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Spatial Insights on Urban Density: A Case Study of Calgary

Jiaao Guo
Department of Geography
University of Calgary
jiaao.guo1@ucalgary.ca

Victoria Fast
Department of Geography
University of Calgary
victoria.fast@ucalgary.ca

ABSTRACT

Calgary, the 3rd most populous city in Canada by census subdivision (CSD) but has a low population density: 1501 inhabitants per km^2, compared to Montreal's density of $4662/km^2$, Toronto's $4334/km^2$, and Vancouver's $5493/km^2$. This study compares the distribution of population densities in sub-municipal levels between Calgary and three other Canadian cities to reveal urban development patterns associated with "density". This is achieved through 3D density mapping using ArcGIS Pro, and Mantel permutation test of density distributions. As a result, compared to the other Canadian cities, Calgary has a great capacity to densify its current urban structures to cope with future population and economic growth. Instead of expanding outwards, we recommend a high density-urban form is what Calgary needs to grow healthily.

1. Introduction

Fourteen new communities have been proposed in the city of Calgary in order to cope with the estimated population growth of 76,000 people in the next 5 years (City of Calgary, 2018). All these new communities are on the outer periphery of the city, encouraging decentralized low-density development (Figure 1). Proponents believe that new outer-city communities help the settlement of population, bringing down the average housing price, and creating tens of thousands of temporary and permanent jobs (Thomas, 2018); others are vehemently opposed to the new communities, citing worsening sprawl and disincentivizing urban densification, lowering connectivity between communities, and rising overall property tax to all Calgarians (Smith, 2018). On a policy note, this goes against Calgary's Municipal Development Plan (MDP) that calls for more compact and efficient use of land by encouraging the redevelopment of higher residential densities in the established communities (City of Calgary, 2017).

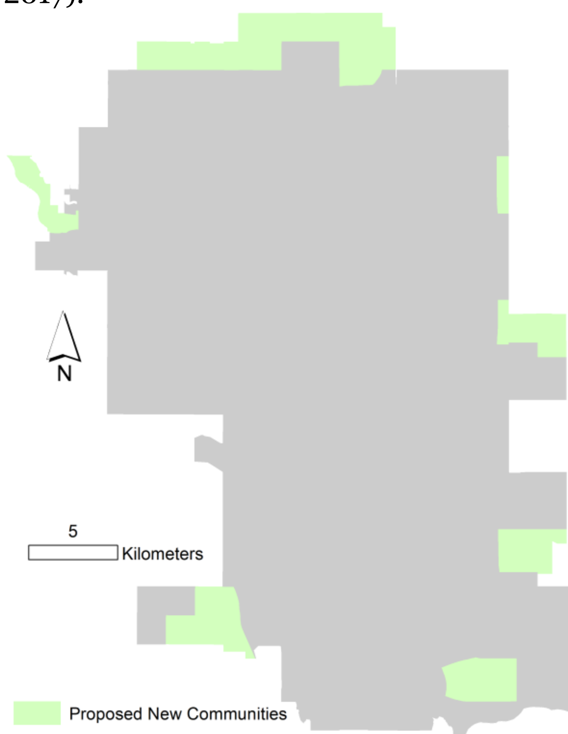

Figure 1. Locations of proposed new communities by the city council of Calgary.

Unlike other large cities in Canada such as Toronto, Montreal, and Vancouver with natural barriers (Lake Ontario, St. Lawrence River, and the Pacific Ocean, respectively) that constrain their sprawl process, Calgary does not have physical barriers to limit outward growth. To contextualize this new outward growth, it is important to understand how Calgary's footprint and density compare to other cities. In this paper, we use GIS and spatial analysis to visualize and compare Calgary's population density in sub-municipal level and its distribution to other cities in Canada (Montreal, Toronto, and Vancouver). We then discuss these findings as they related to urban growth in Calgary.

2. Background: Density

Population density is the number of inhabitants per unit area (km^2). It has a significant impact on an urban area: low-population density is associated with the low densities of infrastructures, transportation system, and even services to be provided to the citizens (McFarlane, 2016). High-density is associated with the mixed-use urban form with significant focuses on public transits, pedestrians, and cyclists (Burton, 1999). Compact and mixed-use urban forms have been suggested by many studies to have positive influences on the livability of the city; it prevents unrestrained urban sprawls and ensures the integral livability of the city (Burgess, 2002; Howley, 2009; Mouratidis, 2017). Optimal density for the urban form depends on local context, and should overall contribute to the health and sustainability of the city (Dempsey et al., 2012).

When it comes to density, it is generally the case that Canadian cities have low urban population density compared with other cities in high-income countries (Filipowicz, 2018). Many European cities favour block-style urban form, while condominiums are the most popular accommodation type in the megacities of Asia which enable significantly higher densities (Bunz et al., 2006). In a quick comparison, we use coarse resolution (1×1 km) population grids (NASA, 2018) to examine population density of Calgary to Berlin (medium density), Madrid (medium-high density), and Osaka (high density). The three cities, representing different density levels, exhibit more evenly distributed pattern of population density compared to Calgary. In comparison, Calgary's overall low density appears to have a disjointed assortment of density grids. Beyond density, the distribution or the consistency of population densities in sub-municipal level, can reveal how well the mix-use form is implemented as a city grows. To understand Calgary's population density further, we will compare it with three other Canadian cities using census records that have a finer spatial resolution.

3. Method and Data

We compare four census subdivisions (CSDs) in Canada: Toronto, Montreal, and Calgary as the first to third largest CSDs in Canada by population and Vancouver as Canada's densest major city (Filipowicz, 2018). Their general statistics are listed in Table 1. To reduce the effect of the modifiable areal unit problem (MAUP) (Openshaw, 1984), dissemination block (DB), which represent the finest unit in the Canadian census record, are used. DB boundary files and attached census data for

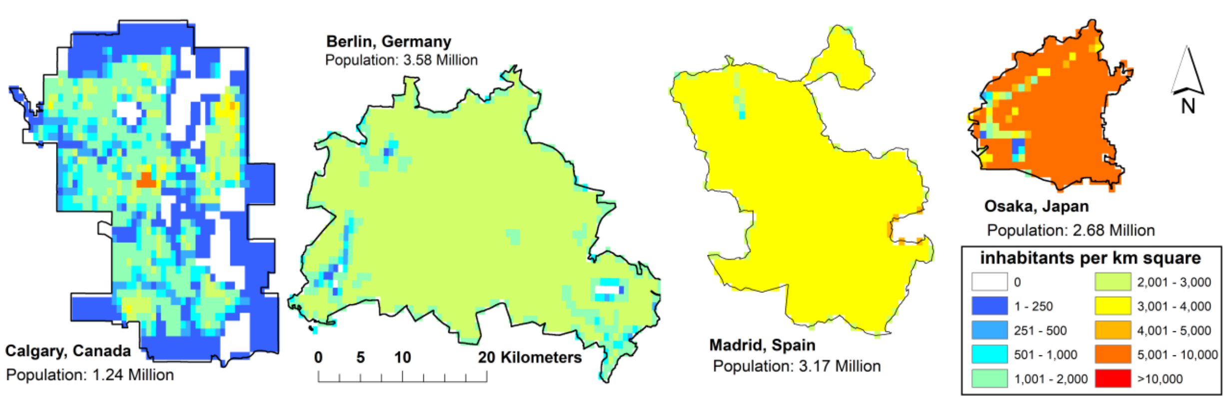

Figure 2. The distribution of urban population densities between Calgary and other international cities based on Gridded Population of the World (GPW) 2015. Grids have a resolution of 1×1 km and the four cities are displayed on the same scale.

Canadian cities are extracted via Statistics Canada (Statistics Canada, 2018a; Statistics Canada, 2018b).

Table 1: Area of selected CSDs and their corresponding population densities.

CSD	Area (km²)	Population (millions in 2016)	Average population density
Calgary	826	1.24	1501/km²
Montreal	366	1.7	4662/km²
Toronto	630	2.73	4334/km²
Vancouver	115	0.63	5493/km²

We map 3-dimensional (3D) population densities with sub-municipal densities as "heights" using ArcGIS Pro. Next, we extract DBs polygons into their centroid points to statistically observe the distribution of population density. We apply the simple Mantel test (Mantel, 1967) to assess the "evenness" of density distributions of the four cities. Simple Mantel test is a non-parametric test and routinely used to access the significance of correlation between two entire distance or dissimilarity matrices by random permutations (Guillot and Rousset, 2013). Accordingly, such permutation mechanism will result "pseudo" distances between paired objects in matrices. Spatial variations of population densities at DB level can make significant differences in the permutation process, and thus, reflect "evenness" of density distribution. The *R* package "vegan" (Oksanen et al., 2013) is used to conduct Mantel Test. It firstly constructs two matrices: dissimilarity in population densities, and spatial distances between centroids of density units. In our context, the null hypothesis (H_o) assumes population densities represented by centroids of DBs are not linearly correlated with their corresponding geographic distance. Then it calculates the sum-product (*M* value) (Giraldo et al., 2018):

$$M = \sum_{i=1}^{n} \sum_{j=2}^{n-1} c_{ij} d_{ij} \qquad (1)$$

where c_{ij} is the *i*th element of column *j* in the dissimilarity matrix *C*, and d_{ij} is the *i*th element in column *j* in the geographic distance matrix *D*. After the *N* times of permutation of one matrix, it compares the new *M* values with the original *M* value. The *p*-value is calculated as follows:

$$p\text{-value} = (1+n)/(1+N) \qquad (2)$$

where *n* is the number of randomized new M values equal to or above (or equal to or below) the original, observed *M* value. A *Pearson's* correlation (ranges from -1 to 1) can also be calculated based on unfolded matrices elements. We set 1,000 random permutations and a significance level (α) of 0.05.

If similar population densities are evenly spread out in their geographical locations, the permutations of spatial matrices will not give distinctly different *M* values. However, if population densities distribute with some gradients from one place to another, the permutations of original distance matrices will be likely to produce very different *M* statistics and result in low *p*-value.

4. Result and Discussion

The 3D population density of Calgary, Montreal, Toronto, and Vancouver, illustrated in Figure 3, show that the distribution of population in Calgary is very segmented and uneven compared to the other three. Extremely low population densities are found throughout the city and especially near the municipal boundary of Calgary. These pockets of no or low density are not typical compared to the other cities. For Toronto, Montreal, and Vancouver, there is a great portion of DBs with density over 5000 inhabitants/km², and generally more consistent density throughout the city.

Results of Mantel test are shown in Table 2. All the observed correlations are close to 0. This is caused by DBs that are geographically far from each other but having similar density value in the same CSD. Thus, we are more interested in the simulated *p*-value as it reflects the "evenness" of population density's

Table 2. Mantel test result at α = 0.05

CSD	*r*-correlation	*p*-value	Null hypothesis
Calgary	0.0134	**0.0134**	reject
Montreal	-0.0577	1.0	accept
Toronto	-0.0283	1.0	accept
Vancouver	-0.0056	0.8182	accept

distribution. At α=0.05, Calgary is the only city with significantly strong spatial gradients of population densities at DB level. In other words, the local population densities in Calgary are extremely diverse and unbalanced.

Admittedly, MAUP is still a factor causing uncertainties even at the DB level. For all the 4 cities, there are DBs with population density less than 250/km². DB is adjusted when population counts are very low to ensure confidentiality (Statistics Canada, 2015), while it does not necessarily have an upper limit in counting. Further study is required to understand uncertainties their potential effects due to MAUP, as well as the appropriate classification in different density illustrations.

Uniquely, Calgary has a large number of DBs with no registered residents, and those areas are mostly used for industrial or transportation (railways and airport) purposes. Montreal has a similar situation. However, many of DBs with residents in Montreal have densities over 10,000 inhabitants/km² that is not commonly found in Calgary. To densify the city, Calgary has to not only redevelop and densify established communities, but also encourage more mixed-use development that balances the needs of residents, commercial and industrial areas.

A dense form of urban structure such as mix-use housing and block style communities is associated with (1) better connectivity and accessibility to different services; (2) higher energy efficiency and utility transpiration (Güneralp et al., 2017); and (3) higher efficiency in operating public transit (Spencer et al., 2015). Instead of constructing new communities on urban fringes, this can be achieved starting from redeveloping established communities in Calgary, densifying their infrastructure layout, and diversifying their accommodation types. There is no statistical evidence that relatively high-density urban forms will result in a decrease in quality of life: Vancouver has a triple amount of general population density compared with

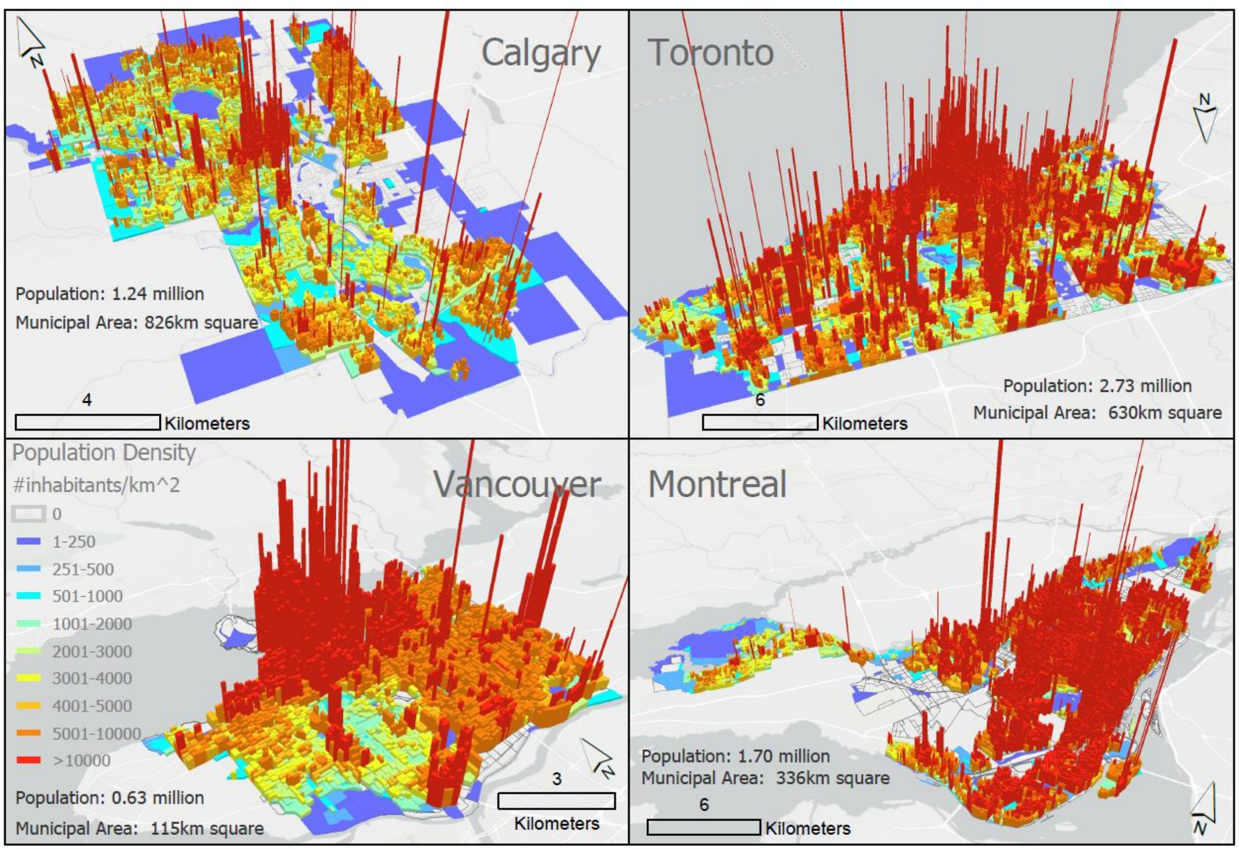

Figure 3. The 3D urban population densities by dissemination block (DB) for Calgary, Vancouver, Toronto and Montreal within their CSD boundaries in 2016.

Calgary, it is frequently ranked as one of the cities with highest living quality (Filipowicz, 2018).

In addition, a compact urban form potentially helps the municipality to manage its revenue more effectively than the decentralized city. The real challenges are to carry out “compact” urban structure: the city continues encouraging monocentric urban structure with downtown-oriented transit system makes it difficult to develop mix-use area outside the city center (Arnott, 2015); while higher taxation in the city center may also drive business away resulting further decentralization (Song and Zenou, 2009). With a densification process surrounding the city center, shared prices for utilities, public transits, housing, and average property tax can eventually be brought down. Thus, this densification process is beneficial to all Calgarians in the long-term, and it should be implemented in a thoughtful way.

5. Conclusion

Calgary has an anomalously segmented population distribution, and its overall density is too low to support a cost-efficient supply of services. Densification and redevelopment of existing communities are recommended over the current model of expansion. Recognizing Calgary’s MDP and transportation plan, we recommend the future urban development in Calgary that: (1) stops expansions of new communities on the fringes of the city; and (2) supports the redevelopment of established areas by encouraging construction of the mix of housing types and transit-oriented development. In addition to these immediate recommendations, future research needs to be done on defining “optimal” density, and how such density can be applied by other municipalities across Canada. For Calgary, many of the new-planned communities will take decades to complete, and it is not too late for the city council to make amendment of Calgary’s future urban form that will contribute to the overall health and connectivity of the city. The former Toronto’s chief planner, Jennifer Keesmaat suggests that Calgary has the building blocks to be transformed, adding that the East Village, one of the communities with the highest population density in Calgary, is an ideal model (Smith, 2019). The question remains, will Calgary keep growing out, or learn to grow up?

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