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The contours of a new urban world? Megacity population growth and density since 1975

Abstract
The problems posed by rapid and large-scale urbanisation are manifold, and are recognised in the UN's *New Urban Agenda*; a declaration of intent that aims to meet such challenges head-on facilitated by the systematic tracking and analysis of global urban growth and change. In this context, the release in 2016 of new small area Global Human Settlement Layer (GHSL) data was said to represent a unique opportunity to facilitate comparative global analyses of urban change dynamics and, perhaps somewhat idealistically, move forward progressive planning agendas. We therefore focus on population growth and density in 30 major urban agglomerations using the GHSL in order to shed light on the scale and extent of global urbanisation over the past four decades and to interrogate the potential role of the GHSL in tracking urban change.

1 Introduction

This paper examines the scale of urban growth across space and over time in 30 global 'megacities', though as we will show, this term in itself needs careful interpretation in the context of global urban development. It does so using the Global Human Settlement Layer (GHSL) dataset, produced by the European Commission and launched at UN Habitat III in 2016. It is the latest addition to a series of advancements made in the quality and accessibility of remotely sensed data for quantifying built-up areas and population across the globe (Bagan and Yamagata, 2015; Griffiths *et al.*, 2010; Taubenböck *et al.*, 2012; Zhang and Seto, 2011). The paper contributes to urban and regional planning discussions by providing a systematic overview of how a consistent global measure of urban expansion, derived through remote sensing data, can be used to facilitate the closer monitoring and evaluation of urban growth in different regional contexts and some of the challenges associated with doing so.

In what has become mooted as the 'urban century' (Kourtit *et al.*, 2015), today more people live in urban areas than ever before. In 2016, the global urban population was estimated at 54.5 per cent, with 500 million people (representing 6.8 per cent of the global population) residing in 31 *de facto* 'megacities' (UN, 2016). Of these, 24 were located in the Global South, and of the 10 new cities projected to be added to this list over the next 15 years, all are expected to come from the Global South (UN, 2016). Typically defined as urban agglomerations with 10 million or more residents, 'megacities' are the result of extending city limits to withstand ever expanding populations of people and firms.

From a policy point of view, this context exposes an important truth: urban concentration is likely to continue, further intensify and present challenges for urban planning and regional development agendas going forward (see Scott and Storper, 2015). This idea is of course nothing new, since for example Gottmann's *Megalopolis* of 1961 echoed similar themes and discussed responses - at length - in relation to suburban development, land use, transport and employment on the Atlantic seaboard of the United States. What is different today, however, is the *scale*, *speed* and *scope* of urbanisation and the fact that it is concentrated in some of the world's poorest regions (McCann and Acs, 2011).

The challenges that such rapid and concentrated urban growth presents are profound (see Bhatta, 2010), recognised in the UN's *New Urban Agenda* in relation to 'housing, infrastructure, basic services, food security, health, education, decent jobs, safety, and natural resources' (UNCHSUD, 2016, 1). In response, international policymakers have set about developing tools and frameworks to help track and quantify urban growth for creating a more systematic evidence base on which to build strategies to plan and manage change (Wong, 2015). The European Union, for example, has implemented a series of policy actions under its Cohesion Policy Programme to observe and check the progress of local development, understand the division between urban areas and rural peripheries, and find ways to reduce disparities between advancing and lagging regions. Yet, there remains something of a conceptual and technical imperative to improve the way that the universal monitoring of urban change is practiced in an international context (Wong, 2015) and the interoperability of research findings for informing planning implementations.

The release of the new Global Human Settlement Layer (GHSL) is said to mark a watershed moment in our ability to understand, compare and contrast urban development across the world in a consistent and precise way overtime. Described in more detail below, the GHSL provides high resolution, small area global population data for 1975, 1990, 2000 and 2014 that improves on the accuracy and consistency of its predecessors. These include the Global Rural-Urban Mapping Project (GRUMP) published in 2011 that uses night-lights data and secondary estimations of built-up areas to produce a global time series of gridded population density data. NASA's Socioeconomic Data and Applications Centre (SEDAC), first introduced in 1995, is another example that uses latest population and housing censuses data to produce a high-resolution, gridded population data collection of the world. Using the GHSL rich new dataset, this paper provides a comprehensive overview of population growth and density in 30 global 'megacities' from 1975 to 2014. We focus here on population growth and density as *the* rudimentary foundations of many composite measures of urban expansion that can assist the development of progressive policy-orientated measurement frameworks so demanded by international agencies, including the UN (see Wong, 2015). In structuring our analysis, two questions are considered:

1) What does the Global Human Settlement Layer reveal about the patterns of change in population growth and densities of global megacities over the past four decades?

2) How might the Global Human Settlement Layer contribute to the monitoring of, and planning for, change in global patterns of urbanisation in the future?

The first question is the main focus in our paper. The second is put forward as a reminder that any such analysis must have practical application in the real world if it is to make a positive contribution to managing global urban population growth. The next section provides a basic framework for the paper, positioning it within recent debates on global urbanisation and the imperative to track it. The paper then details the nature and characteristics of the GHSL dataset and how it was analysed in this research. The UN's 31 *de facto* 'megacities' (UN, 2016) were selected for inclusion in this analysis. This resulted in a sample of 30 global urban agglomerations as a result of Guangzhou-Shenzhen being categorised as one urban area in the GHSL data rather than two as in the official UN list. The majority of these, such as Karachi, Lagos and Manila, are in the Global South, but also included here are cities such as London, Tokyo and Los Angeles.

A pertinent question to ask in this context is where are the boundaries of cities used in the monitoring of change at the global level to be drawn? This paper explores this question through the use of the new GHSL urban boundary dataset. This is explained in more detail in the data and methods section but for the purposes of clarity, the concept of the 'urban agglomeration' (UN, 2016) is used here rather than the more restrictive - and somewhat arbitrary - administrative, 'city proper' boundary. A series of map analyses and associated descriptive data for the 30 cities are then presented in the results section. This simple analysis highlights both the intensive patterns of growth of cities such as Jakarta since 1975, but also the overcrowding seen in parts of cities like Dhaka, where the population density in places approaches 200,000 persons per square kilometre. The data presented are then discussed at more length before a concluding section reflects upon the key messages to take away from this analysis for policy and future research.

2 Background

The transformative process of global urbanisation over the past four decades is the result of rapid population growth and rural-urban migration, combined with a new organisation of the world economy in an era of globalisation (Scott and Storper, 2003; van der Ploeg and Poelhekke, 2008). Dating back to Molotch's (1976) paper *The City as a Growth Machine*, the 'city' has become an important unit of analysis for understanding urban systems. This is owed to their importance as centres of production and consumption, and as the key drivers of the world economy (Friedmann, 1986; Sassen, 1991). However, the idea that associated economic and social gains can be unlocked through urban agglomeration has been strongly challenged recently through critical interventions that render the link between city size and economic growth problematic on various social, economic and environmental grounds (Frick and Rodríguez-Pose, 2016; Fothergill and Houston, 2016;

Haughton *et al.*, 2014). The spatial unevenness of urban expansion is also of growing concern, leading to what Harding and Blokland (2014) refer to as an increasing 'spikiness' in global social, environmental and economic landscapes. This contests Friedman's (2005) claim that capitalist modes of wealth generation have served to 'flatten' the world.

The intensive, rapid and disordered nature of urban expansion found in many global 'megacities' has attracted international policy attention owing to the significant – and unresolved – problems resulting from the contradictions of agglomeration in relation to health (e.g. Krämer *et al.*, 2011), sustainability (e.g. Buijs *et al.*, 2010), inequality and violence (e.g. Koonings and Krujit, 2013) and governance (e.g. Sorensen and Okata, 2010). More broadly, the impacts of rapid urbanisation on air pollution, (e.g. Chan and Yao, 2008; Molina and Molina, 2004), climate change (e.g. Nicholls, 1995; Hunt and Watkiss, 2011) and mental health (e.g. Andrade *et al.*, 2012) have been widely exposed in recent decades. These challenges are found to be particularly abundant in countries of the Global South where infrastructures are less developed and growth is in part driven by the expansion of slum residences and informal employment (van der Ploeg and Poelhekke, 2008). In light of such policy interest, this paper engages with some of the technical considerations that might arise in monitoring change within and between megacities over time and across space beginning with the basics of understanding population growth and changes in density.

Our starting point is the recognition that urban areas have come to assume privileged positions as observational units for the analysis of a range of productive, consumptive and redistributive processes and outcomes (Castells, 1972; Harvey, 1985), even though the features of such analyses (e.g. poverty or income) are not intrinsically urban in nature (Storper and Scott, 2016, 1117). Yet the articulation of the 'urban' is an uncertain and imprecise exercise, relying on vocabularies and concepts that may have different meanings and values depending on where they are mobilised and for what purposes (Scott and Storper, 2015; Barua and Jellis, 2017). As such, there are multiple ways to define or quantify urban and metropolitan areas eliciting different functional and morphological criteria. For example, the EU's Urban Database Portal - a data sharing platform for cities and regions in Europe – publishes data relating to various spatial units, including 'Urban Morphological Zones', 'Morphological Urban Areas', 'Functional Urban Areas' and 'Large Urban Zones'.

There is a voluminous literature charting the technical challenges and policy applications associated with monitoring megacity growth and development using remote sensing data (e.g. Bhatta *et al.*, 2010; Taubenböck *et al.*, 2012; Griffiths *et al.*, 2010; Bagan and Yamagata, 2015; Zhang and Seto, 2011). The great advance in this area, however, came in 2016 when the European Commission published the *Atlas of the Human Planet 2016*, claimed to provide 'the most comprehensive view of urbanisation dynamics ever presented' (EC, 2016, 6). Whilst the veracity of this claim is open to challenge (see Brenner and Schmid, 2015), we do concur with the view that the GHSL data on which the *Atlas* is based is 'a remarkable example of the potential of public data to support global, national and local analyses of human settlements and in particular, support policy and decision making' (EC, 2016, 6).

As a specific articulation of the urban, the GHSL contains a measure of built-up areas which are defined '…as the union of all the spatial units collected by the specific [satellite] sensor and containing a building or part of it' (Pesaresi *et al.*, 2016, 7). The assumption here, therefore, is that human settlements are composed of population and physical infrastructure that are readily observable by satellite as a large spectral assemblage of different objects and entities (Pesaresi *et al.*, 2016*)*. These built-up areas have been aggregated to derive 'megacities', defined in the context of the GHSL as '…urban agglomerations hosting at least 10 million inhabitants' (Melchiorri *et al.*, 2018, 285). Defined in this way, the GHSL-derived megacities are in the mould of a technocratic fix that privileges the 'universal' as opposed to the 'particular' conception of the urban (Roy, 2009; McFarlane, 2011).

This 'universal' conception of the urban is articulated through a consistent lattice of grid cells that are characterised according to the densities of built-up areas, population distribution and the classification of land surface contained in each cell (Melchiorri *et al.*, 2018). For Scott and Storper (2015, 1), for example, cities are characterised by two main processes '… namely, the dynamics of agglomeration/polarization, and the unfolding of an associated nexus of locations, land uses and human interactions'. Although this affirmation to the universalism of the urban has proved contentious (e.g. Mould, 2015), the GHSL-derived megacities certainly demonstrate consistency with this logic and in doing so provide a standard unit with which to track population growth and density changes in rapidly urbanising contexts. It is to exploring the opportunities and challenges in making use of this data that the remainder of the paper now turns.

3 Data and methods

In an era of 'big data' hyperbole, it is wise to remain circumspect about any grand claims made relating to new data sources (e.g. Rae and Singleton, 2015; Zook *et al.*, 2017) and what they can achieve. Despite the advancement of GIS technology, there has long been a gap between its research development and its application in practice owing, among other things, to technical complexity, which Batty (2004, 327) considers to be 'the tragedy of the field'. Therefore, we set out to adopt a geospatial approach to the monitoring of population growth and density change in global megacities that is premised on the idea '…that methodological and technical complexity should be minimised as far as possible and that analytical outputs should communicate results in a clear and uncomplicated style' (Wong *et al.*, 2015, 1022). Accordingly, use is made here of simple visualisation functions and zonal statistics that are readily achievable in propitiatory and open-source GIS software. As outlined by Wong (2015) in relation to seven analytical principles, our intention is to adopt a geospatial approach to monitoring that:

- facilitates consistent and comparable analysis of spatial urban change;
- enables the tracking of change over time;
- promotes benchmarking and cross-comparisons;
- can be used to analyse change across multiple spatial units and scales;
- opens-up discussions on the interactive effects of processes driving urban change;
- generates outputs that can be used in conjunction with soft indicators or qualitative information;
- provides a meaningful platform for learning and communication on policy needs and challenges.

The GHSL population data is not, as the name suggests, a single dataset but rather a collection of global population data layers. This section of the paper therefore explains the GHSL in more detail in relation to the individual layers and specifications. The GHSL layers included in the study are identified, followed by an explanation of how they were used to identify 'megacities' and the spatial analytical approach adopted.

3.1 The Global Human Settlement Layer explained

The Global Human Settlement Layer (GHSL) is a tool for exploring human presence on earth at a granular level that is, importantly, open and free. It provides data for the entire globe in relation to three primary informative layers - 'data types' - at four time points (EU, 2016). The four time points available are 1975, 1990, 2000 and 2014. All data are provided in georeferenced TIF raster format, which can then be loaded, processed and analysed using geographic information system software, such as ArcGIS or QGIS. The three different data types, available at 250 metre or 1km cell resolution, are as follows:

Built-up areas: ***Global Human Settlement built-up areas (GHS-BU)*** these datasets contain information on global built-up presence. The built up area within each 250m or 1km cell is expressed as a continuous value that represents the proportion of each cell containing building footprints. As with all the GHSL data, they are derived from Landsat imagery collections (specifically GLS1975, GLS1990, GLS2000 and Landsat 8 from 2014).

Population: ***Global Human Settlement population grids (GHS-POP)*** these datasets contain the number of people per cell and can be used to convey population distribution and density. For the 1km cell resolution in particular, this gives us an easy-to-understand, globally comparable population density measure. These data are derived from a combination of GHS-BU data (as above) and data from population censuses. Unlike when we attempt to compare unequal census administrative units, the GHSL population grid data allow us to compare the presence and density of population across the globe using a standardised measure. This makes global comparative analysis very efficient.

However, it is important to note that the availability and quality of administrative population data and the estimation methods used to disaggregate these into gridded cells varies between countries. To this effect, the European Commission reports inconsistencies in, for example, the input census data for Egypt and Poland in the GHSL. The European Commission also discloses that the population grid cells for 1975 are less reliable than later years owing to uncertainties in the census population estimates for small areas and shortcomings in identifying and mapping built-up areas. Similar quantifiable errors are found in the GHSL from a multi-scale cross-comparison of low and high resolution urban maps by Klotz *et al.* (2016), although the authors emphasised the overall enhanced precision and sensitivity of this new dataset for mapping settlement patterns across the globe.

Land classification model: ***Global Human Settlement urban/rural classification model (GHS-SMOD)*** the third element of the GHSL data catalogue is generated according to the 'degree of urbanization' model adopted by EUROSTAT, the European Union's statistical agency. This strand of the GHSL data identifies individual grid cells as 'urban centres', 'urban clusters', 'rural' areas and 'no population' areas. Urban centres are defined where cells have a minimum of 1,500 inhabitants or are more than 50% built-up and combine to form a contiguous area with more than 50,000 inhabitants. Urban clusters are contiguous areas with a minimum population of 5,000 inhabitants and where no individual cell contains less than 300 people. There are 110,180 such areas in the GHSL dataset. Rural areas (cells with at least 1 person) and areas with no population account for all other cells in the dataset.

Useful applications and example use cases are provided in the *Atlas of the Human Planet 2016* (EC, 2016). One particularly attractive feature of the GHSL is its ability to pick out refugee camps, informal settlements and other less permanent settlements not normally included in official censuses. A good example of this can be found in Kenya, where the Dagahaley, Hagadera and Ifo camps were constructed in 1992 for Somali refugees (EC, 2016, 98). The new GHSL data identifies Hagadera and Ifo as 'urban centres' and Dagahaley as an 'urban cluster'. Another attractive feature of the GHSL archive is its spatial-temporal comparability that is the focus of the remainder of the discussion.

3.2 Step 1: Isolating relevant GHSL datasets

The analysis of population in this paper is based on the GHS Population Grid (GHS-POP) datasets for 1975, 1990, 2000 and 2014, adopting the 1km cell resolution product. This was deemed to be of a consistently higher quality than the 250m cell resolution product, which was less complete and displayed less granularity for some locations at earlier time points. For example, when some cities are mapped at the 250m cell resolution, there is little variation in population density at this scale over large areas of several cities, in contrast to the 1km resolution product. In order to provide the reader with a better idea of the nature of the dataset, a regionalised example of the GHS Population Grid layer covering part of Nigeria is shown in Figure 1. This is displayed in a simplified fashion using four separate data classes that immediately make visible the settlement pattern. Nigeria and Africa's largest city - Lagos - is clearly identifiable, along with larger regional centres such as Ibadan and Benin City and a range of smaller towns. This presents a different view of the 'urban' than one might see from administrative boundaries alone (cf. McGee, 1991) and allows us to identify patterns of global human settlement in a standardised, comparable manner.

INSERT FIG. 1 HERE

In Figure 2, we can see the other dataset used in this study: the Global Human Settlement urban/rural classification model layer (GHS-SMOD). The same area in Figure 1 is shown in Figure 2, but this time with urban centres and urban clusters displayed. The existence of this classification opens up the possibility of conducting comparative global city analysis. In addition, the fact that this can now be done in time-series fashion is particularly advantageous since it allows us to track the growth trajectories of individual cities - or small parts of cities - over time. More practically, it also allows us to identify and extract urban agglomeration boundaries across the globe, enabling the identification of the 30 'megacities' used for this analysis as described below.

INSERT FIG. 2 HERE

3.3 Step 2: Identifying 'megacities'

Identifying the precise boundaries of cities or urban areas is a perennial problem in urban and regional studies (see Batty and Longley, 1994; Dietzel and Clarke, 2005). It becomes yet more difficult when we attempt to compare cities across nations, each of which might have a different method of identifying their cities. In Tokyo, for example, the 23 'special wards' are sometimes used to identify the boundaries of the city, within which almost 10 million people now live. However, this area contains far fewer people than the wider, continuous urban fabric that urbanists would recognise as Metropolitan Tokyo that according to the most recent Census has a population of more than 36 million (Tokyo Metropolitan Government, 2017). Similarly, in the Philippines, the tightly-defined City of Manila had a population of 1.8 million in 2014, compared to an officially defined Metro Manila population of 13 million (Philippine Statistics Authority, 2017) that comprises only part of the wider urban agglomeration centred on Manila.

These wide differences between 'city proper' populations and urban agglomeration populations can make it difficult to identify growth and understand urban density. Therefore, in order to allow comparisons over time and between cities, the GHSL defined 'urban centre' boundaries as described above were used in the analysis described below. Whilst we do of course recognise that the classification of urban areas is a vexed issue and the GHSL 'urban centre' definition is imperfect, providing a full, in-depth treatment of potential issues is beyond the scope of this paper. We therefore adopt the 'urban centre' definition of the GHSL as a standard measure of urbanisation globally. As previously stated, the UN's list of 31 'megacities' for 2016 was used to identify the global urban agglomerations included in this analysis. This resulted in a sample of 30 global urban agglomerations with Guangzhou and Shenzhen megacities forming one 'urban centre' (i.e. Guangzhou-Shenzhen) in the GHSL rather than two as in the official UN list.

In some cases, the urban agglomeration populations captured by the GHSL 'urban centre' definition are a relatively close match for existing metropolitan populations, as in the case of Tokyo where Statistics Japan (2017) put the figure at 36 million, compared to a GHSL figure of 34 million. In the case of Manila, however, the GHSL population of 22 million across the metropolitan area is far higher than the official figure of 13 million reported above. Nonetheless, such cases are the exception and the new approach enshrined in the GHSL methodology allows us to compare like with like across the globe and to identify the true scale of megacity urbanisation that has taken place over the past 40 years. The full list of 30 megacities is provided in Table 1. The largest was the continuous urban agglomeration of Guangzhou-Shenzhen, with a population of just over 46 million in 2014.

Similarly, the total area of each megacity according to the GHSL 'urban centre' definition (the third column of Table 1) provides further contextual understanding of the 30 selected urban agglomerations. These can be used to compare and contrast the boundaries used in our analysis with official administration data. For example, the GHSL 'urban centre' boundary of London covers 1,854 square kilometres compared to 1,572 square kilometres as reported by the Office for National Statistics (ONS, 2018). This is a relatively close match as opposed to other cities such as Manila, where the GHSL 'urban centre' boundary covers 2,279 square kilometres in comparison to the administrative definition of just 25 square kilometres (Philippine Statistics Authority, 2017). Therefore, whilst metropolitan areas can extend well beyond their city proper boundaries, the physical urban agglomeration potential of some may be restricted. This is the case for London, where the existence of a 15-25 km wide green belt sets an artificial limit and forces London's expanding population to live in physically separate urban areas.

The fourth column of Table 1 displays the population density for the area defined as being the GHSL 'urban centre' in each megacity. Population density provides an indication of the 'lived experience' of growing megacity populations that raw population counts alone are unable to show. Topping the list is Karachi, with a density of just under 18,500 people per square kilometre. This is followed by Mumbai (13,900), Bangalore (13,600), Delhi (11,100) and Istanbul (10,200). At the other end of the scale, the lowest densities were found in Osaka (5,000), New York (3,400) and Los Angeles (2,600). However, an important point to make here is that since population densities can vary considerably within agglomerations (see Figure 4), average densities are potentially poor representations of datasets. Therefore, maximum 1km density calculations for each city were also performed and are reported later in the paper.

INSERT TABLE 1 HERE

3.4 Step 3: Use of a spatial analytical approach

In order to make the analysis both manageable and meaningful, the spatial analytical approach taken was applied only to the 30 urban agglomerations shown in Table 1 rather than the entire 'urban centre' dataset. The analysis was performed in a combination of ArcGIS 10.1 (zonal statistical analysis) and QGIS 2.14 (for map production). An overview of the specific statistical and analytical approach is provided below.

1. The GHS-POP 1km resolution products for 1975, 1990, 2000 and 2014 were loaded into ArcGIS 10.1.

2. The GHS-SMOD product for 2015 was then loaded into ArcGIS 10.1. This was then converted from raster to vector format and each of the individual 13,844 'urban centres' were then included in a new multi-polygon GIS layer.

3. From the full file of 13,844 'urban centres', the 30 cities identified in Table 1 were exported from the larger GHS-SMOD vector file to create a sub-set of global megacity boundaries.

4. Using the boundary files for the 30 cities, Zonal Statistics analyses were then performed for each of the GHS-POP datasets: 1975, 1990, 2000 and 2014. A fixed spatial definition (i.e. the GHSL's 'urban centre' boundary) as of 2014 is used for all years, allowing us to compare like for like across the four time points in each area. This does mean, however, that we are unable to show the spatial extent of growth over time, which in some cases could mean the missed capture of extensive sprawl and the merging of multiple places. Whist this is certainly an important aspect to consider, our focus here is on the population growth and densities of 'urban centres' rather than their spatial expansion. This produced a data table for each year giving the average population density per 1km cell, the maximum value per cell, the mean, and geographic area covered.

5. A series of analytical maps were then styled and produced in QGIS 2.14.

The results of this spatial analysis are presented in the next section.

4 Results

As previously described, a consistent measure of urban expansion can be used to facilitate the closer monitoring and evaluation of urban growth in different regional contexts across the globe. This is imperative to assist urban and regional planners in assessing and minimising the challenges of rapid urbanisation and the rising number of megacities to global social and environmental sustainability, especially in the Global South where urban expansion is often unplanned and difficult to track (see Korcelli and Korcelli-Olejniczak, 2018).

The 30 megacities under investigation contained more than 558 million people: 8.2% of the world's population in 2014. In 1975, however, they contained less than half this total, at 261 million or 6.4% of the global population at the time. Beyond this modest rise in the proportion of the global population living in these megacities, looking deeper into the GHSL data reveals some striking facts. The most populous of the urban agglomerations in 1975 was Tokyo, with just over 23 million people, followed by Kolkata at nearly 17 million. By 2014, there were 12 megacities with a population of 20 million or more and the most populous (Guangzhou-Shenzhen) was home to more than 46 million people, though of course it is also the case that Guangzhou-Shenzhen and the Pearl River Delta area more widely could be considered something of an urban 'megaregion' (Ye, 2013).

4.1 The size of megacities according to the GHSL: population and area

In Table 1 we can see the total population of each megacity as of 2014 according to the GHSL 'urban centre' definition, in addition to the total area. When we compare the list in Table 1 to the data reported by the United Nations in *The World's Cities in 2016*, we find that six of the 30 megacities identified have a population of less than 10 million. However, Rio de Janeiro (9.9 million) and London (9.7 million) were very close to this figure using the 2014 GHSL data, and it is entirely plausible that these two cities have now grown enough to meet the 'megacity' population threshold used by the UN definition taking this number closer to that given in the UN's report.

The largest by area is the urban agglomeration of Guangzhou-Shenzhen in the Pearl River Delta area of China, which covers more than 8,100 square kilometres, followed by the metropolitan area of Cairo at 7,400 square kilometres. Also appearing towards the top of the ranking here are the less densely populated US cities of Los Angeles and New York, whose wider metropolitan areas cover 5,400 square kilometres and 4,500 square kilometres respectively. This is of course consistent with the sprawl-like settlement pattern of many North American cities (see Bruegmann, 2006; Gillham, 2002). At the other end of the scale is Chongqing, which according to the GHSL measure covers just 695 square kilometres.
These baseline data provide useful comparisons and are interesting in themselves, but it is only when we look at growth and density dynamics over time that the real story of global megacity development emerges. The next two sections of the paper in turn look at population growth and population density changes in the 30 megacities since 1975.

4.2 Population growth, 1975-2014

In the fields of urban planning and sustainable development, the impacts associated with rapid population growth are well-documented (see Molina and Molina, 2004; Wang *et al.*, 2015). For example, the extra pressure put on infrastructure, public services, healthcare and the environment are particularly acutely observed. However, it is at the local level where these pressures are most significant. Understanding the scale of the challenge, therefore, can in part come from a more detailed assessment of population growth. This analysis looks at this in terms of absolute and percentage population change in the 30 megacities between 1975 and 1990, 1990 and 2000, and 2000 and 2014. This offers an insight into the remarkable population growth in urban areas in Asia and the Global South over the past 40 years, in contrast to the slower growth found in traditional, long-established urban centres in Europe and the US. It is important to bear in mind when interpreting the analysis, that the middle period (1990-2000) covers only 10 years in contrast to 15 years for the first and last periods. It should also be noted here that this analysis highlights some issues with data relating to Chongqing; more explanation on this follows.

In Table 2 absolute population change and percentage change are shown, sorted in descending order by the absolute population change between 1975 and 2014 for each city. Particularly striking here is the fact that the population of 11 of the GHSL urban centres increased by more than the commonly accepted 'megacity' population of 10 million over this four-decade period alone, with all but one of these found in the Global South. Even though the rate of urbanisation is well documented, particularly in the Pearl River Delta region (e.g. Wei *et al.*, 2017), these figures help highlight an unprecedented rate of hyper-urbanisation in the world's largest agglomerations. Guangzhou-Shenzhen added more than 10 million people in the 1975 to 1990 period *and* in the 2000 to 2014 period, and Jakarta grew by more than 10 million people between 2000 and 2014. These levels of absolute growth stand in contrast to urban population increases in the West where Paris increased in population by just over 2 million in the 1975 to 2014 period, New York by 2.2 million, London by 2.9 million and Los Angeles by 3.6 million.

It is when we look at rates of change across the 30 megacities, however, that we can truly understand the scale of the planning and sustainable development challenge created by this rate of growth. Between 1975 and 1990, Manila, Beijing and Dhaka all grew by 100 per cent or more. The following decade then saw growth rates of over 50 per cent in Dhaka and Bangalore. In the period from 2000 to 2014, further growth of 50 per cent or greater was seen in Bangalore, Beijing, Shanghai and Dhaka.

One apparent error or anomaly is evident in the data presented in Table 2. Chongqing has, according to the GHSL data, experienced a decline in population of 120,000 or 2.4 percentage points since 1975. This is in contrast to growth figures reported in the Statistical

Yearbook of China which report municipal population growth in the region of 500% since 1979 (China Statistical Yearbook, 2014). However, the most recent population GHSL data tallies with official population figures for this urban centre.

INSERT TABLE 2 HERE

4.3 Population density, 1975-2014

Turning to look at population density now, it is clear that in many cases over the past four decades there has been an intensification in population densities in many global megacities. This seems like a particularly apposite observation now, in light of the *New Urban Agenda's* focus on 'sustainable population densities' (UNCHSUD, 2016, para 52). In Table 3 we can see how densities have changed since 1975 in the 30 megacities selected for analysis, presented in the form of mean densities and the maximum value in any one square kilometre. The Table is sorted by mean densities in 2014, so that it is ranked in descending order from the most densely populated megacity in 2014 (Karachi) to the least (Los Angeles).

Most striking in Table 3 is the very high maximum density figures for a number of cities. These values are displayed for 2014 in Figure 3, where Dhaka's maximum density of nearly 200,000 people per square kilometre is the highest: located in part of the Bangshal ward, south of the City. Maximum density values of more than 100,000 are also found in Cairo, Kolkata, Guangzhou-Shenzhen, Manila, and Shanghai. The maximum population densities in each of these cities are between four to seven times as high as the maximum population density in the largest megacity of Tokyo. The most densely populated city outside the Global South is New York, with a maximum 1km density of just over 56,000.

When we look at mean population density and how it has changed over time, the greatest level of intensification has been in Karachi, which had a mean density of 6,830 in 1975 and now has a mean density of 18,471 (the highest overall mean density in 2014). Bangalore has also witnessed a similar increase. Looking now at the percentage change in mean population density between 1975 and 2014, we find the highest rates of change in Beijing (414.0%), Bangalore (408.4%), and Dhaka (388.9%). What is particularly notable here is that the highest levels of overall increased population density have all been in the Global South. This is not surprising, but it does help emphasise the urgent need to address the implications of such growth in relation to infrastructure, housing, environmental and a range of other public services highlighted as being a priority in the *New Urban Agenda*.

Finally, in order to provide a visual comparison of density patterns between and within the 30 global megacities selected for analysis, Figure 4 presents a small multiple map series showing population density patterns in 2014. The boundaries used here are the 'urban centre' GHSL geography, which is in most cases far more extensive than the administrative unit covered by the 'city proper' of each city. Even so, in cities such as Delhi, Karachi, and São Paulo we can see that densities are mostly above 10,000 per square kilometre. By way of contrast, we can also see relatively low densities in cities such as Los Angeles and New York (both with mean population densities lower than 3,500 per square kilometre in 2014).

INSERT TABLE 3 HERE

INSERT FIG. 3 HERE

INSERT FIG. 4 HERE

5 Discussion and conclusions

This paper represents an initial foray into a new dataset at a critical moment in the history of global urban development. The new GHSL data - showcasing the latest advancements for monitoring urbanisation across the globe - have been used here to compare and contrast global population growth and density patterns over a four-decade time span. The analysis was concentrated on a sample of 30 megacities that contained more than 558 million people and almost 8% of the world's population in 2014. Overall, this highlighted the intense urbanisation processes seen across the globe in recent decades, particularly in the Global South confirming what is already known about the scale difference of the population growth of megacities between the Global North and South. Whilst this is well-known, however, it is much less well documented, analysed or visualised at a micro-scale across the entire globe in a systematic manner. Furthermore, all too often, Global North perspectives dominate our understandings of 'the urban' that are driven by administrative or bureaucratic definitions of such areas. Our contribution in this paper, therefore, is to use the rich new GHSL dataset to provide a dispassionate comparative analysis of urban areas across the globe over four decades in a way that helps contextualise urban growth worldwide and brings new evidence to light on the scale of it.

There were a number of particularly striking findings from the analysis. First, in 1975 the 30 megacities contained less than half their population total in 2014, at 261 million or 6.4% of the global population at the time. Second, the level of growth in some of the urban agglomerations included in this study equates to entire megacities of 10 million people or more arriving in existing megacities, such as Jakarta in the past 15 years. This rate of urbanisation is often neither sustainable nor desirable, yet it is the lived reality for residents and policymakers in many large cities across the Global South. Third, from the analysis of individual densities, especially high maximum density figures of more than 100,000 people per square kilometre were found in Cairo, Kolkata, Guangzhou-Shenzhen, Manila, and Shanghai in 2014. While density in itself is not necessarily problematic – the affluent urban centres of Seoul, Hong Kong and Tokyo are good examples of high density, megacity living – this requires infrastructure, long-term planning and significant capital investment; none of which are available to the required level in cities such as Kolkata. Therefore, the question of what level of density is 'sustainable' will inevitably vary between urban and national contexts and needs to be carefully considered on a city-by-city basis.

The simple analysis presented here shows the potential of the GHSL dataset for assisting the development of progressive policy-oriented measurement frameworks. The GHSL-derived megacity definitions facilitate consistent and comparable analysis of spatial urban change as demonstrated through various threads of our analysis. The data is flexible and, in a global context at least, highly granular to such an extent that we were able to identify the Bangshal ward in the south of the city of Dhaka as an area with a population density of nearly 200,000 people per square kilometre. Although narrowly focused here due to the constraints of space, the potential to generate creative visualisations and to use what is a relatively uncomplicated set of descriptive data to engage policymakers and stakeholders in learning and communication exercises is not difficult to foresee. It is even the case that the analysis of population growth and density change could feed into wider technical and softer policy discussions on the interactive effects of processes driving urban change as per Martin and Ottaviano (2001) or Wong *et al.* (2015). To this effect, new sources of global, gridded population data could help policymakers look afresh at the kind of sustainability challenges identified in the *New Urban Agenda* and become more proactive than reactive with regard to tackling them. Notwithstanding some imperfections, therefore, the GHSL could serve as the foundation for a new wave of global urban research.

That said, however, the monitoring of population growth and density change using the GHSL and comparable data has faced renewed criticism on conceptual and technical grounds. Conceptually, Brenner and Schmid (2015) present the urban age thesis as little more than a statistical artefact, bolstered by empirical manoeuvres of ever increasing sophistication. In part they point to the way that the use of remote sensing data, among others, is processed and applied to the urban condition on the assumption that the world can be divided into discrete settlement units. These units are then used to arbitrarily argue that certain objects or processes are inherently urban and others inherently rural (see also Scott and Storper, 2016). Turning to the technical perspective, working with the GHSL data is not a trivial exercise and there are a number of imperfections revealed by our analysis that need to be considered carefully when interpreting results. In addition, anyone wishing to explore and exploit the data will need significant computing power and technical expertise, raising the question of how 'open' is this data, like many other purported public data, if it continues only to be the preserve of the technically proficient?

With these challenges in mind, future research in this area would benefit from engaging with the question of whether or not recent developments in remote sensing can provide new and fruitful avenues for creative theoretical engagements and interpretive developments with regard to the urban condition (Brenner and Schmid, 2015, 742). Future users of the GHSL may also want to consider using the 'urban clusters' identified in the GHSL dataset rather than the 'urban centres' used here to analyse an extended list of megacities. This would respond to a growing recognition of the critical links between cities and their wider urban and rural networks. Finally, and linked to the above question on what level of density is considered 'sustainable', further analysis could be conducted into the levels of population density which might be 'appropriate' in different settings.

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