Characterizing the Evolution of Indian Cities using Satellite Imagery and Open Street Maps

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School of Information Technology, Indian Institute of Technology- Delhi

JUNE 16, 2020

COMPASS 2020

Faces of Urbanization

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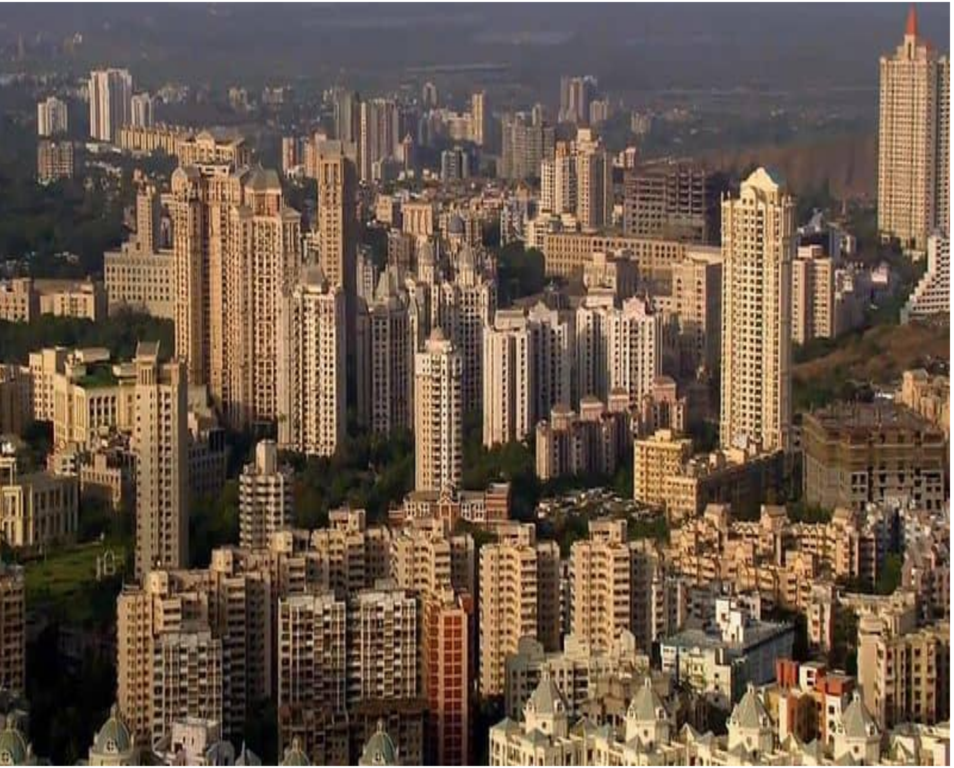

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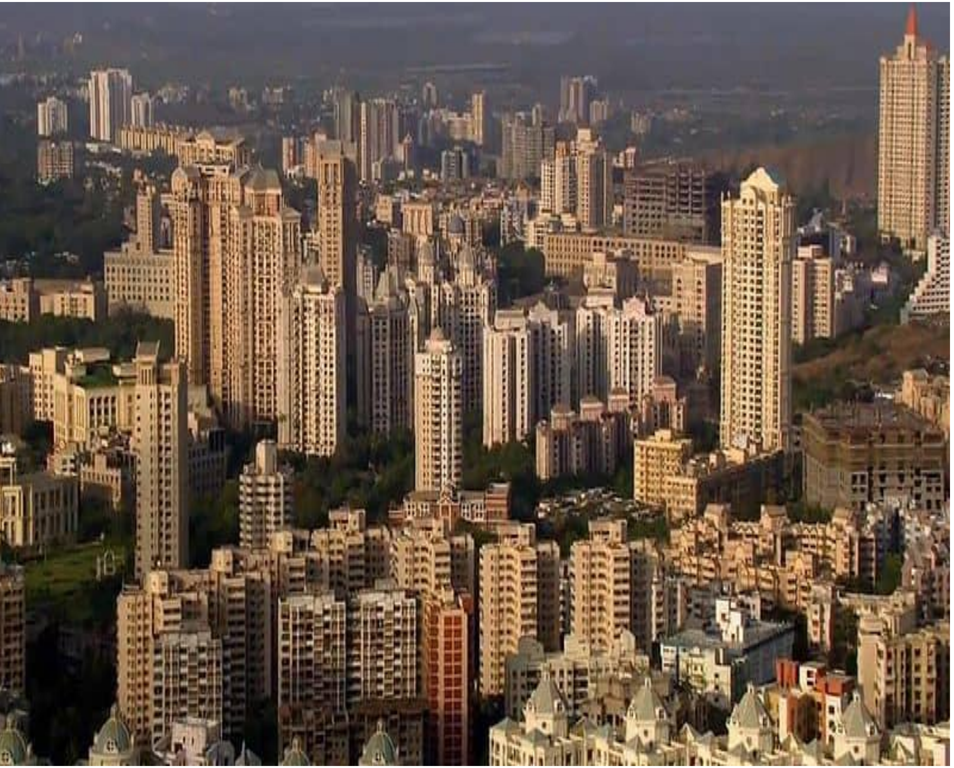

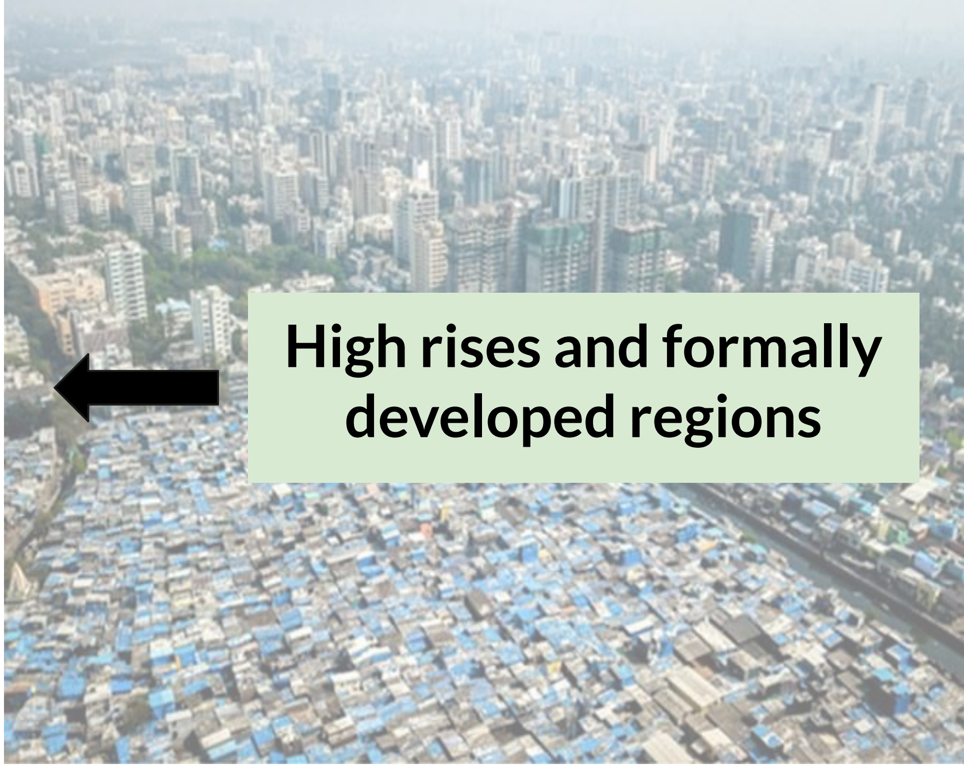

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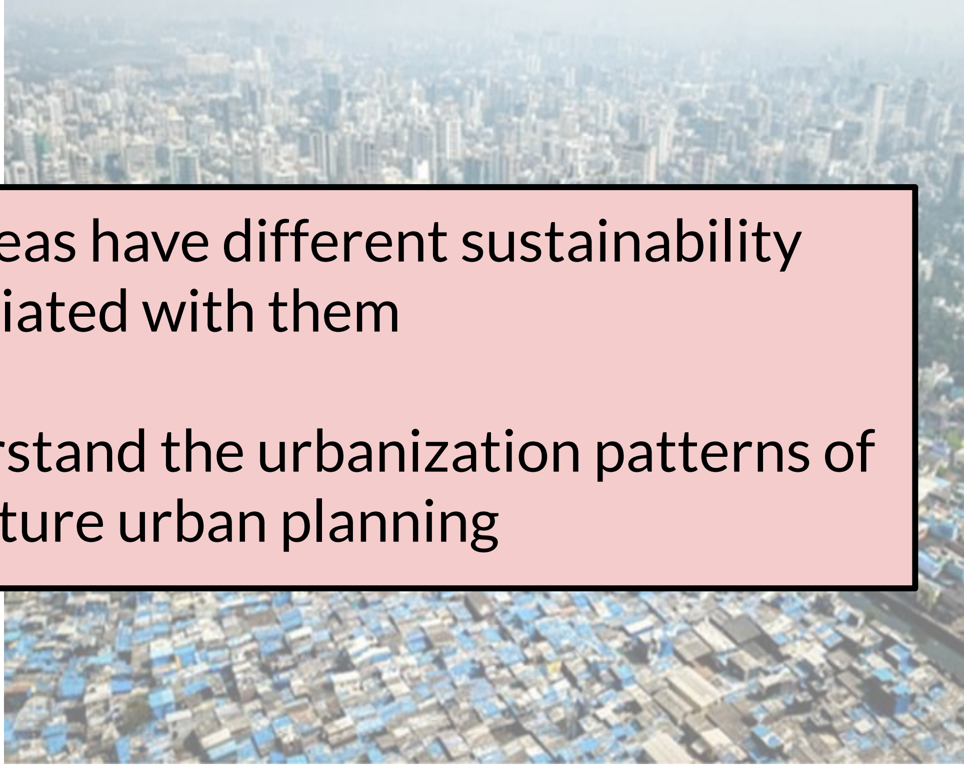

Different segments of urban areas have different sustainability problems associated with them

It is, therefore, important to understand the urbanization patterns of cities to improve future urban planning

Indicators for Quantifying Urbanization

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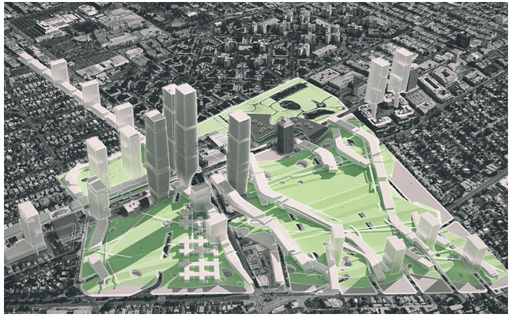
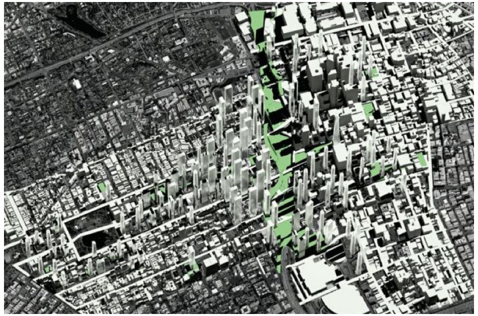
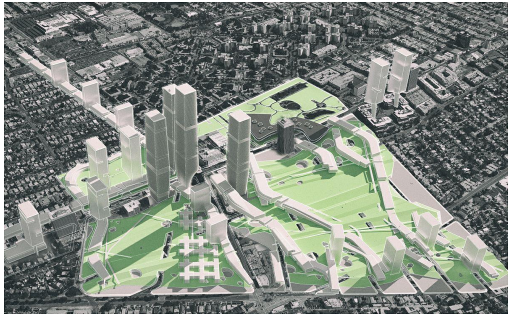
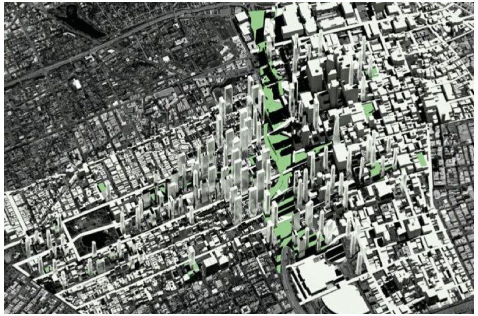




Density of Construction

Indicators for Quantifying Urbanization

Density of Construction


Formally vs Informally Developed Settlements

Indicators for Quantifying Urbanization

Density of Construction

Formally vs Informally
Developed Settlements

Other indicators include Area Under Construction, Urban Mobility, Population living in Urban Slums, Proportion of Urban Population with Access to Improved Health Services, etc.

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Related Studies

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Further, these studies look into the transition of cities over longer timescales (ten years or more)

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Related Studies

The road infrastructure in different neighborhoods can provide useful information about how well planned and developed these neighborhoods are [1]

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Our novel contribution lies in building a method to use data from Open Street Maps to develop road-based indicators of urban living.
It is a relatively new data source that has mostly been used to map land-use classes [3], identify public properties [4], and construct urban transportation-network models [5].

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[4] Mohsen Kalantari and Veha La. 2015. Assessing OpenStreetMap as an open property map. In OpenStreetMap in GIScience. Springer.
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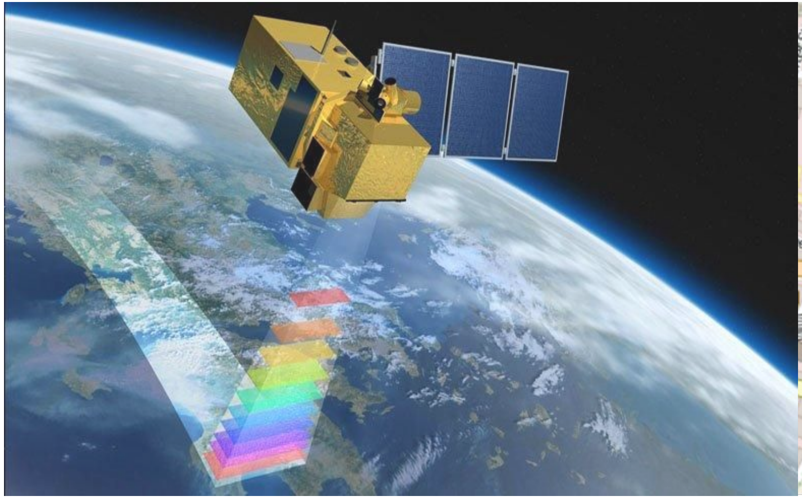

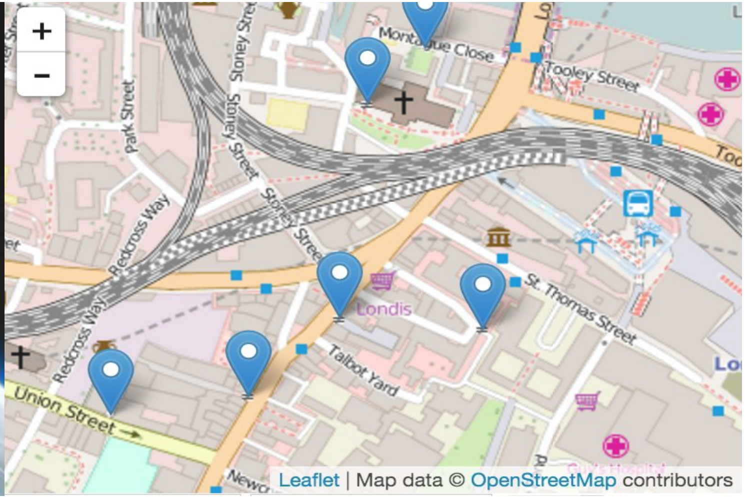

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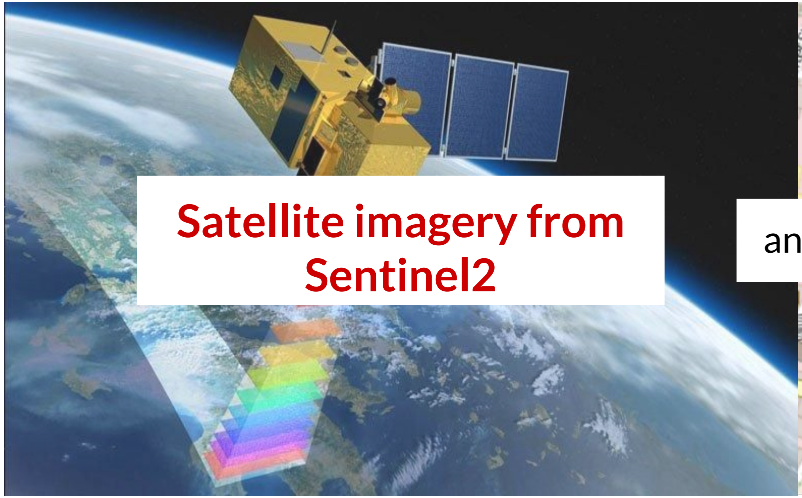

Satellite imagery from Sentinel2

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Road Information from Open Street Maps

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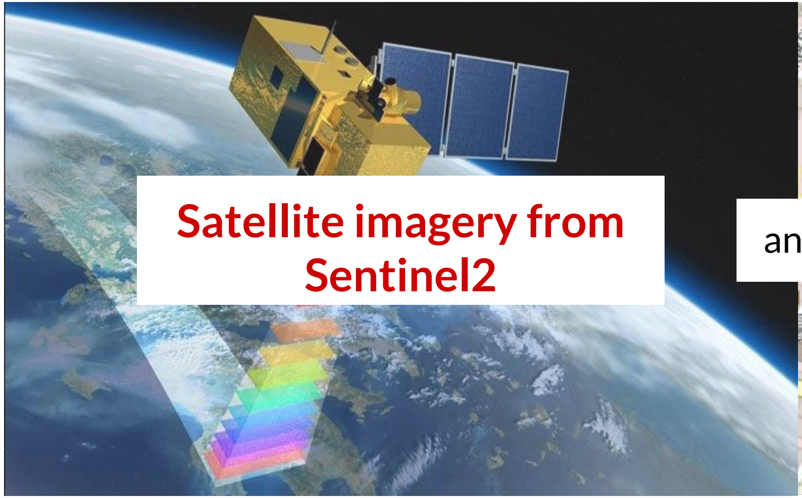

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to develop a series of **standardized indicators** for different aspects of urbanization, which can serve to compare various cities with one another and to track change happening in the cities over time

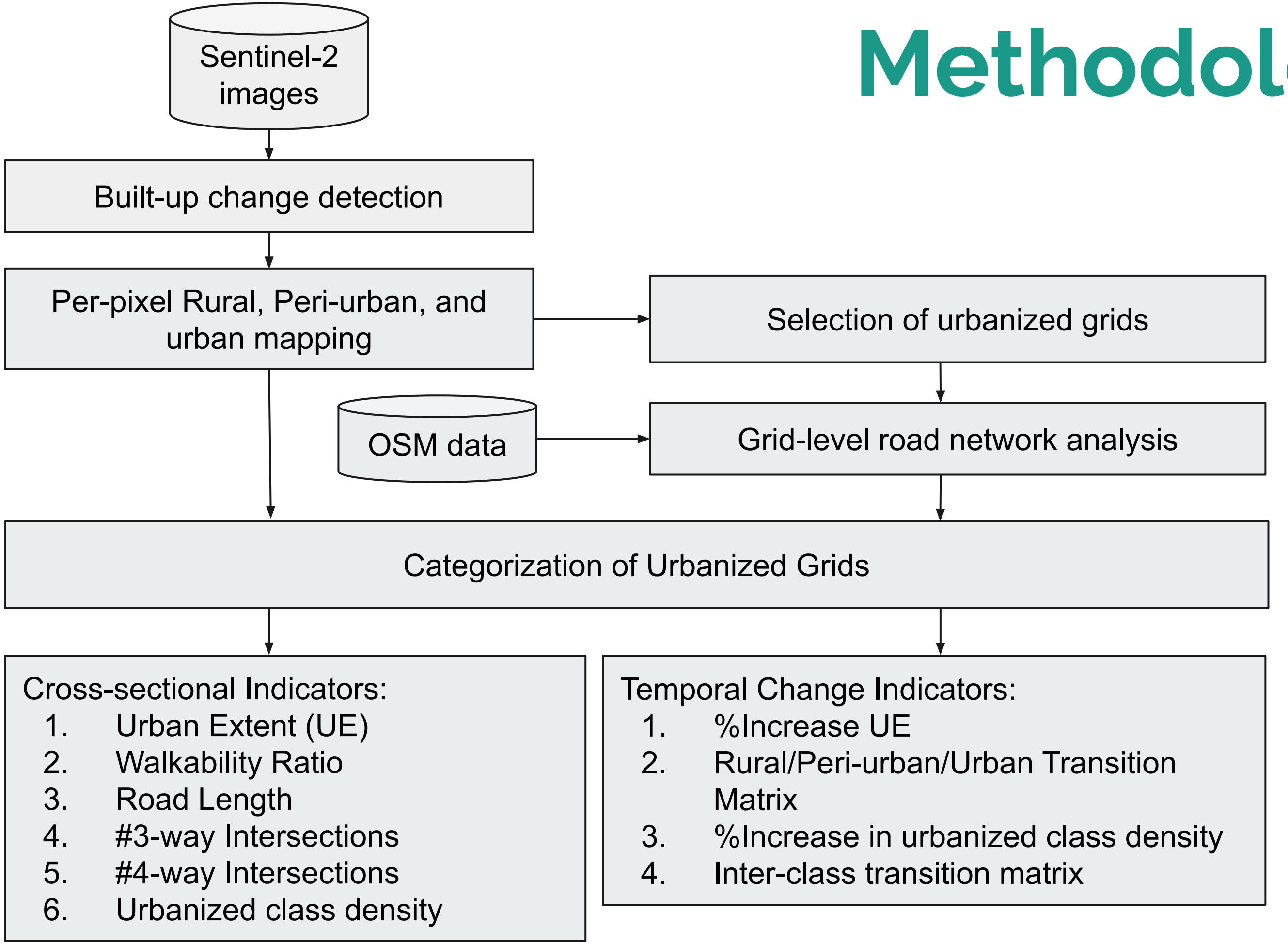
Problem Statement

Our approach will support urban planners, government authorities, and citizens in answering questions such as the following:

- **What is the spatial footprint of built-up areas in different cities? Which cities have undergone rapid spatial expansion of their built-up areas?**
- **How do cities differ in terms of the construction density of their urban settlements? Which cities have the most densely packed settlements?**
- **How are different urban settlements within a city changing over time?**
- **How does information on road networks enhance our understanding on the patterns of urbanization?**

Methodology

Methodology



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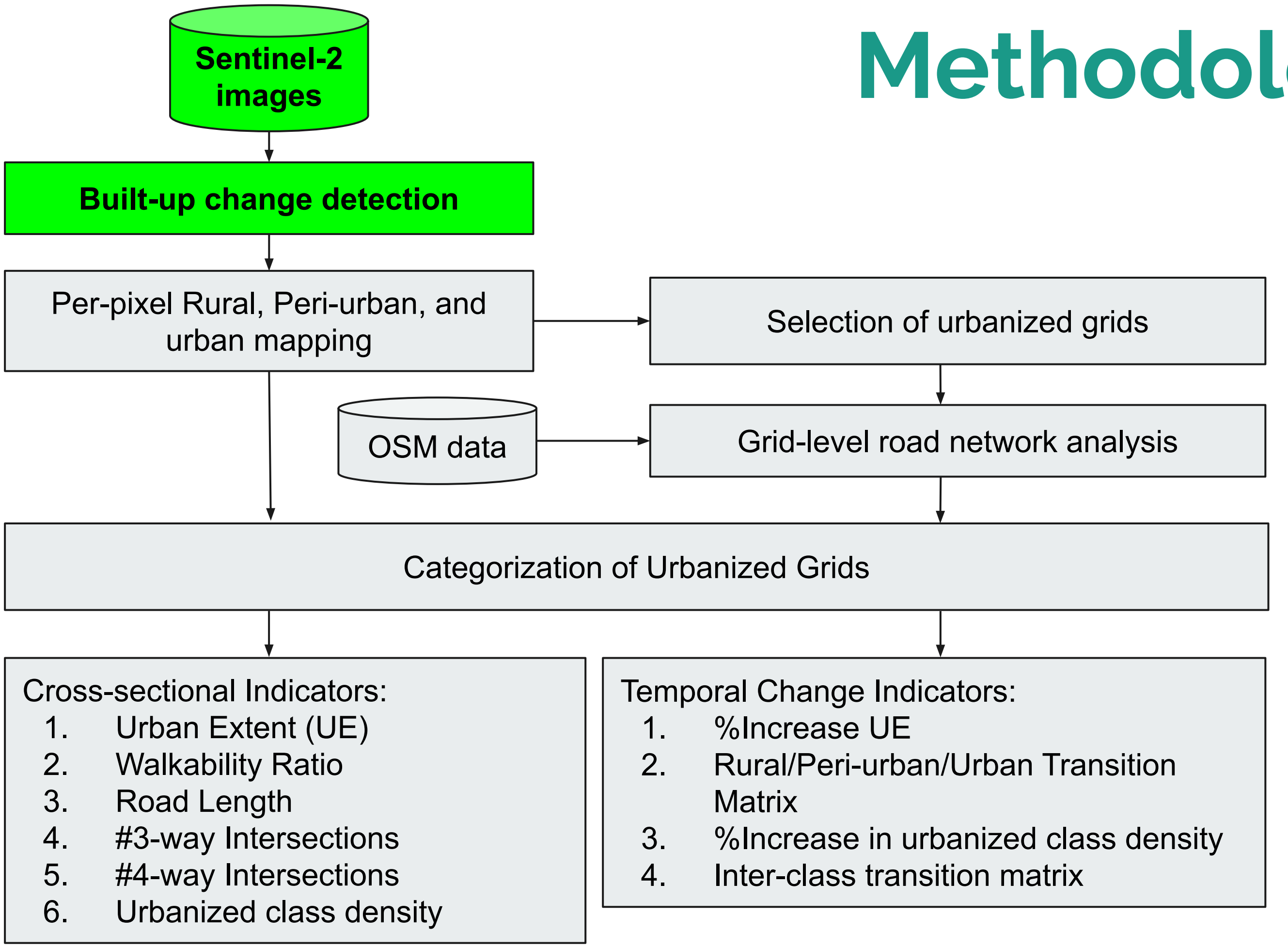
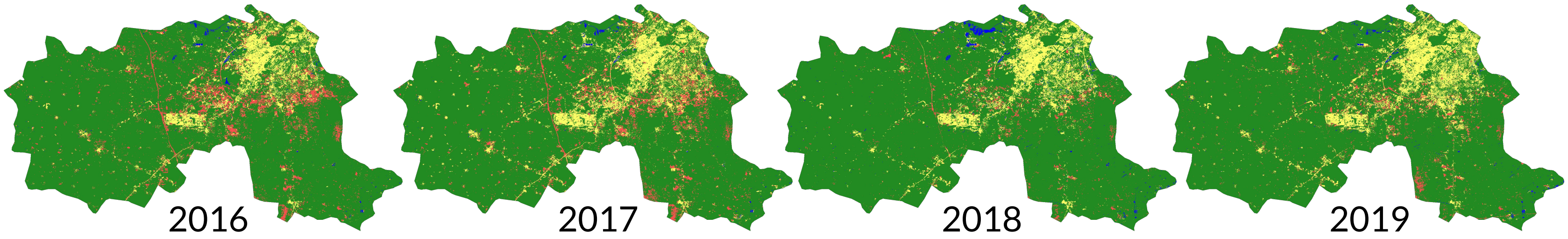


Built-up Change Detection (2016-2019)

We obtained **Sentinel-2 data** and **applied a land-use classifier** as an ongoing study [1].
Classifier Trained on: 3.5M pixels at 30m resolution
Identified Land-cover classes: Water Body, Greenland, Barren Land, and Built-Up area

The classifier produces a single classification for each year but takes images from the entire year into account to apply error correcting rules to handle seasonality.
A robust **accuracy of 97%** has been reported for the classifier.

Land-cover Predictions



[1] HariOm Ahlawat. 2020. An open dataset for landuse classification in India for Sentinel-2. https://github.com/hariomahlawat/An-open-dataset-for-landuse-classification-in-India-for-Sentinel-2

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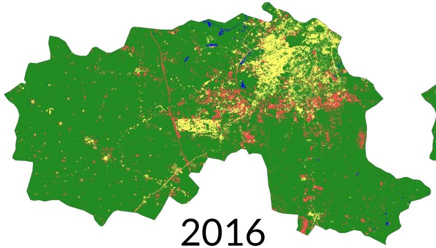
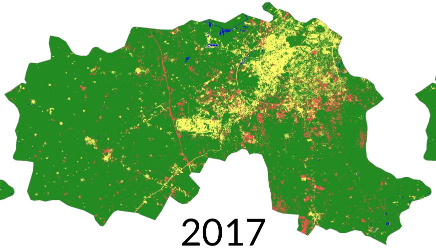
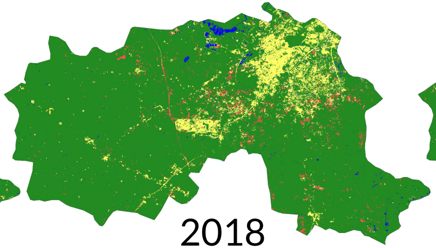


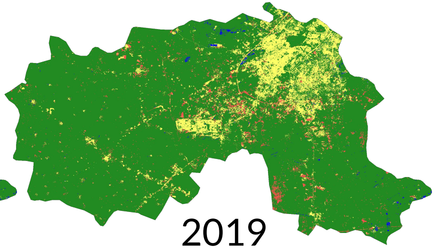
2016



2017



2018



2019

Convert into Builtup/Non-Builtup Maps for each year

Built-up Change Detection (2016-2019)

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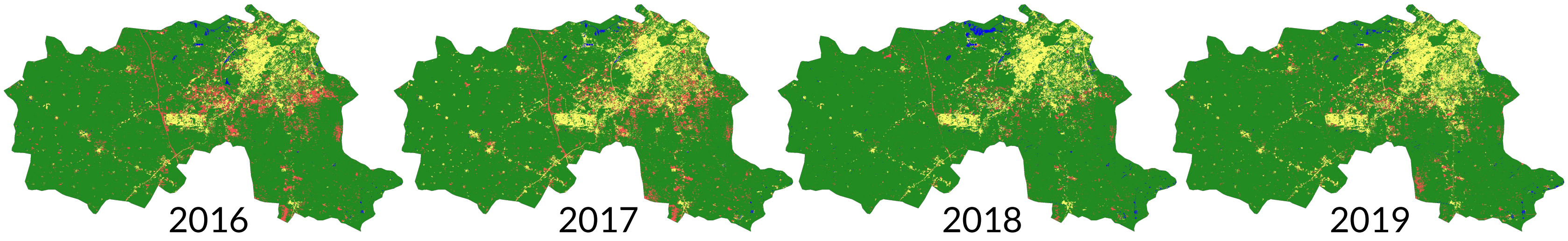

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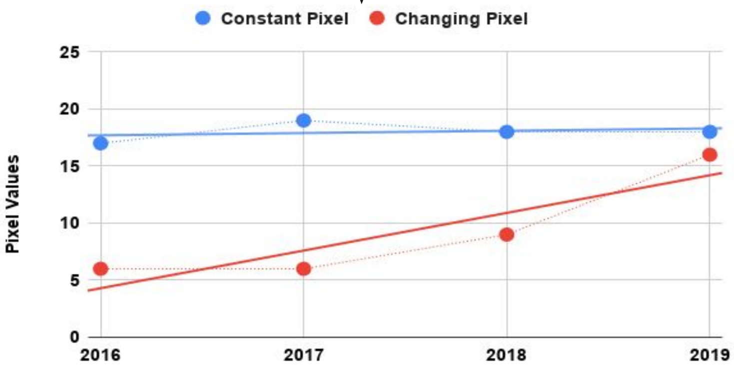

Apply Linear Regression to find constant and changing pixels

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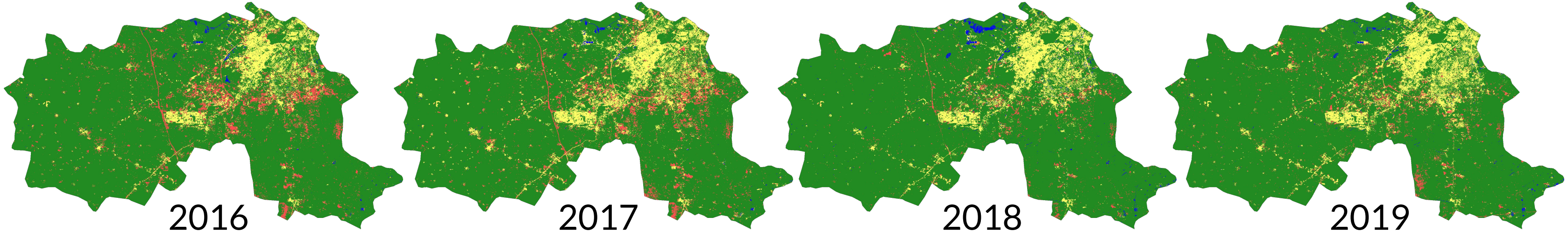

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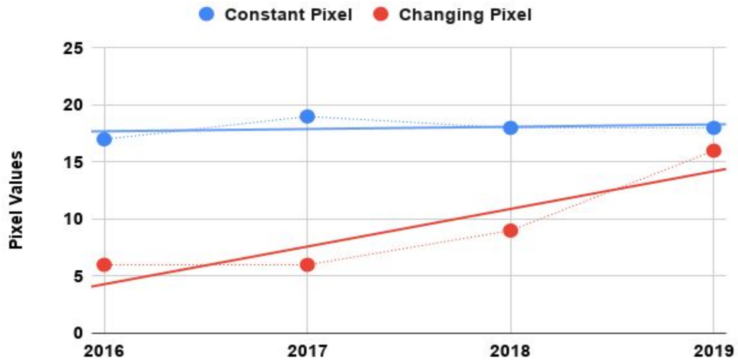

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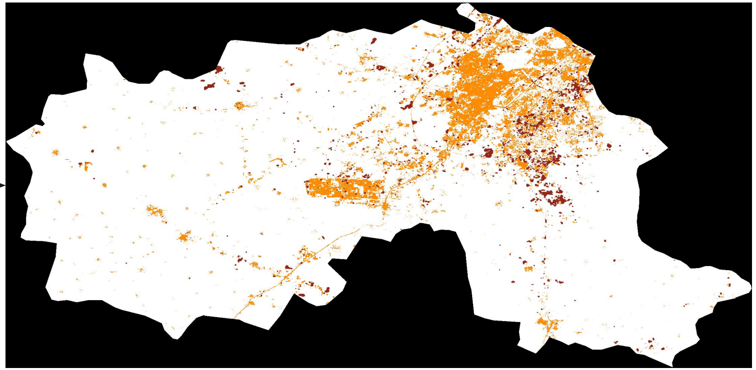

CBU/CNBU/Changing Map

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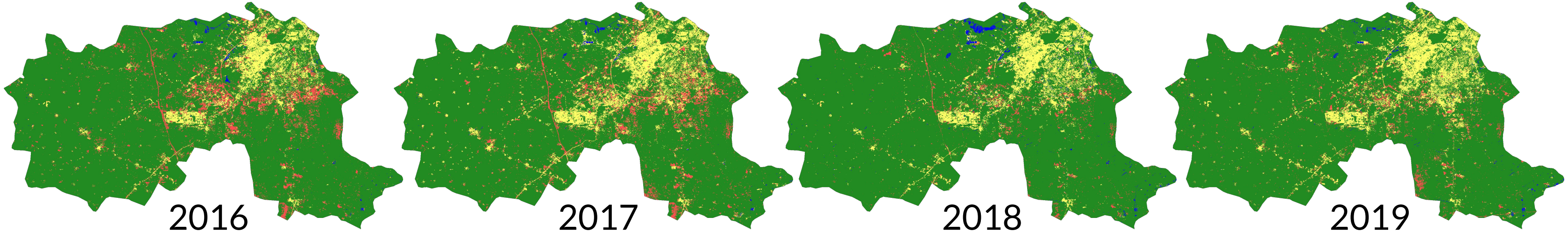

2016 2017 2018 2019

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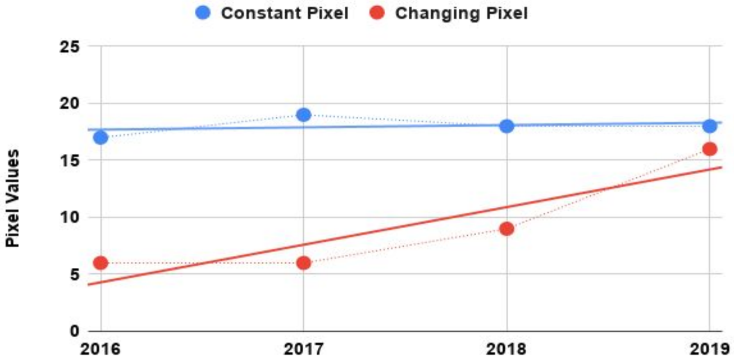

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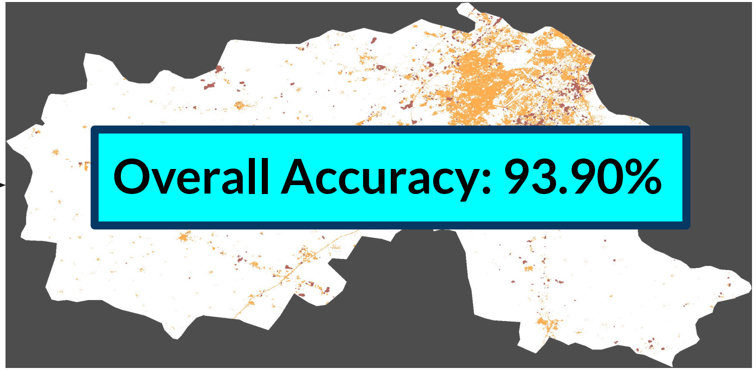

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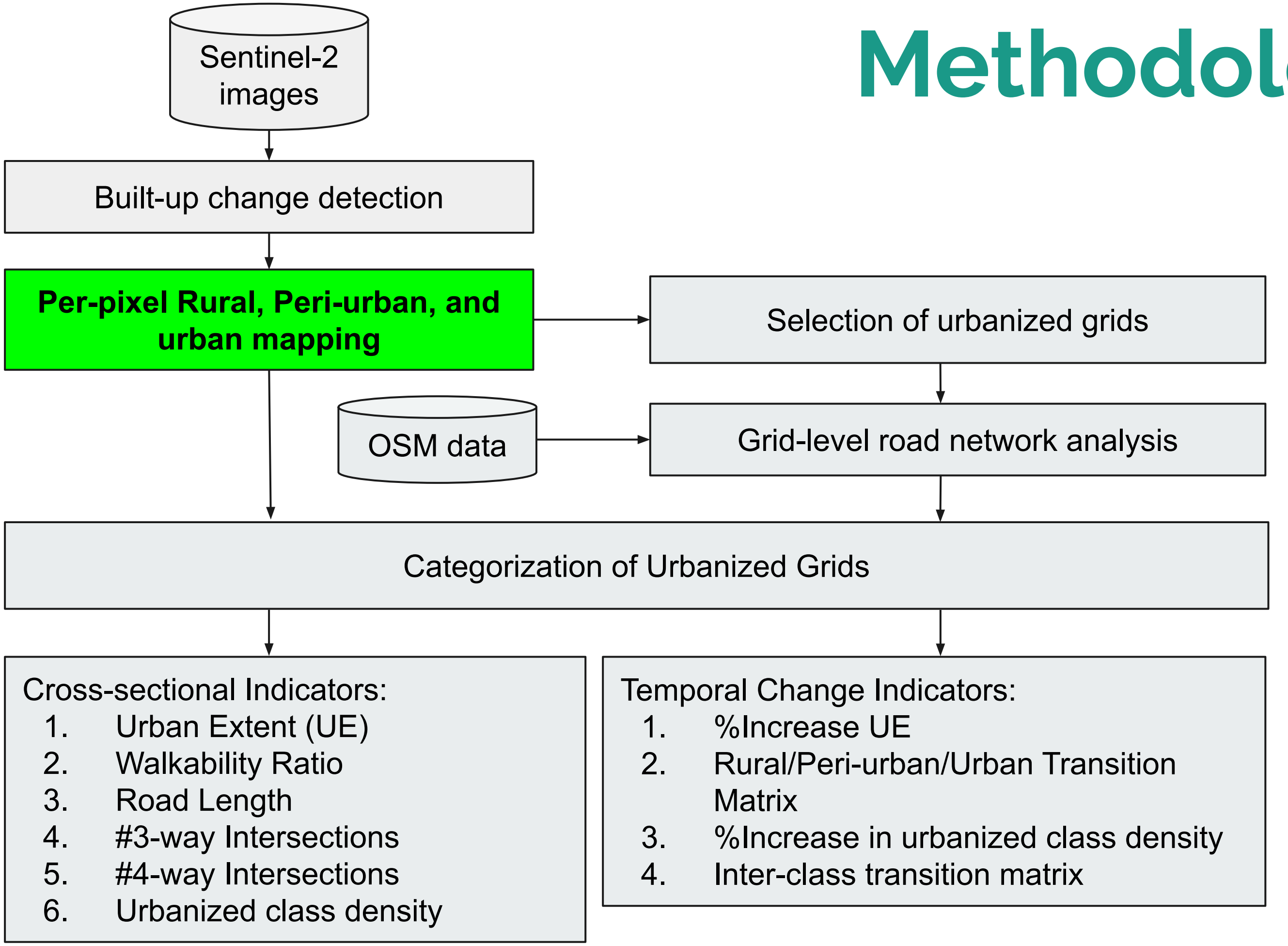
Methodology



Per-pixel Rural, Peri-urban, and Urban mapping

For each pixel, we count the percentage of builtup (BU) pixels in its Walking Distance Circle

If percentage >= 50% ----> Pixel is labeled URBAN
If 25% <= percentage < 50% ----> Pixel is labeled PERI-URBAN
If percentage <25% ----> Pixel is labeled RURAL

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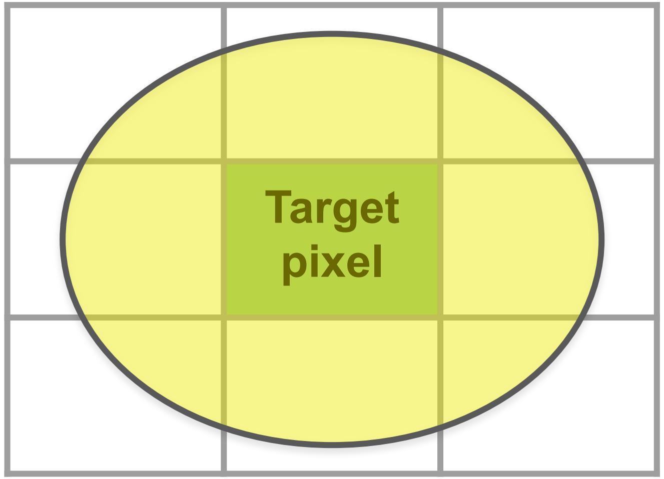

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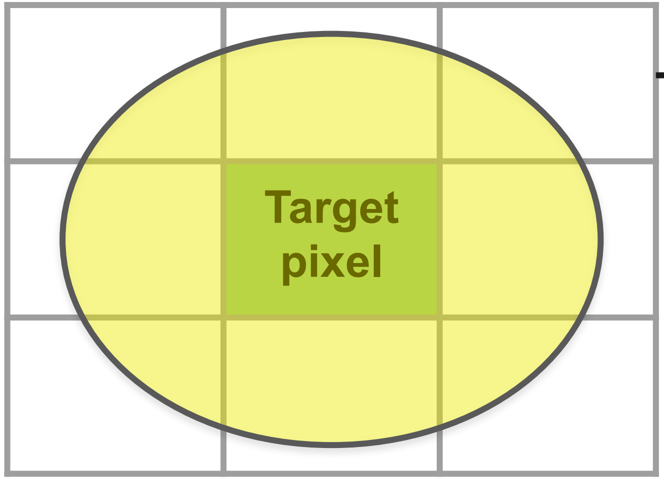
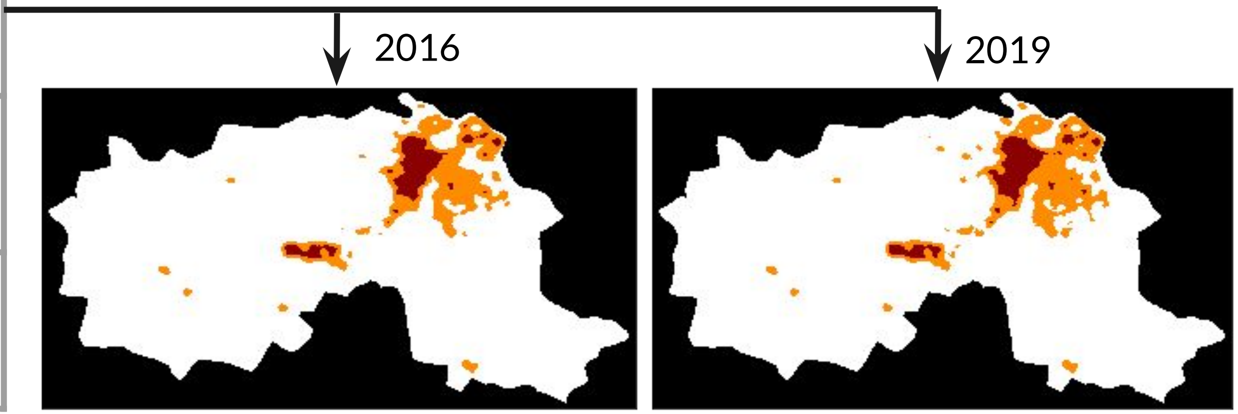


This defines the URBAN EXTENT of each city



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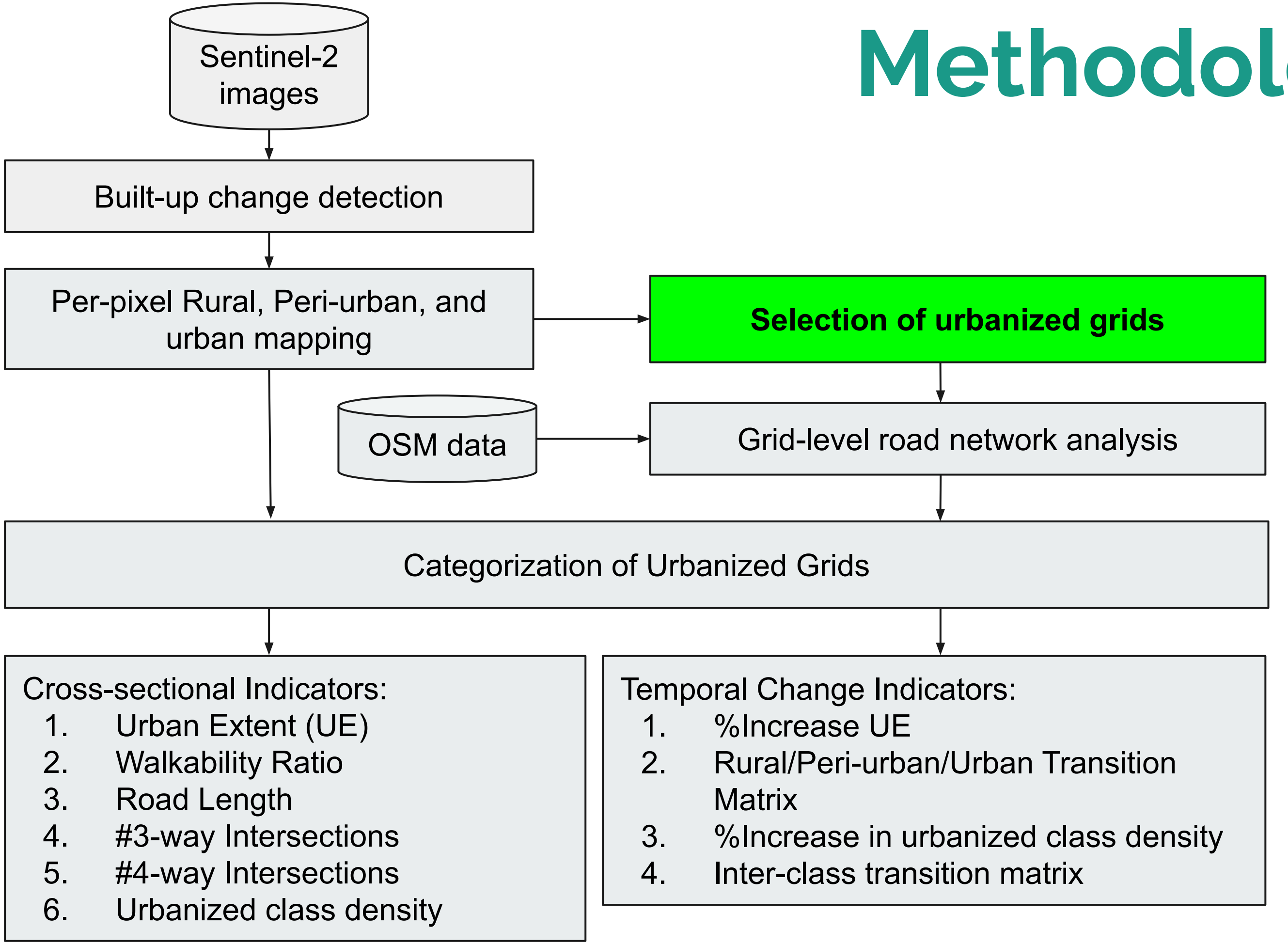

Selection of Urbanized Grids

Each city is divided into **grids of 0.01° latitude and longitud**e in size.
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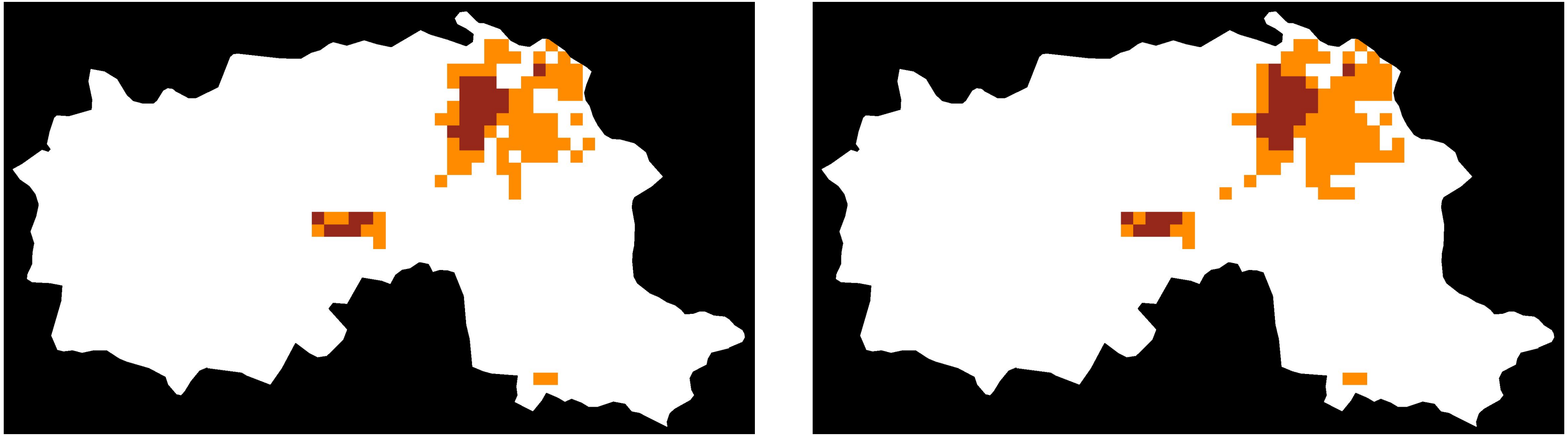
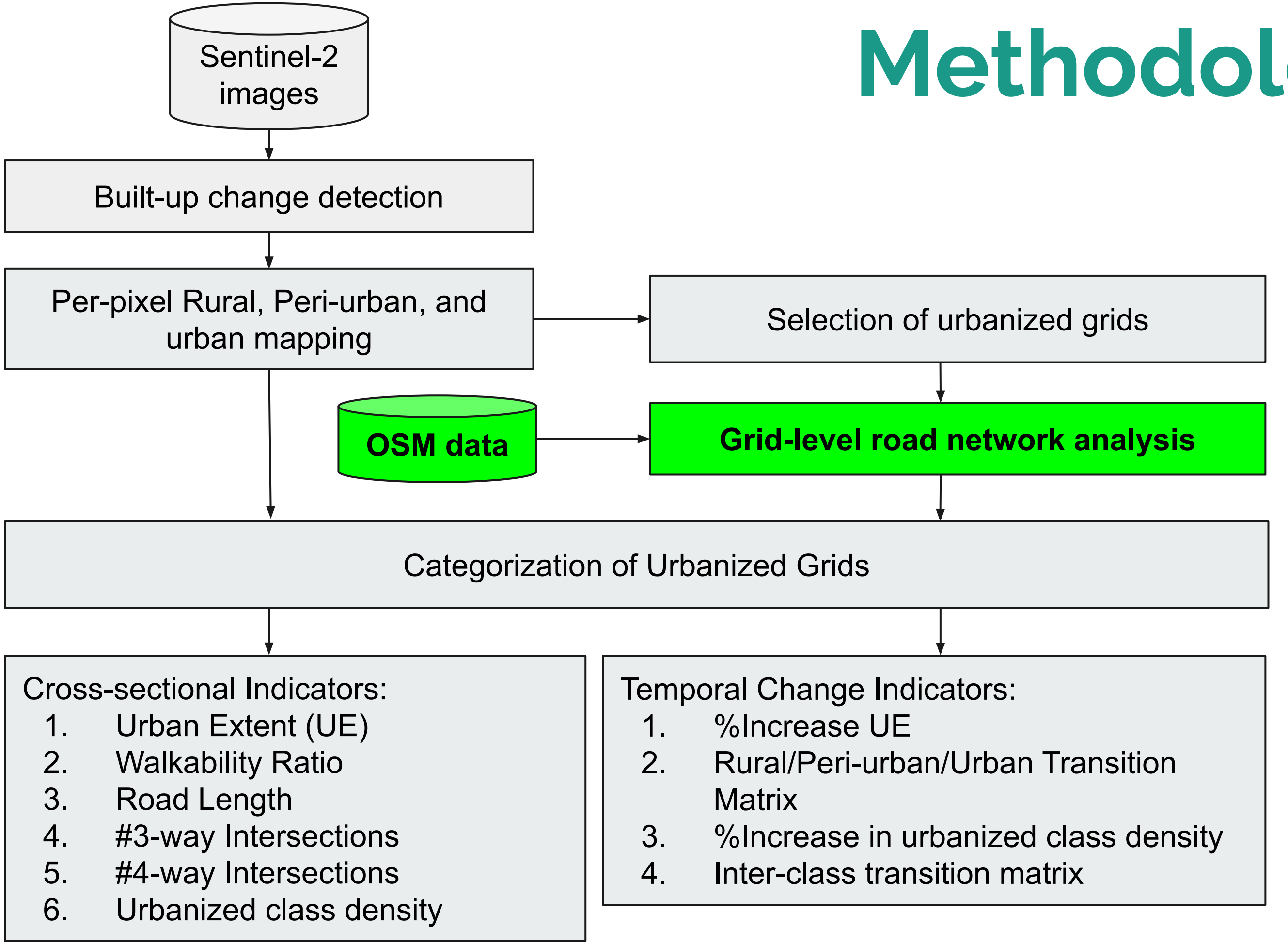


2016 2019

Methodology



Grid-level Road Network Analysis using OSM Data

For each of the urbanized grids, the road information associated with it is downloaded from the **Open Street Maps (OSM)**

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NOTE !!

We select only those cities for which OSM data seems complete, based on not very active updates being performed now

Grid-level Road Network Analysis using OSM Data

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#3-way Intersections

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#4-way Intersections

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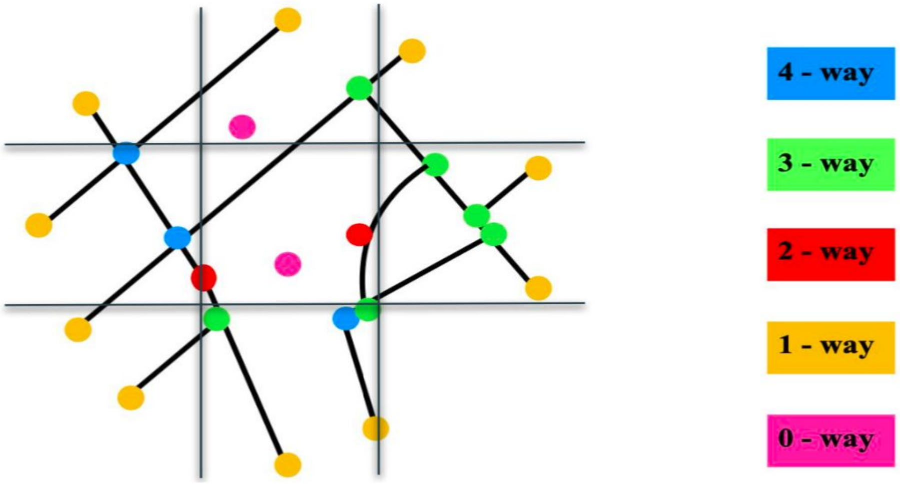

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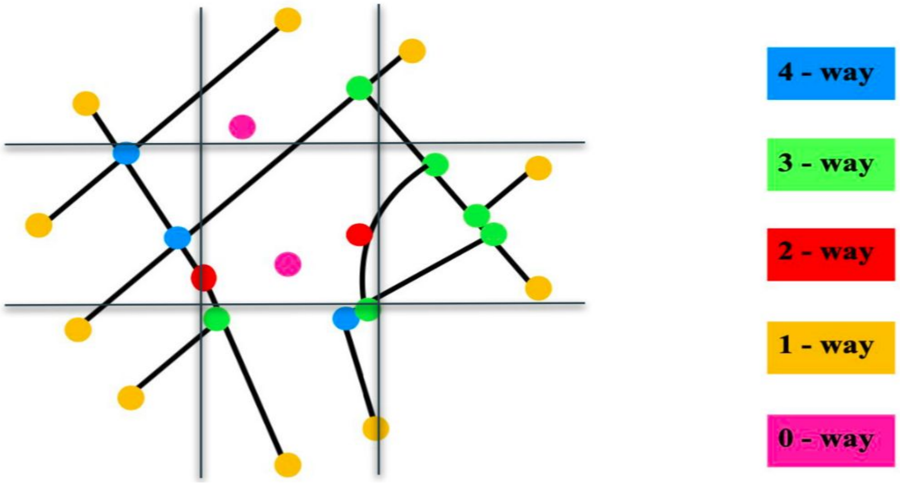
#4-way Intersections

Total Road Length



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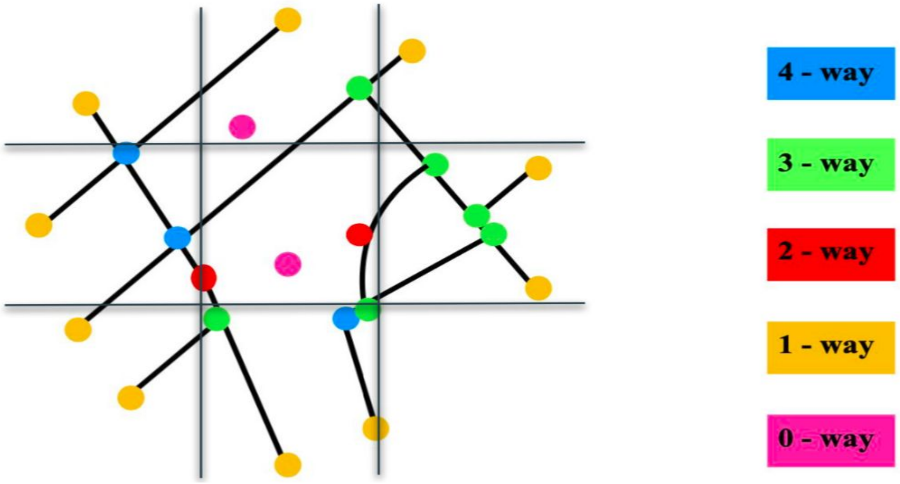
#3-way Intersections	#4-way Intersections	Total Road Length	Walkability Ratio



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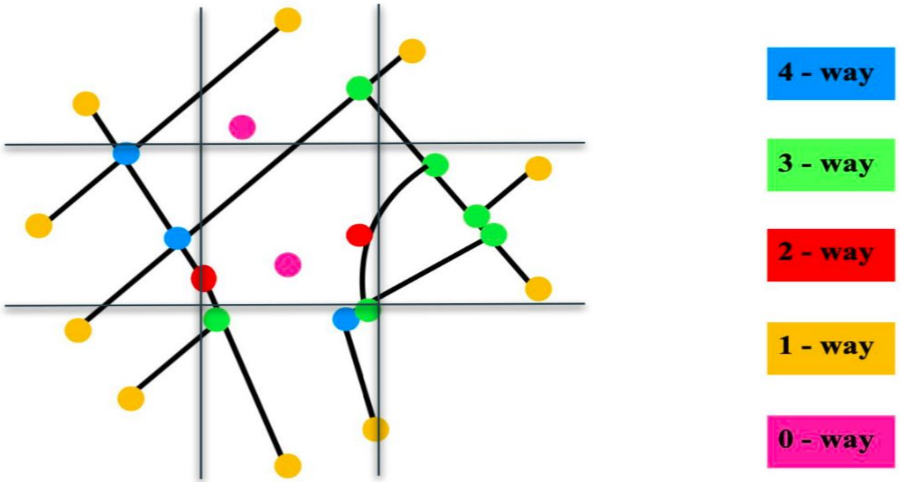
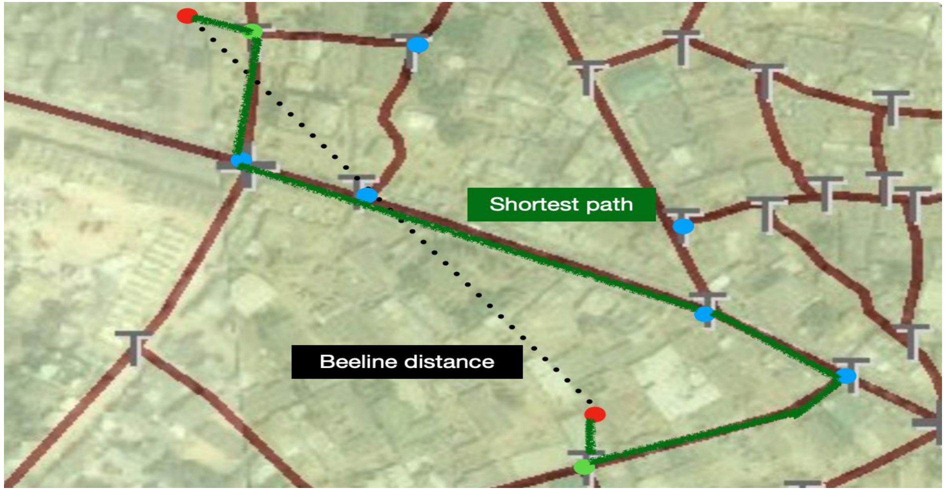
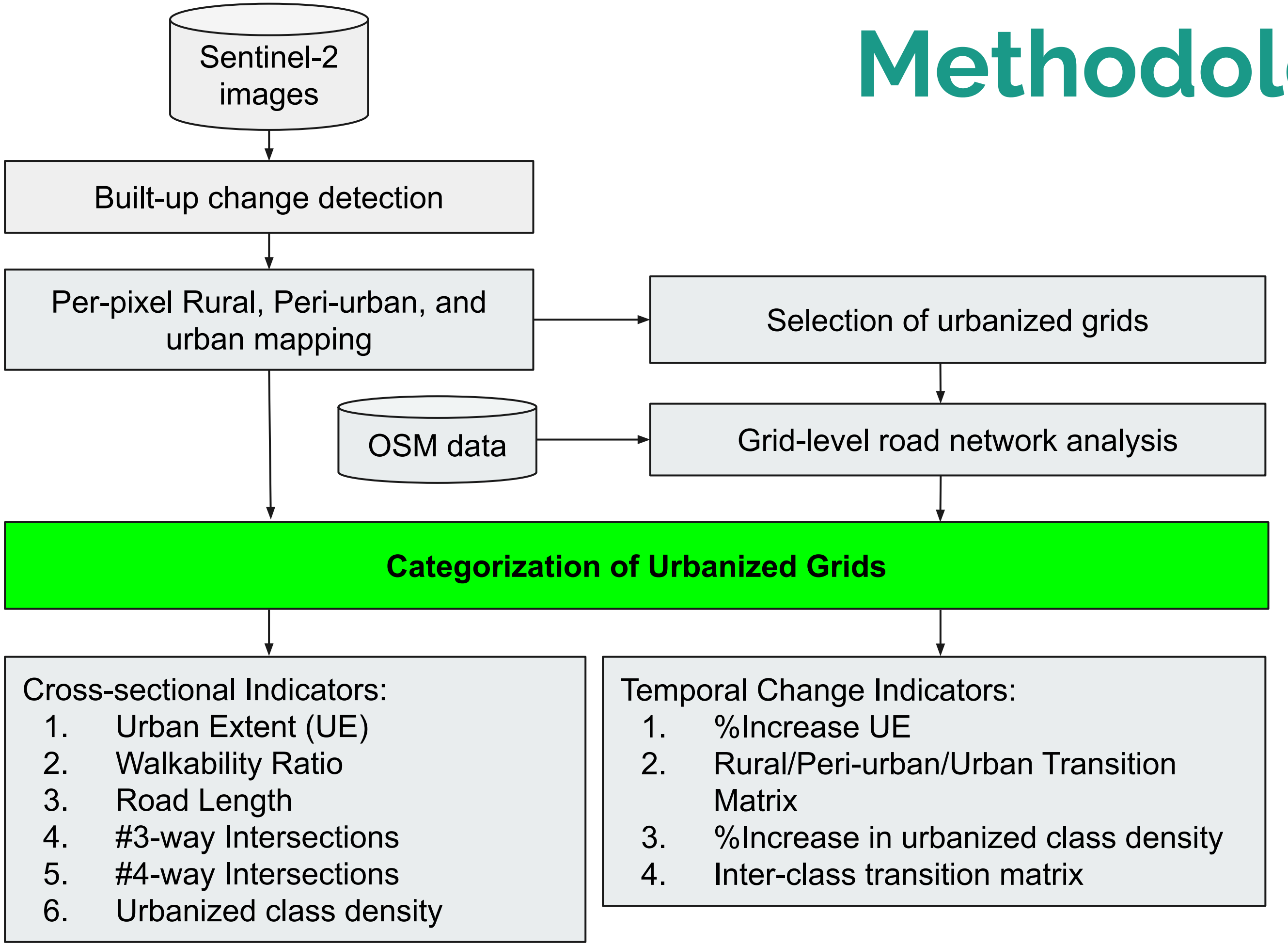
#3-way Intersections | **#4-way Intersections** | **Total Road Length** | **Walkability Ratio**





Walkability Ratio = Beeline_distance / Shortest_path

Methodology



Categorization of Urbanized Grids

We cluster the urbanized grids based on 4 parameters-
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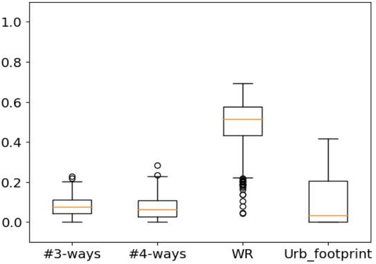

Class 1
Sparse settlements with less road infrastructure

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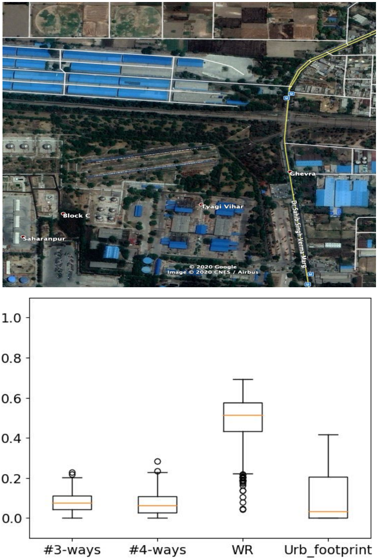

Class 1

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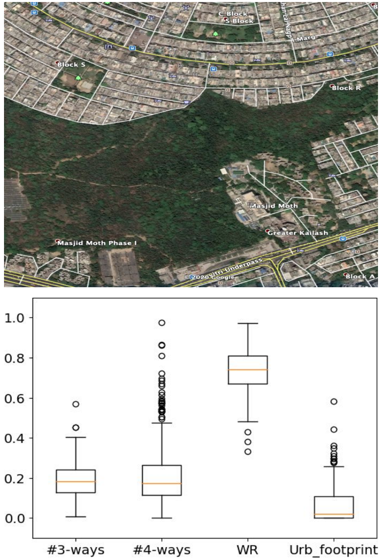
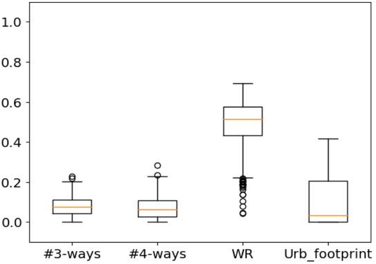


Class 2

Sparse settlements with better road infrastructure

Categorization of Urbanized Grids

Using the **Hierarchical Clustering** method, we obtain **5 Classes of Urbanized Grids**



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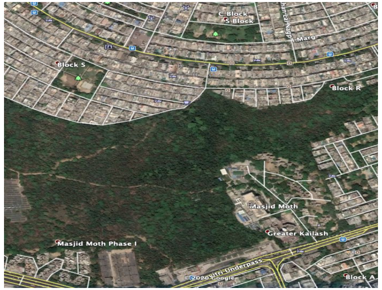
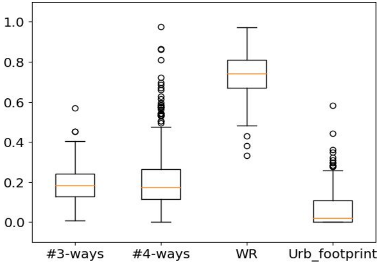
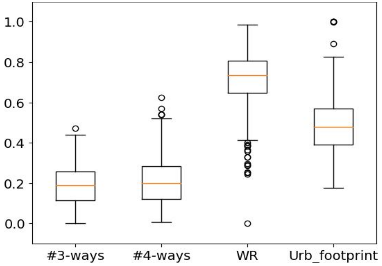




Class 2

Sparse settlements with better road infrastructure



Class 3

Moderately dense settlements with proportionate road infrastructure

Categorization of Urbanized Grids

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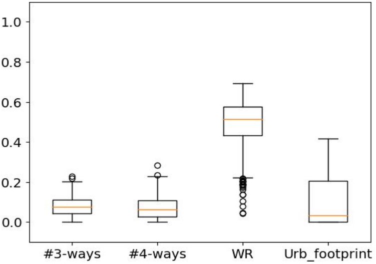

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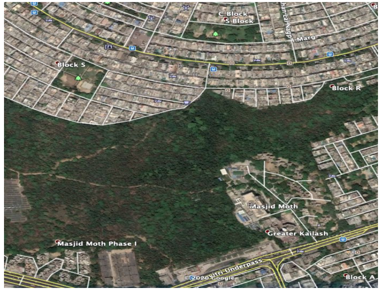

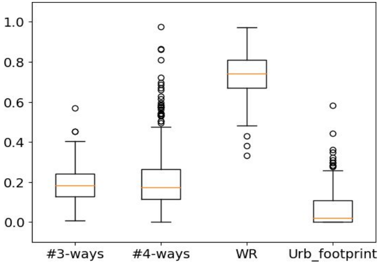

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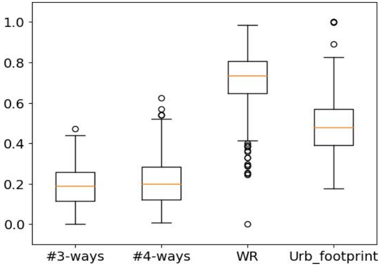

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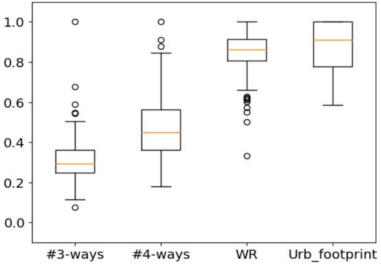
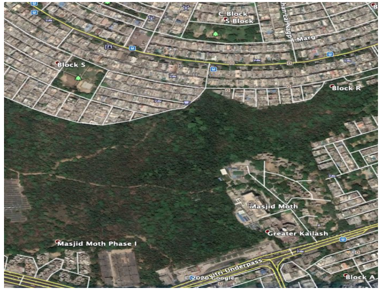


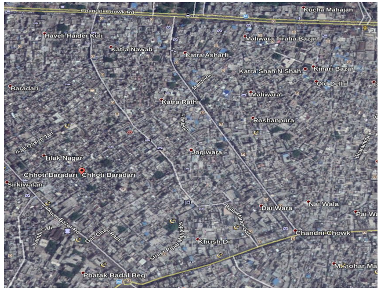
Class 4

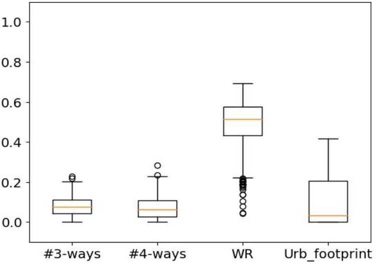
Dense settlements with proportionate road infrastructure & more formally developed

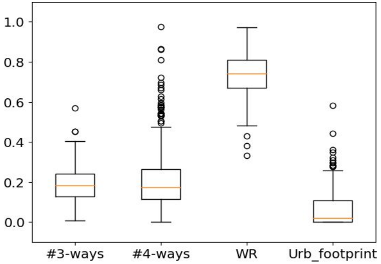
Categorization of Urbanized Grids

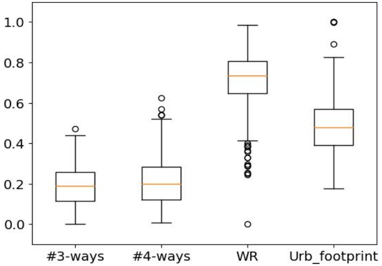
Using the Hierarchical Clustering method, we obtain 5 Classes of Urbanized Grids

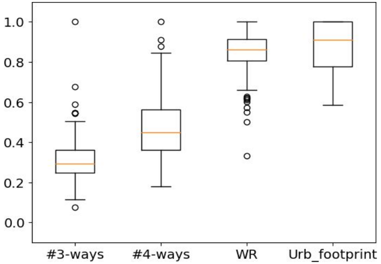



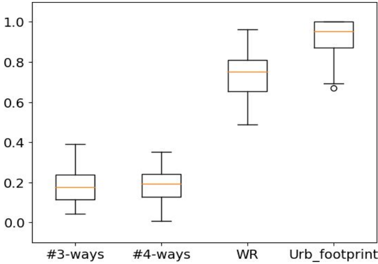













Class 1
Sparse settlements with less road infrastructure

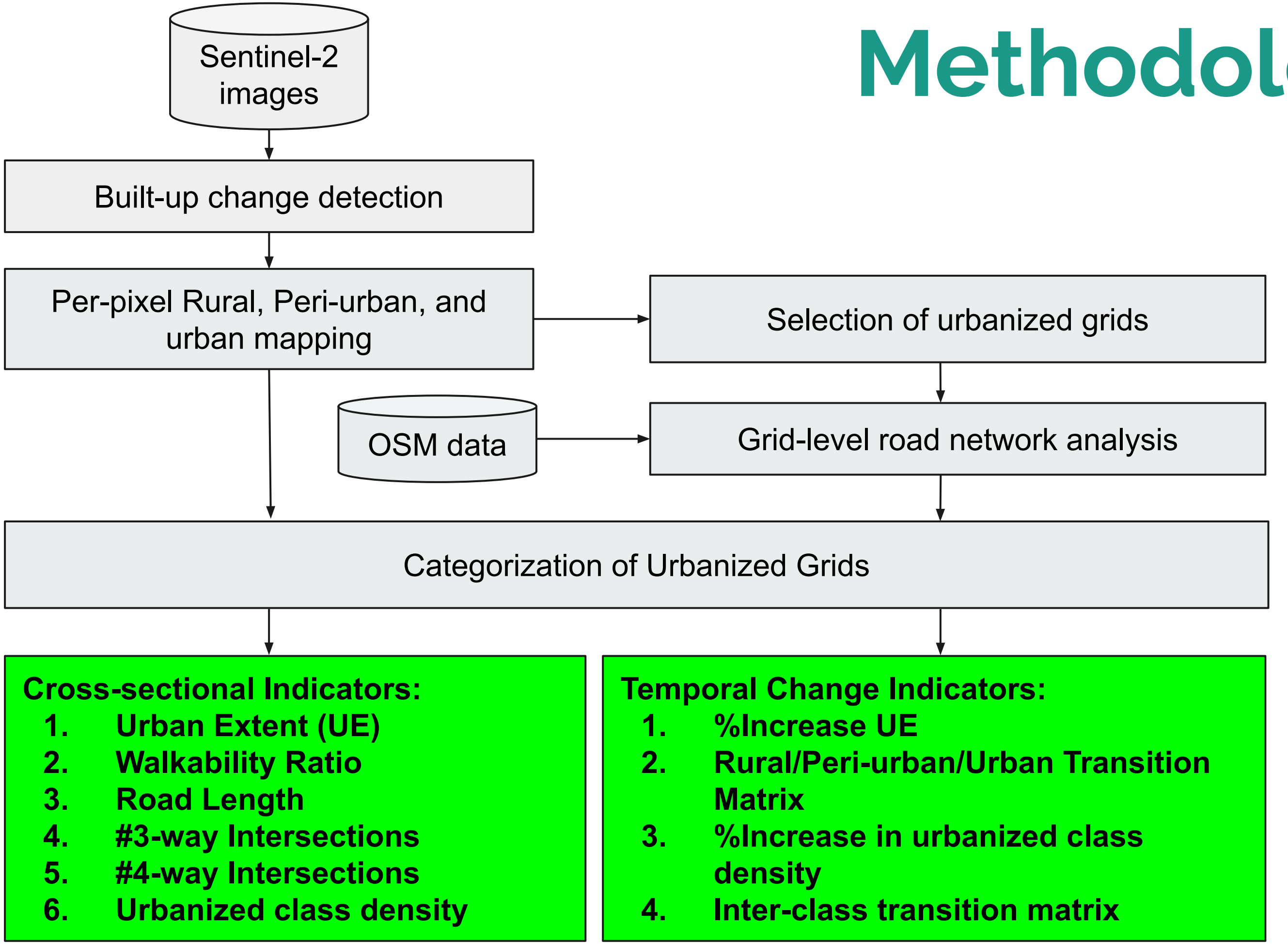
Class 2
Sparse settlements with better road infrastructure

Class 3
Moderately dense settlements with proportionate road infrastructure

Class 4
Dense settlements with proportionate road infrastructure & more formally developed

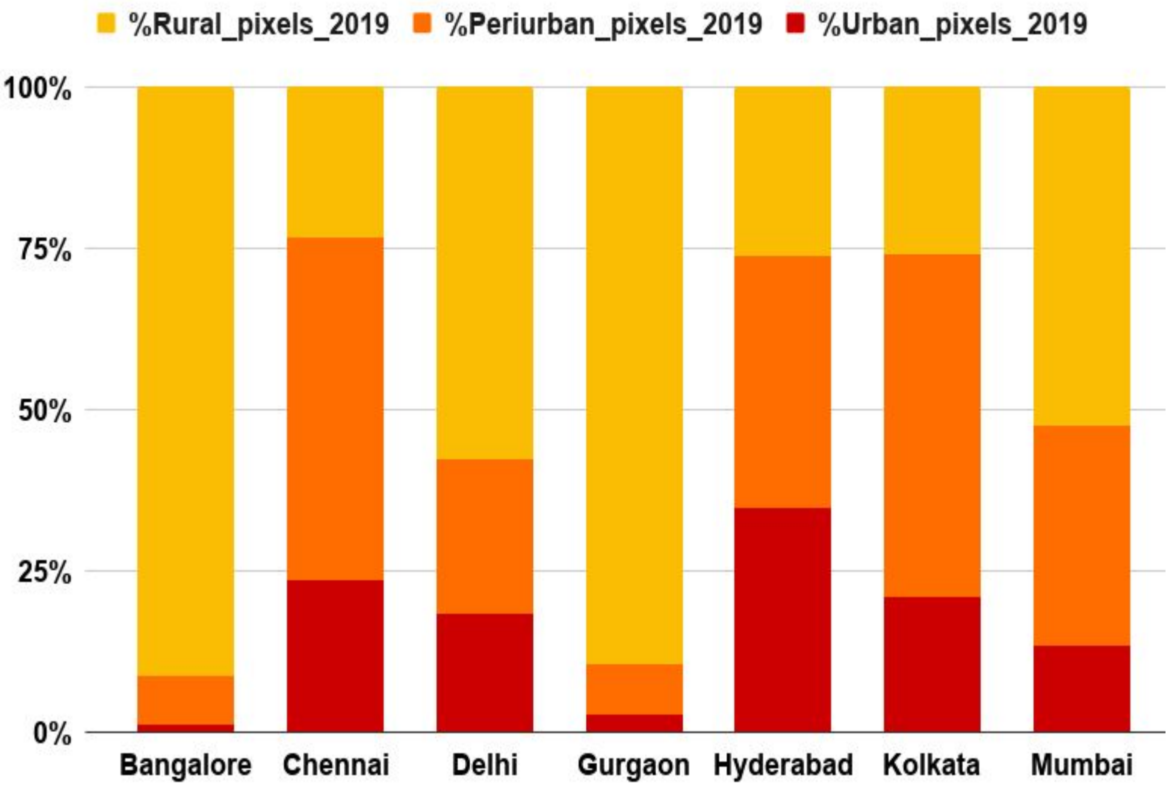
Class 5
Highly dense settlements with insufficient road infrastructure

Methodology



Results

What is the urban extent of different cities?



Urban Extent is the fraction of land in a district that has a reasonably high density of construction for it to be considered as supporting an urban or peri-urban settlement.

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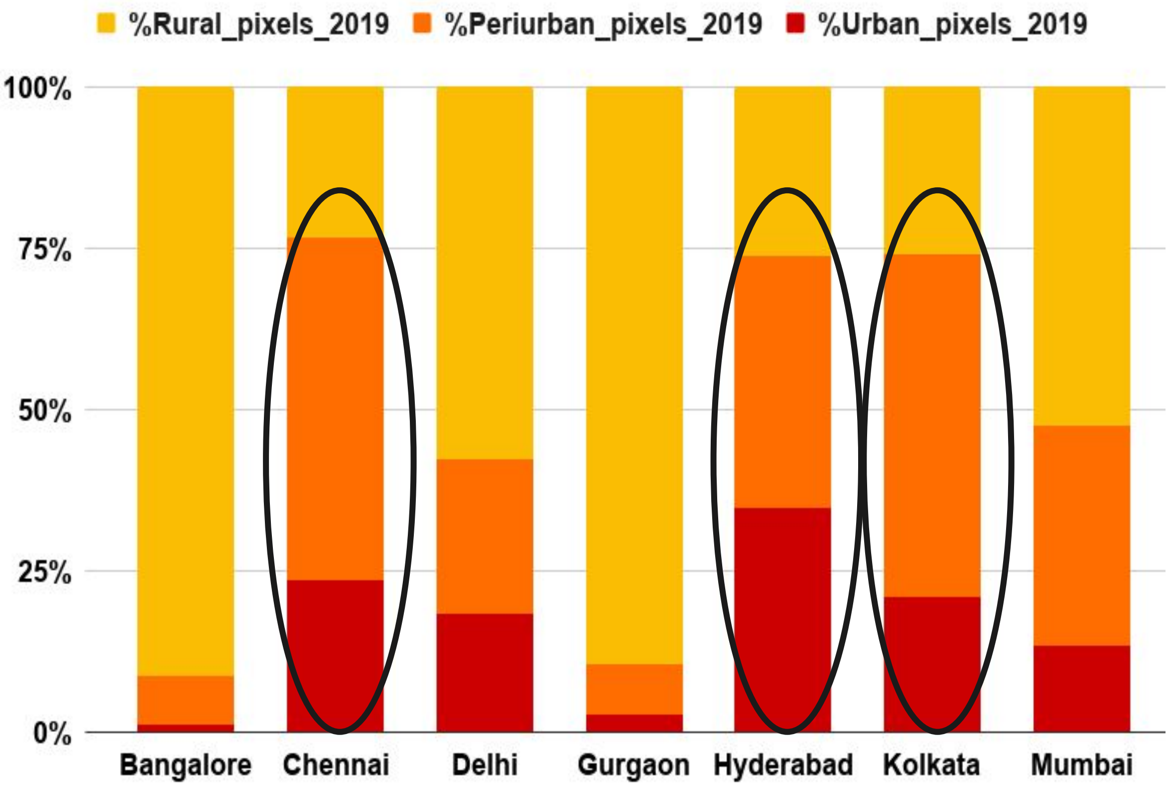

Urban Extent is the fraction of land in a district that has a reasonably high density of construction for it to be considered as supporting an urban or peri-urban settlement.

Chennai, Kolkata, and Hyderabad have the greatest urban extent, followed by Mumbai, Delhi, Gurgaon, and Bangalore.

How do cities differ in terms of the density of their urban settlements?

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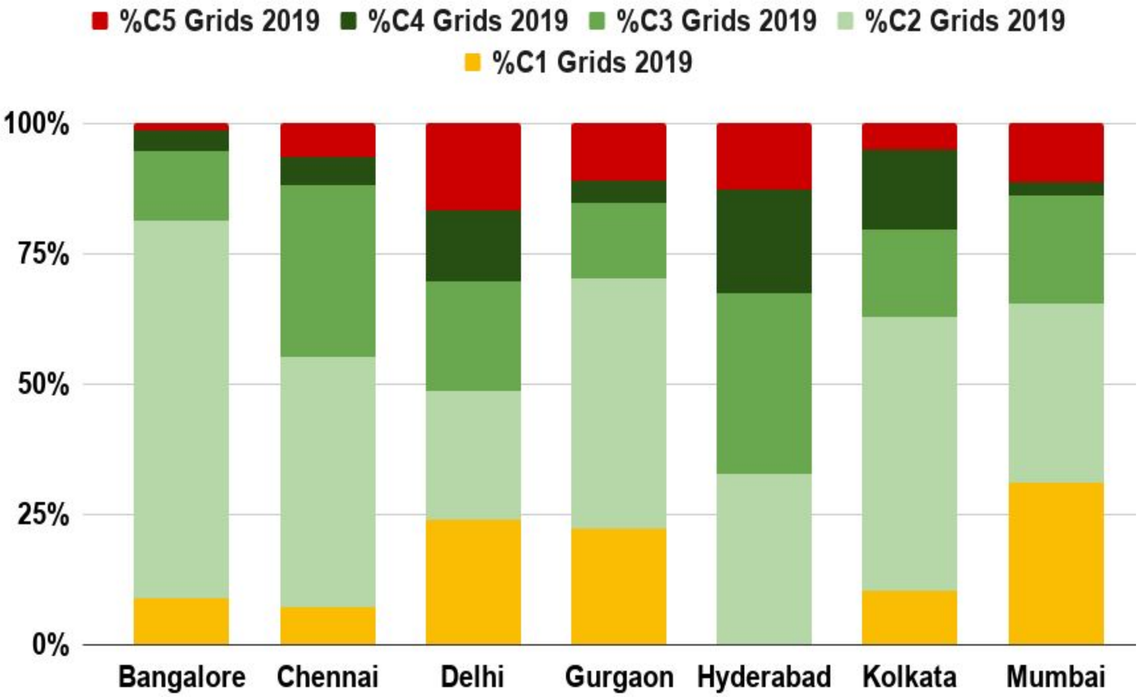

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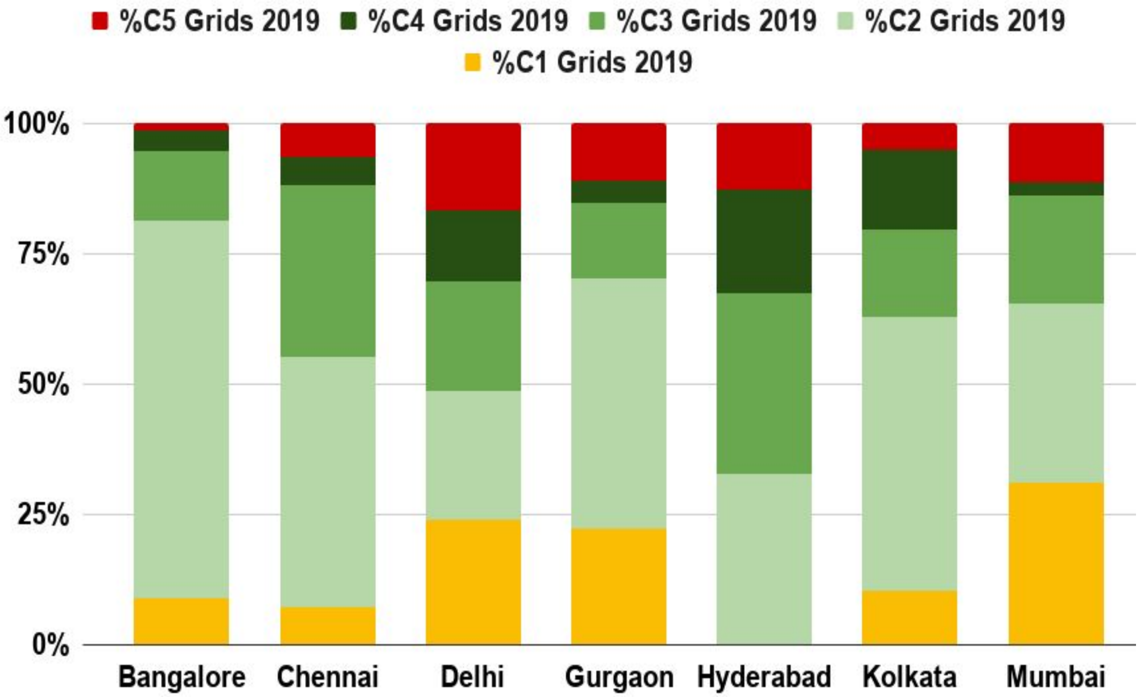

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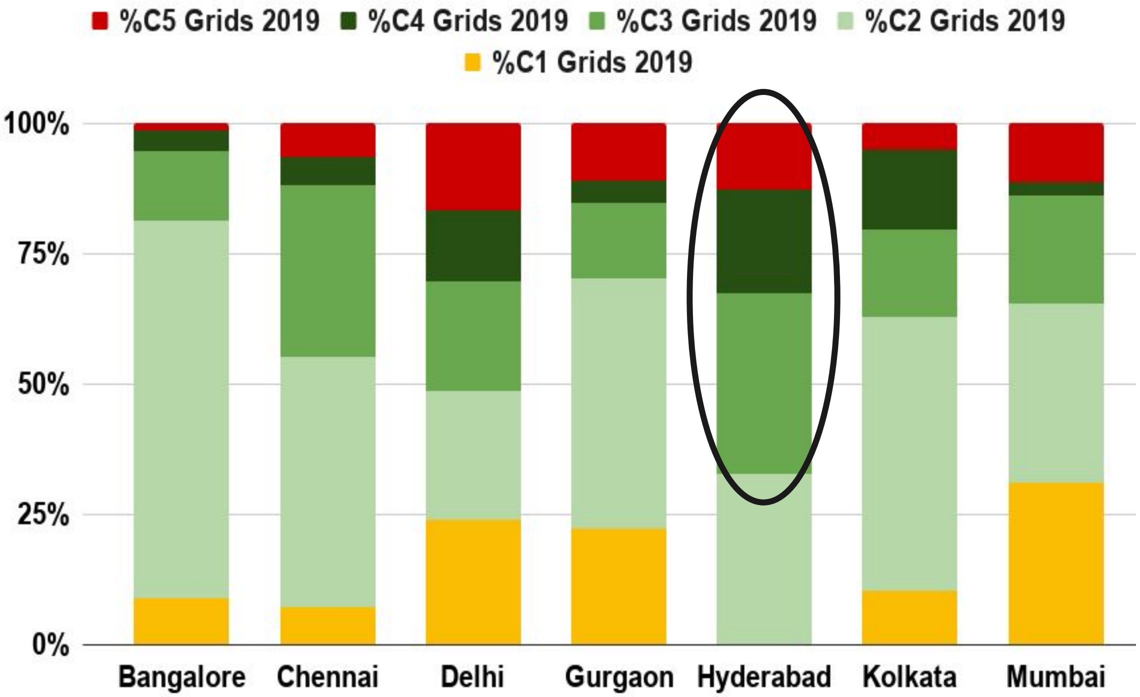

The aggregate density of C3, C4, and C5 grids indicate high density of built-up infrastructure.

Hyderabad is highly dense, followed by Delhi, Chennai, Kolkata, Mumbai, Gurgaon, and Bangalore.

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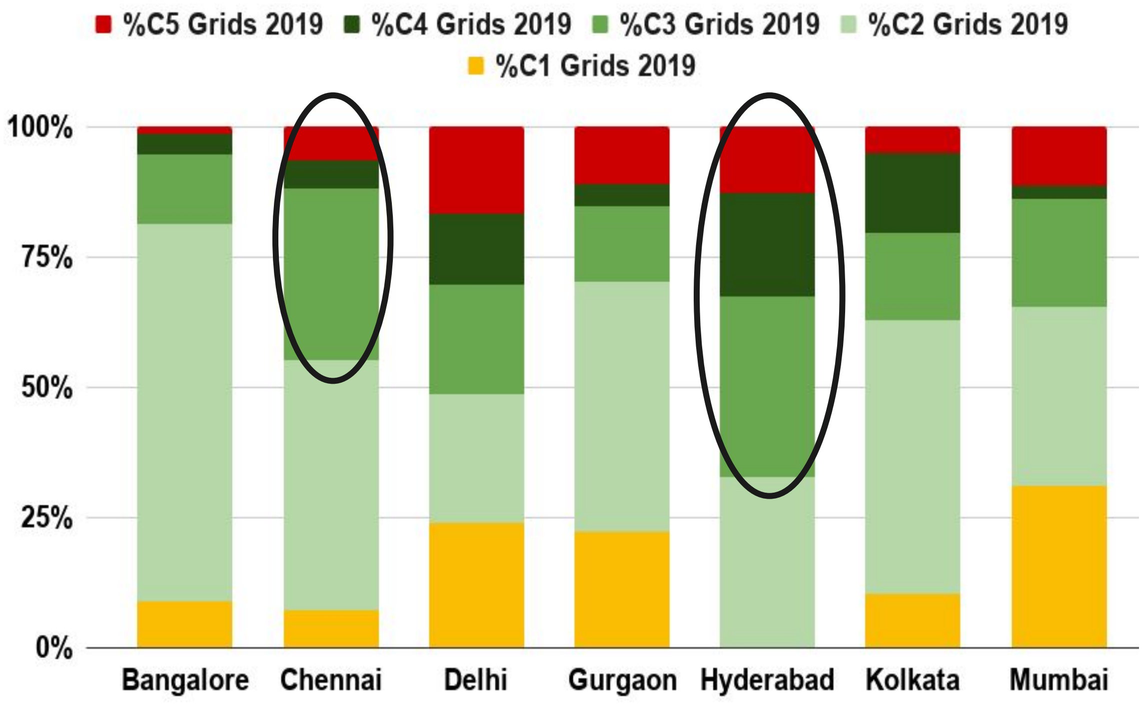
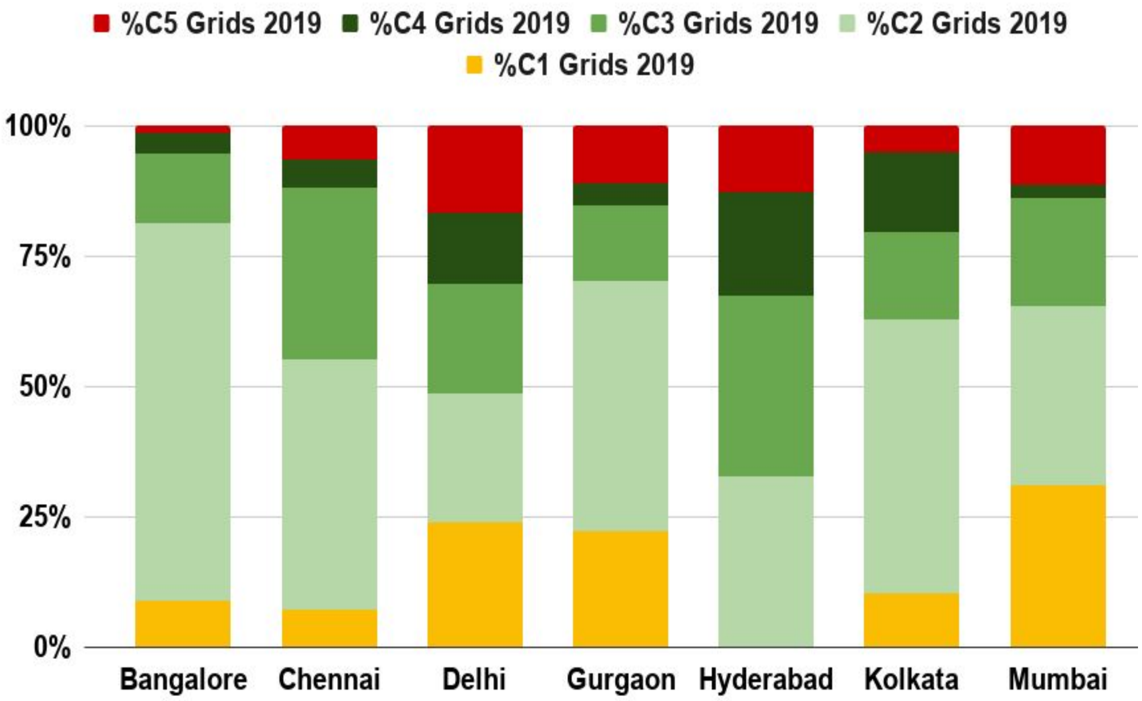


It is interesting to note that Hyderabad not only has a high urban extent, it also has a high density of settlements, indicating that the city has limited room for expansion.

Chennai also has a high urban extent, but not a very high density in its settlements.

Which cities have a large presence of densely packed areas that lack adequate road infrastructure?



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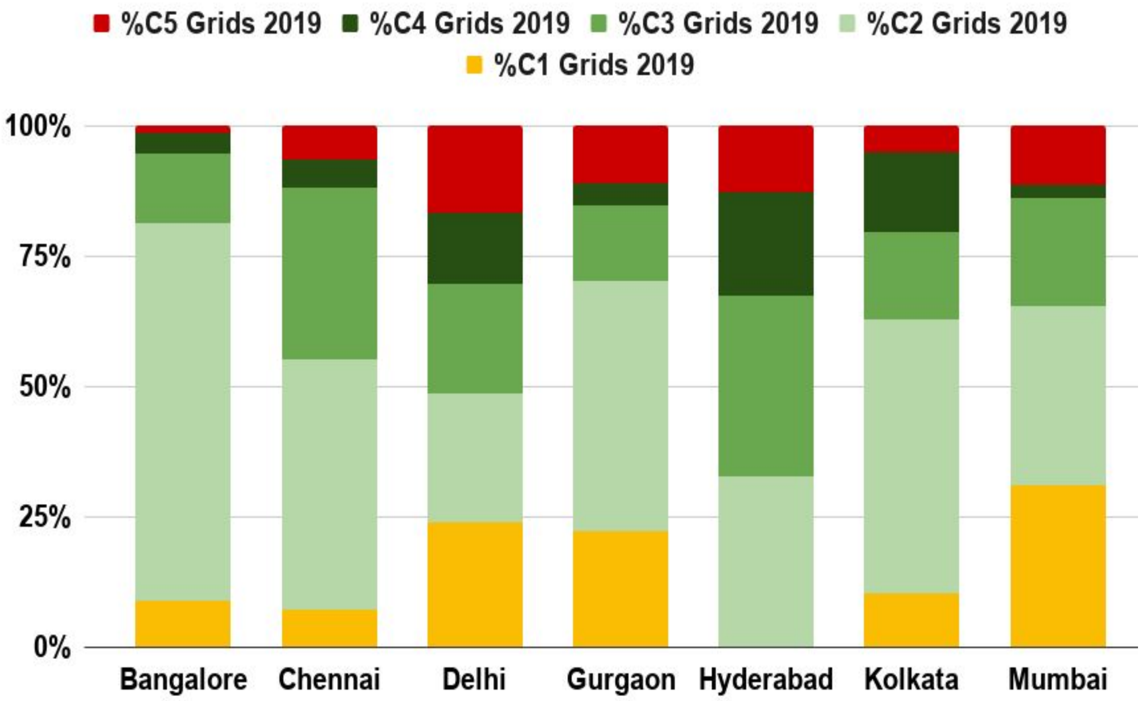

The **density of C5-grids** is an indicator of areas that are densely packed and also lack an adequate road infrastructure.

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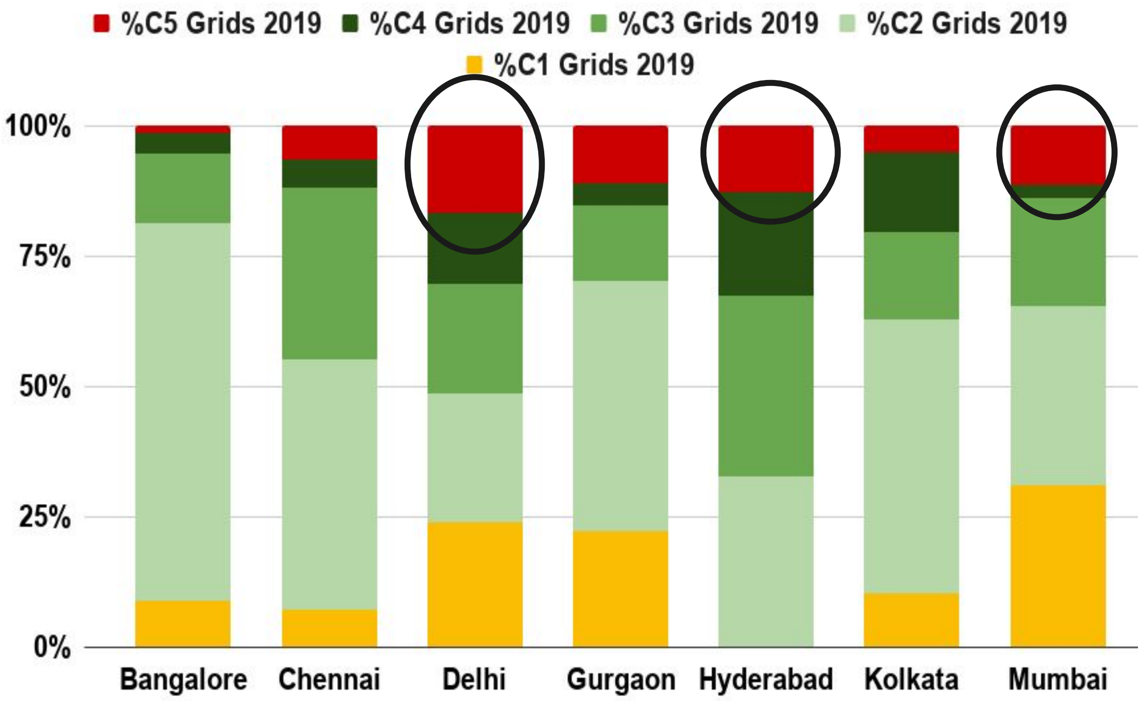

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Delhi has a high density of these grids, and is closely followed by **Mumbai and Hyderabad**.

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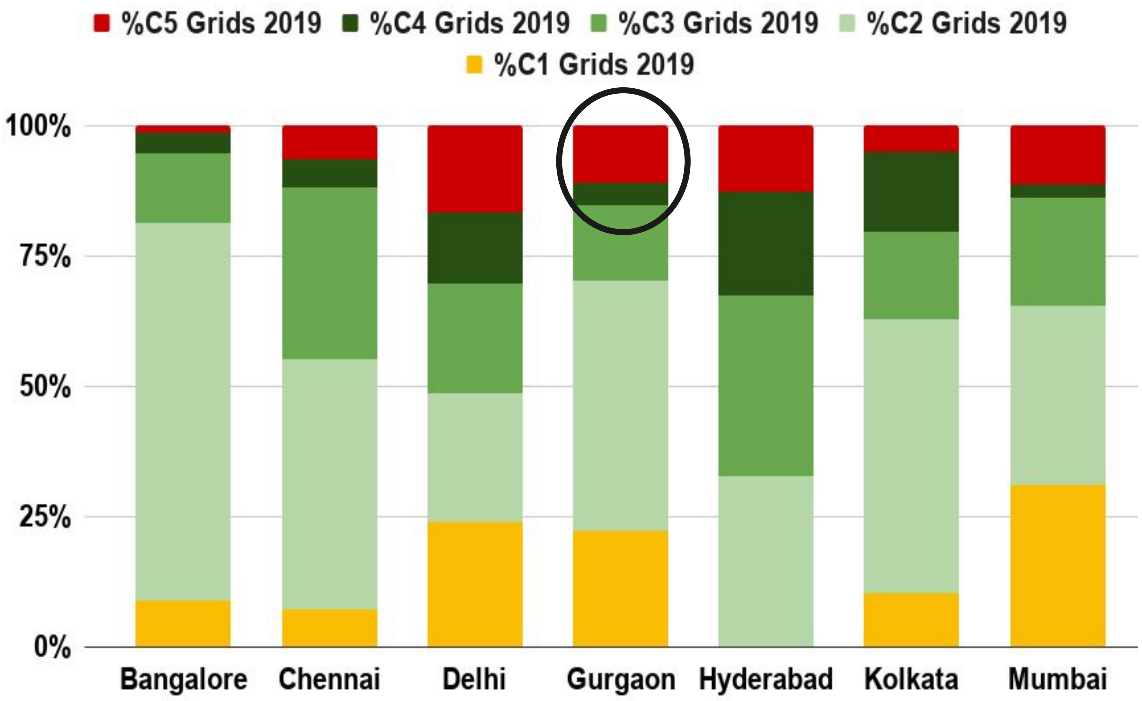

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Even **Gurgaon**, despite being a newer city with heavy industrial development, has over 11% of its urbanized grids lacking adequate road infrastructure.

What are the central hubs around which cities are organized?

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We try to answer this question based on a **heatmap visualization of road-lengths.**

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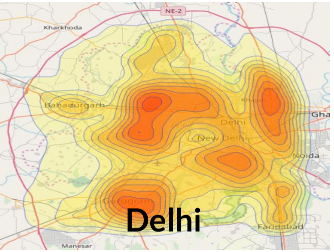

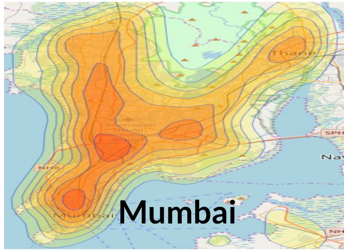

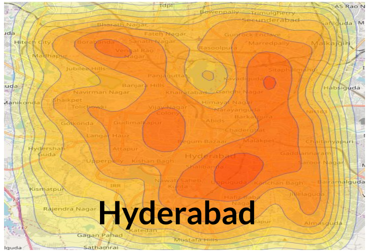

Delhi is highly polycentric having multiple urban hubs, followed by Mumbai and Hyderabad.

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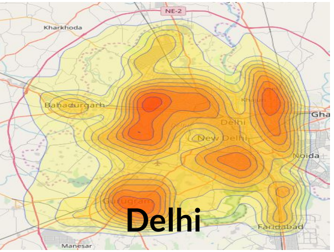

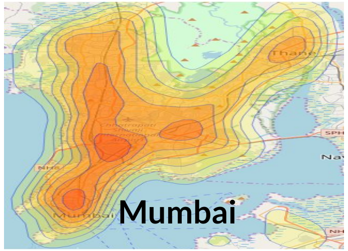

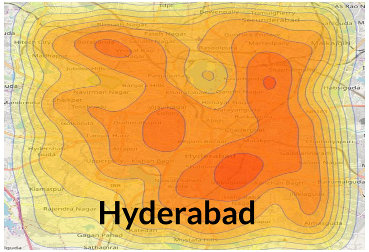

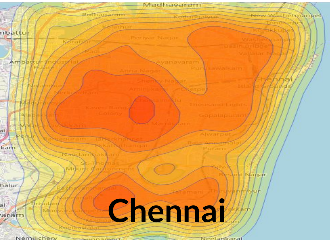

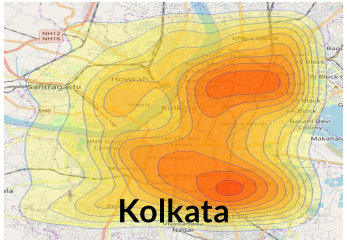

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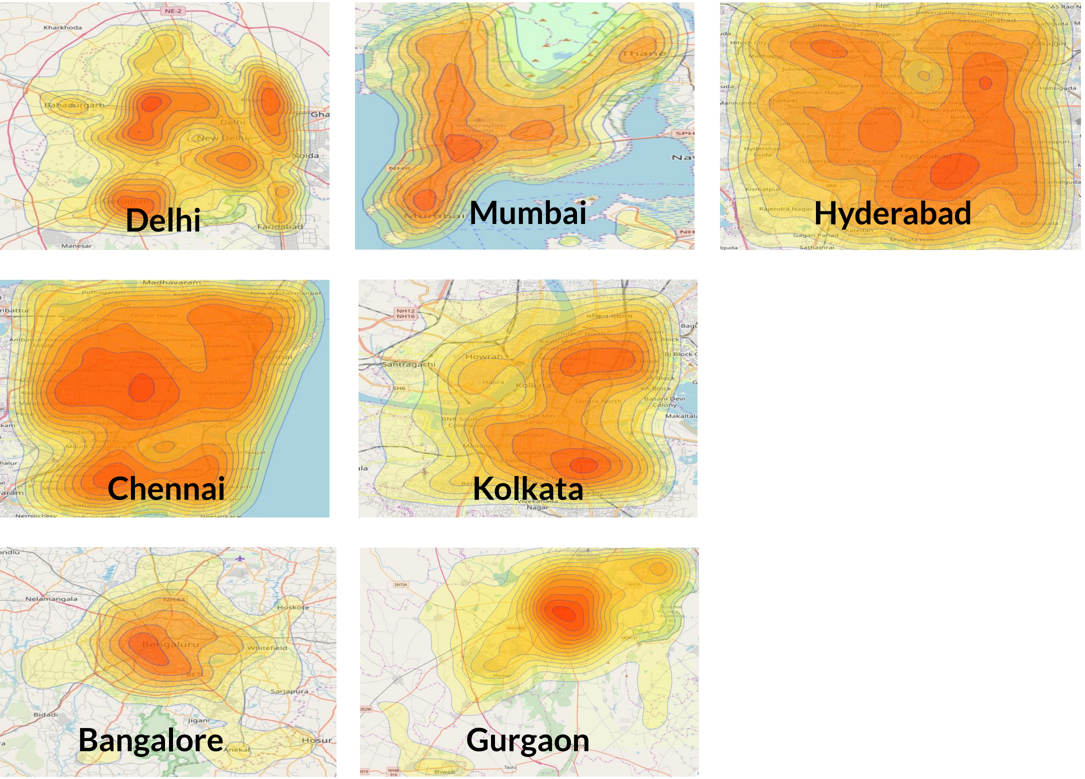

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While **Bangalore and Gurgaon have mostly grown around a center.**

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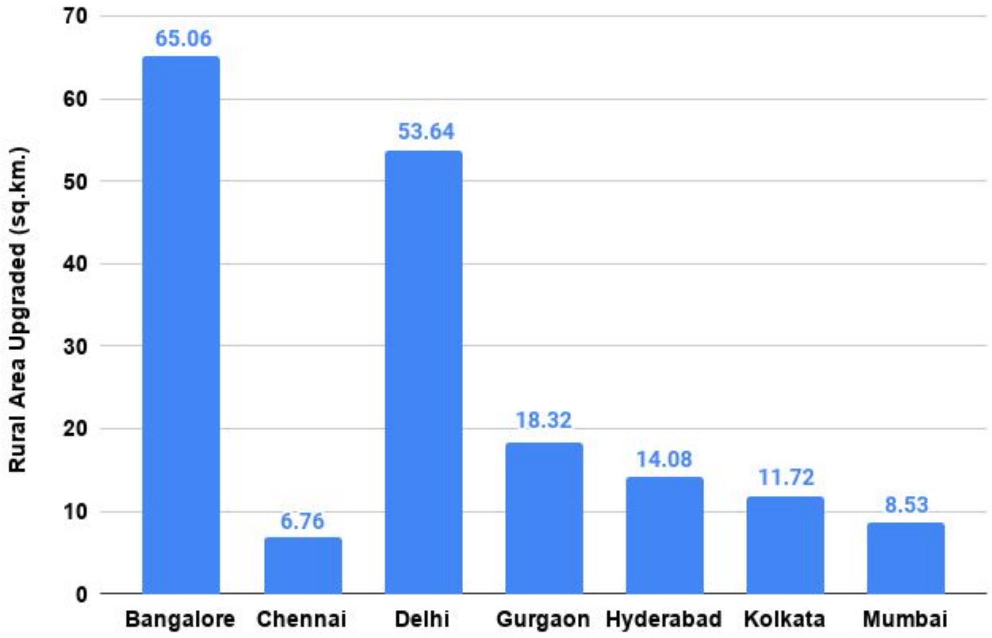

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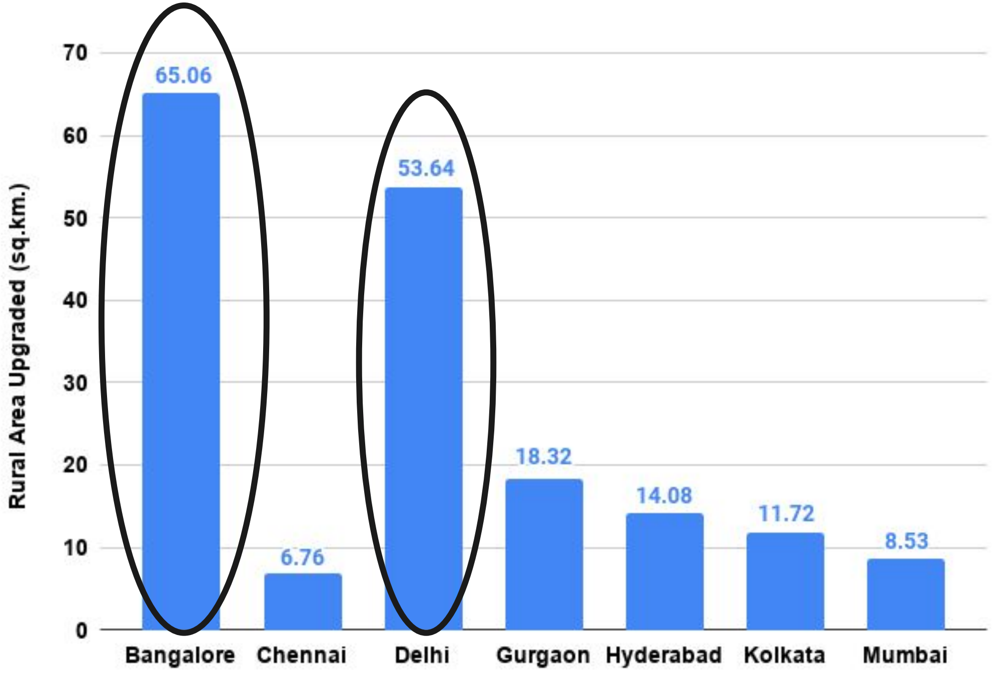

Bangalore and Delhi saw the **largest amount of conversion of rural land into urban settlements**, in terms of the absolute number of square kilometers converted.

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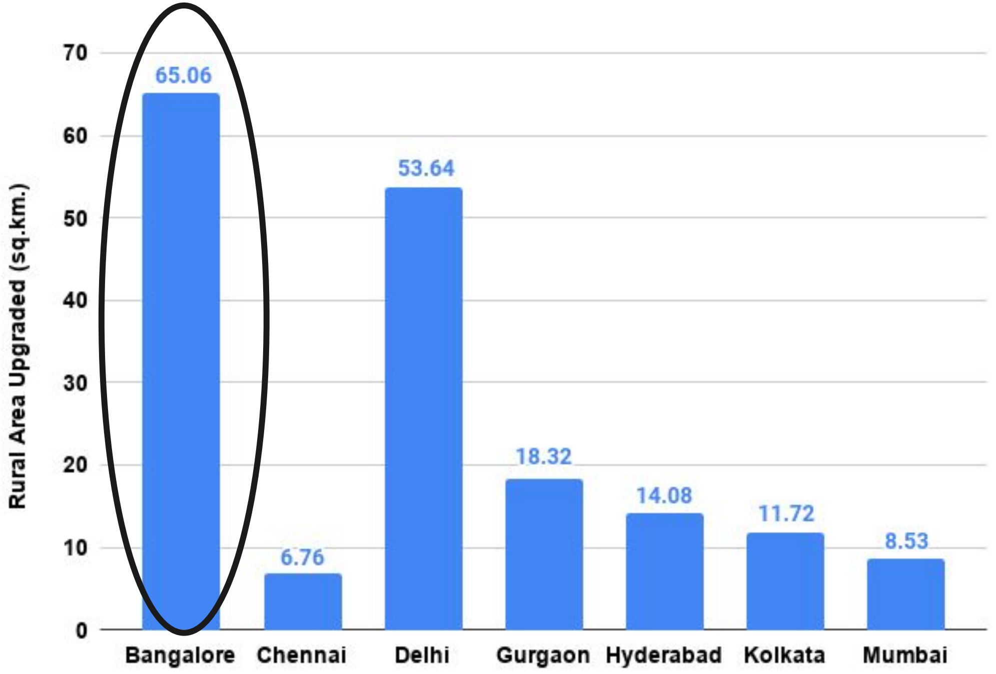

Bangalore and Delhi saw the **largest amount of conversion of rural land into urban settlements**, in terms of the absolute number of square kilometers converted.

Bangalore indeed has recently been ranked as the third fastest growing city in the world [1].

[1] Johnny Wood. 2018. The 10 fastest-growing cities in the world are all in India. https://www.weforum.org/agenda/2018/12/all-of-the-world-s-top-10-cities-with-the-fastest-growing-economies-will-be-in-india/

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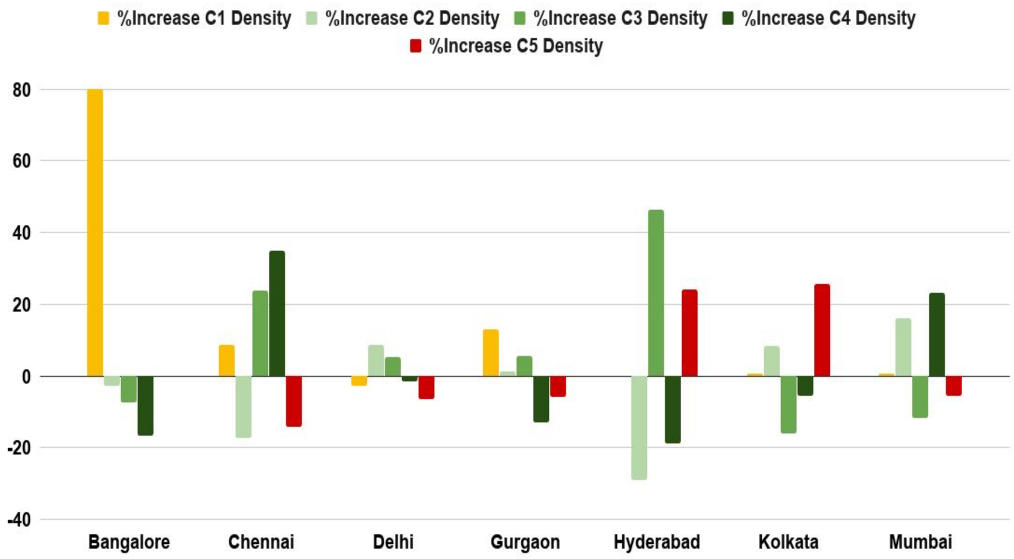

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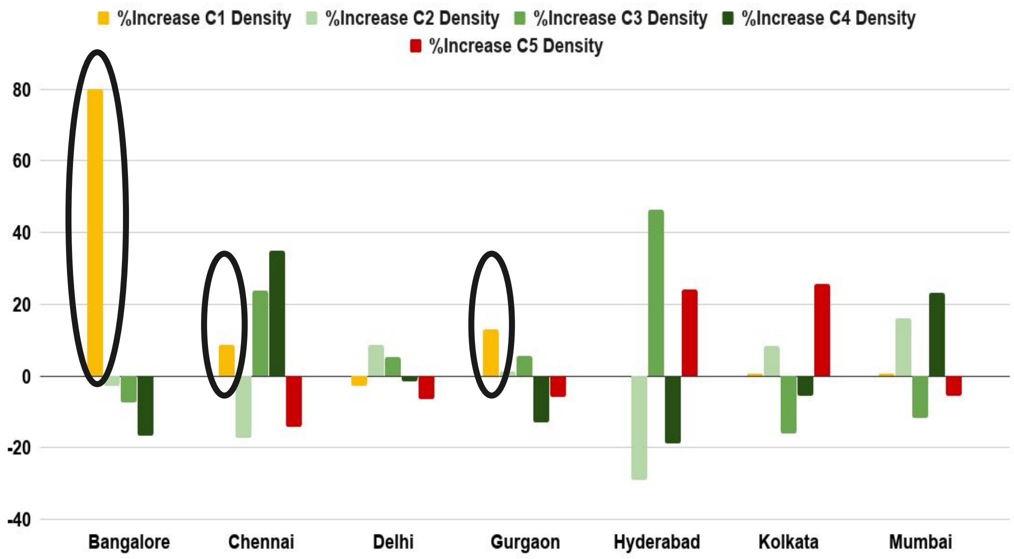

The cities like **Bangalore, Gurgaon,** and **Chennai** have a **net increase in their C1-grids,** showing that these grids indicate **emerging settlements after the year 2016.**

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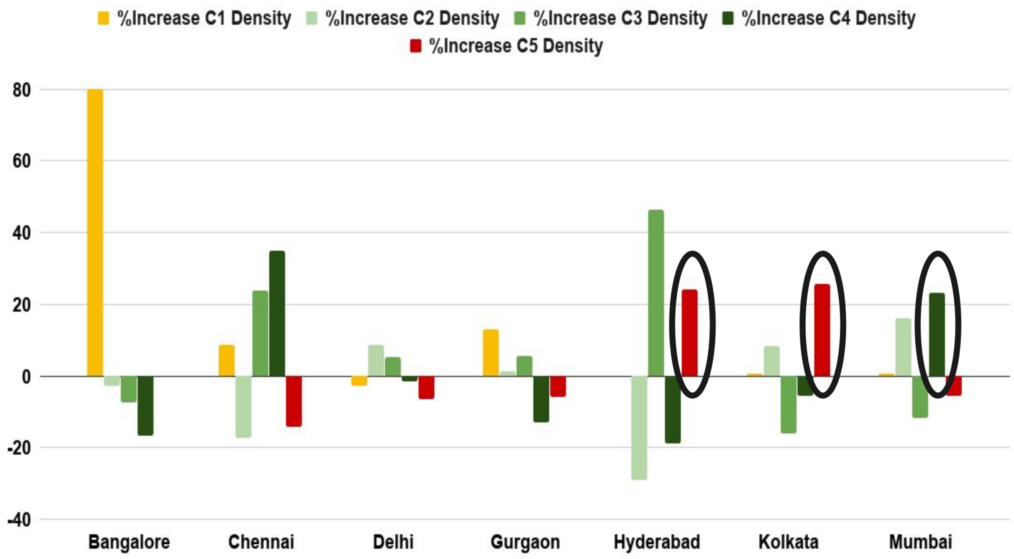

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In other cities like **Mumbai, Hyderabad,** and **Kolkata**, the **increase in the density of either C4 or C5** grids reveals an **infilling pattern of urbanization** which is making them more congested over the years.

Conclusion

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Our work goes beyond state of the art in having developed a standardized methodology that makes it possible to compare different cities with one another, track changes at fine spatial scales across the entire city, and derive a nuanced understanding of the nature of these changes.

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As part of future work, our methods can be easily extended using **alternatives like Google Maps** that have a paid API and are likely to be more complete.

Thank You

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Indian Institute of Technology, Delhi