Determinants of Urban Sprawl: Evidence from Indonesia

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Abstract

In many developing countries, rapid urbanization often led to an urban expansion pattern that exhibit the sprawling patterns observed in developed country. However, we know little about the determinants of urban sprawl in developing countries. We study the determinants of urban sprawls in Indonesia between 2000 and 2010. We combine a new spatial dataset on urban built-ups in East Asia produced by the World Bank with Indonesia's village census and other satellite data on climate, geographic characteristics, and agricultural yields. We study the role of geographic and climatic factors, as well as socio-economic variables and amenities in determining the pattern of urban expansion and sprawling. Interestingly, we find significant differences in the determinants of sprawl between regions at different stages of economic development within Indonesia.

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1 Introduction

In many developed countries, urban sprawl is one of the most important issues faced by policy-makers and city planners. Sprawling is considered to be a costly and socially sub-optimal form of expansion supported by the car-centered transportation model (Glaeser and Kahn, 2004). It has a potentially large, direct impact on the environment in the urban fringes, with its extensive consumption of land and air-polluting motorized transports. Sprawling can also have significant consequences on social-economic conditions. It can cause disparities in the provision of public infrastructures and services across suburban areas, and induce residential segregation and pockets of poverty.

More recently, many developing countries have experienced rapid urbanization, driven by economic growth that disproportionately happen in the urban centers and metropolitan areas. In East Asia alone, more than 200 million people moved to urban areas between 2000-2010 (World Bank, 2015). Although developing countries typically exhibit higher urban population densities than industrialized ones, recent research has found a long-term trend of increasing urban sprawling and fragmentation globally (Angel et al., 2005, 2010). Understanding the causes and consequences of urban sprawl in developing countries are increasingly important. However, there remains a knowledge gap on the causes of sprawl in developing countries, often due to the unavailability of land use and economic data at a fine geographical level. Our study of Indonesia addresses this gap.

We study the determinants of urban sprawls in Indonesia between 2000 and 2010 using a new spatial dataset on urban expansion in East Asia produced by the World Bank. This new spatial dataset is constructed from a combination of a population map and an elaboration of land cover/land use change satellite data from MODIS with 250 meters resolution (World Bank, 2015). More specifically, the dataset mapped built-up extents — i.e., places dominated by the non-vegetative, human-constructed "built environment" — around cities in a set of East Asian countries.

We combine this spatial dataset with Indonesia's rich national survey and census datasets. We utilize a census of the characteristics Indonesian villages (or the *Podes* data) and the 2000 Population Census microdataset to construct village-level socio-economic, geographic, and demographic predetermined variables to help explain the observed patterns of urban sprawl. Our contribution is to provide new evidence on the determinants of sprawling in the context of a developing country, and shed some light on the differences between these determinants in developing and developed economies, such as the United States.

We compute the sprawl index for 77 urban areas with population sizes of at least 100,000 people in 2010. Half of these urban areas are located in the *Inner Islands* of Java/Bali, which are considered the more developed part of the country. The other half are located in the less-developed Outer Islands. We start from the administrative identification of the metropolitan areas provided by the World Bank (2015). For the sprawl measure, we adopt the methodology developed by Burchfield et al. (2006): For each pixel of the satellite images classified as built-up, our measure calculates the percentage of undeveloped land in its immediate square kilometer. The sprawling index of a geographic area can then be defined as the average of the sprawl measures of the newly-built-up pixels of that area.

To empirically examine the determinants of the evolution of urban sprawling, we first construct the core and fringe of each metropolitan area in the baseline year of 2000. A *core* is defined as the pre-existing high-density portion of the metro areas, to wit, the set of built-up pixels with a sprawl measure of less than 50 percent. We then construct a *fringe* from the 20km ring surrounding the core where the expansion occurs, bounded by the administrative lines of the districts into which the metropolitan area expanded. A metro's sprawl index is computed as the average of the sprawling indexes of the fringe.

We find that natural geographic factors, which in previous studies were found to determine patterns of urban expansion, are significant determinants of sprawling across Indonesian metropolitan areas. Similar to the findings in the U.S., terrain ruggedness (but not elevation range) increases sprawling. Sprawling is also constrained by proximity to bodies of water and the average size of the urban core. Interestingly (especially for a tropical country like Indonesia), sprawling is increasing in the temperature of the urban core. On the other hand, we do not find significant effects of precipitations.

Beyond natural characteristics, we explore the role of socio-economic variables. We find some support for the role of local amenities in determining urban structure. We find that amenities at the fringes (measured by a shorter average distance to a market and by the average dispersion of restaurants in villages within a fringe), as well as population pressure in the metropolitan area (measured by population growth) increase sprawling. At the same time, land availability and new residential development reduce urban sprawl.

Finally, we also examine how patterns of urban sprawl differ by the regions' state of development. Historically, development in Indonesia has been unequally distributed between the more-developed Inner Islands (of Java and Bali) and the rest of the (Outer) Islands. We therefore separately analyze determinants of urban sprawl between regions at different initial stages of development in 2000. We find differences in the determinants of urban sprawls between the more developed Inner Islands and the more agricultural Outer Islands. Better road access only increases urban sprawl in the Inner Islands. Similarly, employment sectoral concentration (which proxies for sectoral agglomeration) only reduces sprawling in the Inner Islands. In contrast, higher potential agricultural yields and precipitations at the fringe only affect sprawling in the Outer Islands.

Our study contributes to the small empirical literature on urban sprawl, and an even smaller one that focuses on sprawling in developing countries. Of the few studies that empirically analyze sprawling, most are focused on the U.S. context (Nechyba and Walsh, 2004; Glaeser and Kahn, 2004; Burchfield et al., 2006). In the case of emerging economies, Deng et al. (2008) explore the role of transportation costs and agricultural land value in the urban expansion of Chinese cities. In Indonesia, existing studies focus on the Greater Jakarta area, which has a unique status as the country's political and economic center of activities (Fitriani and Harris, 2011; Fitriani and Sumarminingsih, 2014). In contrast, our paper provides an exhaustive quantitative analysis of urban sprawling across Indonesian cities.

The rest of the paper is organized in 4 sections. Section 2 provides the context for the analysis. It begins with a review of urban development and its spatial characteristics in Indonesia, followed by a brief overview of the conceptual framework for the empirical analysis. Section 3 describes the data source and the methodology to construct our key variables. Section 4 presents our empirical strategy and the results of the analysis, both at the national and subnational level. Section 5 concludes.

2 Sprawl and Urban Development in Indonesia

2.1 Urbanization and Economic Development in Indonesia

Indonesia is today a low middle-income developing country with more than 17,000 islands, making it the world's largest archipelagic state. The past few decades saw the country experience rapid growth and structural transformation. Per-capita GDP grew from U.S.$ 772 (in constant 2010 U.S.$) in 1970 to just over U.S.$ 2,400 by 1997, right before the 1998 Asian Financial Crisis. Between 1970 and 1998, the mean annual growth rates was 4.4 percent. Meanwhile, driven by resource-price booms and outward-looking policies, the country also experienced massive structural transformation as the agriculture's share of GDP rapidly declined, while the share of industry (e.g., manufacturing) and services grew (Hill, 1996).

As the case in many developing countries, the transformation away from agriculture was accompanied with rapid urbanization, as people moved from rural to urban areas. Indeed, the rate of urbanization in Indonesa in the past few decades was among the highest in the East Asian region. The share of urban population in Indonesia increased from 17.2 to 42.2 percent between 1971 and 2000, and this rapid rate of urbanization is expected to continue. Extrapolating from current urbanization rates, World Bank (2012, p. 9) estimated about 4 million people would urbanize in this decade. The United Nations' *World Urbanization Prospects* (revision 14) estimated that about 71 percent of the Indonesian population would reside in an urban area by 2050.[1]

However, urbanization did not proceed with equal speed across the regions. In particular, urbanization rates differ between the country's main islands of Java and Bali (also known as the *Inner Islands*, see Figure 3) and the rest (or the *Outer Islands*). The Inner Islands are the most densely populated part of Indonesia, with a land area of around 8 percent of its total, but with 60 percent of its population. The Inner Islands are also more urban with around 70 percent of

[1] See the UN's *World Urbanization Prospects* at https://esa.un.org/unpd/wup/.

the country's urban population residing there in 2007 (World Bank, 2012, Table 2.3). Greater Jakarta, the world's second-most populated metropolitan area (where the country's capital, DKI Jakarta, is located) is part of the Inner Islands. The urban form in the Inner Islands is therefore characteristically distinct from that in the Outer Islands; a difference that largely reflects the historically unequal development across Indonesia's regions.

Modern economic activity has always been concentrated in the Inner Islands. Economic activities in the Inner Islands contributed about 61 and 66 percent of the country's total and non-mining GDP respectively in 2004 (Hill et al., 2009). The economic structure is also quite different between the Inner and Outer Islands. In 1975, agriculture contributed to more than one-third of the regional GDP in 21 of 26 Indonesian provinces (Hill et al., 2009). By 2000, it did so in only 10 out of 33 provinces, all in the Outer Islands.[2] In contrast, manufacturing contributed more than a quarter of the provincial GDP in only 6 Indonesian provinces in 2000, including in 4 (out of 7) Inner-Island provinces. In the remaining three Inner-Island provinces with less than 25 percent manufacturing share of GDP, the service sector was the main contributor of provincial GDP.

2.2 Spatial Characteristics of Urban Development

Until now, the most important challenge to studying the spatial aspects of urbanization in Indonesia has been data limitation. However, the novel *East Asia and Pacific Urban Expansion* (EAP-UE) maps produced by the World Bank (see Section 3.1) allowed us to examine both the spatial evolution of urban development in Indonesia, and placed it in the broader context of urbanization in East Asia. The maps captured changes in the built-up environments — defined as non-vegetative, human-constructed elements — that happened quite recently, i.e., between 2000 and 2010. However, given the aforementioned heterogeneity in economic development across the archipelago, we could use these maps to understand how these characteristics vary at different stages of urbanization.

By the virtue of Indonesia's total land area, the size of its urban land is the third-largest in the East Asia region.[3] However, given its total size, urban land covers a mere 0.5 percent of total land area and this share is among the lowest in the region. Compared to others in the region, Indonesia is relatively more urbanized. Between 2000 and 2010, urban land increased by 1.1 percent annually, which represented the slowest annual-rate increases in the region. In absolute terms, however, this increase represents the second-largest increase in the region after China.

Indonesia's urban areas vary widely in its population and size. For Indonesia, EAP-UE identifies 83 urban areas with a population of more than 100,000 people in 2010. Greater Jakarta

[2]Authors' calculations using the World Bank's *Indonesia Database for Policy and Economic Research (INDO-DAPOER)* database.

[3]This and the next paragraph rely on some of the main findings from the Indonesia section of World Bank (2015, Appendix A).

is the only urban area with a total population greater than 10 million and there are 2 urban areas with total populations of between 5 and 10 million people. It also has 18 medium-sized urban areas with between 1 and 5 million people, 27 smaller urban areas with between 500,000 and 1 million people, and 29 very small urban areas with between 100,000 and 500,000 people. Medium-sized urban areas have the largest proportion of urban land (27 percent), followed by the smaller urban areas (18 percent) and these shares mimic their urban population shares relative to total urban population. Importantly, a disproportionate share of urban land is located in the Inner Islands. In 2010, about three-thirds of Indonesia's urban land is in the Java. Urban land covered 5.5 percent of total land area in Java, compared to less than 1 percent in every other island or island group.

There is no systematic study on the spatial characteristics of urban expansion nationwide. However, existing case studies that focus on the larger metropolitan areas suggest that, like in many developed countries (e.g., Burchfield et al., 2006; Patacchini and Zenou, 2009), urban expansions in Indonesia's more developed metropolitan areas tend to (but not always) sprawl. World Bank (2012) examined four metropolitan areas, two each in the Inner and Outer Islands They found that in the former, most new built-ups and land conversions happened in the periphery of the metropolitan area, while sprawling was only observed in one of the two metropolitan areas examined (i.e., in Makassar but not Medan). Several push and pull factors could (in theory and in practice) incentivize sprawling urban development. We discuss these factors in the following section.

2.3 Causes of Sprawl: A Conceptual Framework

We use the standard monocentric city model of urban growth as our starting point. The location decision of new residential areas is shaped by the trade-off between commuting costs from the city center on the one hand, and land rents on the other. The main assumption of the model is that productive activities take place at the center of a metropolitan area (e.g., the central business disctrict), while people are willing to pay the cost of commuting in order to enjoy cheaper rent as they move away from the city center.

The monocentric city model, therefore, identifies some key determinants of urban sprawl. First, as transportation becomes cheaper, commuting costs fall and people are more willing to live further away from the city center. Second, the relative cost of land rents at the urban boundary compared to that at the city center would determine whether cities would expand further. In equilibrium, land rents at the city center should equal land rents at the urban boundary plus commuting costs. In regions where a large share of income still comes from the agricultural sector, urban areas next to more productive agricultural land are less likely to sprawl compared to those next to unproductive land (Brueckner and Fansler, 1983). Finally, rising average incomes will also lead to further urban expansion.

Models of urban expansion based on monocentric model typically assume a featureless, homogeneous space. However, natural features of the space can determine urban sprawl. Change in elevation is probably the most significant of these natural determinants. Mountains in the urban, for example, fringe likely leads to more compact built-up patterns, due to an increase in the cost of new constructions. Rugged terrain, on the contrary, can lead to low density developments (Duranton and Puga, 2015). Other natural barriers can force compactness as well, as in the case of large bodies of water or the proximity of the ocean coast. Figure 1, illustrates how a mountainous terrain — in this case, the Kelud volcano — limited the expansion of Ponorogo and Kediri cities in the Java Island.

Other natural features may also be important. On the one hand, temperate climate can influence urban sprawling by increasing the value of outdoor public spaces. On the other hand, long spells of hot temperatures in a tropical country with a yearlong temperature of between 25–35°C (77 – 95°F) might induce people to locate to less crowded residential areas with cooler microclimates from natural shades and vegetation. Finally, aquifers located in the fringe of a metropolitan area gives households the possibility to obtain water from private wells instead of paying the expenses to be connected to the public water system. Aquifers can facilitate sprawling decisions by allowing people to leapfrog.

Finally, amenities can function as push and pull factors away or toward the city center. The role of amenities is typically associated with residential choice within a metropolitan area, instead of the determinants of urban sprawl (Nechyba and Walsh, 2004). The idea, introduced in Tiebout (1956), is that people may sort themselves to local jurisdictions in response to the available local amenities. Local amenities include physical factors, like an open space, as well as intangible amenities with a socio-economic nature, such as ethno-religious homogeneity in a community. This type of model is able to explain discontinuous distributions of built-up in equilibrium, also known as leapfrogging urban expansion (Turner, 2005). However, in relation to sprawl, these amenities are typically studied as a consequence of sprawl, not as its causes.

3 Data

3.1 Data Sources

Urban Expansion. Data for urban expansion come from the East Asia and Pacific Urban Expansion (EAP-UE) *2000-2010* maps produced by the World Bank. The maps identify the expansion of built-up areas in Indonesia's (and a number of other East Asia's) metropolitan areas. EAP-UE uses the *Moderate Resolution Imaging Spectroradiometer* (MODIS) satellite imagery to create maps of built-up areas in East Asia regions. Built-up areas are defined in geophysical terms as areas where each landscape unit (a 250 × 250-meter pixel) has more than 50 percent of its area covered by non-vegetative, human-constructed elements (e.g., buildings, roads, railways, and others) (World Bank, 2015, Appendix C). We use the two maps produced by EAP-UE, i.e., for years 2000 and 2010, to study the spatial evolution of Indonesia's metropolitan areas. Figure 2 illustrates an example of the data for the metropolitan area of Jakarta, with the light blue pixels indicating the 2000 built-up and the orange ones corresponding to the urban expansion between 2000 and 2010.

Village Characteristics. We employ two national-level datasets to capture the demographic and socio-economic characteristics of the villages in our metropolitan area, to wit, *Podes* and the population census microdata. We use the 2000 wave of both datasets. Note that in Indonesia, a *village* is the smallest administrative unit in Indonesia, and can refer to either rural villages (*desa*) or urban villages (*kelurahan*).

Village Potential (Podes) — *Podes* is a census of Indonesian villages collected approximately every three years by Indonesia's statistical agency, BPS Indonesia. It collects detailed information from village informants about village characteristics, such as demographics, geography, as well as social and economic infrastructure. For this analysis, we use data from the 2000 wave of the village census.

2000 Population Census — To construct the sectoral share of employment in each village, we use the 2000 Population Census microdata. The dataset, collected by BPS Indonesia, is a complete enumeration of Indonesia's population, except for Aceh, Maluku, and Papua provinces, which were high-conflict regions in 2000. For these regions, population numbers were estimated using population models.

Rainfall. Precipitation data is provided by the Climate Hazards Group, in collaboration with the U.S. Geological Survey (USGS) (Funk et al., 2015). The Climate Hazards Group InfraRed Precipitation dataset (CHIRPS) combines station-based and satellite data for monthly observations starting in 1981 to near-present. Version 2.0 of CHIRPS is used, which is produced at 180 arc-sec spatial resolution (about 6×6 kilometer pixel size).

Temperature. We rely on the monthly-mean air temperature (in Celsius degrees) provided by the University of Delaware Willmott and Matsuura Global Climate Resource Center (see Matsuura and Willmott, 2017). The data is compiled from several sources, in particular the Global Historical Climatology Network (GHCN2). When data from GHCN2 stations is not available, other data sets or stations are used. We use version 3.1 of the dataset, with a resolution of 1800 arc-sec (about 55×55 kilometer pixel size).

Elevation. Elevation data comes from the Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010) produced by the U.S. Geological Survey (USGS) in collaboration with the National Geospatial-Intelligence Agency (NGA). This is an enhanced version of the previous product known as GTOPO30, with improved resolution of the dataset. We use the data for the mean elevation in the pixel, with resolution 7.5 arc-sec (about 225×225 meter pixel size).

Agricultural Yields. Crop yields data is obtained from the Global Agro-ecological Zones Data Portal version 3.0 (GAEZ v3.0). The GAEZ database is prepared and maintained by the Food and Agriculture Organization (FAO) of the United Nations (UN) coordinated by Land and Water Division (NRL) of the Natural Resources and Environment Department (NR) and International Institute for Applied Systems Analysis (IIASA) (FAO/IIASA, 2011). We use this dataset to construct the total crop production value per hectare for year 2000. The resolution of the dataset is 300 arc-sec (about 10×10 kilometer pixel size).

Population. We obtain population data from the Gridded Population of the World Version 3 (GPWv3). The dataset is provided by the Socioeconomic Data and Applications Center (SEDAC), a data center in NASA's Earth Observing System Data and Information System (EOSDIS). This archive contains population counts, both UN-adjusted and not adjusted, and we use the data adjusted to the country total. The raster data sets are constructed from national- or subnational-input's administrative units to which population estimates are matched to provide a spatially disaggregated population layer that is compatible with data sets from social, economic, and Earth science fields. The population dataset has an output resolution of 150 arc-sec (or about 5×5 kilometer pixel size).

3.2 Metropolitan Selection

City limits are notoriously difficult to define and multiple approaches have been suggested in the literature (see, for instance, Chomitz et al., 2005; Uchida and Nelson, 2010). For our purpose, we start with the list of urban regions provided by the World Bank's EAP-UE. Based on this list, we independently define the physical extents of pre-exiting built-up by constructing the city core and the matching fringe of each urban area based on the Burchfield et al. (2006)'s methodology starting from a broader area in these designated urban regions.

We identify 77 urban metropolitan areas in Indonesia with population larger than 100,000 people in 2010. Out of the original 83 metropolitan regions identified by EAP-UE, 6 of them are dropped from the sample because of their lack of either a well-defined core – e.g., excessively diffuse settlements in 2000 – or a sufficiently strong urban expansion in 2010.

Figure 3 illustrates the geographic distribution of the metropolitan areas, core and fringe together, on the Indonesian map. Half of these areas are located on the Inner Islands of Java and Bali, while the second half are in the Outer Islands, a quarter on Sumatra and a quarter on the other islands. The largest of these areas is Jakarta, the capital of the country, which is a mega metropolis of 10 million people. Four cities have more than 2 million inhabitants – these are Bandung, Surabaya, Medan, and Bekasi, while all others are in the range 100,000 to 2 million people.

3.3 Measures of Sprawl

Even though urban sprawl can be directly linked to the degree of compactness of new urban developments, the complexity of the spatial patterns of urban expansion allows for multiple empirical definitions and measures of sprawl. Summarizing the numerous dimensions of urban sprawl in a single index suitable for quantitative empirical analysis is therefore challenging, if not impossible. Previous studies have used proxies such as median lot size or commuting time and distance (see Glaeser et al., 2001). In this paper, we adopt a fairly common index of sprawl in the literature introduced by Burchfield et al. (2006), which is based on a simple measure of urban development density.

For any pixel classified as built-up in the map of a geographic area, the percentage of open space in the immediate square kilometer around each pixel is a direct and simple measure of the urban development density. Burchfield et al. (2006) construct the sprawling index of a geographic area of interest by averaging this sprawl measure across the newly-built-up pixels of that area at some point in time. This index can then be defined as a measure of the undeveloped land in the square kilometer surrounding an average urban development.

In practice, rather than constructing a box around each newly-built pixel, the map of Indonesia is first reticulated into a pre-determined grid of one square kilometer boxes. The pixels inside each of these boxes are then used to identify new and pre-existing built-up points and calculate the measure of urban density for the newly-built pixels. This procedure approximates the pixel-by-pixel calculation of the measures, but it is computationally faster and more convenient.

Figure 4 illustrates this procedure using two typical sprawling cases. The resolution of our urban expansion data gives us 250×250-meter pixels, which corresponds to square boxes containing 16 of these pixels. Example (a) in the figure illustrates a high-density box or a compact urban expansion: the sprawling measure for the newly created development (the yellow pixel) is quite low and equal to 25 percent. In case (b), we can see a "leapfrog" urban expansion with a quite low density and and high sprawling measure of 62.5 percent for the two newly-built pixels. Our procedure will attribute the same value of sprawling to all the newly-built-up pixels found in a box.

We track urban expansion between 2000 and 2010 and compute the sprawl index for the new built-up of each metropolitan area. To construct the index, we need to first define the *core* of each metropolitan area (from which the urban area will expand). The urban core is defined as a high density built-up area within the administrative metropolitan region formed by the set of pixels for which the sprawl measure in 2000 is smaller than 50 percent. Figure 5 illustrates the construction of the core for the metropolitan area of Medan, the capital of the North Sumatera province. Panel (a) illustrates the built-up in 2000 in light blue and the 2010 expansion in orange; panel (b) shows the outcome of the core computation in dark blue. The core would typically identify a large, compact block of pre-existing built-up that corresponds, in some sense, to the inner part of a city. However, smaller satellite centers around the main core might also satisfy the definition of core, as it can be seen from the figure.

Next, we construct a buffer area around the core (or the *fringe*), which will be used to compute the sprawl index. Following Burchfield et al. (2006), we define the fringe as the 20 kilometer ring within the administrative boundaries of the metropolitan region surrounding the core where the urban expansion between 2000 and 2010 actually occurs.[4] Panel (c) of Figure 5 shows the fringe matching the core in panel (b). The Medan fringe is limited by the administrative boundaries of the districts belonging to the metropolitan region, as we can see from the South-East side of the fringe and explicitly also from Figure 6. Once the fringe is defined, the sprawl index of a metropolitan area is the average of the the sprawl measures for the 2010 built-up pixels in this fringe.

3.4 Location Characteristic Variables

We constructed a rich set of variables to capture the location characteristics of the metropolitan area. In general, almost all of the location characteristics variables are constructed either for the whole metropolitan area or for its fringe.[5] The source of most of our climatic and terrain characteristic variables come from a digitized map, which we aggregate accordingly across the relevant spatial unit (i.e., the overall metropolitan or its fringe). While most of the variables have an intuitive definition, we describe the specific definitions of some of the variables below.

Ruggedness —. The terrain ruggedness index is constructed following the methodology of (Riley et al., 1999). The index is computed for each pixel in the GMTED2010 dataset and then aggregated as a simple mean over the fringe. The index is computed as follows: let $e_{r,c}$ indicate the elevation value for the pixel in position r, c of the elevation raster. The index is then $TRI_{r,c} = [\sum_{i=r-1}^{r+1} \sum_{j=c-1}^{c+1} (e_{i,j} - e_{r,c})^2]^{\frac{1}{2}}$.

Precipitation differences—. We compute the difference in mean precipitations between the two pre-2000 decades (1980-2000) and the post-2000 decade (2000-2010) in two steps. First, we sum the monthly data provided by GHCN2 for each year and across pixels of the raster at the metropolitan area level. Second, we take the annual means over the two periods (pre/post 2000) and, then, compute the difference between the two periods. This index measures rainfalls abundance relative to its historic mean.

Temperature (cooling degree days) —. Mean cooling degree days captures hot climate effects with an index that measures by how many degrees the daily temperature goes over the 18°C threshold during a year. Cooling degrees in a given day is the $\max(0, T > 18°C)$, where T is the average temperature for that day in a metropolitan area. These daily measures are then aggregated over the year summing up the cooling degrees for each day.

Employment centralization index —. The employment centralization index is constructed in the

[4] Burchfield et al. (2006) choose a 20 kilometer fringe because it contains almost 100% of the new developments around built-up areas at the beginning of their sample. Simple visual inspection of the maps confirm this also holds for urban expansion between 2000 and 2010 in Indonesia.

[5] An exception is the manufacturing employment share variable, which we constructed for the metropolitan *core* to capture the extent to which urban income are driven by the modern sector.

spirit of Burchfield et al. (2006) using information on the sectoral employment of the population from the 2000 Population Census. The census classifies employment into 9 main sectors, including food and non-food agriculture, fishery, trade, transportation, plantation, animal husbandry, manufacturing, services, and other sectors. The index compares the sectoral employment shares in the metropolitan area to its distribution within the average metropolitan core (where employment tends to concentrate in more centralized sectors).

The index expresses the share of employment that would be located in the core if employment in each sector of a metropolitan area were distributed as it is in the average metropolitan area. Defining $S^m_{j,i}$ the employment share of sector i in the overall metropolitan area j and $\bar{S}^c_i$ the average share of sector i across city cores, the index for the metro area j is computed as $\sum_i S^m_{j,i} \times \bar{S}^c_i$. Note that our measure does not exactly campture the employment shares for the activities located inside/outside the core, but instead the employment shares based on the workers' residence.

Village Census variables —. The remaining variables come from the Village Potential (*Podes*) data and are calculated for the metropolitan fringe. These variables is reported for each village across Indonesia and they can be in the form of a binary or a continuous variable. To aggregate these village-level variables for each fringe, we calculated the weighted average over all villages that overlap with the fringe. We consider two types of weights, depending on the variables. For variables related to land use, we use the village area as weights. Meanwhile, for all other variables, we weight these variables using village population. Table 1 list the variables, their definition, aggregation strategy, and source.

Table 1: Location Characteristics

Variable	Definition	Aggregation		Dataset
		Area	Weight	
Elevation range	(max − min) elevation	Fringe	None	GMTED2010
Ruggedness	Terrain ruggedness index (Riley et al., 1999)	Fringe	None	GMTED2010
Cooling-degree-days	Total annual degrees while $T > 18°C$	Metro	None	GHCN2
Pop. g. rate 90-00	Average pop. growth over the decade	Metro	None	GPWv3
Distance to market	Distance to the nearest market	Fringe	Population	Podes
Distance to clinic	Distance to the nearest clinic	Fringe	Population	Podes
Distance to core	Distance between village/metro-core centroids	Fringe	Population	GIS/Podes
Restaurant dispersion	Gini I. for per-capita village restaurants	Fringe	Population	Podes
New houses/hh	Number of new houses per household	Fringe	Population	Podes
Ground water	Ground water for drinking/washing (Yes/No)	Fringe	Population	Podes
Possible built-up expansion	Share of unused land	Fringe	Land area	Podes
All year main road	Main road is accessible all year round (Yes/No)	Fringe	Population	Podes
Agr. Yield/Agr. land	Mean yield per agricultural land area	Fringe	Land area	GAEZv3/Podes
Share coastal border	Share of villages lying by the coast	Metro	Land area	Podes
Pre/post 2000 rainfall diff.	Precipitations difference 1980-2000/2000-2010	Metro	None	CHIRPS
Manufacture emp. share	Employment share in manufacturing	Core	Population	Podes
Empl. centralization index	Potential concentration in centralized sectors	Metro	Population	Pop Census

4 Urban Sprawling and Its Causes in Indonesia

This section reports our findings on the causes of urban sprawl in Indonesia. We begin with a summary of the state of urban sprawl in Indonesia according to our index. We then discuss the empirical strategy and specification to estimate the causes of sprawl. We then report our baseline results for the overall sample, and the separate estimates for the Inner- and Outer-Island metropolitan areas.

4.1 Urban Sprawl in Indonesia

We find a wide variation of the sprawling index across metropolitan areas. The sprawl index across metropolitan areas ranges between 10.6 and 92.8, with mean of 41.2 standard deviation equal to 15.5. Outer-Island metropolitan areas are typically less compact, but even in the Inner Islands we can find a large variation in the sprawl index. Figure 7 illustrates the geographic distribution of the index across the Inner-Island cities. The index is quite low, as one could expect, for major cities like Jakarta and Bandung (on the west of the Island) and it increases as we move east toward the East Java province.[6]

The distribution of the sprawling index is characteristically different between the Inner and Outer Islands. Figure 8 presents the distribution of the sprawl index overall. The mode for the overall distribution is around 40, but then a second peak of mass concentration is found at the higher level of 70. This fatter right tail, however, is not due to the Inner-Island cities as shown in Figure 9. The distribution for the Inner-Island metropolitan areas is actually quite symmetric and regular, whereas the distribution for the Outer Islands is bi-modal. The high values of the index are observed for the cities on these islands. This is an important difference: since the share of urban land in the Outer Islands is much lower than that in the Inner Islands, cities can still grow into more rural and underdeveloped areas in their fringe. In Section 4.4, we show that the differential characteristics on Inner and Outer Islands led to heterogeneous determinants of sprawling in the two regions.

4.2 Estimating the Causes of Sprawl

We estimate the model

$$SI_{i,j} = {F_i}'\beta^f + {C_i}'\beta^c + {M_i}'\beta^m + \lambda_j \mathbb{1}(I = j) + u_{i,j} \quad (1)$$

where $SI_{i,j}$ is sprawling index computed over the new built-ups occurred between 2000 and 2010 for metro area i on island j and λ_j is the island fixed effect; the three vectors of regressors F, C, M indicate determinants defined at the fringe, the core, or the entire metro area respectively. For

[6] As discussed above, this part of Java exhibits different orographic characteristics and metropolitan areas not necessarily on the shore.

instance, temperature is a characteristic of the entire metro area, while average distance from the market is measured at the fringe level. Finally, variables obtained from village level sources are then aggregated at the metropolitan area level either by using population or land size weights, depending on the type of variable.

The maximum cross-section sample is 77 metropolitan areas; however, the actual sample of each estimated model varies in function of the specification in use. We use pre-2000 data for all of our regressors. This use of pre-2000 mitigates some of the endogeneity concerns associated with the socio-economic variables with respect to urban sprawling. For instance, the location of amenities (e.g., a restaurant), is affected by new built-up expansions and in the long-run, these location decisions and economic factors will be endogenous to patterns of urban expansion. Therefore, in presenting our results below, we begin by regressing sprawl on the sets of (exogenous) natural features, and then progressively add some of the socio-economic variables in successive columns.

4.3 Main Results

We analyze the causes of urban sprawl in Table 2. We begin with a set of geographic and climatic determinants found to be important determinants of urban development in the literature. We then attempt to better characterize these effects by including a richer set of socio-economic variables in our dataset in the following columns. All variables are standardized to aid comparability. A positive coefficient indicates an increase of the sprawling index associated to a specific factor.

Column 1 presents the impact of geographic and climatic variables on sprawl. We find results consistent with our expectations of these effects. Physical barriers, such as coasts and mountains limit sprawling, while ruggedness – which captures the irregularity of the terrains – facilitates less dense developments as development leapfrogs over the irregular parts of the terrain. Hotter climate, with more days in which indoor cooling is necessary, increases sprawling. With a tropical climate, where there are no extreme temperature fluctuations over time and space, our measure captures a (persistently) higher local temperature. Persistently higher temperature encourages the search for more open and ventilated areas where natural shades and vegetation help cool down living spaces for new residential constructions. As shown in Columns 4 and 5 below, the point estimates for cooling days fell once we control for the share of unused village land at the fringe. Cooling days and coastal borders (unlike ruggedness and elevation) remain statistically significant with the inclusion of population growth and the distance-to-core variables.

Columns 2 to 4 augment the model with factors that are relevant to the monocentric model of urban equilibrium. To proxy for the cost of commuting, we construct the weighted average distance of the villages in the fringe from the core. We find that this distance has a significant, negative impact on sprawling. The negative effect of the distance from the core on sprawling is consistent with the predictions of the monocentric model on the impact of commuting costs. Similarly, higher manufacturing employment share in the core significantly discourages sprawling because it requires proximity of workers and it is, hence, a pulling factor towards the city core.

Built-up expansion possibilities, represented by the share of unused land in the fringe villages, has a negative, significant coefficient in Column 5. We clarify these somewhat puzzling results when we examine the heterogeneous determinants of urban sprawl in the more-developed Inner Islands (where the land-value gradient away from the core tends to be steep) and the less-developed Outer Islands. On the contrary, average population growth and access to ground water, which were significant factors in Burchfield et al. (2006) for the U.S., are not found to be significant in our case, and neither are newly-built houses. Interestingly, after controlling for space not occupied by built-up, the coefficient and significance of cooling days drops.

Columns 6 to 8 consider some of the amenities associated with urban sprawl. We include in the regression an index of restaurant dispersion, average distance of villages from the market and, alternatively, the distance from shopping center. The three factors have negative and significant effects. Restaurants turn out to be an important amenity: an uneven restaurant distribution reduces sprawling pushing people to locations where there is higher concentration of facilities. An equivalent explanation holds for distance from markets and shopping areas. We can observe from the table that these two measures of distance within the metropolitan area replace the more generic distance to the core we had up to column 5, providing a better description of the underlying mechanism.

With the inclusion of the amenities variables, newly-built houses and built-up expansion possibilities became significant. This suggests that the share of unused land probably also reflects the distance from amenities, while the availability of new houses provides negative incentives to the construction of more scattered developments. Finally the positive coefficient of population growth rate for the decade before the urban expansion increased and became significant. If previous population growth is a good predictor of the future growth, it might provide information on migration inflows and expected growth of population density, which (conditional on the amenities) convinces people to move to (and developers to build in) less concentrated areas.

4.4 Sprawling and Level of Development

We discuss in Section 2.1 the different level of development between the Inner and Outer Islands. Figure 10 illustrates this distinction using the night lights (in red) in 2010. The differences across islands are striking: the Inner Islands are much brighter relative to the rest of the country. There is a strong correlation between nightlights and income levels and urban land coverage (Henderson et al., 2012, see e.g.). Figure 10 then shows that the level of economic development and urban covers in the Inner Islands are quite different than in the remaining Outer Islands. For this reason, we proceed with a separate analysis of the two groups of islands in Tables 3 and 4.

Inner-Islands —. We present the determinants of sprawling in the Inner Islands in Table 3. To facilitate comparison, we include in Column 2 estimates of the Column 1 specification for the

Outer Islands. We find that the effect of restaurant dispersion is very significant and large across the board, this is an important amenity in an urban environment. Distance from the market is not relevant; instead, distance from an health services provider is more important. We find the exact opposite result for the Outer Islands. Terrain characteristics and cooling days do not matter indicating a more uniform type of development, and possibly climate, across the region. They may also reflect the scarcity of available land in the densely-populated Inner Islands.

Three other important differences between Table 3 and the nationwide results (Table 2) came from variables related to the monocentric theory. First, the effect of built-up expansion possibilities is now strongly positive and significant. This is expected, especially when land-value gradient outside the high-productivity core is steep that residential development is pushed outward. Second, the manufacturing-employment share is replaced by an employment concentration index, which closely reflects the composition of sectors that benefit from agglomeration economies: when manufacturing is no longer the leading sector, agglomeration has a more important role in shaping urban expansion. Finally, better-quality roads (i.e., year-long accessible roads) *ex ante* makes it easier for developers to expand the current road network, cuts down commuting cost, and makes sprawling easier. We find positive, large and significant coefficients for roads in the Inner Islands, but not in the Outer Islands.

Outer-Island —. Table 4 presents the determinants of sprawl in the Outer Islands. As before, we facilitate comparison by estimating a similar specification for the Inner Islands in Column 2. We find that urban expansion patterns in the Outer Islands are driven by distinct aggregate economic forces. Unlike in the Inner Islands, we do not find that economic agglomeration is a significant determinant of urban sprawl. Instead, we find that manufacturing-sector employment share is significant. This suggests how modes of production can shape urban expansion at different stages of economic development.

Meanwhile, amenities and residential development potential also play different roles in shaping urban expansion in these two regions. We find that restaurant dispersion remains an important determinant of urban sprawling in the Outer Islands. However, distance to the market (which did not play in important roles in the Inner Islands) is negative and significant. Both new housing development and the share of unused land negatively affect urban sprawling, although they are not always precisely estimated across specifications. The sign of the coefficient for the latter variable is opposite that for the Inner Islands. One possible reason would be if built-up expansion possibilities signal the unavailability of modern infrastructure and amenities in the Outer Islands.

We find access to ground water to be negative (albeit marginally significant) overall and separately for the two island groups. The negative estimates for ground water deserve scrutiny. Typically, the possibility of accessing water by using private wells allows developers to avoid the connection costs to the main public water system, reducing the cost of building far from pre-existing built-up areas. The negative effect in Indonesia could be explained by the low quality of the urban water system and the lack of a widespread network. In this context, the access to an aquifer might encourage developers to bear the fixed cost of digging a well and build a large size developments on top of the aquifer. In some sense, this is a private supply of a public good.

Moreover, there are three determinants that reflect the more rural characteristics of the fringes of the metropolitan areas in the Outer Islands. First, hotter temperature have a strong positive effect on sprawling which was missing for the Inner Islands. This may be partly explained by the greater variability of temperature across the Outer Islands metropolitan areas due to its wider geographic coverage compared to the Inner Islands. It is also consistent with built-up of housing in more open areas with natural shades, and the construction of countryside dwellings to escape the downtown humidity and heat.

Second, and more sharply related to the rural nature of these islands, agricultural yields per hectare (but not roads) are now significant. The effect is negative, as predicted by the monocentric theory: in economies where agriculture is important, more productive agricultural land would create a natural barrier to further sprawling. Third, the difference in the mean precipitations before and after 2000 has a significant and positive effect on sprawling. This effect was not observed for Inner Islands metropolitan areas either. One possible explanation would be that more abundant rain, which potentially leads to higher agricultural output, would act as a "push factor" that encourages urban workers to live (and farm) in the more fertile areas at the fringe.

5 Conclusion

We study patterns of urban expansion in Indonesia. We find natural causes of sprawls. Large terrain irregularities, such as mountains and coasts, create a wall to sprawling, but small terrain irregularities can cause further sprawl. Climatic factors like temperature and rainfall can also affect sprawling, although the effects differ between different the different regions in the country. Similar, agricultural productivity can limit sprawling possibilities. We identify some of the amenities that may act as push and pull factors to induce sprawl.

Importantly, we find evidence for the heterogeneous role of aggregate economic forces on urban expansion patterns within Indonesia. Determinants of urban sprawl can differ, not only between countries but also within within a country. In Indonesia, we find a greater role of agglomeration forces in shaping urban sprawl in the more-developed Inner Islands (whose economy is more dominated by industrial and service activities), while agricultural yield and the share of manufacturing are more important in the less-developed Outer Islands.

We intend to expand our analysis across a number of directions. First, we plan to improve the specificity in the definition of a built up by incorporating additional maps to separate between residential and other types of built-ups. Second, we also would like to introduce the role of community composition in the fringes as a determinant of sprawl, given the increasing importance of identity politics in Indonesia.

References

Angel, Shlomo, Jason Parent, Daniel L. Civco, and Alejandro M. Blei, "Atlas of Urban Expansion," Cambridge, MA: Lincoln Institute of Land Policy 2010.

_ **, Stephen C. Sheppard, and Daniel L. Civco**, "The Dynamics of Global Urban Expansion," Washington, DC: World Bank 2005.

Brueckner, Jan K. and David A. Fansler, "The Economics of Urban Sprawl: Theory and Evidence on the Spatial Sizes of Cities," *The Review of Economics and Statistics*, August 1983, *65* (3), 479.

Burchfield, Marcy, Henry G. Overman, Diego Puga, and Matthew A. Turner, "Causes of Sprawl: A Portrait from Space," *The Quarterly Journal of Economics*, 2006, *121* (2), 587–633.

Chomitz, Kenneth M., Piet Buys, and Timothy S. Thomas, "Quantifying the Rural-Urban Gradient in Latin America and the Caribbean," Policy Research Working Paper 3634, Development Research Group, Infrastructure and Environment Team, World Bank, Washington, DC. 2005.

Deng, Xiangzheng, Jikun Huang, Scott Rozelle, and Emi Uchida, "Growth, population and industrialization, and urban land expansion of China," *Journal of Urban Economics*, 2008, *63*, 96–115.

Duranton, Gilles and Diego Puga, "Urban Land Use," in "Handbook of Regional and Urban Economics," Vol. 5, Elsevier, 2015, pp. 467–560.

FAO/IIASA, "Global Agro-ecological Zones (GAEZ v3.0)," FAO Rome, Italy and IIASA, Laxenburg, Austria. 2011.

Fitriani, Rahma and Eni Sumarminingsih, "The Dynamic of Spatial Extent of Land Use in the Fringe of Jakarta Metropolitan: A Semivariogram Analysis," *APCBEE Procedia*, 2014, *10*, 198–202.

_ **and Michael Harris**, "The Extent of Sprawl in the Fringe of Jakarta Metropolitan Area from the Perspective of Externalities," 2011 Conference (55th), February 8-11, 2011, Melbourne, Australia 100700, Australian Agricultural and Resource Economics Society 2011.

Funk, Chris, Pete Peterson, Martin Landsfeld, Diego Pedreros, James Verdin, Shraddhanand Shukla, Gregory Husak, James Rowland, Laura Harrison, Andrew Hoell, and Joel Michaelsen, "The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes," *Scientific Data*, 2015, *2* (66), 1–21.

Glaeser, Edward L. and Matthew E. Kahn, "Sprawl and urban growth," in J. V. Henderson and J. F. Thisse, eds., *Handbook of Regional and Urban Economics*, Vol. 4 of *Handbook of Regional and Urban Economics*, Elsevier, 2004, chapter 56, pp. 2481–2527.

— , — , **Richard Arnott, and Christopher Mayer**, "Decentralized Employment and the Transformation of the American City [with Comments]," *Brookings-Wharton Papers on Urban Affairs*, 2001, pp. 1–63.

Henderson, J. Vernon, Adam Storeygard, and David N. Weil, "Measuring Economic Growth from Outer Space," *American Economic Review*, 2012, *102* (2), 994–1028.

Hill, Hal, *The Indonesian economy since 1966: Southeast Asia's emerging giant*, Cambridge, UK ; New York: Cambridge University Press, 1996.

— , **Budy P. Resosudarmo, and Yogi Vidyattama**, "Economic Geography of Indonesia: Location, Connectivity, and Resources," in Yukon Huang and Alessandro Magnoli Bocchi, eds., *Reshaping Economic Geography in East Asia*, Washington, DC: World Bank, 2009.

Matsuura, Kenji and Cort J. Willmott, "Terrestrial Air Temperature and Precipitation: 1900-2014 Gridded Monthly Time Series," 2017. Center for Climatic Research Department of Geography Center for Climatic Research, University of Delaware.

Nechyba, Thomas J. and Randall P. Walsh, "Urban Sprawl," *Journal of Economic Perspectives*, 2004, *18* (4), 177–200.

Patacchini, Eleonora and Yves Zenou, "Urban sprawl in Europe," *Brookings-Wharton Papers on Urban Affairs*, 2009, *2009* (1), 125–149.

Riley, Shawn J., Stephen D. DeGloria, and Robert Elliot, "A Terrain Ruggedness Index that Quantifies Topographic Heterogeneity," *Internation Journal of Science*, 01 1999, *5*, 23–27.

Tiebout, Charles M., "A Pure Theory of Local Expenditures," *Journal of Political Economy*, 1956, *64* (5), 416–424.

Turner, Matthew A., "Landscape preferences and patterns of residential development," *Journal of Urban Economics*, 2005, *57* (1), 19–54.

Uchida, Hirotsugu and Andrew Nelson, "Agglomeration Index: Towards a New Measure of Urban Concentration," Background paper for World Development Report 2009: Reshaping Economic Geography. World Bank, Washington, DC. 2010.

World Bank, "Indonesia - The rise of metropolitan regions : towards inclusive and sustainable regional development," Technical Report, World Bank, Washington, DC 2012.

— , *East Asia's Changing Urban Landscape: Measuring a Decade of Spatial Growth*, The World Bank, January 2015.

Figures

Figure 1: Effects on urban development of natural barriers: the Kelud volcano between the urban areas of Ponorogo & Kediri

Figure 2: Change in built-up for the metropolitan area of Jakarta. Period 2000–2010

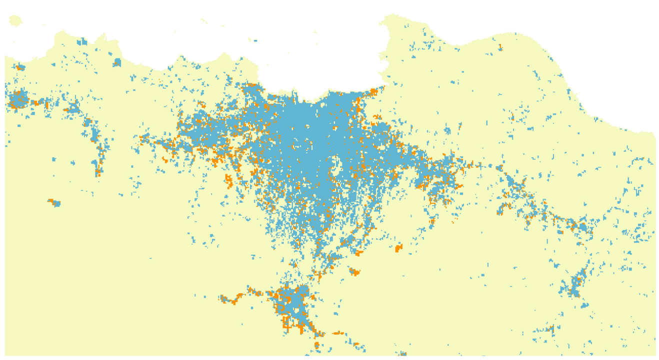


Figure 3: Indonesian map with the identified metropolitan areas – cores and fringes together.

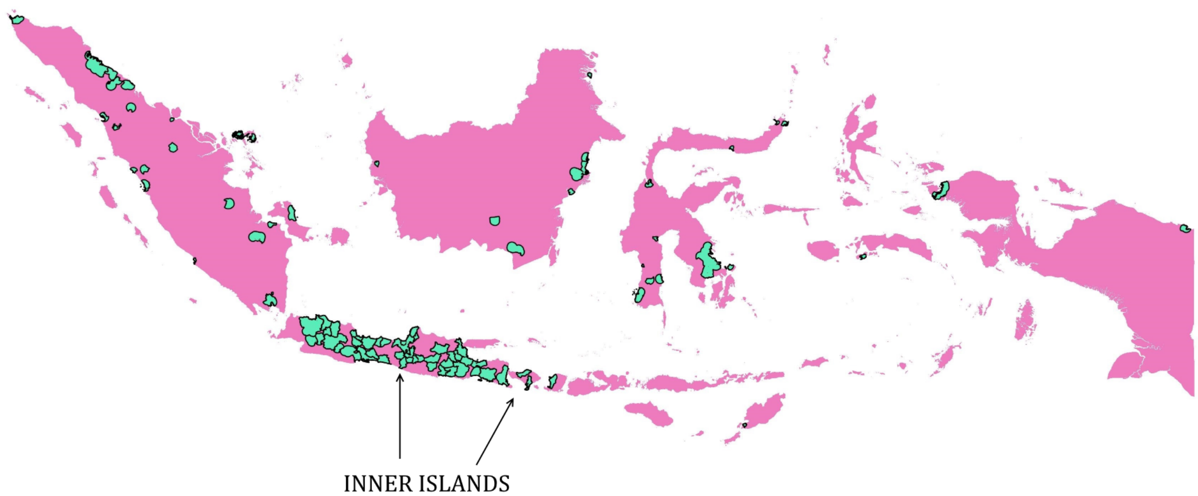


Figure 4: Two examples of the urban development density measure for our data type used in the computation of the Burchfield et al. (2006)'s sprawling index.

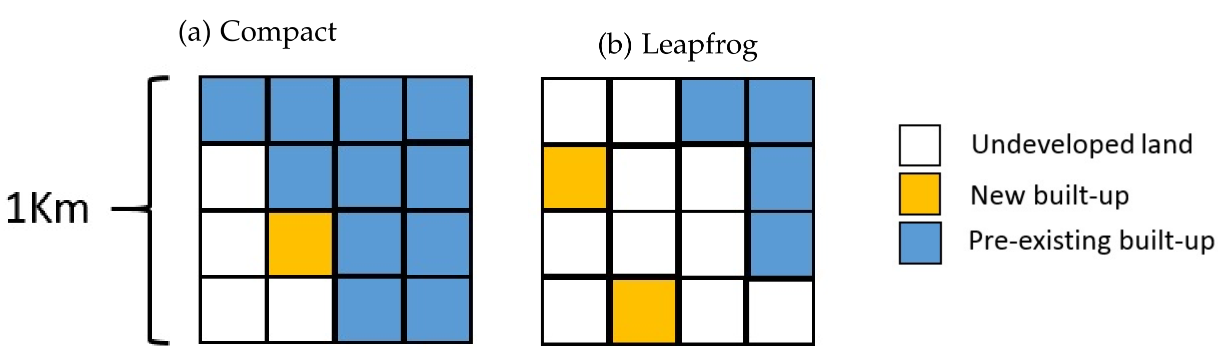
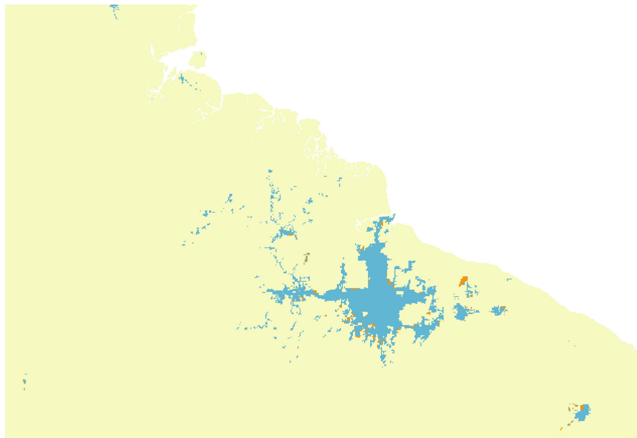
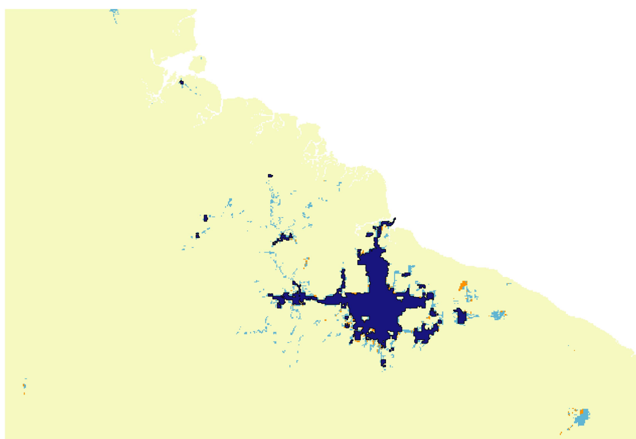


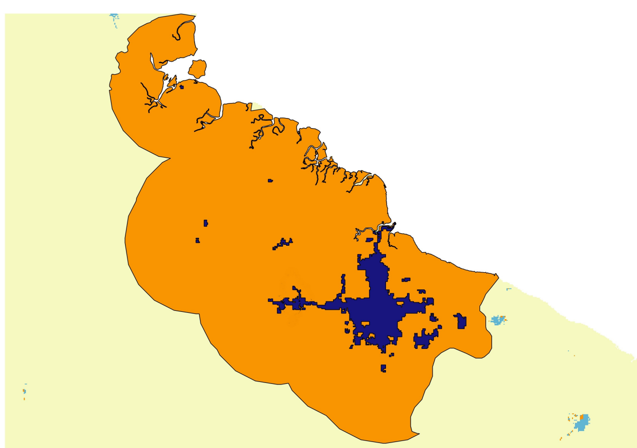
Figure 5: An example of construction of core and fringe for 2000 for the metropolitan area of Medan – Sumatra Island.



(a) Urban Coverage: 2000 light blue, 2010 orange

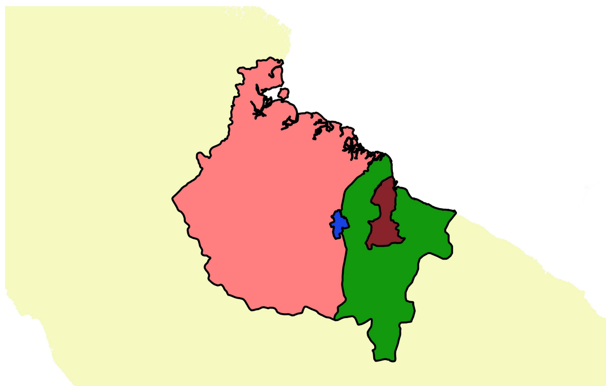


(b) Core: dark blue

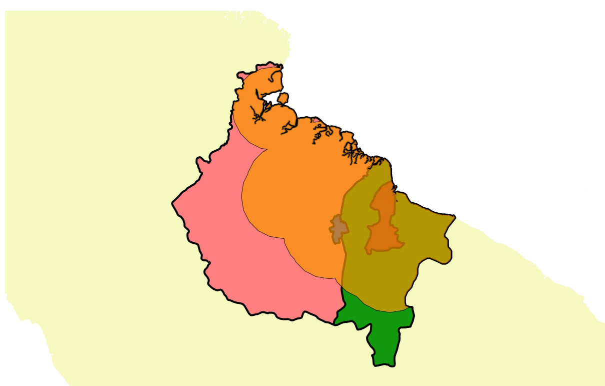


(c) Fringe: golden

FIGURE 6: MEDAN ADMINISTRATIVE BOUNDARIES AND METRO AREA.



(a) The four districts of the Medan metropolitan region



(b) Overlapping fringe and districts

Figure 7: Urban Sprawling Index in the Inner Islands

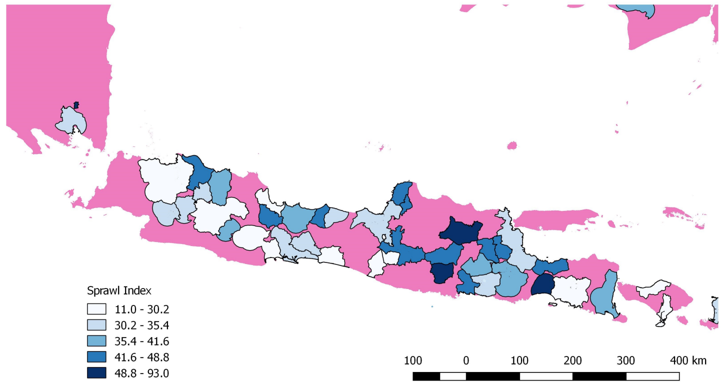


Figure 8: Distribution of the Urban Sprawling Index

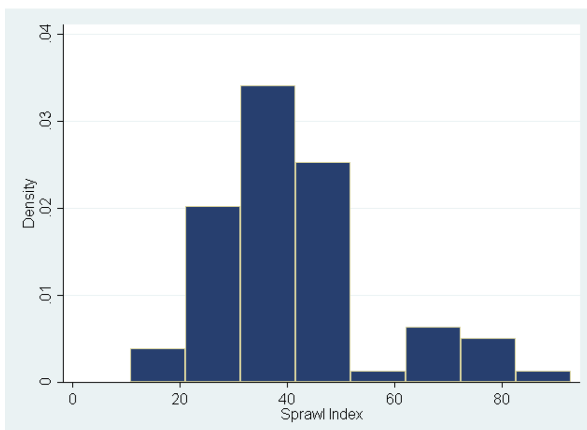


Figure 9: Distribution of the Urban Sprawling Index, Inner and Outer Islands

(a) Inner Islands (b) Outer Islands

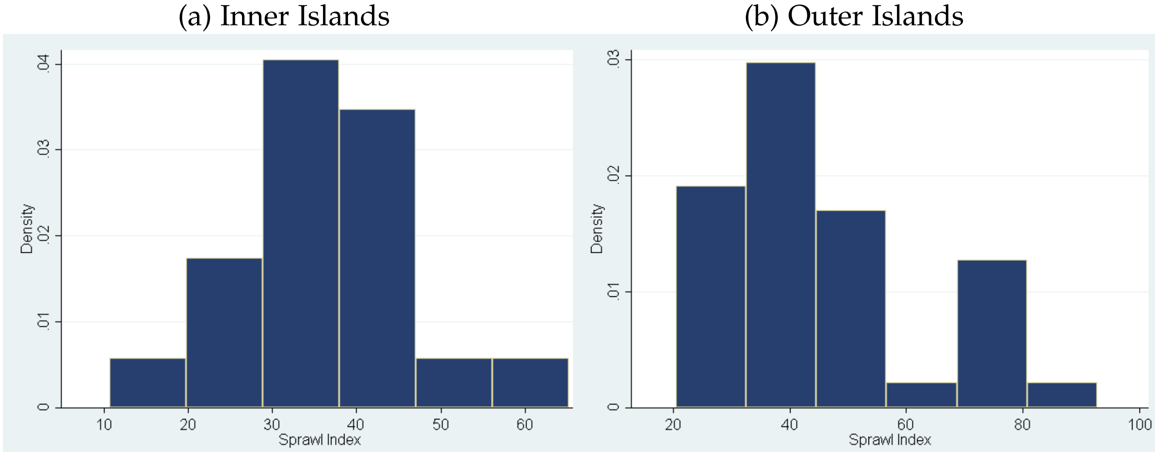
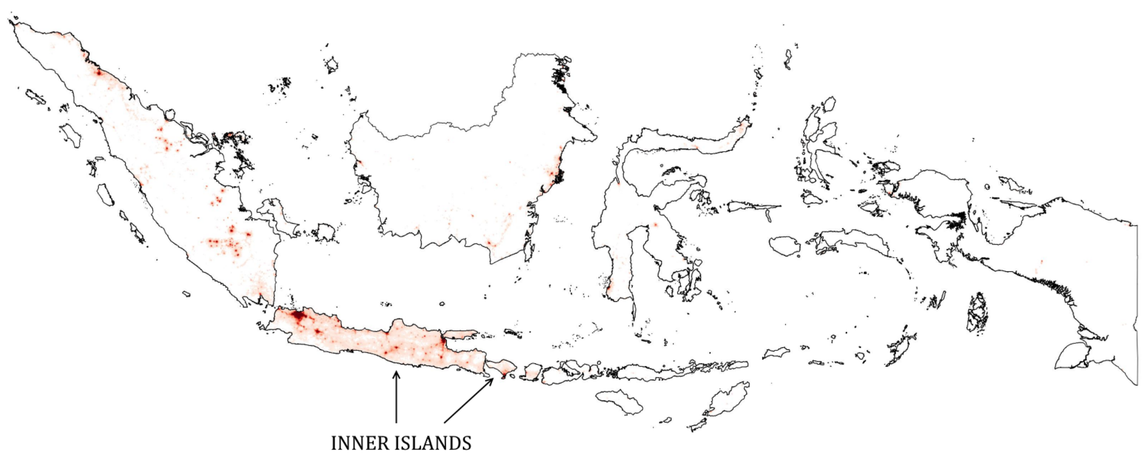


Figure 10: Indonesia Map with Night Light Luminosity in 2010



Tables

Table 2: Determinants of Urban Sprawling in Indonesia.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Elevation range (F)	-0.285	-0.062	0.010	-0.029	-0.034	-0.086	-0.084	-0.102
	(0.150)*	(0.176)	(0.177)	(0.187)	(0.190)	(0.171)	(0.171)	(0.167)
Ruggedness (F)	0.319	0.165	0.090	0.105	0.105	0.192	0.160	0.215
	(0.116)***	(0.129)	(0.111)	(0.115)	(0.115)	(0.114)*	(0.117)	(0.117)*
Cooling degree-days (M)	0.203	0.197	0.172	0.164	0.168	0.207	0.202	0.213
	(0.097)**	(0.094)**	(0.093)*	(0.107)	(0.108)	(0.109)*	(0.107)*	(0.110)*
Share coastal border [M,Wl]	-0.349	-0.369	-0.397	-0.359	-0.308	-0.250	-0.190	-0.222
	(0.131)***	(0.124)***	(0.143)***	(0.142)**	(0.138)**	(0.135)*	(0.076)**	(0.110)**
Pre/post 2000 rainfall diff. [M]	-0.067	-0.061	-0.009	0.002	-0.028	-0.037	0.019	-0.019
	(0.127)	(0.104)	(0.097)	(0.105)	(0.115)	(0.101)	(0.108)	(0.099)
Distance to core (F,Wp)		-0.362	-0.378	-0.319	-0.338	-0.245	-0.115	-0.123
		(0.115)***	(0.130)***	(0.107)***	(0.104)***	(0.107)**	(0.099)	(0.109)
Pop. growth rate 90-00 [M]		0.094	0.009	0.089	0.162	0.219	0.324	0.294
		(0.143)	(0.131)	(0.156)	(0.167)	(0.162)	(0.128)**	(0.162)*
Manufacture empl. share [C,Wp]			-0.272	-0.337	-0.265	-0.210	-0.345	-0.218
			(0.143)*	(0.128)**	(0.150)*	(0.142)	(0.142)**	(0.142)
Ground water use [F,Wp]				-0.046	-0.083	-0.053	-0.169	-0.109
				(0.168)	(0.176)	(0.171)	(0.157)	(0.169)
Builtup expansion possib. [F,Wl]				-0.276	-0.325	-0.403	-0.340	-0.442
				(0.171)	(0.174)*	(0.183)**	(0.158)**	(0.180)**
New houses/hh [F,Wp]					-0.194	-0.318	-0.282	-0.378
					(0.155)	(0.173)*	(0.163)*	(0.177)**
Restaraunt dispersion [F,Wp]						-0.239	-0.249	-0.229
						(0.107)**	(0.099)**	(0.106)**
Distance to market [F,Wp]							-0.374	
							(0.075)***	
Distance to shop. center [F,Wp]								-0.214
								(0.111)*
Observations	74	74	72	72	72	72	72	72
R^2	0.30	0.40	0.45	0.48	0.49	0.52	0.58	0.54
Adjusted R^2	0.20	0.30	0.33	0.35	0.35	0.38	0.45	0.40

Notes: M, F, and C in labels indicate if the variable is constructed at the metropolitan, fringe, or core level respectively; Wp and Wl indicate weighting schemes based on population or land size of villages for the variables computed from village data. */**/*** denotes significance at the 10/5/1 percent level. Robust standard errors in parentheses.

Table 3: Determinants of Urban Sprawling in the Inner Islands.

	Inner Islands	Outer Islands	Inner Islands				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Elevation range (F)	-0.072	-0.495	-0.103	-0.070	-0.074	-0.085	-0.078
	(0.143)	(0.368)	(0.179)	(0.131)	(0.138)	(0.133)	(0.191)
Ruggedness (F)	-0.045	0.570	0.122	-0.039	-0.072	-0.195	0.059
	(0.145)	(0.182)***	(0.176)	(0.142)	(0.212)	(0.205)	(0.184)
Cooling degree-days (M)	0.025	0.506	0.084	0.002	-0.006	-0.086	0.063
	(0.094)	(0.226)**	(0.112)	(0.082)	(0.092)	(0.110)	(0.109)
Share coastal border [M,Wl]	0.283	-0.470	0.266	0.306	0.293	0.244	0.239
	(0.258)	(0.343)	(0.387)	(0.232)	(0.230)	(0.221)	(0.373)
Restaraunt dispersion [F,Wp]	-0.503	-0.339	-0.480	-0.491	-0.501	-0.321	-0.599
	(0.140)***	(0.250)	(0.146)***	(0.131)***	(0.136)***	(0.132)**	(0.245)**
Distance to market [F,Wp]	0.087	-0.086	-0.113	0.072	0.093	0.395	-0.363
	(0.113)	(0.247)	(0.165)	(0.106)	(0.148)	(0.266)	(0.448)
Distance to clinic [F,Wp]	1.141	-0.361	1.578	1.268	1.266	1.043	1.595
	(0.477)**	(0.324)	(0.430)***	(0.475)**	(0.491)**	(0.561)*	(0.378)***
Builtup expansion possib. [F,Wl]	1.452	0.107	1.518	2.425	2.434	2.669	2.162
	(0.903)	(0.293)	(1.212)	(1.022)**	(1.033)**	(0.998)**	(1.180)*
Empl. centralization index [M,Wp]	-0.273	-0.171		-0.327	-0.338	-0.325	
	(0.108)**	(0.305)		(0.114)***	(0.144)**	(0.127)**	
Manufacture empl. share [C,Wp]			-0.100				-0.136
			(0.181)				(0.172)
All year main road [F,Wp]				2.747	2.904	4.371	
				(1.260)**	(1.624)*	(1.885)**	
Agr. yield/Agr. land [F,Wl]					-0.050	-0.044	
					(0.214)	(0.173)	
Pre/post 2000 rainfall diff. [M]						-0.561	
						(0.364)	
Pop. growth rate 90-00 [M]							0.259
							(0.512)
New houses/hh [F,Wp]							-0.528
							(0.262)*
Ground water use [F,Wp]							-0.368
							(0.208)*
Observations	40	34	40	40	40	40	40
R^2	0.57	0.49	0.52	0.63	0.63	0.67	0.56
Adjusted R^2	0.43	0.20	0.35	0.48	0.46	0.50	0.34

Notes: M, F, and C in labels indicate if the variable is constructed at the metropolitan, fringe, or core level respectively; Wp and Wl indicate weighting schemes based on population or land size of villages for the variables computed from village data. */**/*** denotes significance at the 10/5/1 percent level. Robust standard errors in parentheses.
† column (b) report the same specification as (a) for the Outer Islands for comparison.

Table 4: Determinants of Urban Sprawling in the Outer Islands.

	Outer Islands	Inner Islands	Outer Islands				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Elevation range (F)	-0.520	-0.175	-0.328	-0.562	-0.230	-0.354	-0.217
	(0.311)	(0.178)	(0.320)	(0.300)*	(0.317)	(0.322)	(0.274)
Ruggedness (F)	0.414	-0.043	0.207	0.420	0.125	0.252	0.021
	(0.141)***	(0.197)	(0.217)	(0.131)***	(0.219)	(0.220)	(0.169)
Cooling degree-days (M)	0.433	0.048	0.271	0.532	0.600	0.182	0.654
	(0.164)**	(0.121)	(0.156)*	(0.168)***	(0.217)**	(0.179)	(0.205)***
Pop. growth rate 90-00 [M]	0.403	-0.603	0.306	0.305	0.012	0.344	-0.115
	(0.144)**	(0.475)	(0.172)*	(0.155)*	(0.146)	(0.174)*	(0.156)
Distance to market [F,Wp]	-0.381	0.522	-0.536	-0.405	-0.673	-0.495	-0.726
	(0.073)***	(0.474)	(0.107)***	(0.083)***	(0.125)***	(0.108)***	(0.123)***
Restaraunt dispersion [F,Wp]	-0.435	-0.310	-0.398	-0.459	-0.430	-0.340	-0.397
	(0.117)***	(0.221)	(0.148)**	(0.161)**	(0.146)***	(0.155)**	(0.142)**
New houses/hh [F,Wp]	-0.559	-0.528	-0.336	-0.545	-0.178	-0.264	-0.085
	(0.106)***	(0.339)	(0.238)	(0.194)**	(0.195)	(0.240)	(0.209)
Ground water use [F,Wp]	-0.361	-0.284	-0.303	-0.357	-0.442	-0.204	-0.393
	(0.133)**	(0.278)	(0.230)	(0.174)*	(0.292)	(0.239)	(0.284)
Builtup expansion possib. [F,Wl]	-0.381	2.318	-0.414	-0.319		-0.428	
	(0.182)**	(1.213)*	(0.191)**	(0.196)		(0.189)**	
Manufacture empl. share [C,Wp]			-0.452		-0.428	-0.495	-0.546
			(0.199)**		(0.228)*	(0.191)**	(0.224)**
Agr. yield/Agr. land [F,Wl]				-0.156	-0.207		-0.194
				(0.069)**	(0.064)***		(0.057)***
Share coastal border [M,Wl]						-0.155	
						(0.103)	
Pre/post 2000 rainfall diff. [M]							0.276
							(0.121)**
Observations	34	40	32	33	32	32	32
R^2	0.66	0.40	0.74	0.66	0.71	0.75	0.74
Adjusted R^2	0.47	0.19	0.54	0.43	0.50	0.54	0.52

Notes: M, F, and C in labels indicate if the variable is constructed at the metropolitan, fringe, or core level respectively; Wp and Wl indicate weighting schemes based on population or land size of villages for the variables computed from village data. */**/*** denotes significance at the 10/5/1 percent level. Robust standard errors in parentheses.