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Megacities Spatiotemporal Dynamics Monitored with the Global Human Settlement Layer

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1 ABSTRACT

Megacities are urban agglomerations hosting at least 10 million inhabitants. The rise in number, population size, and spatial extent of megacities are among the most prominent manifestations of the process of urbanisation taking place in the contemporary urban age.

Until recently, urban growth has been quantified with data derived from satellites mainly for single megacities or for a limited subset of them. With the current advances in Remote Sensing and data processing, the integration of satellite data with other datasets could become a key contributor to the data revolution and support more complete urban studies and better informed policymaking. Although many remote sensing-derived products exist, few are open and free and possess the adequate resolution, information and contents to monitor the process of urban expansion. This research article builds on the premier open and free geospatial information contained in the Global Human Settlements Layer (GHSL) data package (produced at the European Commission - Joint Research Centre). This research takes advantage of existing GHSL data to identify megacities and to analyse their spatial and demographic change over the last 25 years (between 1990 and 2015). This paper quantifies how much and how fast megacities have expanded in spatial and demographic terms, and we provide graphical examples of the different manifestations of growth across megacities.

The main findings of our research reveal an average demographic growth in megacities exceeding 2% a year between 1990 and 2000, and of 1.9% a year between 2000 and 2015. In the first period (1990 to 2000), megacities have expanded faster than the global average and more than the average of other urban centres. In the second period, global urban population increase has been greater than that of megacities. The comparative analysis of megacities however, reveals swift population growth in several cases: in seven cities population more than doubled between 1990 and 2015, and in six the average annual population growth exceeded 4% a year. Spatial expansion of megacities tends to occur at rates slower than that of population. In 27 cities built-up per capita has decreased over 25 years, by more than 10% in 17 cities. Megacities also differ in population density (in 2015), which in five is above 10,000 inhabitants per square kilometre, while in others, especially the ones in high-income countries, density remains around half this figure.

Results highlight the value of new remote sensing-based data and methods for mapping and characterizing global urbanisation processes, in a consistent and comparable manner across space and time. The provision of open and free data ensures methods and findings can be audited and analyses extended to other cities, while the temporal dimension enables monitoring urbanisation and intergovernmental policies on sustainable urban development.

Keywords: planning urban growth, earth observations, megacities, urban expansion, GHSL

2 DETERMINANTS OF URBAN ANALYSIS: SPACE, DEMOGRAPHY, AND TIME

Over the past few decades the human species has increased its urban character. The process of urbanisation has supposedly achieved a planetary reach [(Brenner 2013)] even though estimates about the share of global population living in urban areas are not homogeneous. Recently, multisectoral policy agendas on sustainable urban development have proliferated (Post-2030 Development Agenda and thematic international frameworks) while narratives and analyses of the trajectories of urban development at the city level were mainly conducted for case study cities. Megacities, the urban agglomerations where population reaches 10 million or more inhabitants, have captured the attention of scholars across several disciplines. Since the 1990s research has focused on: the junctions between globalisation and urbanisation [(Burdett et al. 2007); (Taylor 1999)], on the socio-economic traits of megacities [(Friedmann 1986); (Stratmann 2011); (Derudder 2012), and (Kraas 2007)] and more recently on case studies to monitor the process of growth of megacities [(Taubenböck et al. 2012), (Bagan and Yamagata 2012), (Angel et al. 2015)]. Contemporary technology and information sources, especially remote sensing imagery, allow to capture the process of spatial expansion of urban areas [(Bruzzone and Marconcini 2009); (Potere et al. 2009); (Pesaresi et al. 2011)]. Technological advances can be merged with the traditional concepts and methods of urban analysis [(Ayeni 1979)] to fully support the understanding of human settlements and to guide sustainable urban development [(Geertman, Toppen, and Stillwell 2013)].

The analysis of urban expansion is a domain in which earth observation data are extensively used [(Mundia and Aniya 2005), (Xiao et al. 2006), (Seto et al. 2011)]. The proliferation of products that use satellite imagery to detect land cover typologies has supported a conspicuous scholarship focusing on the spatial growth of human settlements. In particular, some research has been dedicated to mapping urban extent [(Schneider, Friedl, and Potere 2010)], to monitor the changes of the extent of urban land over time (1990-2000) across few case study cities [(Schneider and Woodcock 2008)], to monitor the changes in the urbanized area of 27 megacities across time (1975-1990-2000-2010) [(Taubenböck et al. 2012)], to map spatial changes in a large number of cities [(Angel et al. 2015)], or to detect changes in land use in one megacity [(Bagan and Yamagata 2012)]. Accordingly, a conspicuous amount of urban analysis with remote sensing information has provided characterisation of the spatial and physical components of urban areas.

The demographic component of urban growth has traditionally been the main indicator to describe the process of urbanisation since the first studies on this phenomenon [(Davis 1955)]. Although the very definition of urbanisation (ibid.) has a pure demographic nature (i.e. the ratio between the population of urban areas over the national total), data availability and quality have oftentimes limited these studies [(Cohen 2006)]. Comparative analysis of urbanisation and urban growth requires homogeneous datasets. This requirement was unmet for long, both in terms of geographical coverage and historical depth [(Satterthwaite 2010), (Brenner 2013)]. Most urban analyses with a focus on demography (i.e. [(Montgomery 2008) and (Taubenböck et al. 2012)] refer to population figures contained in the World Urbanization Prospects, a report periodically produced by UNDESA. Downscaling the analysis of urban growth from global and national levels to that of the individual city has considerably advanced thanks to the Global Human Settlement Layer (GHSL) project of the European Commission - Joint Research Centre. The GHSL contains information on human settlements across four epochs (1975-1990-2000-2015) and has global coverage. The data package includes for each grid cell the densities of built-up areas, population distribution and classification of land surface according to a settlement model. Data production is based on the detection of built-up areas from Earth Observation (EO) data [(Pesaresi 2014); (Pesaresi, Ehrlich, et al. 2016)], the modelling of population distribution [(Freire et al. 2016)], and the DG-Regio-OECD degree of urbanisation model [(Dijkstra and Poelman 2014)] - a population-based definition of human settlements. The application of this model to the GHSL data supports the proposal and ongoing discussions on a global harmonised definition of cities and settlements – a voluntary commitment of the European Union[1], The Food and Agriculture Organization of the United Nations (FAO), the Organisation for Economic Co-operation and Development (OECD) and World Bank.

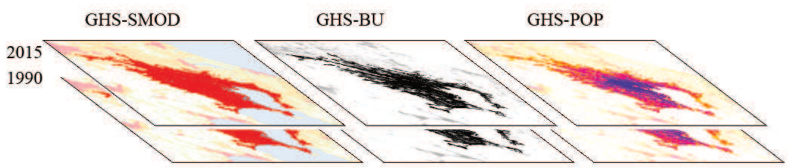

Figure 1 Layers of the GHSL Suite used in the study. Settlement Model (left), Built-up Grid (centre), Population Grid (right)

[1] https://ec.europa.eu/commission/commissioners/2014-2019/cretu/blog/presenting-voluntary-commitments-eu-meet-new-urban-agendas-objectives_en

The discussion on a global definition of cities was first announced at the UN-Habitat III conference organised by UN-Habitat to adopt a policy framework to guide sustainable urban development for the next 20 years. In this framework, the GHSL data have become a baseline dataset to produce the Global Human Settlement (GHS) Settlement Model (SMOD). The GHS SMOD allows to identify human settlements and their extent by mapping types of urban areas in a consistent and systematic manner across the globe. With the GHSL data it is ultimately possible to analyse several characteristics of a human settlement among which: the process of urbanisation [(Pesaresi, Melchiorri, et al. 2016)], urban and rural growth [Melchiorri and Siragusa, 2018 –forthcoming, (Melchiorri 2017)], and population densities [(Smith 2017)]. The aim of this research paper is to identify systematicly all megacities in the world in 2015 with the GHSL data package, and analyse in a comparative way the trajectory of their spatial and demographic change that took place in between 1990 and 2015. In this wrok, we define megacities the urban centres in the GHS SMOD data (2015), where population reaches at least 10 million people in 2015. The contribution broadens existing research for several reasons: the number of case study city is expanded, the number of indicators adopted to characterise the process of urban growth is extended, the time span of the analysis is prolonged to 2015, the spatial and demographic components are derived from a single and consistent data package to identify interdependences. In addition, the methods adopted are replicable and the materials used are open and free. This allow extending the research to any of the other 10 thousand urban centres mapped by the GHSL data.

3 MATERIALS AND METHODS

The GHSL is a suite of global spatial information data sets to map the human presence on Earth across different epochs. In this work, we are using the analytics extracted using the GHSL data package P2016[2] released as open and free data during the UN Habitat III conference. The three thematic layers in GHSL are:

(1) GHS Built-up grid, containing multitemporal information about density of built-up area [(Pesaresi et al. 2015)];

(2) GHS Population grid, containing multitemporal information about population distribution [(JRC and CIESIN 2015)];

(3) GHS SMOD grid, [(Pesaresi and Freire 2016)] classifying each 1km square of the land mass into one of three classes (urban centres, urban clusters or rural area) by analysing population and built-up density grids.

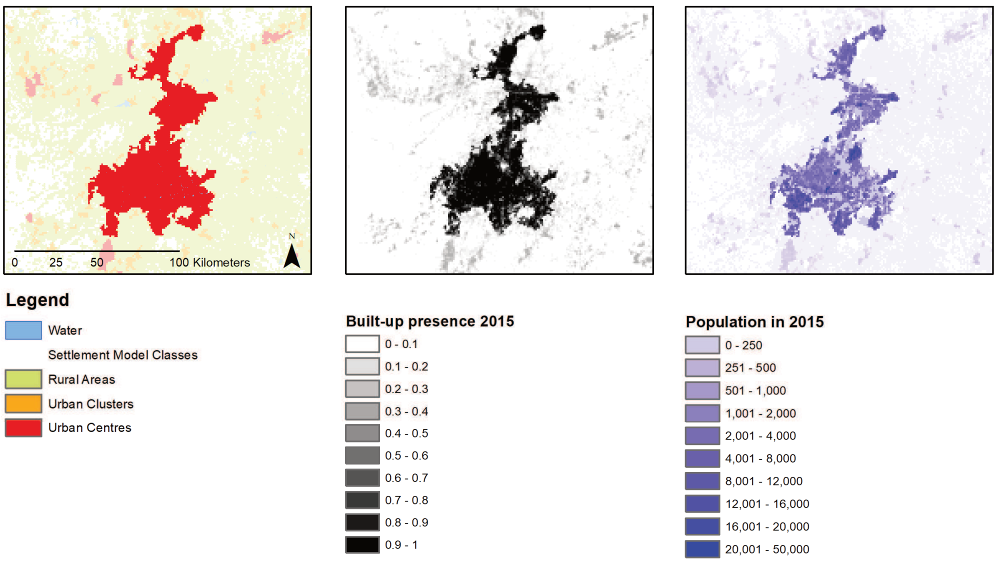

Figure 2 Settlement model (left), built-up areas (centre), and population density (right) in Johannesburg (2015)

The layers are available at various spatial resolutions: approximately 38m (GHS Built-up grids), 250m (GHS Built-up grids and GHS Population grids) and 1km (all the layers in the package), for each epoch (1975-1990-2000-2015). For the purpose of this city level analysis, we used the family of GHSL grids at 1km resolution. Despite finer resolutions being available, the adoption of input data at finer resolution (i.e. at 250m) is appropriate for more in depth analysis of individual case studies. For a comparative purpose the

[2] http://ghsl.jrc.ec.europa.eu/datasets.php#2016public

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patterns of built-up and population dynamics are clearly observable at the 1km resolution. One example of the geospatial information used for the research is displayed in Figure 2. The GHSL layers are available in a grid format as follows. The earth surface is divided into 1km² grid cells, and each cell contains values for the density of built-up areas (GHS Built-up grid), population (GHS Population grid) and the settlement model typology (GHS SMOD grid). The grid approach makes possible to overcome administrative boundaries for data collection and reporting. Data required to perform the presented analysis were produced through spatial analysis with GIS software, taking as input the GHSL data packages available on the Joint Research Centre Global Human Settlements website.[3] Additional information on the individual urban centres were sourced from country summaries.[4] The GHSL Settlement Model grid classifies settlements in three categories: Urban Centres, Urban Clusters and Rural Areas. Urban Centres are urban agglomerations having at least 50 thousand inhabitants, population density is above 1.5 thousand inhabitants per square kilometre or built-up density is above 50% [(Dijkstra and Poleman 2014)]. Accordingly, megacities are Urban Centres where population in 2015 is at least 10 million. This work builds on the preliminary snapshot of megacities proposed in the Atlas of the Human Planet 2016 [(Pesaresi, Melchiorri, et al. 2016)] and it goes furhter presenting a comparative analysis of the spatial and demographic changes that took place in the individual megacities between 1990 and 2015 using the data extracted from the GHSL suite. Megacities are here compared vis-á-vis the following eight indicators: a) total population (1990 and 2015) and change (between 1990 and 2015); b) total built-up surface (1990 and 2015) and change (between 1990 and 2015); c) population density in 2015; d) area in 2015 e) built-up per capita per epoch and change. In the article, we provide tables and maps to illustrate and quantify the size of megacities. In the analysis of megacities with GHSL we have calculated the indicators using both statistical tools and spatial analytics. Despite the relevance of this novel information, space constraints forced to communicate the findings with digits in the text, with few tables, and only more rarely with maps.

4 RESULTS

In the GHS SMOD 2015 it is possible to identify around 13 thousand urban centres. The analysis of the statistics generated for these centres (accounting population and built-up areas) identifies 32 urban agglomerations with a population of 10 million people or more – Figure 4. These 32 megacities are home to some 618 million people in 2015, equivalent to 10% of the global urban population. Between 1990 and 2015 population in megacities has grown more than the global average of urban areas (aggregate of urban centres and clusters), and also more than the global average of urban centres (52%) –Figure 3. Comparing the average yearly population growth[5] in the period 1990-2000 population in megacities has grown faster than in any other settlement class (above 2% a year). In the second period (2000-2015) both the average growth of global urban population, and that of urban centres has been greater than that of megacities.

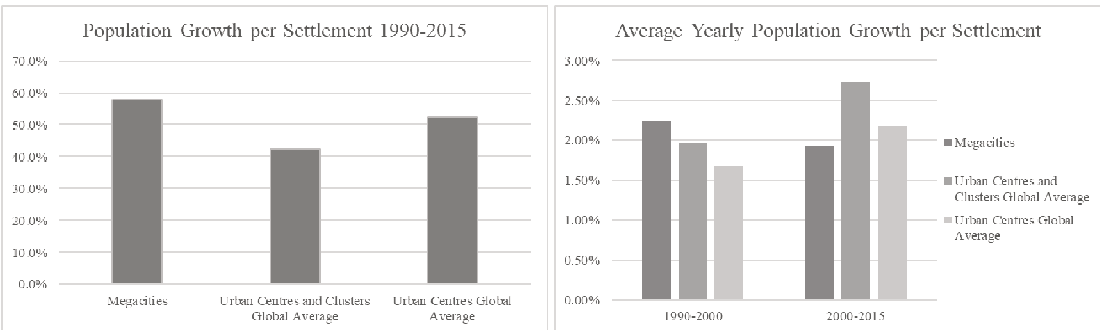

Figure 3 comparison of relative population growth in settlement typologies (left), and yearly population growth per epoch (right)

Figure 4 shows the list of the 32 urban centres megacities and respective statistics. The following sub-sections synthetically quantify the indicators adopted to characterise megacities.

[3] http://ghsl.jrc.ec.europa.eu/data.php

[4] Summaries are are supporting materials for the global discussion on the city and settlement definition. Example of country summary for Belgium http://ghsl.jrc.ec.europa.eu/gate.php?waw=205021135170

[5] $$Average\ yearly\ population\ growht = \frac{\%\ population\ change_{epoch1,2}}{year\ span_{epoch1,2}}$$

N	Megacity	Country	Built-up (sqkm)			Population (millions)			BU/capita (m)	Pop Density (inhab/sqkm)
			Year 1990	Year 2015	Change 90-15	Year 1990	Year 2015	Change 90-15	Year 1990	Year 2015
1	Guangzhou	China	1979	3666	85.2%	24.30	46.04	89.5%	80	5620
2	Cairo	Egypt	1626	2020	24.2%	24.1	37.84	57.0%	53	5134
3	Jakarta	Indonesia	3184	3867	21.5%	19.7	36.40	84.4%	106	6051
4	Tokyo	Japan	3551	3874	9.1%	28.0	33.74	20.4%	115	6214
5	Delhi	India	890	1184	33.0%	15.5	27.63	78.8%	43	11058
6	Kolkata	India	700	844	20.6%	21.3	26.87	26.2%	31	5838
7	Dhaka	Bangladesh	256	498	94.5%	10.2	24.83	144.5%	20	9067
8	Shanghai	China	889	1738	95.5%	10.5	24.67	134.8%	70	7514
9	Mumbai	India	661	825	24.8%	16.7	23.41	40.4%	35	13870
10	Manila	Philippines	840	932	11.0%	12.6	22.45	78.0%	42	9850
11	Seul	Republic of K	878	1086	23.7%	17.6	22.13	25.9%	49	8757
12	Mexico City	Mexico	1219	1390	14.0%	17.2	20.09	16.5%	69	8234
13	Sao Paulo	Brazil	1659	1696	2.2%	15.3	20.02	30.7%	85	8907
14	Beijing	China	1949	2217	13.8%	7.9	19.90	150.7%	111	6641
15	Osaka	Japan	2288	2357	3.0%	16.1	16.53	2.8%	143	4990
16	New York	USA	2900	3540	22.1%	14.1	15.19	8.0%	233	3364
17	Bangkok	Thailand	1046	1366	30.6%	6.2	15.16	142.8%	90	5382
18	Moscow	Russian Fede	1115	1298	16.4%	10.5	14.50	38.0%	90	7316
19	Buenos Aires	Argentina	1418	1610	13.5%	10.5	14.25	35.3%	113	6251
20	Istanbul	Turkey	680	866	27.4%	7.8	14.23	83.1%	61	10181
21	Los Angeles	USA	4495	4734	5.3%	12.0	14.20	18.5%	333	2616
22	Karachi	Pakistan	297	379	27.6%	7.8	13.21	70.2%	29	18471
23	Tehran	Iran	658	730	10.9%	7.6	12.78	67.4%	57	8488
24	Changzhou	China	504	1570	211.5%	7.1	12.22	71.6%	128	4162
25	Ho Chi Minh	Viet Nam	425	676	59.1%	4.5	11.78	163.5%	57	7917
26	Johannesbur	South Africa	2610	3170	21.5%	5.4	11.63	115.7%	273	2972
27	Lagos	Nigeria	701	1064	51.8%	6.0	11.57	92.7%	92	8736
28	Chaozhou	China	1478	1563	5.8%	8.3	11.49	38.6%	136	3451
29	Lahore	Pakistan	183	427	133.3%	6.4	11.47	78.8%	37	8658
30	Bangalore	India	225	422	87.6%	4.1	10.61	160.4%	40	13572
31	Paris	France	1349	1456	7.9%	9.0	10.22	14.1%	142	5249
32	Chennai	India	289	480	66.1%	6.6	10.03	52.9%	48	9531

Figure 4 List of the 32 megacities and corresponding statistics (sorted by population in 2015)

4.1 Population

The population size of the above centres varies. Chennai slightly exceeds the 10 million inhabitant threshold, while Guangzhou, the most populated urban centre in the globe exceeds 45 million inhabitants. Fifteen megacities have a population ranging between 10 and 15 million inhabitants. Population changes in the period 1990-2015 are prominent in almost all megacities. In 31 urban centres population increased by more than 1 million in 25 years (only in Osaka growth has been lower, about 440 thousand inhabitants). In Delhi, Cairo, Shanghai, Dhaka, and Jakarta population increased between 60 and 145% equivalent to more than 10 million inhabitants in each of the centres. Overall, in 2015 megacities hosted about 225 million more people than 25 years earlier, an increase of 58%. Most notable average annual population increases between 1990 and 2000 took place in Ho Chi Minh City, Dhaka, Bangalore (above 5%).

4.2 Built-up

The most populated megacities are not the ones having the most built-up surface [(Melchiorri and Siragusa 2016)]. The present morphological form of megacities is derived from GHS Built-up grids. Karachi and Los Angeles have similar population in 2015, but the total built-up surface mapped in Karachi is 379 square kilometres, while that detected in Los Angeles (the megacity accounting for the largest built-up surface in 2015) exceeds 4.5 thousand square kilometres (12 times the built-up surface in Karachi). Considering the changes in built-up surface over the observed period, the most considerable relative expansion of built-up took place in Changzhou where detected built-up areas triple between 1990 and 2015, and in Lahore and Shanghai where they double. In absolute terms in Changzhou and Guangzhou built-up has increased the most. In both centres, in 2015 GHSL accounts one thousand square kilometres more built-up areas compared to 1990. Megacities having the smalles expansion of built-up surface are Sao Paulo, Osaka, Tehran, Karachi, Chaozhou and Manila. In all these built-up growth was below 100 square kilometres. Overall, over the observed 25 years built-up expanded by 25% in the 32 megacities.

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4.3 Built-up per capita

This indicator is the ratio between the total built-up detected within the megacity and its population (to identify interdependence between patterns observed in sections 4.1 and 4.2). Highest built-up per capita ratios are observed in Los Angeles (330 square meters), Johannesburg, and New York (above 200 square meters in both); the lowest are found in Dhaka (20), Karachi, and Kolkata (under 20). The multitemporal change (1990-2015) in Built-up per capita in megacities is mostly negative (it declines in 27 megacities). In ten megacities[6] it declined between 10 and 20%, and in seven[7] by more than 20%. The magnitude of built-up per capita reduction has been most considerable in Johannesburg (-211 square meters per inhabitant, or -45%), and Beijing (-134, or -55%). However, the most salient changes in the built-up per capita might be observed in cities like Dhaka and Karachi where the availability of built-up per capita was limited already in 1990 (25 square meters per inhabitant in Dhaka and 43 in Karachi), but it has reduced further (by more than 5 square meters in the first and by 10 in the second). A potentially positive trajectory is observed in Lahore where built-up per capita increased by 30% (8 square meters per inhabitant) between 1990 and 2015, reaching 30 square meters per person.

4.4 Area

The areal extent of megacities (the area of the Uurban centre in the Settlement Model) has been extracted from the GHSL only for the epoch 2015. Their extent in 2015 are quite diverse: two megacities (Karachi and Bangalore) cover an area under one thousand square kilometres, nine an area between 1 and 2 thousand square kilometres, ten between 2 and 3 thousand, four between 3 and 4 thousands, two both between 4 and 5 thousands (New York and Kolkata) and between 5 and 6 thousands (Los Angeles and Tokyo), while Jakarta, Cairo and Guangzhou exceed 7 thousand square kilometres. Although the propositions above might be meaningful per se, the calculation of the indicator quantifying the surface of megacities is most useful as parameter to calculate the population density indicator (section 4.5).

4.5 Population Density

One example of population density (inhabitants per square kilometre) at the megacity level as extracted from the GHSL[8] is visible in Figure 2. In 2015 there are five megacities where overall population density exceeds 10 thousand inhabitants per square kilometre: Karachi, Mumbai, Bangalore, Delhi and Istanbul. A second indicator to monitor population density has been extracted taking as areal operator the extent of built-up areas.[9] It is in fact the reciprocal of the built-up per capita and it depicts the modelled density of people per unit of built-up area. The highest overall concentration of people per square kilometre of detected built-up occurs in Dhaka with nearly 50 thousand people per built-up unit, followed by Karachi (35 thousand), and Kolkata (32 thousand). Over the observed period (1990-2015), the density of population per built-up has decreased in Lahore (-8,000 people), Changzhou (-6,300), Chennai (-1,800), New York (-500) and slightly in Osaka. Most considerable increase took place instead in Dhaka (+10,000), Manila (+9,000) and Karachi (+8,600). Especially in Dhaka and Karachi, densities were already very high in 1990 (40,000 in Dhaka and 26,000 in Karachi).

5 DISCUSSION

The previous section has provided the results of the data analysis and has proposed elements of comparative statistics of multitemporal changes of the selected indicators across megacities. This section presents the most salient traits to characterise the „facts behind urban expansion". To make this explicit and to show alternative trajectories of change, we selected three pairs of megacities for which we show the changes in the settlement model class, the built-up coverage and the population density at the 1km grid level. This section presents exemplary cases of urban expansion to manifest: changes in the areal extent of the urban centre megacity (Kolkata and Bangalore), changes in built-up areas (Lagos and Karachi), and to show the change in population (Beijing and Lahore) at the grid level.

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[6] Sao Paulo, Cairo, Buenos Aires, Chaozhou, Guangzhou, Karachi, Bangalore, Delhi, Tehran, and Manila.

[7] Lagos, Jakarta, Istanbul, Ho Chi Minh City, Bangkok, Johannesburg, and Beijing

[8] A classification of population threshold has been applied.

[9] $People\ per\ Built\quad up_{epoch} = \frac{Population_{epoch}}{built-up_{epoch}}$

The change in the spatial extent of megacities is linked to the characteristics of the settlement in 1990. Figure 5 shows for Kolkata (left) and Bangalore (right) the extent of the megacity in 1990 (yellow) and in 2015 (dark red). The extent of Kolkata in 2015 includes 19 individual settlements classified as urban centres in 1990. The process of spatial and demographic growth has led to them merging between the two epochs. In particular, the spatial expansion tends to occur within the perimeter of the megacity in 2015 (especially in the eastern and western end of the megacity). In Bangalore, instead, the pattern of expansion has been incremental from the single centre already existing in 1990. Other seven megacities[10] have grown around a single urban centre core; all other megacities enclose in their form in 2015 multiple urban centres that were separated in the previous epoch, marking the evolution from a polycentric status in 1990. Most prominent examples of the conjunction of centres took place in Guangzhou, Dhaka, Kolkata and Cairo.

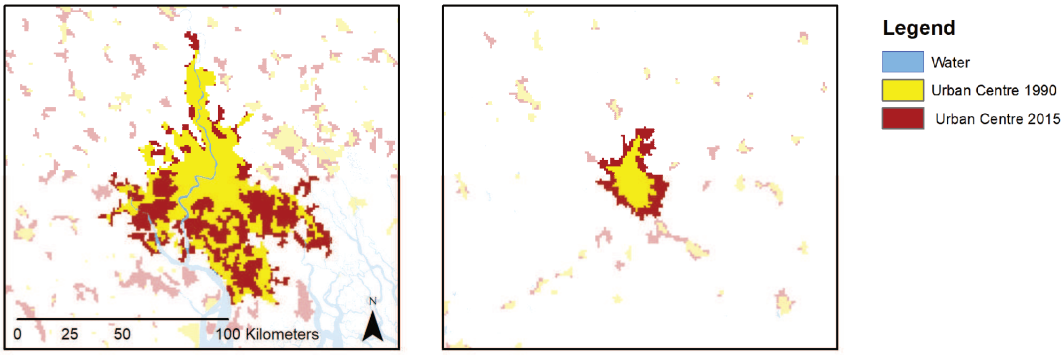

Figure 5 Change in the urban centre extent from a polycentric pattern in 1990 (Kolkata, left) and monocentric core (Bangalore, right)

The second pair of megacities (Figure 6) shows the increment in the built-up coverage at the pixel level. In Lagos (left), substantial increase of built-up surface took place in the outer edges of the urban centre. In these areas, built-up change has been frequently between 0.9 and 1. Such change show how some areas in the edges of the city become fully built (or almost fully) in 25 years, while there was almost no built-up detected in 1990. In contrast to Lagos, in Karachi, most evident changes in built-up occurred within the perimeter of the urban centre form of 1990.

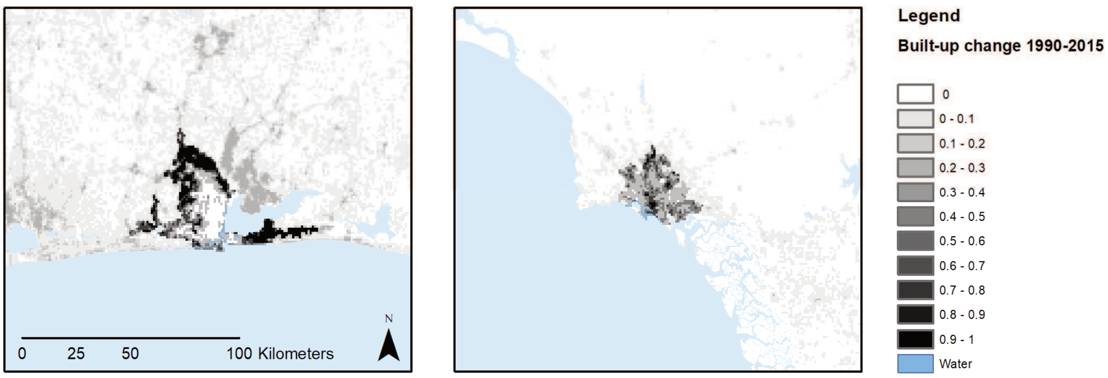

Figure 6 Change in the Built-up areas 1990-2015 in Lagos (left) and Karachi (right)

The last example (Figure 7) shows the changes in population density modelled at the 1km pixel level. In Beijing population grows especially in the core (dark red color), where population change per pixel is frequently above 7.5 thousand people, and also in the fringes. Instead in Lahore, population in the core declines (blue) while it increases around the core.

Some final considerations should be drawn on the interdependence between built-up and population growth and on the magnitude of the spatial and demographic change that occurred in megacities over the past 25 years. Figure 8 (left) shows the reason for the frequent decline in the built-up surface per capita. Most megacities have grown (in relative terms) in population more than in built-up surface (upper left part of the chart).

[10] Los Angeles, New York, Buenos Aires, Moscow, Tehran, Istanbul and Karachi.

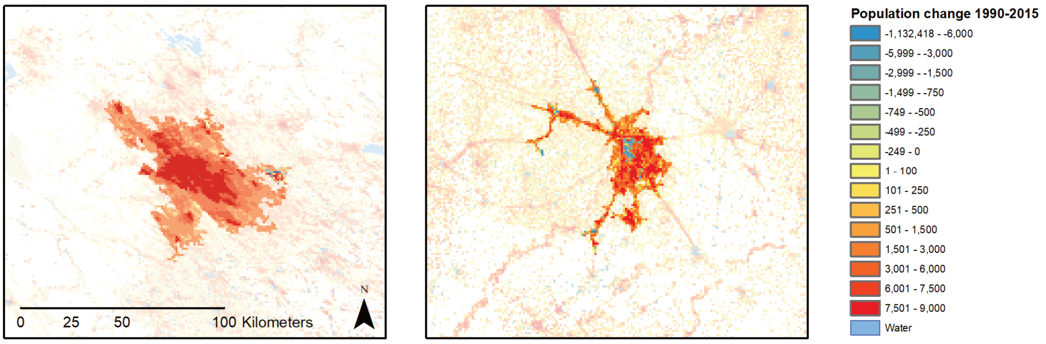

Figure 7 Change in population 1990-2015 in Beijing (left) and in Lahore (right)

Figure 8 displays the second proposition to express the substantial spatial and demographic growth of megacities over the observed period. The two charts (right) display the share of population and built-up areas already present in 1990 compared to the total estimate in 2015. In several megacities (Tokyo, Paris, Chaozhou, Los Angeles, Osaka and Sao Paulo) 90% of the extent of built-up reached in 2015 was already there in 1990. Concerning population, in 1990 seven megacities had half or less of the population they contain in 2015. This latter phenomenon can also be related to the number of Urban Centres that were reaching the megacity threshold in 1990 (extracted from GHSL Settlement Model 1990). These were Tokyo, Guangzhou, Cairo, Kolkata, Jakarta, Seoul, Mexico City, Mumbai, Osaka, Delhi, Sao Paulo, New York, Manila, Los Angeles, Buenos Aires, Shanghai, Moscow and Dhaka, altogether they hosted in 1990 nearly 300 million inhabitants. Among the seven megacities in which population doubled, five were not megacities in 1990, and in the other two (Dhaka and Shanghai) population in 1990 was just above 10 million (10.2 in Dhaka and 10.5 in Shanghai).

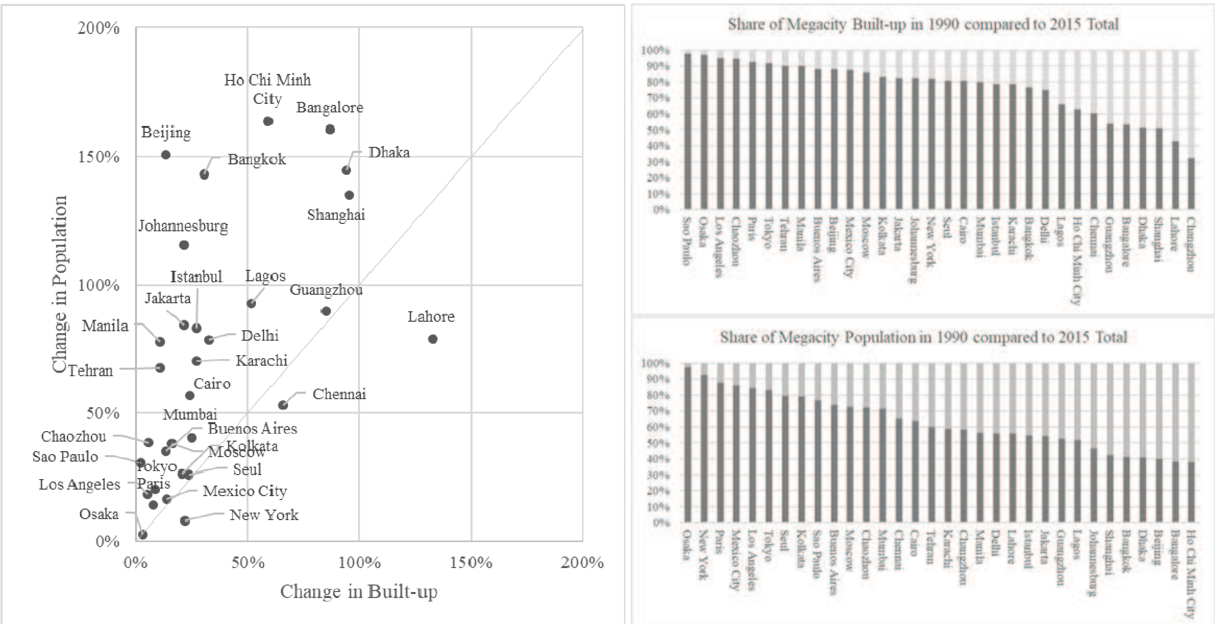

Figure 8 Relative change of built-up areas and population 1990-2015 (left), share of megacity population in 1990 compared to 2015 total (upper right), and share of megacity built-up in 1990 compared to 2015 total (lower right)

6 CONCLUSION

This paper analysed the recent process of urban growth in current megacities. Although megacities have been observed from various angles and information sources, this study extended the number of case studies, expanded the number of indicators to characterise urban growth, and has simultaneously analysed the spatial and demographic components of urban growth to manifest the interdependence between these two determinants. This study was made possible thanks to the open and free release of the Global Human Settlements Layer suite of data and tools. In particular, this study exploited the possibility to compare individual cities across space and time thanks to the characteristics of the GHSL. The GHSL produced information for the four epochs 1975, 1990, 2000 and 2015 as these satellite imagery from which the informaiton were derived were organized and made available as open data for those time invervals. With the multitemporal coverage it was possible to monitor the rise in number and the growth in population in today's megacities. To this end it is key to have periodical updates of the dataset. This is dependent on the availability of suitable satellite imagery and updated national census to feed the GHSL workflow.

In this work, we adopted a multisectoral toolkit that combines statistical and spatial analysis to quantify and display the process of urban growth in megacities. The study also underlines the added value of characterizing urban expansion through statistics and spatial analysis. The analysis is illustrated with graphical representations of the spatial evolution of the urban extent, built-up and population change of a few cities (Kolkata and Bangalore, Lagos and Karachi, Shanghai and Lahore). In the comparative analysis of these illustrative cases, it was possible to showcase the alternative trajectories of urban change. In some megacities urban growth manifested as conjunction of multiple urban centres (polycentric nature), while in others revealed an expansion from a single core. Built-up expansion took place oftentimes at the edges of existing cores and more rarely within. Population change mostly occurred in the original cores, and on the fringes, and in few cases a decline in population was observed in city cores.

The paper also presented a replicable methodology to analyse the process of urban expansion in other urban centres using the GHSL data. Further work could analyse in more detail the process of growth by grouping megacities in population classes in 1990 or by annual population increase. More detailed studies, especially with a restricted sample of megacities could be explored adopting the GHSL at 250m resolution, aiming at a finer characterisation of the urban dynamics below the city scale.

7 REFERENCES

ANGEL, S., A. M. Blei, D. M. Civco, P. Lamson-Hall, J. Parent, N. Galarza Sanchez, and K. Thom. 2015. Atlas of Urban Expansion - The 2015 Edition. Edited by New York: The NYU Urbanization Project, Cambridge MA: The Lincoln Institute of Land Policy, and Nairobi, Kenya: U.N. Habitat.

AYENI, Bola. 1979. Concepts and Techniques in Urban Analysis. Croom Helm Series in Geography and Environment. London: Croom Helm.

BAGAN, Hasi, and Yoshiki Yamagata. 2012. "Landsat Analysis of Urban Growth: How Tokyo Became the World's Largest Megacity during the Last 40years." Remote Sensing of Environment 127 (December):210–22. https://doi.org/10.1016/j.rse.2012.09.011.

BRENNER, N. 2013. "Theses on Urbanization." Public Culture 25 (1 69):85–114. https://doi.org/10.1215/08992363-1890477.

BRENNER, Neil, and Christian Schmid. 2015. "Towards a New Epistemology of the Urban?" City 19 (2–3):151–82. https://doi.org/10.1080/13604813.2015.1014712.

BURDETT, Richard, Deyan Sudjic, London School of Economics and Political Science, and Alfred Herrhausen Gesellschaft für Internationalen Dialog, eds. 2007. The Endless City: The Urban Age Project by the London School of Economics and Deutsche Bank's Alfred Herrhausen Society. London: Phaidon.

COHEN, Barney. 2006. "Urbanization in Developing Countries: Current Trends, Future Projections, and Key Challenges for Sustainability." Technology in Society 28 (1–2):63–80. https://doi.org/10.1016/j.techsoc.2005.10.005.

DAVIS, Kingsley. 1955. "The Origin and Growth of Urbanization in the World." American Journal of Sociology 60 (5):429–37. https://doi.org/10.1086/221602.

DERUDDER, Ben, ed. 2012. International Handbook of Globalization and World Cities. Elgar Original Reference. Cheltenham ; Northhampton, MA: Edward Elgar.

DIJKSTRA, Lewis, and Hugo Poleman. 2014. "A Harmonised Definition of Cities and Rural Areas: The New Degree of Urbanisation." Publications Office of the European Union.

FREIRE Sergio, Kytt MacManus, Martino Pesaresi, Erin Doxsey-Whitfield, and Jane Mills. 2016. "Development of New Open and Free Multi-Temporal Global Population Grids at 250 M Resolution." In . Helsinki.

FRIEDMANN, John. 1986. "The World City Hypothesis." Development and Change 17 (1):69–83. GEERTMAN, Stan, Fred Toppen, and John Stillwell. 2013. Planning Support Systems for Sustainable Urban Development. Berlin, Heidelberg: Springer.

GEERTMAN, Stan, Fred Toppen, and John Stillwell. 2013. Planning Support Systems for Sustainable Urban Development. Berlin, Heidelberg: Springer

JRC and CIESIN. 2015. "GHS Population Grid, Derived from GPW4, Multitemporal (1975, 1990, 2000, 2015)." European Commission, Joint Research Centre, JRC Data Catalogue.

KRAAS, Frauke. 2007. "Megacities and Global Change: Key Priorities." The Geographical Journal 173 (1):79–82. https://doi.org/10.1111/j.1475-4959.2007.232_2.x.

MELCHIORRI, Michele. 2017. "Analyzing Urban and Rural Settlements with Remote Sensing: Comparing National Trends of Rural Growth with the Global Human Settlement Layer." In Proceedings of the Joint Conference ISOCARP-OAPA - 53rd ISOCARP Congress. ISOCARP.

MELCHIORRI, Michele, and Alice Siragusa. 2016. "City Analysis Using the GHSL." In Atlas of the Human Planet 2016: Mapping Human Presence on Earth with the Global Human Settlement Layer. Publications Office of the European Union.

MONTGOMERY, M. R. 2008. "The Urban Transformation of the Developing World." Science 319 (5864):761–64..

MUNDIA, C. N., and M. Aniya. 2005. "Analysis of Land Use/Cover Changes and Urban Expansion of Nairobi City Using Remote Sensing and GIS." International Journal of Remote Sensing 26 (13):2831–49. https://doi.org/10.1080/01431160500117865.

PESARESI, Martino. 2014. “Global Fine-Scale Information Layers: The Need of a Paradigm Shift.” In Conference on Big Data from Space (BiDS’14), edited by Pierre Soille and Pier Giorgio Marchetti, EUR 26868 EN:8–11. ESA-ESRIN, Frascati, Italy: JRC. https://doi.org/10.2788/1823.

PESARESI, Martino, Daniele Ehrlich, Stefano Ferri, Aneta Florczyk, Sergio Freire, Matina Halkia, Andreea Julea, Thomas Kemper, Pierre Soille, and Vasileios Syrris. 2016. “Operating Procedure for the Production of the Global Human Settlement Layer from Landsat Data of the Epochs 1975, 1990, 2000, and 2014.” JRC Technical Report EUR 27741 EN. Ispra, Italy: Publications Office of the European Union. http://publications.jrc.ec.europa.eu/repository/handle/JRC97705.

PESARESI, Martino, Michele Melchiorri, Alice Siragusa, and Thomas Kemper. 2016. “Atlas of the Human Planet 2016. Mapping Human Presence on Earth with the Global Human Settlement Layer.” EUR 28116 EN. Luxembourg: Publications Office of the European Union.

PESARESI, Martino, Daniele Ehrlich, Aneta Floczyk, Sergio Freire, Andreea Julea, Pierre Soille, and Vasileios Syrris. 2015. “GHS Built-up Grid, Derived from Landsat, Multitemporal (1975, 1990, 2000, 2014).” European Commission, Joint Research Centre, JRC Data Catalogue.

PESARESI, Martino, and Sergio Freire. 2016. “GHS Settlement Grid Following the REGIO Model 2014 in Application to GHSL Landsat and CIESIN GPW v4-Multitemporal (1975-1990-2000-2015).” European Commission, Joint Research Centre, JRC Data Catalogue

SATTERTHWAITE, David. 2010. Urban Myths and the Mis-Use of Data That Underpin Them. Helsinki: WIDER. http://hdl.handle.net/10419/54031.

SCHNEIDER, Annemarie, Mark A. Friedl, and David Potere. 2010. “Mapping Global Urban Areas Using MODIS 500-M Data: New Methods and Datasets Based on ‘urban Ecoregions.’” Remote Sensing of Environment 114 (8):1733–46. https://doi.org/10.1016/j.rse.2010.03.003.

SCHNEIDER, Annemarie, and Curtis E. Woodcock. 2008. “Compact, Dispersed, Fragmented, Extensive? A Comparison of Urban Growth in Twenty-Five Global Cities Using Remotely Sensed Data, Pattern Metrics and Census Information.” Urban Studies 45 (3):659–92. https://doi.org/10.1177/0042098007087340.

SETO, Karen C., Michail Fragkias, Burak Güneralp, and Michael K. Reilly. 2011. “A Meta-Analysis of Global Urban Land Expansion.” Edited by Juan A. Añel. PLoS ONE 6 (8):e23777. https://doi.org/10.1371/journal.pone.0023777.

SMITH, Duncan A. 2017. “Visualising World Population Density as an Interactive Multi-Scale Map Using the Global Human Settlement Population Layer.” Journal of Maps 13 (1):117–23. https://doi.org/10.1080/17445647.2017.1400476.

STRATMANN, Bernhard. 2011. “Megacities: Globalization, Metropolization, and Sustainability.” Journal of Developing Societies 27 (3–4):229–59. https://doi.org/10.1177/0169796X1102700402.

TAUBENBÖCK, H, T Esch, A Felbier, M Wiesner, A Roth, and S Dech. 2012. “Monitoring Urbanization in Mega Cities from Space.” Remote Sensing of Environment 117:162–176.

TAYLOR, Peter J. 1999. “Worlds of Large Cities: Pondering Castell’s Space of Flows.” Third World Planning Review 21 (3):3.

XIAO, Jieying, Yanjun Shen, Jingfeng Ge, Ryutaro Tateishi, Changyuan Tang, Yanqing Liang, and Zhiying Huang. 2006.
“Evaluating Urban Expansion and Land Use Change in Shijiazhuang, China, by Using GIS and Remote Sensing.” Landscape and Urban Planning 75 (1–2):69–80. https://doi.org/10.1016/j.landurbplan.2004.12.005.