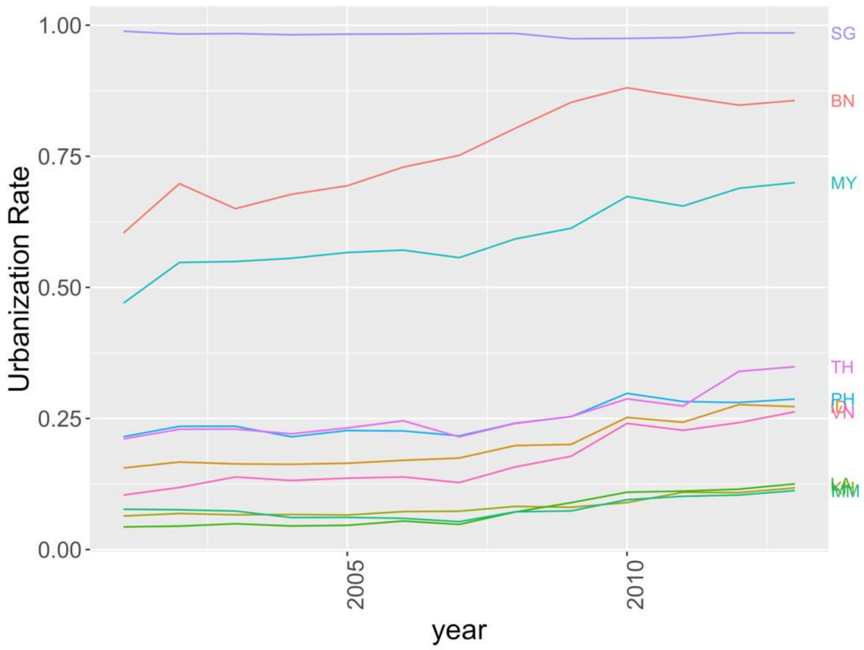
Notes: Computed by author based on DMSP-OLS, GAUL and Opensourcerouting. KH: Cambodia, ID: Indonesia, MY: Malaysia, PH: Philippines, TH: Thailand, VN: Vietnam.

Figure 5-2. Aggregated Urban Area by Combinations of Thresholds in ASEAN



Notes: Computed by author based on DMSP-OLS, LandScan, GAUL and Opensourcerouting. BN: Brunei, LA: Laos, MM: Myanmar, SG: Singapore.

Figure 6: Urbanization Rate in ASEAN based on Remote Sensing Data



Note: Computed by the author based on DMSP-OLS, LandScan, and GAUL. Urban area is identified by the grid with a population from 300 and NTL from 40 and above.