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LETTER

Synthesizing land use and demographic change in Southeast Asia's smaller urbanized areas from 2000–2015

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Abstract

The majority of the human population now reside in urban areas today. The United Nations estimates that nearly half of all urban dwellers currently live in cities smaller than 500 000 persons and the majority of future urban growth will take place in Asia and Africa, likely in these smaller urban areas, not mega cities. Thus, understanding the factors that influence urban demographic trajectories in small urban areas is critical to address sustainable and equitable policy initiatives related to food security, changing climate hazard exposure, and economic opportunities. Here we focus on Southeast Asia—a region historically characterized by lower urban population proportions, yet with a rapidly shifting dynamic demographic—to examine correlates of demographic change among smaller cities. We combine two open-source satellite-informed datasets: GHS urban center database (2015) and age-sex gridded data from WorldPop to calculate socio-demographic characteristics to model drivers of change in annualized urban population growth from 2000–2015 for 505 urbanized places. We find a general pattern of decreasing dependency ratios as city-size increases for most urban areas in Southeast Asia. Higher rates of growth and more variation is observed for smaller cities—those with fewer than 300 000 persons, the lowest population limit for UN data on urbanization. When examining covariates of urban population growth, we find significant statistical associations of population change in smaller urbanized areas with climatic, economic, and land cover/land use variables, but with country-specific variations. Characterizing a continuum of urban population development in the context of changing environmental, economic and climate conditions has been an important sustainable development and equity issue for decades, but newer analysis of city-level drivers allows for systematic inquiry thus moving beyond total population counts for policy-relevant insight.

1. Introduction

In the next half century, the bulk of population growth is expected to take place in cities and towns in Africa and Asia. In Southeastern Asia, urban settlements are projected to add over 150 million new residents by 2050, a 42% increase, whereas rural areas are projected to lose nearly 60 million people, an 18%

decrease (UN DESA 2018). Our understanding of urbanization processes in the region is largely focused on large cities (e.g. Schneider *et al* 2015, Xu *et al* 2019, Fan 2022) or national-level aggregation (UN DESA 2018, Das and Paul 2021). However, demographic transitions in smaller urbanized localities will drive the complex ways land use/land cover dynamics manifest differently across various urbanized spaces

(Egidi *et al* 2021). Ensuring sustainable social, economic, and environmental development requires a concrete understanding of how demographic and population changes characterize urban spaces along with factors that constrain or facilitate those changes notably in these smaller urbanized areas (SUAs).

Advances in combining satellite, GIS, and demographic data allow us to describe spatiotemporal change in environmental, built settlements and population distribution at high spatial resolutions, beyond what is capable with national census data (Leyk *et al* 2019, Phiri *et al* 2020, Melchiorri 2022). For example, Melchiorri (2022) and Phiri *et al* (2020) demonstrate applications and database construction for using remotely sensed data in mapping and monitoring human-environment systems, whereas Leyk *et al* (2019) provides an overview of large-scale gridded population dataset production flows and underlying considerations. Such advancements are especially useful for understanding urbanization and cities in a spatial context where no harmonized data otherwise exist (Dijkstra *et al* 2021). Such data are also valuable in their temporal (1975–2015) coverage, but their accuracy depends in part on the quality of underlying population and built-up area data (Linard and Tatem 2012, Leyk *et al* 2019, Balk *et al* 2021), with the least understood areas being smaller cities where consistent identification and measurement of growth rates and intra-urban heterogeneity is more challenging to quantify (Chai and Seto 2019, Zimmer *et al* 2020). However, gridded demographic datasets, such as the ‘top-down unconstrained’ WorldPop age-sex grid (e.g. population estimates made for all land grid cells), provide useful insight into changing demographic structures when applied with consideration to spatial and temporal limitations (Thomson *et al* 2022, Alessandrini *et al* 2024).

Shifting urban demographic patterns and their underlying drivers have received some attention (Jiang and O’Neill 2018, Menashe-Oren and Bocquier 2025). But smaller localities—in part because such localities are not an objective of global data collections—have lacked the same critical attention (Cohen 2006, Birkmann *et al* 2016, Balk *et al* 2021). Similarly, studies of large cities place demographic change alongside land cover/land use processes as critical to the tri-fold intersection of urban social, economic, and environmental sustainability (Fan *et al* 2019). Yet few studies examine these intersections, or their implications, for smaller urban areas.

Southeast Asia contains transitional economies and a continuum of population growth, with rapid urban land expansion alongside economic and social changes (Fan *et al* 2019). As such, we focus on the rapidly changing Southeast Asian region to evaluate the urban demographic patterns for smaller urbanized localities from 2000 to 2015—city sizes where demographic

shifts will have outsized impacts on development outcomes.

2. Objectives

We specifically focus on SUAs <300 000 and we model the change in annualized growth rate from 2000 to 2015 to understand potential drivers of urban growth patterns across the region. Focusing on 300 000 people or fewer targets historically understudied urban agglomerations in UN estimates and projections (UN DESA 2018). Our specific objectives are to: (1) describe spatiotemporal urbanized demographic patterns for different sized urban areas across Southeast Asia and (2) model change in estimated annualized growth rates from 2000 to 2015 for SUAs (that is, places with a population less than 300 000 in 2015). The complementary objectives situate larger demographic patterns of the region for further context of associated mechanisms that facilitate or constrain change in total population for SUAs. The approach will synthesize multiple factors characterizing the environment, land systems, economics, and demography.

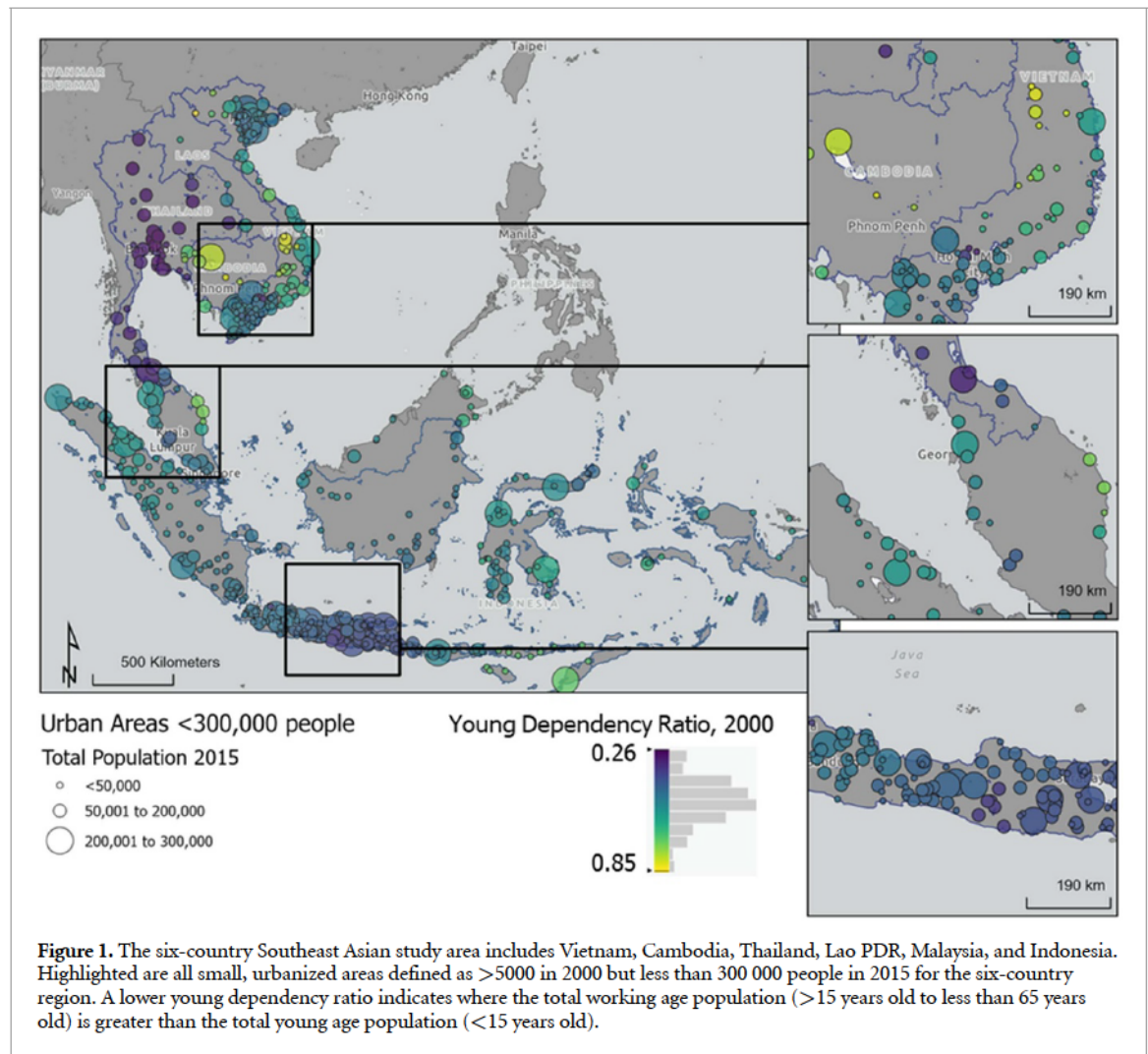
3. Materials and methods

3.1. Study area

The study area includes countries from mainland Southeast Asia (Vietnam, Thailand, Laos, and Cambodia) as well as peninsular (Malaysia) and Oceania (Indonesia) regions. These countries were chosen as illustrative examples of where a complex confluence of population, land and water, coastal interface, and environmental change is taking place in diversified cultural and socioeconomic conditions (King 2008). In addition, these countries have within-country variation across city size and change in population (figure 1).

3.2. Data construction and processing

To examine spatiotemporal patterns in demographic characteristics, we use the unconstrained WorldPop age-sex datasets at a 1 km × 1 km resolution, annually from 2000 to 2015 (Tatem *et al* 2013, Pezzulo *et al* 2017). The unconstrained version of the data differs from the constrained version in that all pixels, regardless of location, may have a non-zero allocation of people. The underlying modeling makes the final data product less sensitive to a specific built area product (e.g. GHSL-POP), and the approach can lead to underestimation in high population areas and overestimation in low population areas, subsequently creating a lower-bound estimate for growth. However, for purposes of this study, it is the most appropriate and useful data product for aggregating to urban polygon



centers and representing demographic characteristics in a consistent way across space and time.

The 2015 GHS urban centre database (GHS-UCDB) describes spatial entities called ‘urban centers’ which are defined by resident population and built-up surface thresholds (Florczyk *et al* 2019). The 2015 GHS-UCDB is a global scale product of 13 135 urban centers boundaries that includes a suite of multi-thematic information harmonized across all cities in the dataset. The decision to use the GHS-UCDB provides one approach for urban boundary designation and represents a set of conditions for designated SUAs that existed at the outset of the study period (2000) along with place-based information. The static boundary is an assumption we carry through in the modeling but even with dynamic boundaries, there would still be underlying challenges of arbitrary designations and differences in data and definitions to contend with (Van Migerode *et al* 2024). Equally important in our case, by using the GHS-USDB and WorldPop data, we intentionally focus on the importance of what such ancillary data and statistical records can tell us regarding urbanization in smaller localities. We extracted all urban

centers across our six-country region and summed the WorldPop age-sex data within the GHS-UCDB 2015 polygons to generate demographic variables for analyses (Zimmer *et al* 2026a). The full Zimmer *et al* dataset includes global observations for 13 000 urban settlement locations, each age-sex combination (36 total) and each year (2000–2020, 21 years) (Zimmer *et al* 2026b).

We use the GHS-UCDB to delineate spatial extents and calculate descriptive summaries of demographic change in age/sex metrics across all urban areas in Southeast Asia. In addition to the demographic summaries, we extracted a set of the existing GHS-UCDB thematic variables representing land structural components, environmental and economic characteristics of the urban centers (table 1). Next, we subset urbanized localities based on the population summaries using WorldPop gridded population estimates within the GHS-UCDB polygons. We define our SUAs as urban areas with >5000 people in 2000 and <300 000 people in 2015 (referred to henceforth as ‘smaller urbanized areas’ or SUAs). The minimum threshold of 5000 people in 2000 ensures the SUA existed for the entire period of analysis. The

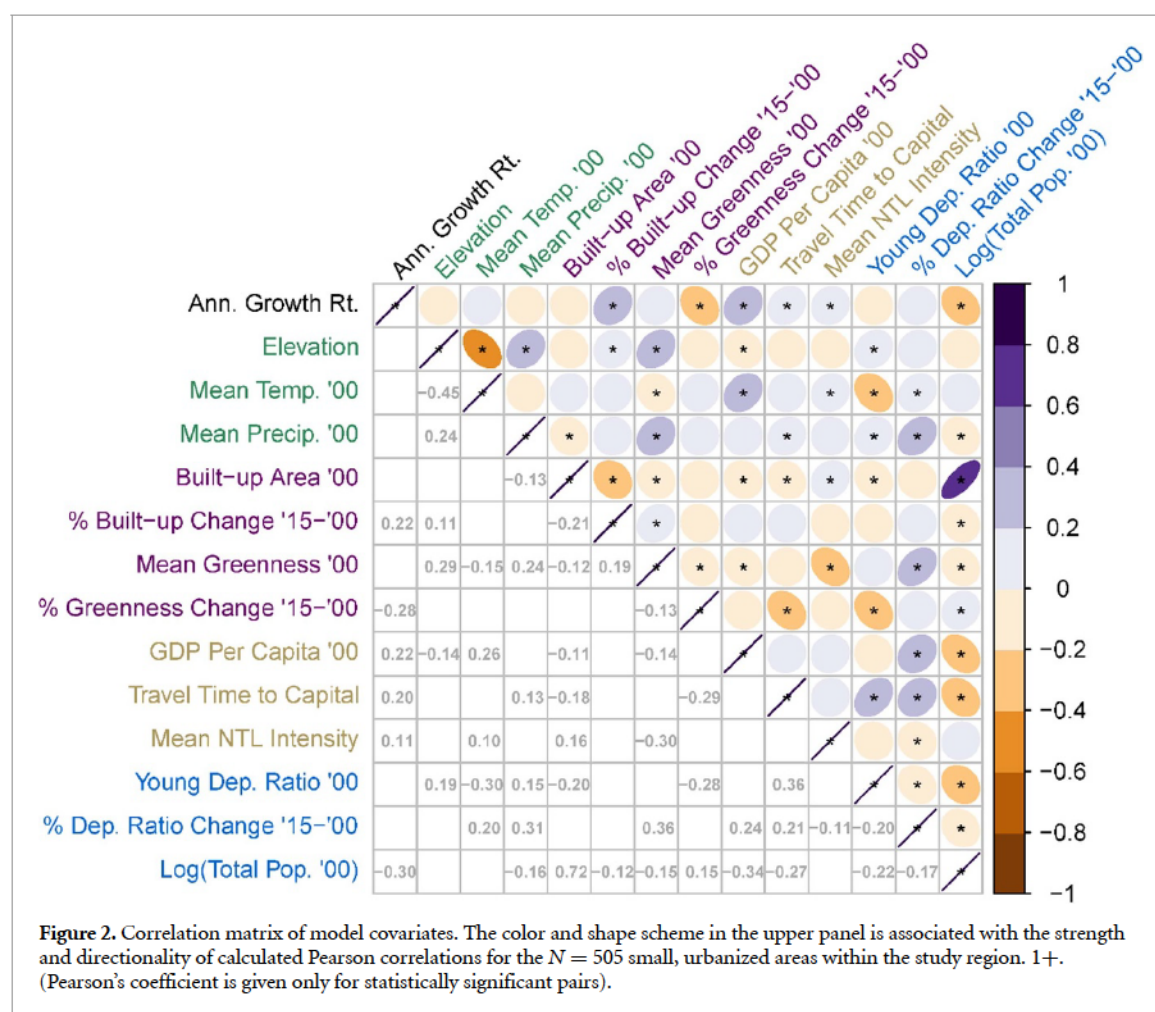
Table 1. Predictor variables from UCDB were used in the Bayesian mixed effects model.

Theme	Variable	Definition	Source
Environment	Elevation	The average elevation estimated within the spatial domain of the urban center, and expressed in meters above sea level (MASL)	(Tadono <i>et al</i> 2014), (EORC & JAXA 2017)
	Mean temperature (2000)	Average temperature calculated from annual average estimates for time interval centered on the year 2000 within the spatial domain of the urban center, and expressed in Celsius degrees (°C)	(Kottek <i>et al</i> 2006), (Rubel <i>et al</i> 2017)
	Mean precipitation (2000)	Average precipitations calculated from annual average estimates for time interval centered on the year 2015 (the interval spans from 2012 to 2015) within the spatial domain of the urban center; and expressed in millimeters (mm), the amount of rain per square meter in one hour)	
Land Systems	Built area (2000)	Total built-up area in 2000 calculated within the spatial domain of the urban center of 2015, expressed in square kilometers	(Pesaresi <i>et al</i> 2016), (Corbane <i>et al</i> 2017), (Corbane <i>et al</i> 2018)
	Built area change (2000–2015, %)	Percent change in built-up area, 2015 minus 2000, calculated within the spatial domain of the urban center of 2015	
	Mean greenness (2000)	Average greenness estimated for 2000 located in the built-up area of epoch 2000, and calculated within the spatial domain of the urban center of 2015. The values are expressed in unit less measures in range −1:1	(Corbane <i>et al</i> 2020), (Florczyk <i>et al</i> 2019)
	Mean greenness change (2000–2014, %)	Percent change in average greenness, 2014 minus 2000, calculated within the spatial domain of the urban center of 2015	
Economic	NTL	Mean night time light emission calculated within the urban center spatial domain, expressed in nano-watt per steradian per square centimeter	(Elvidge <i>et al</i> 2017)
	GDP per capita (2000)	GDP estimates based on total annual GDP (PPP) for the year 2000, and harmonized within the spatial domain of the urban center of 2015, per capita calculation was done using WorldPop estimates	(Kummu <i>et al</i> 2019)
	Travel time to capital	Travel time to country capital, expressed in minutes	(Weiss <i>et al</i> 2018)
Demographic	Total population (2000)	Total population in 2000 calculated within the spatial domain of the urban center of 2015, expressed in number of people, based on WorldPop estimates	(Stevens <i>et al</i> 2015)
	Young dependency ratio (2000)	Young dependency ratio in 2000 calculated within the spatial domain of the urban center of 2015, expressed in number of people, based on WorldPop age-sex estimates	(Pezzulo <i>et al</i> 2017)
	Young dependency ratio change (2000–2015, %)	Percent change in young dependency ratio, 2015 minus 2000, calculated within the spatial domain of the urban center of 2015	

maximum threshold of 300 000 keeps a bound on medium-sized urbanized areas but results are presented in the S1 that include all city sizes. While we tested varying thresholds and other designations for the cutoff, our definition captures the majority of urbanized areas within the region and represents a distinct set of urbanized spaces that have yet to see

the growth and expansion associated with urbanized areas of larger population sizes.

The dataset we analyze contains 505 smaller urbanized localities designated by the GHS-UCDB that have a complete set of data across the six countries of interest. The dependent variable represents the annualized growth rate of population between 2000 and



2015, as defined by the UN population division (UN DESA 2018). Years were aligned with the temporal availability of the GHS-UCDB data product and the WorldPop gridded demographic data product was subsequently matched to that same time frame even though the WorldPop product extends to 2020. For purposes of this study, explanatory variables were selected only from the GHS-UCDB data product that 1) matched the time period of interest, and 2) theoretically aligned with predicting population change and 3) are globally and regionally consistent. We chose to represent change over time in a subset of these explanatory variables by using percent change relative to 2000 (2015 minus 2000 divided by 2000).

The final set of predictors (table 1) is based on available, theoretically reasonable choices from the GHS-UCDB product available at the time of analysis combined with a set of demographic variables extracted and aggregated from the WorldPop global age/sex data product. We include the total population and young dependency ratio (YDR) in 2000 and change in YDR as our main demographic metrics for characterizing demographic structural change in the model. YDR is a critical indicator for overall population structure, intrinsically linked to fertility rates and changes in the working age population related to migration and/or development processes. For further

information on the GHS-UCDB underlying data and compilation, refer to (Florczyk *et al* 2019).

Furthermore, we assessed the correlation structure of the constructed, theoretically justified covariates (figure 2) amongst each other and with annualized growth rates to anchor our model specification. While strong collinearity between urbanized area population ($\log(\text{total pop. '00})$ and the amount of built-up area (built-up area '00) should be expected (built-up area is a primary predictor of gridded population products and naturally induces endogeneity concerns when both are inferentially assessed), the lack of a statistically significant correlation between built-up area and annualized growth rates indicates that overall model specification and fitting should not be impacted by collinearity but is discussed further in our results.

3.3. Model approach

In model construction, we focus on the underlying mechanisms that constrain or facilitate change in population for SUAs. We consider individual SUAs as the unit of observation (i), grouped within each study area country (j) and exposed to prevailing economic, environmental, and social conditions. Such a grouped data structure (SUAs within each country) are assumed to share common features and

exposures. We use a Bayesian mixed effects model with country-based intercepts which estimates the annual population growth rate based on thirteen predictor variables (table 1) as shown in (equation (1):

$$\frac{\ln\left(\frac{\text{Pop. in 2015}}{\text{Pop. in 2000}}\right)}{15}_{ij} = \alpha_0 + \beta_{1...13}x_{ij} + \alpha_j + \epsilon_{ij}. \quad (1)$$

Where: $i = 1.505$ SUAs from $j = 1...6$ SE Asian country contexts, α_0 is the global intercept (average annualized growth rate for SE Asian cities while conditioning on covariate effects), $\beta_{1...13}$ are estimated coefficients for measured covariates (table 1) within the 2015 UA boundaries, α_j is the country-level difference from the estimated global intercept (i.e. a random effect on UA growth rates within each country j), and ϵ_{ij} is the estimated residual error for each observation in the data.

The likelihood model is defined with respect to a continuous, normal distribution. We set weakly informative, normally-distributed priors for each standardized $\beta_{1...13}$ covariate (zero-centered, in units of standard deviations) of $N(0,1.5)$, and assumed a weakly informative, bounded exponential prior on each estimated standard deviation (expected value of 0.2) (see S1 for model fitting code, prior specification, and additional diagnostic output, in addition to alternative model exploration). We fit the random effects model using the brms package (Bürkner 2017) (using the Stan backend (Stan Development Team 2024)) in the statistical environment R 4.4.0 (R Core Team 2024).

To simplify the model presentation, details on model fitting, diagnostics, alternative model structures and model fit have been included in the S1. These provide further details on models fit with a full subset of cities including large populations (all >5000 in 2000) as well as those fit with maximum likelihood-based fitting methods to accommodate readers more versed in non-Bayesian statistical approaches. Posterior predictive checks on the fitted models are also presented in S1.

4. Results

4.1. General characteristics SE Asia

Figure 3 shows the change in YDR alongside the change in total urban population from 2000 to 2015 for each country. All six countries show an overall decline in YDR with the spread of YDR values across all urbanized areas shrinking over time (i.e. all urbanized areas, regardless of size, see lower overall YDR in 2015). The study area has mostly SUAs as the number of cities with more than 1 million is very few. The larger urban areas started with a lower YDR in 2000 but there remains an observable decline across the time period even though the rate is slower. As

table 2 shows, there is between country variation in YDR decline, but on average the region is undergoing a demographic shift in SUAs. Note that there are very few SUAs experiencing a decline in estimated annualized growth rate, with the exception of a handful of cities in the more developed countries of Indonesia, Vietnam, and Thailand.

4.2. Model results

Examining the basic correlation structure, we see associations that align with well-established expectations between demographic-related features and biophysical/built-up characteristics (figure 2, (Stevens *et al* 2015)), namely relatively strong positive correlations between population size and changes in population and built-up area totals and change. These are in turn associated in predictable ways with annualized growth rate, as per the expectations we might observe from figure 3. Urbanized areas with lower populations in 2000 are growing at faster rates on average ($r = -0.30$, $p < 0.001$), and areas exhibiting land cover change either in decreasing average greenness ($r = -0.28$, $p = 0.024$) or expanding built-up area ($r = 0.22$, $p < 0.001$) are associated with higher growth rates.

Posterior distributions of the standardized coefficient estimates from the Bayesian mixed effects model (figure 4) illustrate the effects of the different predictor variables on annualized growth rates from 2000 to 2015 while controlling for each of the other covariates, and any between-country, baseline (intercept-level) effects. The model explains approximately one-third of the variation (Bayesian $R^2 = 0.259$, 95% CR = [0.027, 0.31], Gelman *et al* 2019) in annualized growth rates across the 505 localities, accounting for country-level differences in average annualized growth rate (indicated by estimated random effects relative overall intercept in figure 5).

Furthermore, the distributional pattern of country-level intercepts varies by country, but figure 5 suggests there are country-level contexts that differ in the distributional pattern, but all country-level intercepts include a distribution that includes zero which indicates an estimate with low confidence and a non-zero marginal effect. In figure 6, the general pattern is captured showing what drives population change from 2000 to 2015, but significant unexplained variations are present. There are both under- and over-predictions across the range of observed annualized growth rates which suggests the model does not capture important drivers of demographic patterns for rapidly growing localities or slower growing ones (figure 6).

As expected, there is a strong positive association for two land system components, built-up area in 2000 and percent change of built-up area. In addition, there is a strong associated negative effect with change in percent greenness change. These three

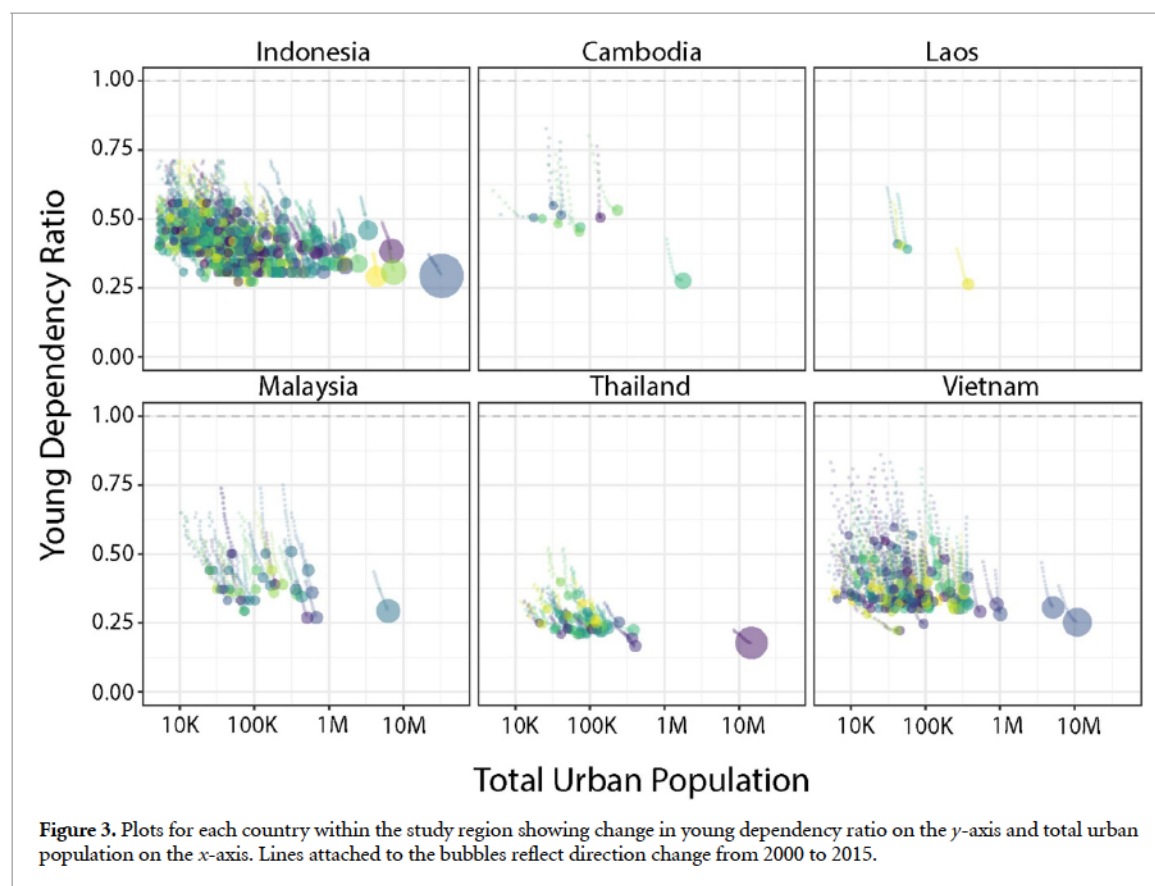


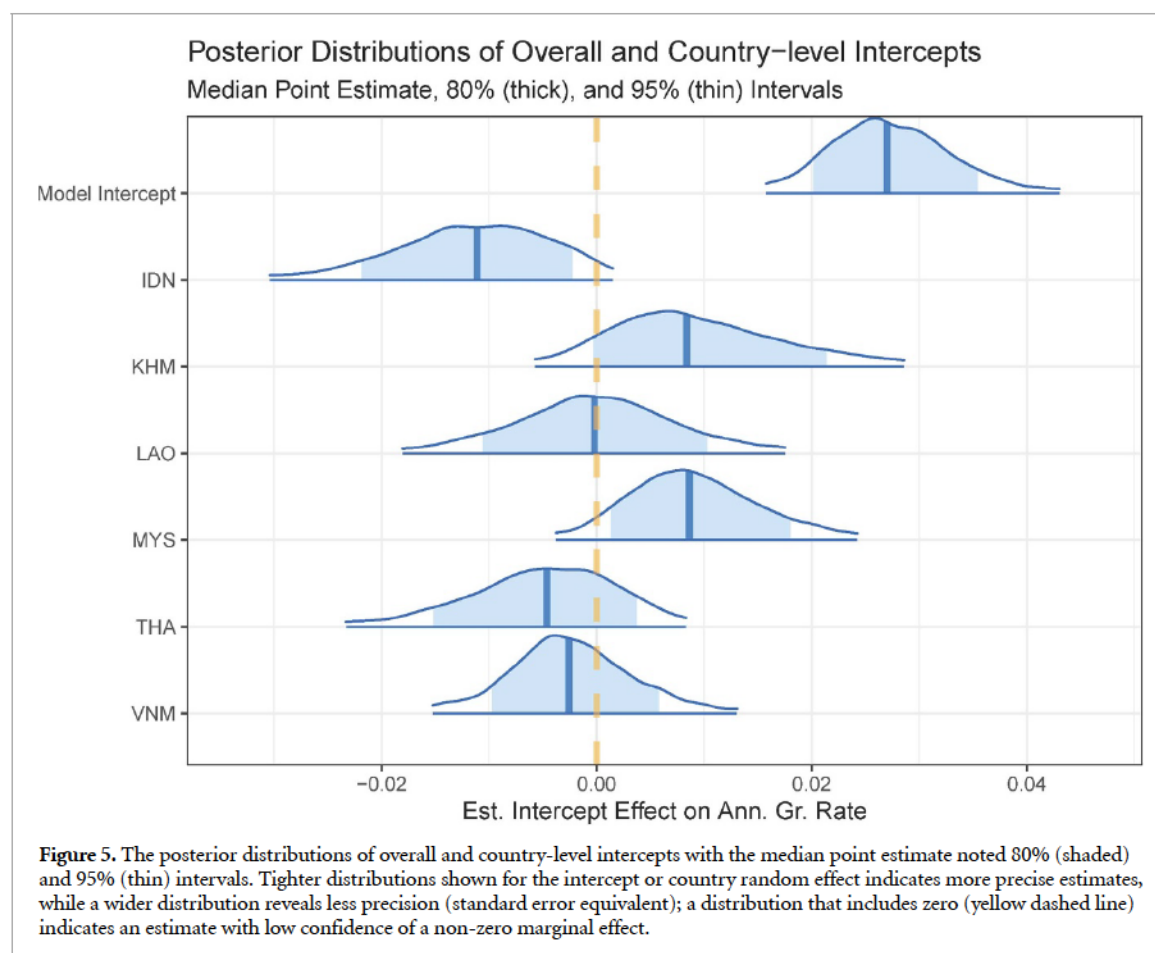
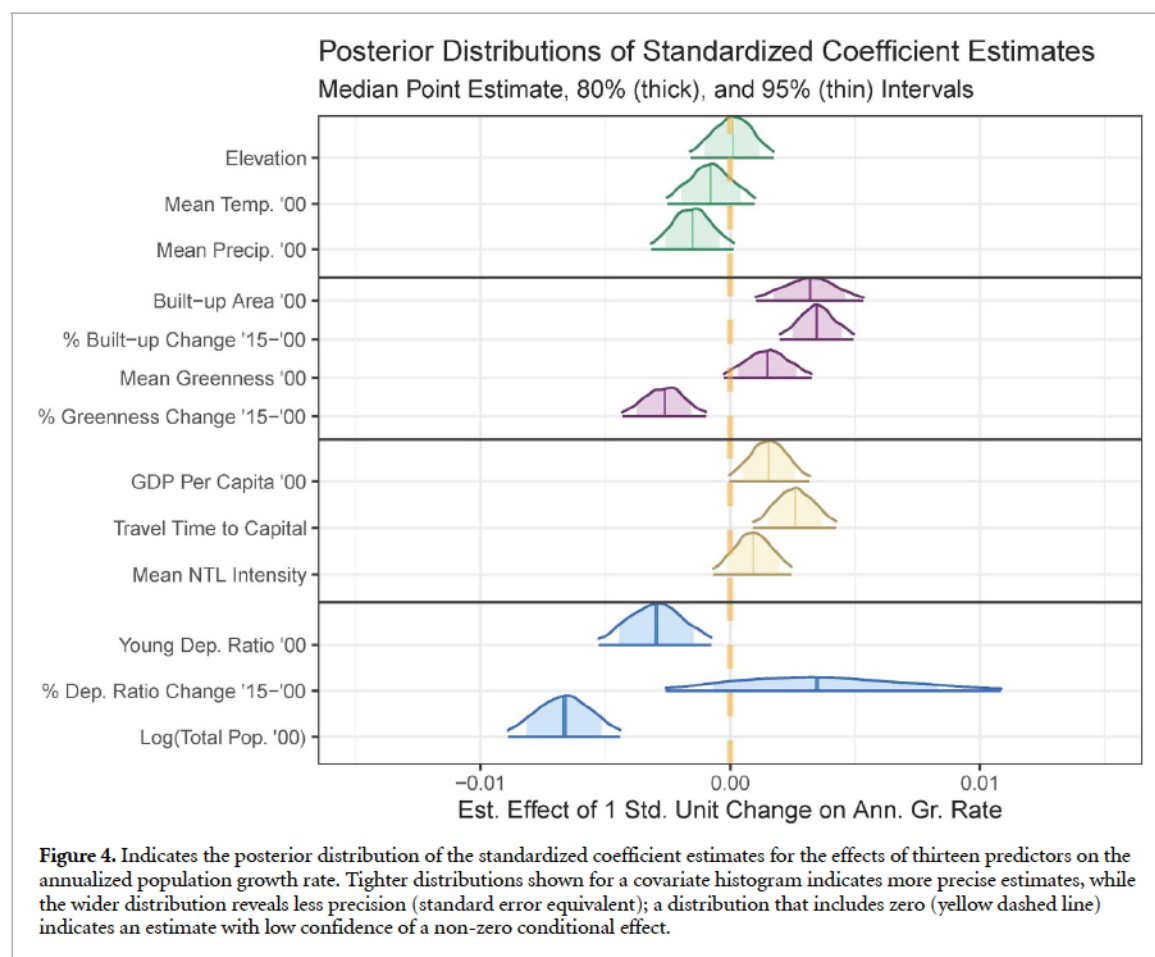
Table 2. Summary of key demographic changes in small, urbanized areas, 2000–2015 by country.

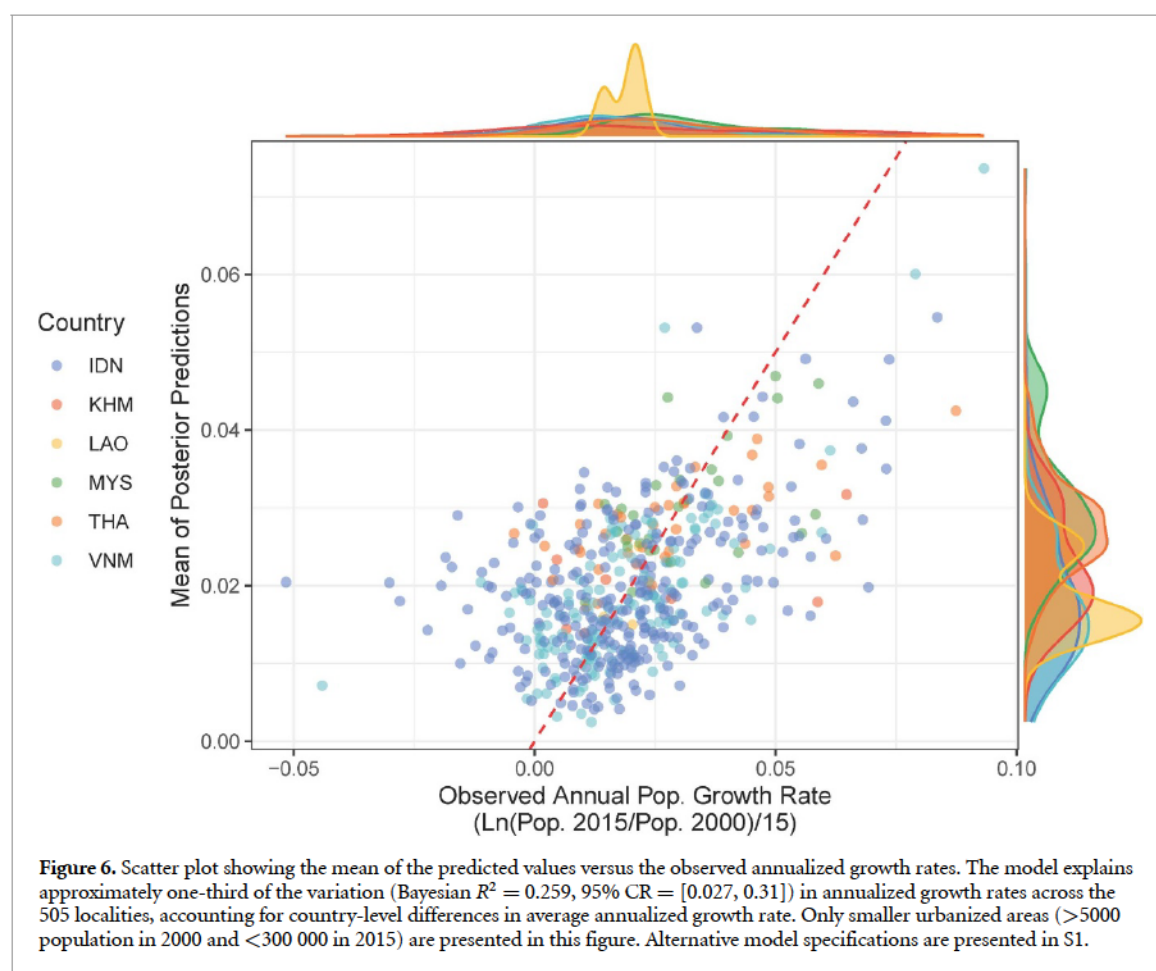
	IDN (<i>N</i> = 296)	KHM (<i>N</i> = 7)	LAO (<i>N</i> = 3)	MYS (<i>N</i> = 28)	THA (<i>N</i> = 40)	VNM (<i>N</i> = 131)	Overall (<i>N</i> = 505)
Estimated annualized growth rate (2000–2015)							
Mean (SD)	0.019 (0.019)	0.026 (0.026)	0.019 (0.0038)	0.031 (0.014)	0.027 (0.018)	0.018 (0.017)	0.020 (0.018)
Median [min, max]	0.018 [−0.052, 0.084]	0.015 [0.0018, 0.065]	0.020 [0.014, 0.021]	0.028 [0.011, 0.059]	0.025 [−0.0042, 0.085]	0.016 [−0.044, 0.093]	0.019 [−0.052, 0.093]
Young dependency ratio change (2000–2015, %)							
Mean (SD)	−21.6 (1.46)	−33.7 (0.584)	−31.3 (3.76)	−32.4 (0.291)	−23.4 (2.11)	−34.1 (1.48)	−25.8 (5.84)
Median [min, max]	−21.4 [−23.7, −18.2]	−33.9 [−34.2, −32.5]	−33.1 [−33.7, −26.9]	−32.6 [−32.7, −32.0]	−23.3 [−32.5, −20.1]	−34.1 [−37.8, −29.5]	−23.6 [−37.8, −18.2]

components represent expected structural land system changes with a generally increasing annualized growth rate over time. Regarding proxy predictor variables for economic effects, only travel time to capital had a strong positive association. Both GDP per capita in 2000 and the average nighttime light intensity were weakly associated. The three environmental variables were only weakly associated with annualized growth rate as well. With respect to the demographic predictors, YDR in 2000 and the total population in 2000 indicate strong negative associations while the percent YDR change was weakly associated.

5. Discussion

There is a pressing need to prioritize SUAs with respect to implementing sustainable, smart-growth policies and management practices to help growth of these smaller areas happen in a way that does not lead to poverty, inequity, and lack of basic services (Cohen 2006, Potts 2018). Our study emphasizes that SUAs are growing rapidly across Southeast Asia while also experiencing decreasing YDR—perhaps signaling a continuing demographic transition—for all GHS-UCDB-designated areas. Slower growth (though still increasing in population) in larger urbanized areas





is expected (Montgomery 2008), but growth in the smallest urbanized areas such as those covered in this study, has not been previously assessed. Overall, the combination of increasing population and decreasing YDR suggests a recent shift in demographic make-up across localities <300 000. Since SUAs are at heightened risk of environmental impacts, and increased climate risk especially for those localities in low coastal elevation areas (Birkmann *et al* 2016, MacManus *et al* 2021, McGranahan *et al* 2023), how population changes impact land consumption patterns remain a priority (Sharma *et al* 2012, Colsaet *et al* 2018).

We show that land system variables (figure 4) are intrinsically linked to population growth for these smaller urban localities, fitting hypothetical relationships regarding urbanization and land consumption and conversion patterns. Those relationships between land system variables are similar to findings in the literature that explore patterns of urbanization in larger urban localities (Pham *et al* 2011, Dadashpoor *et al* 2019). Results further suggest that travel time to capital has a strongly positive association with the annualized growth rate but other economic proxies such as mean nighttime lights and GDP per capita have weak associations. It is important to recognize that these variables (NTL and GDP) are coarse approximations of economic development that might

drive an increase in population growth rate and that travel time to capital is a coarse proxy for proximity to important foci of development. Time to main urban centers is an important economic proxy for growth, but equally important is an understanding that as these smaller urbanized localities continue to develop, increased accessibility to the economic, educational, and health resources will positively associate with sustainable development goals (Weiss *et al* 2018, United Nations 2025). In addition, the negative association of total population in 2000 suggests SUAs are growing faster from 2000 to 2015, consistent with Montgomery's finding (2008), emphasizing the importance regarding national-level policy and development support outside major urban areas (Satterthwaite and Tacoli 2006, Randolph *et al*, 2020).

The negative association with YDR in 2000 suggests a more complex and multifaceted aspect of how SUAs are growing and the characterization of their demographic makeup. We acknowledge that 2000–2015 is too short a time period to capture long term demographic transitions but our time frame does provide insight regarding decadal urbanization across the region. Notably, YDR is often considered a proxy for fertility (Hauer *et al* 2013), and literature has shown strong associations between fertility decline and rising education (Adhikari *et al* 2025), perhaps signaling that YDR in 2000 represents

more of an economic productivity proxy (Bloom and Canning 2004). Yet, people living in these SUAs might experience a comparatively higher cost of living than in their place of origin and then ensuing poverty (Tacoli *et al* 2008) that is associated with these demographic shifts. Added complexity comes from considering urban–rural migration (Adger *et al* 2024) and while migration is not represented in the model, it is evident that there exists a complicated set of factors to consider moving forward in how demographic transitions across Southeast Asia will impact the growth and development of these smaller urbanized landscapes. Balancing transitions in socioeconomic development with demographic transitions will be a critical component for sustainably developing SUAs (United Nations 2025).

There are limitations to our approach. Alternative modeling approaches that leverage finer grained assessments or ascribe different indicators that are not part of the GHS-UCDB product may yield more direct insights. Covariates that we normally would consider good predictors of growth rate (such as education or in-migration) that are not in the model, could provide further explanatory power. Such data pulled from collections of survey or census micro data (such as the demographic and health surveys (DHS) or the IPUMS census micro-samples) would allow for inclusion of educational gradients and estimates of urban in-migration, albeit at a coarser level. Use of these vector-based data that reflect regional estimates (e.g. DHS, IPUMS) with higher resolution gridded spatial data draws attention to challenges associated with data integration and any additional assumptions implicit in their use (Morlighem *et al* 2023).

As in many studies, random-effects modeling capture much unknown variation that is shared by the units being analyzed. Data derived from global data sets such as those used here may result implicitly in smoothing across units because some of the underlying inputs such as moderate-resolution administrative boundaries will contain multiple small cities within its boundaries. Here we used country-level random effects and interpret their power as capturing factors like economic development and policy-related conditions that operate on a national scale. Many prior studies focus on changes in big city or national urban shares of whole countries (Xu *et al* 2019, Güneralp *et al* 2020, Chakraborty *et al* 2022), whereas we show variation at an urban-scale for smaller cities drawing attention to the need for studies that embrace subnational and urbanized areas. This remains a priority for future studies including data collection that allows for robust inquiry along these lines.

Nevertheless, we conclude that there is utility in working with the pre-existing set of GHS-UCDB and WorldPop-derived variables, with general insights provided from this study underpinning the relevance

of SUA growth and demographic transition in more recent years. The identified urban localities for Southeast Asia are part of a much larger database, the GHS-UCDB, which provides a tractable and standardized approach for exploring associations with the various geospatial and statistical variables included in the data product. Additional insight using the same data products could be applied using more complex, hierarchical approaches that take advantage of individual countries with many small, urbanized areas (e.g. Vietnam, Indonesia) that provide a subnational level for data assessment.

Combining the satellite-informed GHS-UCDB and WorldPop data creates new opportunities to explore the dynamics of population–environment processes and patterns globally (Pezzulo *et al* 2017, Melchiorri 2022). However, it is important to acknowledge the limitations of both datasets and the inheritance of certain errors from the underlying approaches with respective data production. With continuous updating and evolution of these open source data products or their logical successors—not to mention feedback between data users and producers (Leyk *et al* 2019)—we can expect more thematic breadth and spatial refinements. Notably, on the gridded population side, there exists a new set of WorldPop residential populations with accompanying age–sex data, known as their Global 2 dataset (WorldPop 2025), although the dataset covers a different period (2015–2030) than this study. And as the GHS-UCDB is continually updated with extended time series (Mari Rivero *et al* 2026), these data, along with other new population data, should be compared to our findings for later or longer periods of growth. There is also a recently released UN world urbanization prospects which uses the degree of urbanization methodology alongside country-specific definitions to measure cities, towns and rural areas (United Nations 2025). The report underscores the importance of small and medium sized urban localities playing a critical role in future sustainable urban development. Recognizing the evolving data landscape, we contend that our study emphasizes, even with a limited set of available variables and the specific period of 2000–2015, the complexity in population growth rate and population–age structure dynamics for SUAs and, thus, can be useful for policy and decision-making initiatives.

6. Conclusion

Our synthesis approach investigates how these SUAs changed during 2000–2015 using a quantitative set of constrained but globally consistent predictors for understanding patterns and drivers of SUAs. We highlight that all six countries show an overall decline in

YDR and that those urbanized areas with a lower population in 2000 are growing at a faster rate on average. Further, land cover changes observed in typical urbanizing contexts (e.g. decreasing average greenness, increase in built-up area) (Dadashpoor *et al* 2019) are associated with high population growth rates in the SUAs that are the focus of this study. These demographic patterns and associated drivers suggest it is critically important to focus on SUAs in Southeastern Asia where we will observe the majority of population growth coincident with places where inequities are higher and capacities and resources are less than other areas. (Birkmann *et al* 2016). This study is a first to our knowledge that starts to disentangle urban demographic patterns and underlying correlates associated with smaller urbanized localities in one of the more rapidly urbanizing and continually growing regions of the world.

We emphasize the importance of the interdisciplinary approach including urban demographic conditions and changing patterns over time in the integration of city-level indicator frameworks that inform policy decision-making. While coarse-level or sparse data is often a limiting factor, we demonstrate the utility of using globally standardized data products at subnational levels to provide insight regarding short-term changes in demographic and population patterns for smaller urbanized localities in Southeast Asia. Understanding the demographic characteristics for smaller urbanized localities along with the factors that constrain or facilitate change is critical to ensure sustainable social, economic, and environmental development. Our results underscore the importance of near-term policy and decision-making toward considerations for how developing burgeoning urbanized spaces might take on more sustainably focused initiatives.

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Data availability statement

Data compiled and used in this work are from publicly available data sources. Data were sourced from the NASA Socioeconomic Data and Applications Center (SEDAC): <https://doi.org/10.7927/4rjm-vf23>. WorldPop age-sex structures data are available from WorldPop: <https://hub.worldpop.org/project/categories?id=8>. GHS-UCDB is available from the European Joint Commission Research Center: <https://ghsl.jrc.ec.europa.eu/datasets.php>. Finally, all compiled and summarized data used for modeling along with code to reproduce all analyses presented here are uploaded to Figshare, <https://doi.org/10.6084/m9.figshare.20459802> for archival and reproducibility of this research.

The data that support the findings of this study are openly available at the following URL/DOI: <https://doi.org/10.7910/DVN/GMV8W>.

UCDB SE Asia Data & Scripts available at <https://doi.org/10.1088/1748-9326/ae5fb1/data1>.

Conflict of interest

The authors declare no competing interests.

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