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Analysis of the Urban Growth through the observation of the Urban Expansion Patterns in Belo Horizonte, Brazil, and Hyderabad, India from 1988 to 2017.

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Abstract: Analysis of remote sensing images and spatial metrics can be used to measure changes in landscape structure over time and to compare spatial patterns among different locations. Observation of urban growth and metrics to characterize the new development areas was used to describe and compare the spatial urbanization patterns in the cities of Belo Horizonte, Brazil and Hyderabad, India, for the years of 1988, 1998, 2008 and 2017. Results indicate different stages in the urbanization process between these two cities. The metrics show that *extension* was the principal form of growing pattern in both cities. However, in the last periods new developments based on *leapfrog* have increase its importance. The understanding of these forms of growth becomes important given its consequences on the use and management of resources, different environmental impacts and on the quality of life of the inhabitants.

Keywords: Spatial metrics; remote sensing; urbanization, growth patterns

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1. INTRODUCTION

The dynamics of land use and land cover patterns of a region are driven by natural and socio-economic factors evolving over time and space. Rapid urbanization and urban growth has been a powerful force in changes in land cover and landscape patterns around the globe. As a city grows, the increasing concentration of population and economic activities demands more land to be developed for public infrastructure, housing, industrial and commercial uses. So, in this process changes are expected in land cover/land use resulting in more built-up area of different kinds and a spatial reconfiguration of the urban landscape.

However, there are important differences in the way urban expansion happens. According to Ojima (2007), challenges faced by the cities are not just the ones regarding the pressure of urban population growth but how urban spatial forms are shaped by the necessity of this expansion.

Both spatial configuration and dynamics of urban growth have a direct impact on energy consumption and material flow and land accessibility with consequences to the environment, infrastructure demands and quality of life of people living in cities.

The objective of this study is to make a preliminary assessment of the differences on the urban patterns of expansion observed in the processes of urban growth in Brazil and India by taking two cities, Belo Horizonte in Brazil and Hyderabad in India, in different stages of their urban transition but being both very relevant at local, a metropolitan scale, and at regional and national levels when taking development issues into account.

In this paper we have conducted an exploratory analysis of the urban growth patterns, in particular those related to urban expansion configurations, and their trajectories over a period of time for both cities. This has been done based on the Angel et al (2010) urban sprawl comparability framework. In this study a subset of the *urban expansion* metrics, that captures *infill*, *leapfrog*[1] and *extension* patterns of urban growth have been chosen and applied over Belo Horizonte and Hyderabad, taking the 1988, 1998, 2008 and 2017 as the base years for observing their evolution. In order to calculate the *urban expansion* metrics, a simplified urban land use/cover classification map was produced for both cities using freely available remote sensing image data and classification procedures.

In the next section, a brief analysis is made of expansion metrics with an emphasis on metrics that analyze new urban developments. The third section presents the study area, the methodology and methods used. Finally, the results and conclusion are presented in the fourth and fifth sections.

[1] The expression is a reference to the infantile play that consists in jumping an obstacle using this one to generate the impulse of the jump. Analogously, the corresponding urbanization process performs, for its growth, "jumps" that leave undeveloped interstices as a characteristic. (COELHO, 2016).

2. URBAN EXPANSION METRICS

Spatial metrics arise in the field of landscape ecology, but it has been largely used in urban studies to quantify urban expansion within a city over time and to compare patterns between cities.

Angel et al. (2007) propose specific metrics to measure urban sprawl through the use of satellite imagery and population data. Among the measures, the authors proposed that new development areas could be distinguished into *infill*, *extension* or *leapfrog* types.

Infilling happens when the new development occurs in a location of the urbanized area where previously there was an open space. In other words, urban growth filled a gap that already existed in urban space. *Extension* refers to the growth in the adjacent patch of an urban footprint. Finally, the *leapfrog* type is defined when new urban patches are isolated, occurring in open space away from urban or suburban built-up areas.

These growing patterns could bring different economic, social and environmental consequences. Westerink et al. (2013) shows that *leapfrog* development is associated with higher management costs (energy distribution, waste collection, etc.), high cost of infrastructure and energy, larger travel distances, increase in social segregation and farmland loss. Travisi et al. (2010) emphasized a negative impact of expansion in the transport system. But, on the other hand, the *infill* process is associated with higher density areas, which generates congestion problems, an increase in housing prices, and the loss of green space areas.

As we can see, the three processes have pros and cons. Therefore, it is important to observe and measure the form of urban growth so that their negative effects can be mitigated and controlled. "*Cities have huge potential to ensure those consequences are advantageous but making that happen demands an appropriate policy framework*" (McGram and Martine, 2012, p.2).

3. METHODS

3.1 Study area

The aim of this study is to assess the differences on the urban patterns of expansion observed in the processes of urban growth in Brazil and India by taking two cities, Belo Horizonte in Brazil and Hyderabad in India, in different stages of their urban transition but being both very relevant at local, metropolitan scale, and at regional and national levels, taking development issues into account differences. Although both countries are emerging economies at similar stages due to their economic development, their urbanization trajectories differ vastly, with Brazil having faced a faster urbanization process than India.

Brazil has already carried out its transition process from rural to urban. It has in the 50's begun to present a rapid urbanization process, and in 1970 already had more than 50% of its population in urban areas. By 2014, the United Nations report showed that 85% of the Brazilian population already lived in urban areas.

On the other hand, India still has a large part of its population living in rural areas. In comparison, the fraction of urban population in 1970 and 2014 are, respectively, 26% and 32%. McGranahan and Martine (2012), state that "*India appears ambivalent about urbanization, particularly for the rural poor... It seems inevitable that India will have to transfer a massive number of people form primary to secondary and tertiary industrial*

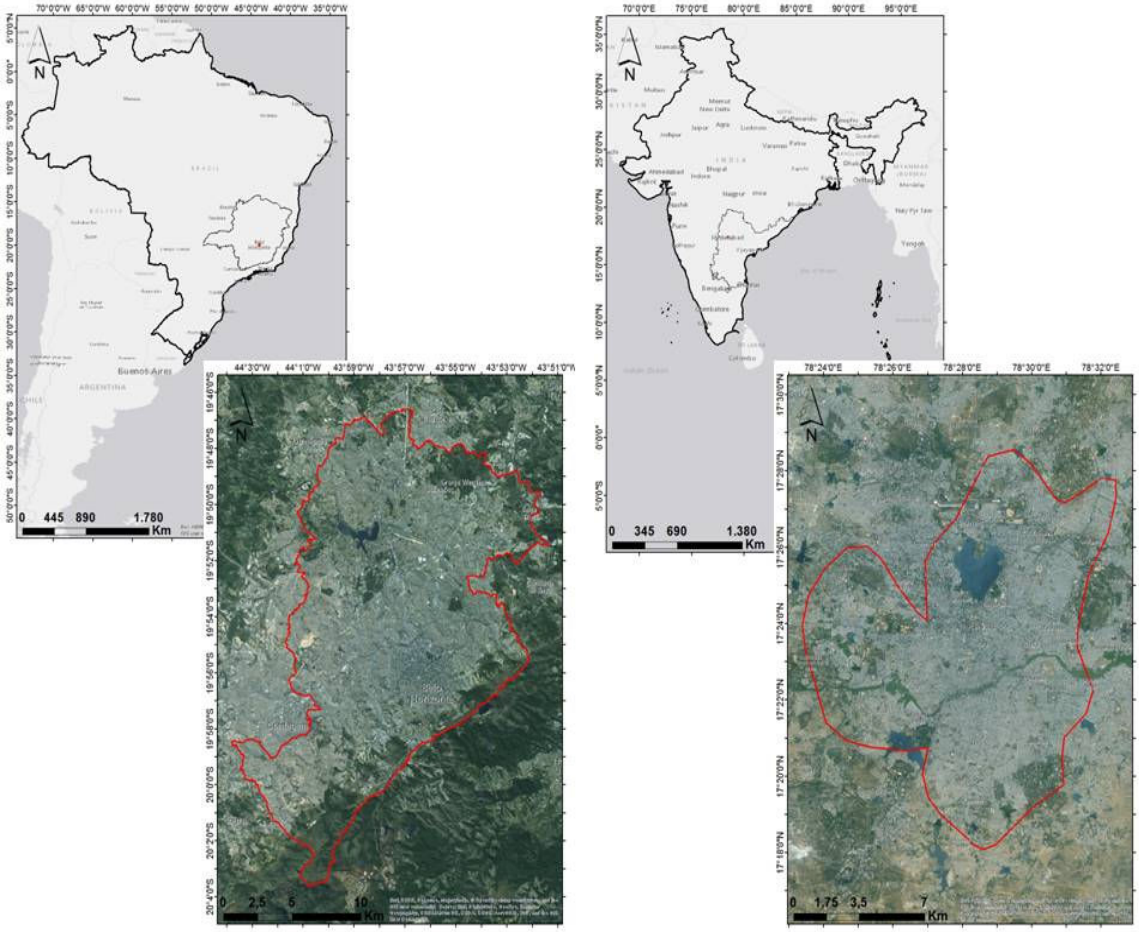
sectors, and from rural to urban living. How and where this happens will be decisive for the country's development".

As an exploratory analysis, we selected one city in both countries to observe their processes of urban growth from 1988 to 2017.

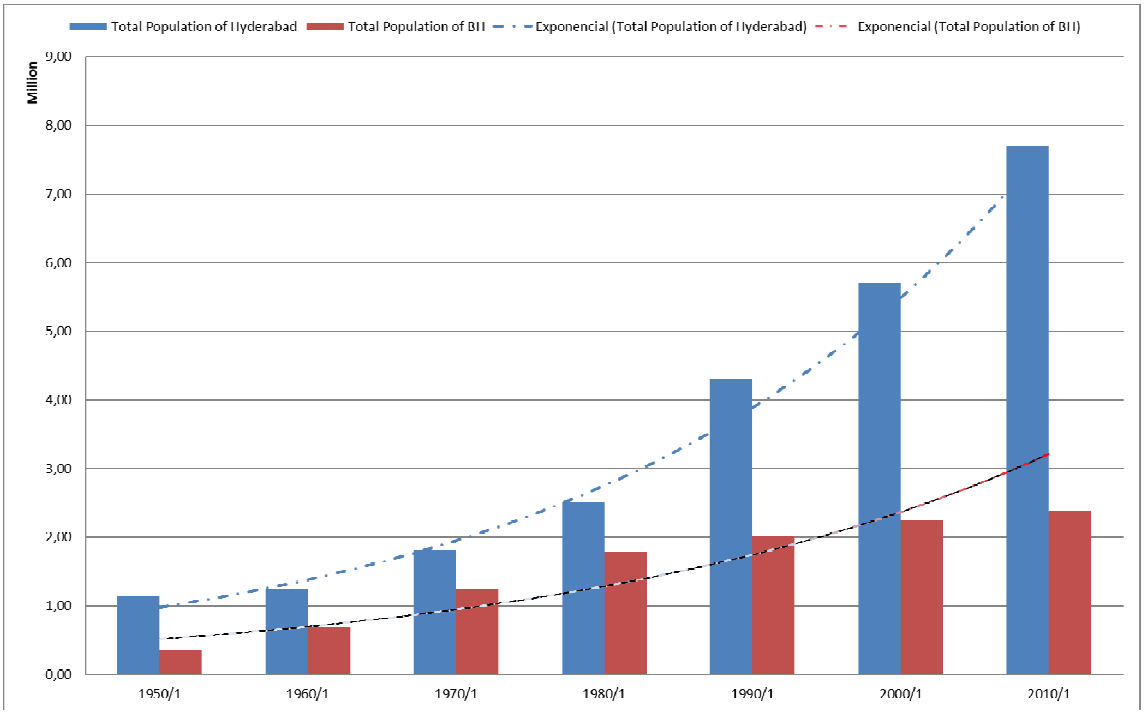
In India the study area is the city of Hyderabad, state capital of Telegana, located in the Southern India (Figure 1). Hyderabad is a historical city founded in 1591. Since 1960, the city began to accommodate a number of heavy industries, which lead to a massive influx of people (Das, 2015). Nowadays, the city is one of the fastest growing urban agglomerations in India, with a population of 7,7 million in 2011.

Belo Horizonte, located in the Minas Gerais state, is the study area in Brazil. The city, founded in 1897, was constructed and planned by local government to function as a political and administrative capital. In the last decades there has been a strong advance of industrialization, which has culminated in an accelerated process of urbanization. The population added to 2,4 million in 2010 and the urban agglomeration counts 4,7 million in 2010, being the third most populated urban concentration in Brazil (IBGE, 2010).

Figure 1 – Location of study areas.



Graphic 1 – Total Population for the cesus year in Belo Horizonte, Brazil and Hyderabad, India.



Source: IBGE and Das (2015).

3.2 Data, Images Classification and Urban Metrics Calculation

The classification of land cover and the detection of its changes for the years of 1988, 1998, 2008 and 2017, was made from satellite images of TM/Landsat-5 and OLI/Landsat-8, with 30m spatial resolution. Since the interest is not simply in the administrative limits of the cities, a cut of the images was made considering a larger area, the size being equal for the two cities with approximately 60km horizontally and 55km vertically.

For the classification process, the procedure was conducted using a two-step method: (1) first, a supervised classification based on a region growing image segmentation coupled with a supervised clustering method making use of the *Bhattacharyya* distance followed by (2) an editing procedure based on visual interpretation. Images were classified into four types of land cover: hydrography, vegetation, urban area and others. Remote sensing images classification used Geographic Information System (SIG) Spring (version 5.2.7) (Câmara et al. 1996).

The metrics calculation was processed in the Urban analysis software, a computational tool created in C++ language that allows the calculation of the expansion and urban form indexes with an intuitive graphic interface designed for non-expert users.

This paper focus on metrics of new development, which refers to built-up pixels existing in the land cover for T_2 but not T_1 (Angel et al., 2007). Based on the difference of classification of two time periods, the new developments are calculates as:

- Infill: new development that occurred within interior open space.
- Extension: New development in exterior open space that were less than 564 meters[2] away from rural open space.
- Leapfrog: New development in exterior open space that were more than 564 meters away from urban or suburban build-up pixels.

4. RESULTS

The classification of the multi-temporal satellite images into three classes: water, urban and non-urban areas for the periods of 1988, 1998, 2008 and 2017 are presented in Figures 2 and 3, for Belo Horizonte and Hyderabad, respectively. These maps show a clear pattern of increased urban expansion both prolonging from urban center and detached from the central area.

It is interesting to note that Hyderabad, despite having a population contingent well above that of the city of Belo Horizonte, has a smaller built-up area throughout the period. Population growth is not accompanied by the same rate of territorial expansion as in Brazil, which results in higher population density indices in Hyderabad.

The results presented in Tables 1 and 2 show some numbers regarding this growth. The city of Belo Horizonte had its greatest expansion at the beginning of the studied period, where the urban area has grown from 280 km^2 in 1988 to 496 km^2 in 1998, which represents an increase of 76,6% in ten years. However, there is a slowdown in the urban expansion of Belo Horizonte at the end of the period. The opposite occurs in Hyderabad, where the greater expansion it is observed at the end of period, with an increase of 59,8% between 1998 and 2008, and 41,4% between 2008 and 2017.

The form that the expansion took place is observed by the metrics calculated in Table 2. It is natural that most of the new developments occur through the extension form, that is, the aggregation of new land parcels around the preexisting urban area. In both cities this percentage is very significative, always representing more than half of the new extensions.

However, as stated by Angel et al. (2007), a characterization of urban sprawl refers to the decreasing of contiguity of the build-up areas of cities, and thus, represented by a tendency of new developments by *leapfrog*. In Hyderabad the phenomenon of sprawling became more intense over the years, incorporating by *leapfrog* 8,5 km^2 in 1988 to 1998, 33,9 km^2 in 1998 to 2008, and 40,8 km^2 between 2008 to 2017. In Belo Horizonte, the new development by *leapfrog* has its peak between 1998 to 2008, with an incorporation of 43,3 km^2. As the spatial growth slowed down in the city in the subsequent period, the increase by *leapfrog* was only 17,7 km^2, but represented 21,5% of the new developments.

The new developments by *infill* despite of the lowest values in the processes for both cities has an important consequence that refers of the reduction of fragmentation. It is possible to notice from the Figures 2 and 3 that the two cities, in addition to expanding along and beyond their borders, were also filling the "holes" left behind, with a more significant percentage happening in Belo Horizonte.

[2] The value of 564 meters is the software default, which is based on the methodology of Angel et al. (2010).

Figure 2 – Belo Horizonte: Results of imagem classification.

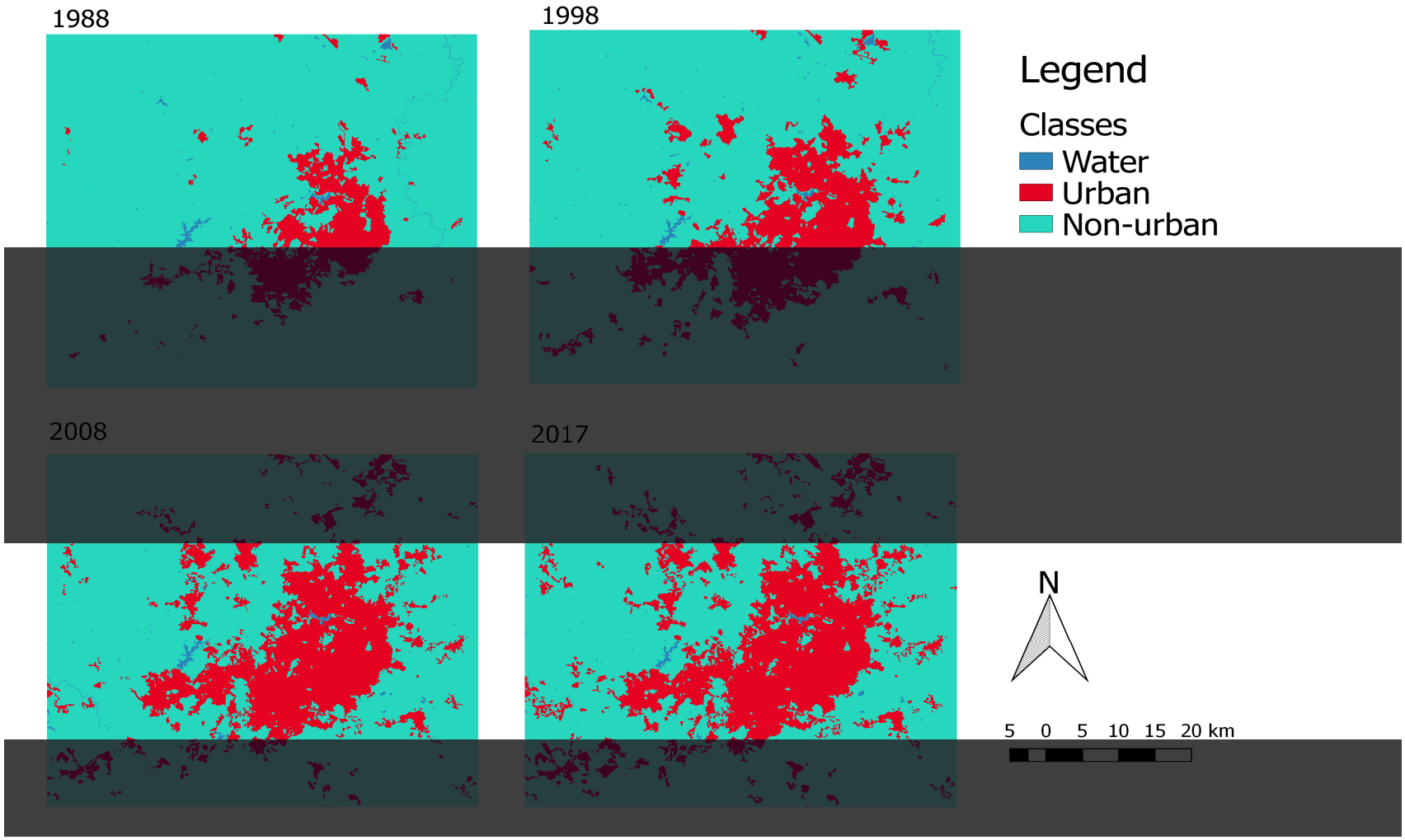


Figure 3 – Hyderabad: Results of imagem classification.

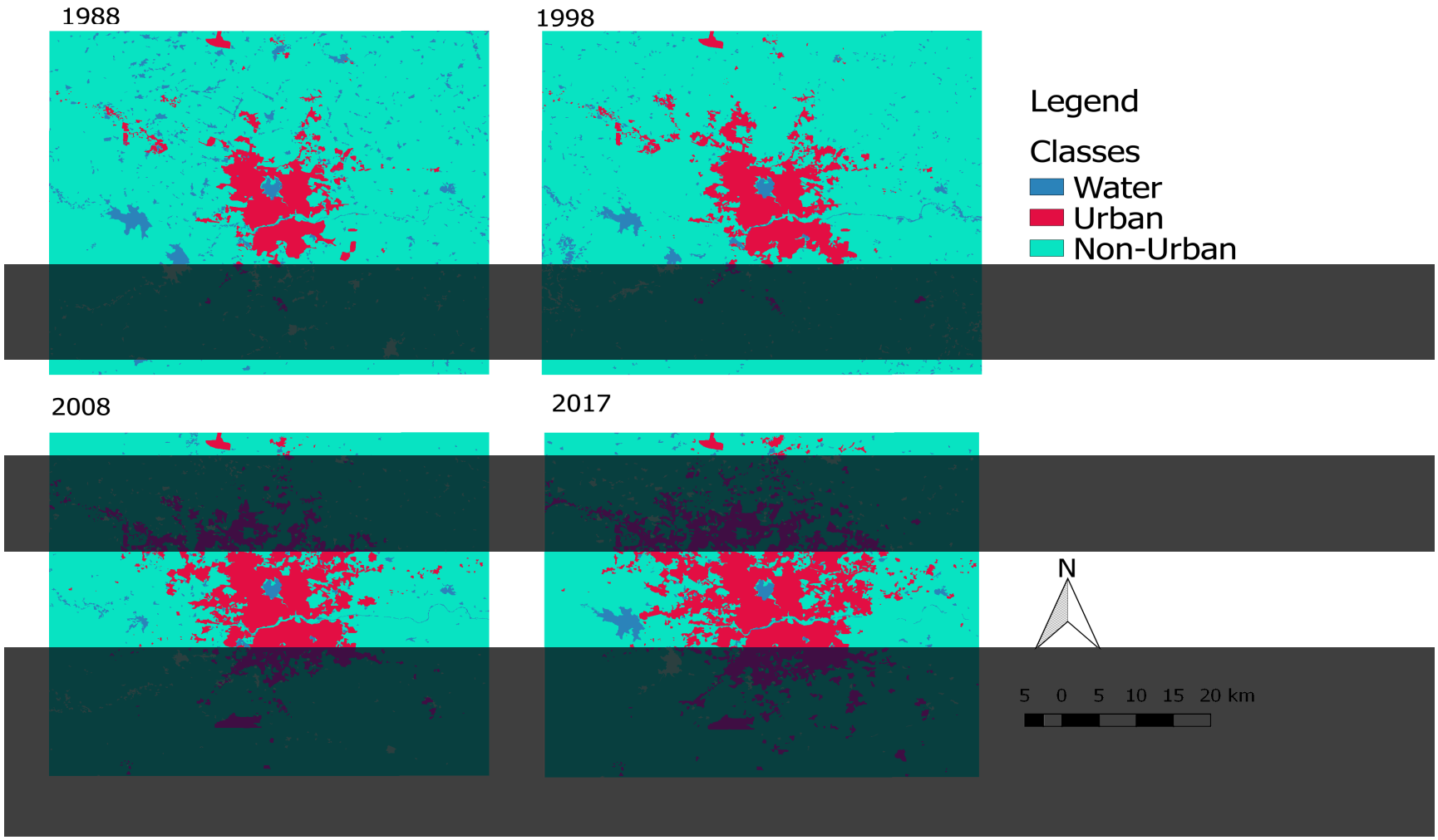


Table 1: Summary of the classification classes: area and percentage per year.

Cities		1988		1998		2008		2017	
	Classes	Area (Km)	%	Area (Km)	%	Area (Km)	%	Area (Km)	%
Hyderabad	**Water**	138,20	4,28	89,73	2,78	60,49	1,87	69,95	2,17
	Urban	197,16	6,11	258,07	8,00	412,62	12,79	583,62	18,08
	Non-Urban	2.891,73	44,26	1.378,31	42,71	2.208,29	68,43	1.476,57	45,76
Belo Horizonte	**Water**	22,16	0,69	19,72	0,61	20,83	0,64	15,07	0,47
	Urban	280,89	8,69	496,01	15,33	631,44	19,52	714,09	22,07
	Non-Urban	398,77	12,33	620,01	19,16	293,22	9,06	456,39	14,11

Table 2: Results of spatial metrics calculation.

New Development Metrics (km2)	**Hyderabad**					
	Δ 1988-1998	**%**	**Δ 1998-2008**	**%**	**Δ 2008-2017**	**%**
Infill	3,1815	5,17	8,2728	5,35	12,2868	7,17
Extension	49,8033	80,99	112,3434	72,69	118,0728	68,94
Leapfrog	8,5113	13,84	33,9264	21,95	40,8996	23,88
Total New Development	61,4961		154,5426		171,2592	
	Belo Horizonte					
	Δ 1988-1998	**%**	**Δ 1998-2008**	**%**	**Δ 2008-2017**	**%**
Infill	21,5919	9,94	17,0199	12,57	9,2916	11,24
Extension	172,2843	79,29	75,1185	55,46	55,5849	67,25
Leapfrog	23,3973	10,77	43,3008	31,97	17,7723	21,50
Total New Development	217,2735		135,4392		82,6488	

5. CONCLUSION

The intent of this analysis was to investigate the differences on the urban patterns expansion using the spatial metrics to characterize the new development areas among the periods of 1988, 1998, 2008 and 2017. Angel et al. (2010) points out that "*infill, extension and leapfrogging are but temporary designations that apply to new construction that has occurred during a specified time period. In the longer run, when we look at fully built-up areas of the city at a given point in time, we can no longer tell which part originated as infill, which as extension, and which as leapfrogging*". However, the identification of the type of expansion and their trend over time it's important to understand the configuration and for planning urban space, since each type has different consequences for the development, environment and the life style of the population.

In this study we compare two cities, Belo Horizonte in Brazil and Hyderabad in India, which are very relevant cities in the development of their respective countries. Although both countries are emerging economies at similar stages their urbanization trajectories differ vastly. Considering the period of study, we observed that Belo Horizonte has its peak of expansion in the period of 1988 to 1998, while Hyderabad is experiencing its fastest growth in the recent period. The type of *extension* in the new development areas

was the principal form of growing pattern in both cities. In the recent period, the *leapfrog* started to gain importance, having more than 20% participation in the period from 2008 to 2017 in both cities.

The increase by *leapfrog* pattern is associated with urban sprawl. Angel et al. (2007) brings the idea of sprawl as a fragmentation of the city. This fragmentation could have impacts associated to higher management, infrastructure and energy costs, larger travel distances, increase in social segregation and farmland loss. Also, Angel et al. (2007) draws attention to the phenomenon of sprawling as the "*manifestation of their drawing apart, of their repulsion from each other, and of their desire to limit their social and economic contacts while increasing their privacy, the size of their homes and businesses, and their enjoyment of open space*".

This study is a preliminary analysis of the urban expansion of these cities, but that already brings some interesting inquiries about the differences in their urban growth. In the literature a variety number of other spatial metrics have been used to analyze the urban phenomenon. It is recommended for future studies the use of other metrics to have a more complete picture of the urban dynamics in these cities.

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