Categorization of 48 Mega-Regions by Spatial Patterns of Population Distribution: The Relationship between Spatial Patterns and Population Change

Comparative Study of Mega-regions: Toward a Dynamic Observation of Transformation

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1. Introduction

Megacities, defined as urban agglomerations that have more than 10 million inhabitants, often face difficulties related to physical management. Their size, heterogeneity, and accelerated speed of change often go beyond what can be managed through urban planning. Cities also must take into account global influences such as migration and the investment of external capital. In addition, recent shifts in priority from economic growth to sustainability present the integrated challenge of maximizing quality of life while minimizing impact on climate change.

These facts make it crucial that the governance of megacities by multiple-actors is strongly required to complement the actual governmental management led by planning. The activities of these actors should be based on shared observation and understanding of the realities of megacities and involve information that makes global comparisons possible. Even if megacities have quantitatively similar populations, their urban requirements are rather diverse. Megacities in Africa and Asia are not only increasing in number, but in population size as well, with an estimated population growth of more than 2% per year expected until the year 2025 at least (UN DESA 2011). Only in some cases, such as those of New York or Tokyo, are large urban agglomerates not expected to grow.

Some megacities must prioritize issues of overcrowding, traffic congestion, and social divisions, while others struggle with sprawl, expansion of artificial land use, climate change, and the degradation of central areas (Sorensen & Okata 2011). Sharing the assumption that urban form or spatial patterns must deal a lot with urban problems, the polycentric structure is discussed widely with the expectation to solve the contemporary problems of megacities, not only hyper-growth megacities but also mature megacities as well (Camagni & Salone 1993, McGee & Robinson 1996, Davoudi 2003).

Because megacities have huge extended areas, spatial pattern is an important attribute for comparison. While many attempts have been made to compare megacities around the world, the majority involve comparison on the basis of indicators such as population, GDP, or emissions (Susteren 2005, UN HABITAT 2008). Analyses of spatial patterns are rather scarce, and those that exist are mainly qualitative and include a limited sample of megacities. For example, Burdett and Sudjic (2008, 2011) have compared nine cities by visualizing spatial patterns of population distribution and urban fabric involving three-dimensional representations. Similar three-dimensional representations of 10 cities have been introduced in the report of the World Bank (World Bank 2010).

In this paper, we attempt to categorize megacities by their spatial characteristics in order to provide a platform for global comparison. Then, we analyze the categorized groups by spatial patterns and speed of growth.

2. Data and Mega-Regions

There are two critical barriers preventing the categorization of megacities by spatial patterns. First, the real agglomeration areas of megacities often extend over several administrative units, and no common global standard has been established for identifying megacity areas. Second, while collecting data through individual primary census units or smallest units is indispensable to the analysis of spatial patterns, it is almost impossible to do so in megacities, particularly in emerging urban agglomerations in Africa and Asia that are experiencing rapid growth.

In order to overcome the first barrier, recognizing that megacities have two-dimensional expanses, we have defined "mega-regions" on the basis of the level of population in an area of the same size[1].

In order to overcome the second barrier, we relied on population distribution patterns in analyzing spatial characteristics. We adopted a high-resolution population data set[2], which was created through the use of remote sensing imagery, to estimate population distribution. While we are well aware that spatial characteristics of mega-regions can be explained not only in terms of population but also land cover, built environment, and traffic networks, among others, we consider population distribution to reflect—to a certain extent—other elements that determine spatial characteristics. Further, on a pragmatic level, population data is the most accessible data and can be found for all cities worldwide.

This paper is based on LandScan population data set (grid resolution: 30 arc seconds). LandScan is different from nighttime population by census. It shows population over an average span of 24 hours, not only in residential areas, but also in business. Developed by using population censuses for each country, as well as traffic networks, remote sensing imagery, etc., it is updated more frequently than other world population data sets.

We identified mega-regions through three steps.[3] First, all areas that have more than 10 million people within a radius of 50 km were identified; the centers of these circular areas were denominated central grids (each of the red grid areas in fig. 1, below, is a central grid). Then, from these grids, the central grid with the largest population within a radius of 50km was chosen and denominated the peak grid. Finally, the circular area within a radius of 50km from the peak grid was defined as the mega-region.

Based on this process, we were able to identify 48 mega-regions around the world (see Table 1). These mega-regions did not necessarily contain megacities (cities with a population of more than 10 million people) as a core. Approximately 70% (34 regions) of 48 mega-regions were found to be located in Asia. India has the largest number of mega-regions (11 mega-regions), with China following in the second place (9 mega-regions). Mega-regions are found worldwide, except on the Australian continent. For this study, we defined urban areas as areas that comprise grids that have 20 people/ha or more. Half of the world's population lives in urban areas.[4]

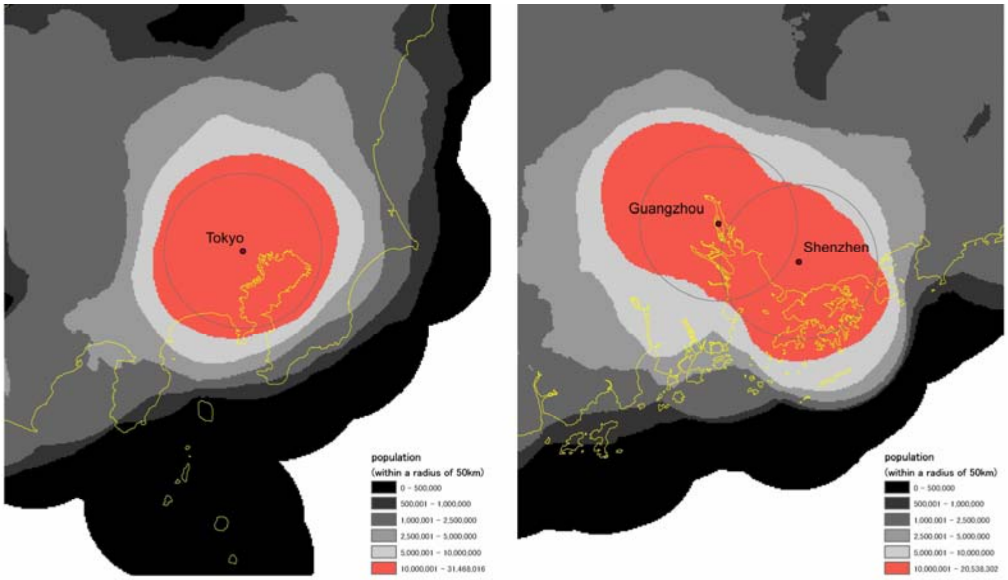


Fig. 1: Identification of mega-region: Tokyo region (left); Shenzhen region and Guangzhou region (right)

3. Indicators of Characteristics of Population Distribution

We developed a categorization of mega-regions on the basis of the following two aspects:

- Distribution diversity among different ranges of population density
- Two-dimensional distribution patterns

The former aspect was examined by using M- and N-values, as defined below, while the latter was examined by using indicators of Moran's I and gravity of main urban area. Before conducting our examination, we confirmed that there was no strong correlation between these indicators and population numbers.

Region	Country	Mega-Region	Total Population ('000)	Population in Urban Area ('000)	Urban Area (sqkm)	Average Density in Urban Area (people/sqkm)	Main Urban Area (sqkm)	Rate of Population Change*(%)
Africa	Nigeria	Lagos	10,459	8,995	773	11,637	566	3.57
Asia	Bangladesh	Dhaka	23,319	18,941	2,324	8,150	600	2.68
	China	Beijing	14,252	10,687	1,551	6,891	1,027	1.72
		Changzhou	10,335	6,733	1,099	6,127	124	2.07
		Chengdu	11,430	7,860	1,074	7,319	391	1.89
		Guangzhou	20,536	17,499	2,301	7,605	663	1.78
		Shanghai	18,650	15,688	1,918	8,180	1,155	1.69
		Shantou	11,593	8,690	1,527	5,691	333	1.95
		Shenzhen	20,786	18,839	2,032	9,271	720	1.80
		Suzhou	11,240	8,014	1,141	7,024	159	2.07
		Xian	10,132	6,599	898	7,349	262	1.91
	India	Ahmedabad	10,178	7,578	919	8,247	335	2.58
		Bangalore	10,218	7,695	906	8,494	391	2.53
		Chennai	10,931	8,075	699	11,552	545	2.51
		Delhi	25,013	21,254	1,943	10,939	1,243	2.38
		Kolkata	26,559	22,796	3,012	7,568	1,647	2.36
		Lucknow-Kanpur	11,157	8,091	1,088	7,437	320	2.71
		Mumbai	22,050	20,593	1,281	16,076	904	2.34
		Muzaffarpur-Darbhanga	12,401	7,873	1,693	4,651	59	no data
		Muzaffarpur-Patna	12,486	8,285	1,499	5,527	179	2.76
		Patna	10,216	6,444	1,190	5,415	183	2.76
		Varanasi	10,140	6,055	1,356	4,466	256	2.83
	Indonesia	Bandung	11,386	7,952	1,296	6,137	700	2.22
		Jakarta	24,374	21,221	2,917	7,275	2,758	1.96
		Semarang	11,648	7,996	1,346	5,941	376	2.31
		Surabaya	13,233	9,822	1,241	7,915	456	2.19
	Japan	Osaka-Kobe	16,337	14,932	1,978	7,550	1,630	0.04
		Tokyo	31,536	29,732	3,796	7,833	3,448	-0.02
	Pakistan	Gujranwala	10,493	6,149	800	7,687	178	3.04
		Karachi	12,256	11,809	614	19,234	556	2.63
		Lahore	14,575	11,326	843	13,436	433	2.75
	Philippines	Manila	20,751	19,485	1,533	12,711	1,122	2.44
	South Korea	Seoul	22,856	21,146	1,807	11,703	1,419	0.04
	Thailand	Bangkok	10,891	8,589	1,122	7,656	772	1.82
	Vietnam	Hanoi	12,071	7,701	1,731	4,449	192	2.74
Middle East	Egypt	Alexandria	10,266	8,127	1,053	7,718	162	2.33
		Cairo	27,776	25,005	2,729	9,163	767	2.15
	Iran	Tehran	11,989	11,144	800	13,931	440	1.04
	Turkey	Istanbul	11,137	10,396	980	10,609	868	1.55
Europe	France	Paris	11,275	9,215	1,300	7,089	1,028	0.81
	Russia	Moscow	13,870	12,509	1,424	8,785	1,007	0.16
	UK	London	11,990	9,588	1,876	5,111	1,268	0.92
Latin America	Argentina	Buenos Aires	13,778	12,965	1,794	7,227	1,609	0.86
	Brasil	Rio de Janeiro	12,562	11,479	1,436	7,994	990	0.91
		Sao Paulo	21,292	19,820	1,866	10,622	1,486	0.82
	Mexico	Mexico City	22,260	21,092	1,918	10,997	1,398	1.13
North America	USA	Los Angeles	12,346	10,491	2,673	3,925	2,512	1.02
		New York	15,481	12,417	1,912	6,494	1,609	0.95

*2020-2025(/year)

Table 1: 48 mega-regions
Sources: Rate of population change: World Urbanization Prospects: The 2011 Revision, other figures: ORNL LandScan TM 2007/UT-Battelle, LLC.

3.1 Distribution Diversity among Different Ranges of Population Density

We created bar charts (see fig. 2) for each of the 48 mega-regions to describe distribution diversity among different ranges of population density.

i) Maldistribution among different ranges of population density (M-value)

In order to compute this indicator on the basis of population amounts among different ranges of population density in each mega-region, we first calculated the mean of the population amount in each range of population density, except ranges that had no population. Second, we calculated the absolute values of differences between the mean and the population amounts in each range of population density, except ranges that had no population. Third, we calculated the sum of the absolute values and divided the sum by the total population amount in order to obtain the M-value.
The higher this indicator was, the more unequal distribution among different ranges of density was shown. Hanoi was found to have the highest M-value (1.21) among the 48 mega-regions, while Tehran had the lowest (0.29). The mean value was 0.76, which was also the value for Alexandria.

ii) Number of ranges of population density (N-value)
This indicator shows how diverse ranges of population density are. N-value represents the number of different ranges of density in a mega-region, except for ranges with no population. Ranges of low density exist in almost all mega-regions, which means that the N-values were greater for mega-regions in which a higher percentage of the total population was living in relatively high-density areas. Of the 48 mega-regions, Dhaka was found to have the highest N-value (85), while Varanasi had the lowest (18). The mean value was 48.5, which was almost the same as Seoul's value (49).

3.2 Two-dimensional Distribution Patterns

i) Global Moran's I
Moran's I is defined as

$$I = \frac{n \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} (x_i - \bar{x})(x_j - \bar{x})}{W \sum_{i=1}^{n} (x_i - \bar{x})^2}.$$

x_i : Population density of gird *i*

$\bar{x}$: Mean of x_i

w_{ij}: An element of a matrix of spatial weights $= \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}$

W: (A matrix of spatial weights)
(Cliff & Ord 1973, Tsai 2005)
We used an inverse of distance between grids as the element of a matrix of spatial weights. The value of Moran's I ranges from -1 to 1. If the value is near 1, the densities of neighboring grids tend to be similar. This indicator shows how grids of different densities are spatially intermingled. Paris was found to have the highest value (0.91) of the 48 mega-regions, while Muzaffarpur-Darbhanga had the lowest (0.18). The mean was 0.77, which was also the value for Surabaya.

ii) Gravity of main urban area
This indicator is the percentage of the largest continuous urban area (main urban area) in all urban areas in the region. The higher this indicator is, the more monocentric the urban form is; on the other hand, the lower the indicator is, the more diffused the urban form is. Jakarta was found to have the highest value (95%) among the 48 mega-regions, while Muzaffarpur-Darbhanga had the lowest (3%). The mean was 51%, which was almost the same as the value for Lahore (52%).

4. Result of Categorization

4.1 Distribution Diversity among Different Ranges of Population Density

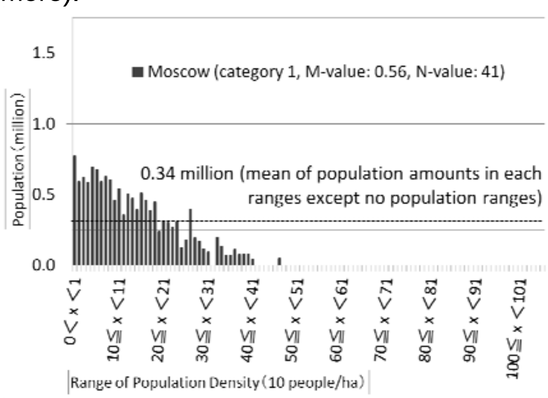
Hierarchical cluster analysis (Ward's method) has been used and, four categories (1, 2, 3, and 4) have been detected (see figs. 2, 3, and 4). The regions nearest to the centre of the set for each category were Moscow (1), Shantou (2), Lahore (3), and Shanghai (4).

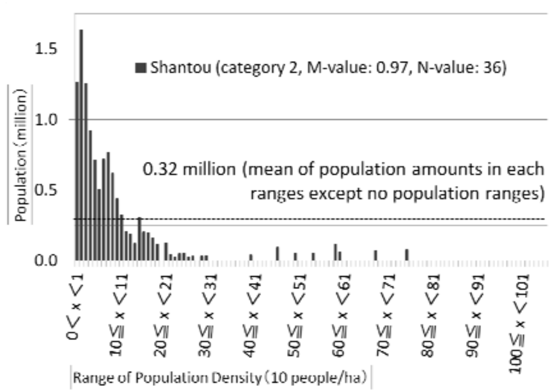
i) Category 1 (M-value: low, N-value: low): Moderate and narrow distribution among different ranges of density, high percentage of population in middle density area
In this category, more than 50% of the total population was in areas of 40 to 200 people/ha. Approximately 20% of the total population was in low density (40 people/ha or less) or high density (200 people/ha or more) areas. People in mega-regions in this category were concentrated in relatively medium density areas.

ii) Category 2 (M-value: high, N-value: low): Unequal and narrow distribution among different ranges of density, high percentage of population in low density area
In this category, roughly 50% of the total population was in areas of 40 people/ha or less, and only roughly 10% of the total population was in areas of 200 people/ha or more. In this category, the highest percentage of people were in areas of 40 people/ha or less. Most of the people in mega-regions in this category were concentrated in relatively low density areas.

iii) Category 3 (M-value: low, N-value: high): Equal and wide distribution among different ranges of density, high percentage of people in high density area
In this category, roughly 50% of the total population was in areas of 200 people/ha or more, with people concentrated in relatively high density areas and across a relatively wide range of densities.

iv) Category 4 (M-value: high, N-value: high): Unequal and wide distribution among different ranges of density, high percentage of people in low and high density areas
In this category, 30% of the total population was in limited low density areas (40 people/ha or less) and the same percentage of total people were in high density areas (200 people/ha or more).





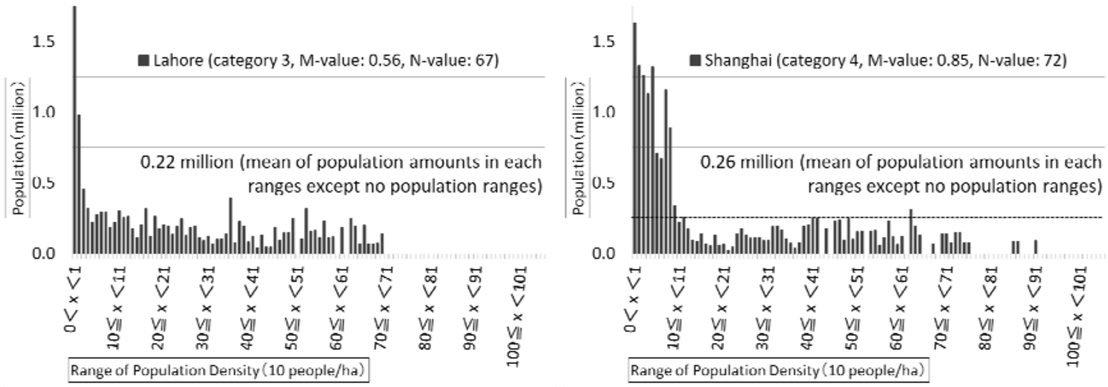


Fig. 2: Distribution diversity among different ranges of density in four categories (1,2,3,and 4)

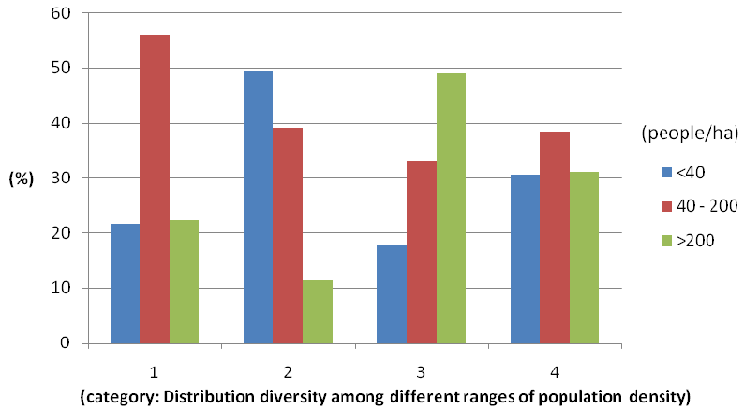
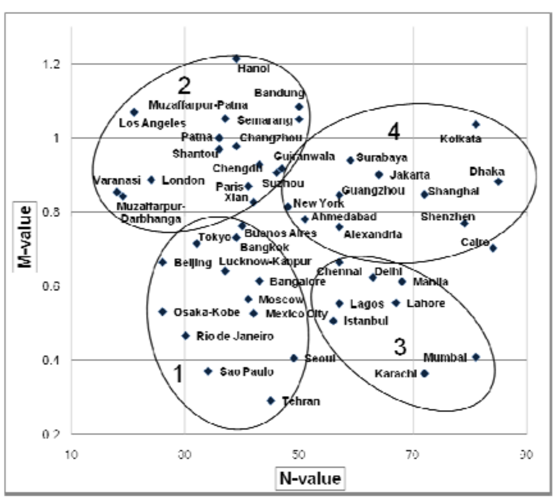


Fig. 3: Percentages of population in 3 ranges of density among total population



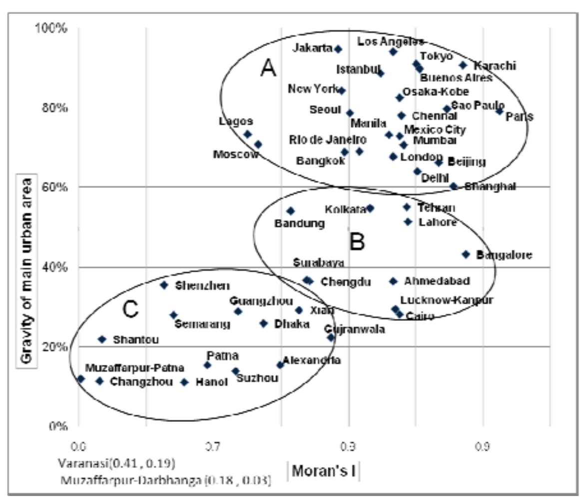


Fig.4: Four categories (1,2,3,and 4) by M and N-values.

Fig.5: Three categories (A, B, and C) by Moran's I and Gravity of main urban area.

4.2 Two-dimensional Distribution Patterns

Hierarchical cluster analysis (Ward's method) has been used and, three categories—A, B, and C— have been detected (see fig. 5).

i) Category A (Moran's I: high, gravity of main urban area: high): Not very intermingled different density grids, not so diffused urban form
Mega-regions in this category contain a megacity, as defined by the UN, or a capital city as a core. In this category, populations in mega-regions are concentrated in a core and their spatial patterns of population distribution are relatively simple.

ii) Category B (Moran's I: high, gravity of main urban area: medium): Not very intermingled different density grids, diffused urban form
Some mega-regions in this category contain a megacity, as defined by the UN, or a capital city, but they also include other cores or high density areas around their main core. For example, in Lahore, at least two cores are contained around the main core in what seems to be a polycentric urban form. Cairo and Kolkata contain many small, separate urban areas. These small urban areas demonstrate the importance of high density farming villages; moreover, almost all land cover in these urban areas is not built-up, but is made up of farm land, paddy fields, or other agricultural land.

iii) Category C (Moran's I: low, gravity of main urban area: low): Intermingled different density grids, very diffused urban form
Numerous mega-regions in this category do not have a clear main urban area. They have small, separate urban areas and some have several significant urban cores. Their spatial patterns of population distribution are very complicated, and each urban area is not co-related with a clear regional structure like the mega-regions in category A.

Category A represents the simplest urban form, while category C represents the most complex one. Karachi or Paris of category A contrast sharply with Muzaffarpur-Darbhanga or Varanasi of category C.

4.3 Integrating Two Areas of Categorization

By integrating the two areas of categorization mentioned above, we obtained 10 groups of mega-regions (see fig. 6), from A-1 to C-4, ranging from less to more diversity in population distribution among different ranges of density, and from less to more complex in urban form.
Category A comprises 23 mega-regions, and 17 out of these 23 fall into categories 1 and 3. They tend to have a high percentage of their population concentrated in the center of the main urban area, and their urban forms are not so diffused. Their density tends to gradually get lower from the center to the periphery, and grids with different densities do not tend to be intermingled. All three mega-regions in group A-2 are in developed countries.

Category B comprises 10 mega-regions and these can be sub-distributed into categories 1, 2, 3, and 4. We did not observe any common tendencies in distribution diversity among different ranges of density.

Category C comprises 15 mega-regions and out of these, 11 have been classified as part of category 2. These tend to have high percentages of the population concentrated in low density areas and have diffused urban forms. The remaining four mega-regions of C-4 do not only involve maldistribution into different ranges of population density but also in terms of complexity of urban form. Different density grids tend to be intermingled in the mega-regions of category C.

5. Discussion

5.1 Population Size and Ten Categorized Groups

There are 13 mega-regions with more than 20 million inhabitants. Out of these 13, 8 mega-regions belong to category A and involve single large urban agglomerates. These are subdivided into three groups, four for A-1, three for A-3, and one for A-4.

All 5 mega-regions with populations of over 20 million in categories B and C belong to category 4 (high percentage of people living in both extremes of density, low and high). In particular, 3 out of 4 mega-regions in C-4 (most heterogeneous) have more than 20 million inhabitants.

There is no mega-region with a population of over 20 million in category 2.

5.2 Regional Specifics and Ten Categorized Groups

The 34 mega-regions in Asia (11 in India and 9 in China) fall into all 10 groups except A-2, which consists exclusively of two European cities and one American. Out of 15 mega-regions in category C, 14 are in Asia, and all 11 mega-regions in C-2 are in Asia. Further, 8 mega-regions of 11 in category 4 are also Asian. Category C involves the most complex urban form, and category 4 indicates variety in the range of population density. Therefore, the mega-regions whose characteristics are most complicated are concentrated in Asia.

Eleven Indian mega-regions are distributed among four groups, with three in A-3, two in B-1, two in B-4, and four in C-2. Mega-regions in C-2 or A-3 tend to have a high percentage of population in either low or high density areas. In the mega-regions of B-4, population is widely distributed at both extremes of density and the urban form is diffused and complex.

Nine Chinese mega-regions are distributed among five groups. More than half of them (six) are in category C, while Shanghai and Beijing are in A and Chengdu is in B.

All four Latin American mega-regions are in A-1 and include single large urban agglomerates.

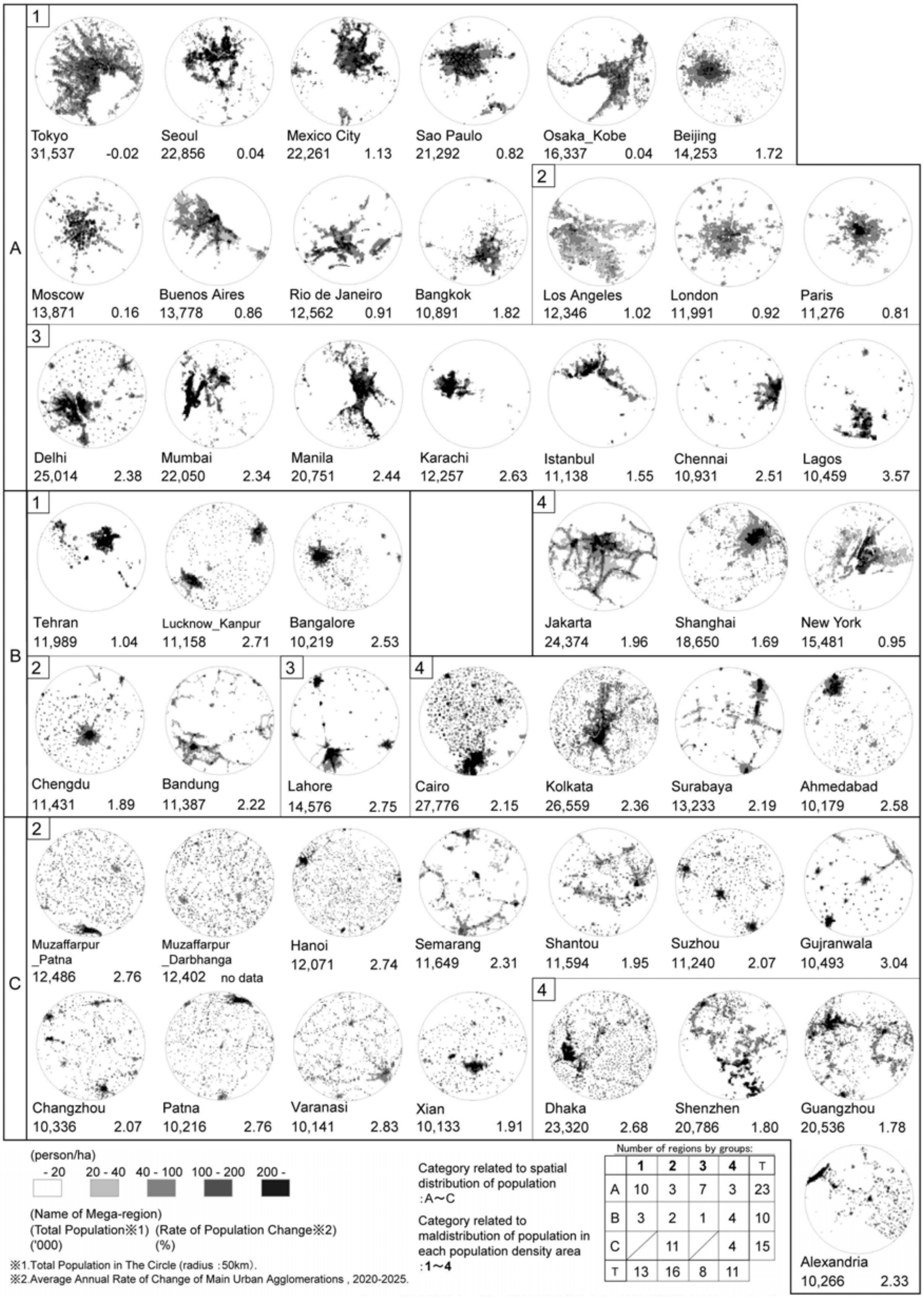


Fig. 6: Categorization of ten groups

*Sources: *1. ORNL LandScan TM 2007/UT-Battelle, LLC. *2. World Urbanization Prospects: The 2011 Revision.*

5.3 Population Change and Ten Categorized Groups

The mega-regions of A-1 and A-2 are predicted to experience low growth (average 0.79% per year for the period 2020–2025). Out of these 13 regions, 7 are mega-regions in developed countries; all 4 Latin American mega-regions within the group have an estimated annual growth rate of around 1%. They have high shares of their populations in relatively medium density ranges and simple population distribution patterns. These can be called mature mega-regions, as their speed of growth has already slowed down.

In contrast, the population of mega-regions in C-2 tends to grow fast (average 2.47% per year for the period 2020–2025). If this high-speed growth tendency continues, their populations will be more than 1.4 times larger after 15 years. All 11 mega-regions in this group are Asian. Four of them are Chinese, and these have lower growth estimates than the rest[5]. They have high percentages of their populations in the low density range and have complex urban forms. C-2 could become the next generation of mega-regions. The A-3 group also expects similar high growth. Out of seven mega-regions in this group, five are Asian. These mega-regions include large urban agglomerates, while mega-regions in the C-2 group do not.

6. Conclusion

In this study, four categories (1, 2, 3, and 4) were identified by examining distribution diversity among different ranges of population density. Then, three categories (A, B, and C) were identified on the basis of two indicators related to two-dimensional distribution patterns—Moran's I and gravity of main urban area. By integrating the two category areas, we obtained 10 groups of mega-regions.

While mega-regions in groups A-1 (e.g. Tokyo) and A-2 (e.g. Paris) have urban forms that are relatively easy to recognize, most mega-regions at the other end of the spectrum—in groups C-4 and B-4—have very complicated and heterogeneous urban forms. The mega-regions in these latter groups that have populations of over 20 million are Dhaka, Shenzhen, and Guangzhou in C-4 and Cairo and Kolkata in B4.

In mega-regions in categories 4 (A-4, B-4, C-4) and 3 (A-3, B-3,) populations tend to be divided into both extremes of density. This suggests the possibility of socially divided urban forms, including very high density slum areas and low density gated communities for high-income groups. These mega-regions are located in Asia and the Middle East, with the exception of New York. A high population growth of over 2% annually is expected in these regions during the period 2020–2025, except for the Chinese mega-regions and Istanbul.
None of the 11 mega-regions of C-2 contain a dominant megacity, and several urban cores are scattered throughout these regions. Their populations are slightly over 10 million and not yet large in size. However, the population growth of most of these regions is over 2.5%, except for four Chinese regions.

This study reveals that the emerging groups C-4, C-2, and B-4 have different urban forms from the mature mega-regions of A-1 and A-2. This suggests that the growing mega-regions of the new generation are unlikely to develop into the mature mega-regions. While the absence of a clear urban core could make it more difficult to elaborate a future vision for urban form, the multi-core structure could potentially lead toward polycentric mega-regions that avoid the problems of enormous single agglomerates. Appropriate urban strategies, different from those of the mature mega-regions, will be required to cope with the accelerated speed of transformation and severely divided societies of emerging mega-regions.

7. Further Research

The categorization of mega-regions developed in this paper reveals that mega-regions with similar populations can have relatively diverse spatial characteristics. As such, it will contribute to coping effectively with urban issues and forecasting the future of mega-regions with regard to their spatial potentiality.

This research has focused exclusively on distribution patterns of population on the basis of the premise that this must be closely related to land use patterns, urban fabric patterns, and traffic networks. However, further research that clarifies the relation between population distribution patterns and other spatial attributes will be required for the categorization developed in this paper to be applied to the dynamic observation of the transformation of mega-regions, which will involve monitoring on-going urban policies and managing mega-regions strategically beyond physical master plans.

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Endnote

1. In a former study (Uchiyama & Okabe 2011), we have developed a similar categorization of megacities, adopting a list provided by UN. In this study, we developed a new methodology for more precisely detecting mega-regions in order to improve comparability of spatial form and analyzed the categorized groups by spatial patterns and speed of growth.
2. LandScan 2007 < http://www.ornl.gov/sci/landscan/ > accessed on July 9, 2012.
3. In a case that two or more peak grids that are more than 50km apart have been detected in an agglomeration of central grids, mega-regions have been identified by each peak grid. For example, in the Pearl River Delta, there is a large agglomeration. It has two peak grids, corresponding to Shenzhen and Guangzhou. According to this definition, the Shenzhen and Guangzhou mega-regions are connected and partially overlap. The pair of Jakarta and Bandung (Indonesia) is a similar case. The Muzaffarpur-Patna region and Muzaffarpur-Darbhanga region (India) are also connected to each other.
   If the circular area within a radius of 50km—drawn from the peak grid in an agglomeration that comprises 20 or more central grids—does not overlap with the circular area from another peak grid in another agglomeration and, the latter circular area does not have more five million people than the former circular area, the former one is defined as a mega-region.
   If a small agglomeration, which comprises less than 20 central grids, exists more than 50km away from an agglomeration with 20 or more grids, the circular area around the peak grid in the former small agglomeration is defined as a mega-region.
4. According to UNFPA, half of the world’s population is found in urban areas, as of the year 2008. (UNFPA 2009)
5. The average estimated growth for Chinese mega-regions for the period 2020–2025 is roughly 1.9% per year. Shanghai (A-4) and Beijing (A-1) are estimated to experience lower growth rates of roughly 1.7%.

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