# Tin and cement roofs in Bogota: understanding the implications of the urban expansion of Bogota through the case of Bosa and Ciudad Bolivar.

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### Abstract

Colombia's accelerated economic growth has been contrasted by its uneven geographical distribution of wealth. This inequality is evidenced by Colombia's Gini coefficient (51.1, World Bank, 2019) which is similar to Cameroon's Gini coefficient, a country without Colombia's economic growth. This secular inequality reveals how regions outside of the economic centers have been lagging from receiving the dividends of the national economic growth process. For this reason, Remote Sensing (RS) provides information not provided by the official data about the visible changes in the territory that might be connected to the economic growth. In this sense, Colombia's growth has created an influx of housing and commercial infrastructure. These capital investments have two visible detectable signs using RS: they reduce vegetation, but more importantly, they change the roofs of housing units and commercial zones. In this sense, this paper uses the visual analysis capabilities provided by Google Earth Engine to identify the urban expansion in two of the poorest boroughs in Bogota D.C. Finally, to understand if these urban expansions have increased poverty or wealth, I use image classification tools to visually test if those urban expansions have changed the roofs of the selected boroughs. Findings suggest mixed results: Bosa's expansion seems to be explained by a housing densification process with more cement roofs. Ciudad Bolivar's results seem to indicate a more aggressive process of vegetation, but the image classification was constrained to greater misclassification errors.

### Background

The economic development of Bogota has been a key part of Colombia's structural development process. According to Guerrero et al. (2020, p. 7), from 2014 and 2019, Colombia grew 3.6% which contributed to 25% of the national GDP. These GDP trend changes have not been homogenous from 2011 to 2020 given several socioeconomic shocks like protests directly affecting economic activity. For this reason, this paper focuses on a period of stable economic growth like 2014-2020. As a direct consequence of this growth and other social phenomena, Bogota has experienced an accelerated and disorganized urban expansion (Pastran, 2020).

From a general perspective, Colombia's economic growth shows a positive trend with substantial social improvements. However, the information provided by indicators like the Gini coefficient exhibit deep development gaps across its territories. This uneven growth distribution is related to the development process experienced in Colombia. Classic development economists like Nobel laurate Arthur Lewis described this structural development process as the migration of farmers to the urban centers seeking to improve their wages in nascent industrialization processes. In practice, Bogota has attracted migration from rural areas because of its concentration of employment opportunities, but also given Colombia's internal rural conflict. As a result, after the

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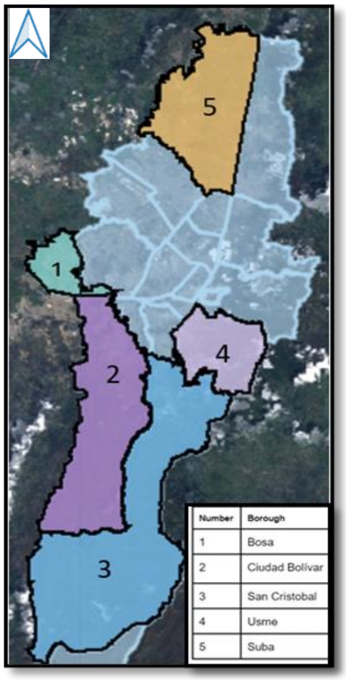
second half of the 20th century, Colombia's economic growth and internal conflict have configured a specific urban setting: Bogota's outskirts have been receiving rural immigrants whereas the center gathers the wealthiest residents (Portfolio, 2018). Bogota's urban configuration is named by urban scientists as a Concentric Zone Model primarily characterized by having extensive geographical outskirts that serve as receptive areas for the most economically disadvantaged population (Centric Zone Theory, 2022). In Bogota's case, the lack of urban planning control and the difficult conditions faced by millions of migrants during decades originated a series of illegal settlements in Bogota's outskirts commonly known as slums: houses made with precarious construction like aluminum roofs and wood to cover their house walls. According to the data provided by Techo (2015), the number of illegal settlements had an increasing period of expansion between 1970 and 1999 with 37 illegal settlements. The latest data shows a declining number of slums during the 2000-2015 period with 21 illegal settlements. The expansion of these illegal settlements has been accumulating an environmental impact that can be evidenced through the vegetation loss between Bogota's urban limits and the expansion of both illegal and legal settlements. The next section defines the region of interest and the method for analyzing Bogota's expansion in two boroughs located in Bogota's borders

## Methodology

### Regions of Interest

Figure 1 shows the boroughs in Bogota with more concentration of illegal settlements. Among the possible boroughs, the present study is focused on two localities: Bosa and Ciudad Bolivar; identified with numbers one and two within the figure's legend. The concentration of these illegal settlements obeys to the Concentric Zone model description where the areas in blue are the center of the city, and the colored areas are the outskirts where historically migrants and the most disadvantaged communities have been extending the city since the urban explosion in 1960. Bosa, identified with number 1, was chosen as a region of interest considering that it is the region with the largest acceleration rate of constructed area with 4.08% variation of square meters of new built-up areas (Celis, 2020). However, more than 50% (12.139 Ha) of the total urban area is still without urban projects that offer standard affordable housing. As a result, Bosa offers a significant sample of heterogeneous built-up areas that allow an analysis of urban expansion per roof type. The second chosen borough is Ciudad Bolivar whose urban distribution presents an interesting case for the purpose of the present study: this region has the highest deficit of housing in Bogota with 17.840 Ha (Secretaria de Planeación, 2020). Furthermore, Ciudad Bolívar represents an interesting case because it's surrounded with intensively vegetated areas. The delimitation of the region of interest was done by using the feature collection provided by the Bogota's Open Data platform and Google Earth Engine (GEE) capabilities.

**Figure 1:** Bogota boroughs with more illegal settlements




Source: created by David Castro, March 15, 2022. Representative fraction: 1:1,140,000.

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## Dataset construction

Using LANDSAT 8 raw 16-day image collection, it was filtered the collection from October to November of 2014 and 2020, respectively, considering that these months presented stable levels of precipitation and radiance. Afterwards, it was necessary to use the Simple Composite algorithm to choose the most useful pixels from the initial filtered image collection. By compositing both 2014 and 2020, an optimal image was obtained without clouds for posterior NDVI analysis.

After having clean images from the created composites in 2014 and 2020, the next step consisted in adding Bogota's boroughs using a vector layer (feature collection). These feature collections allowed for the visualization of the city borders and the city's internal administrative division. Furthermore, the attributes of the feature collection allowed to select and assign a variable name to those boroughs with the higher concentrations of illegal settlements and standard housing deficits.

Finally, in order to identify the urban expansion using vegetation reduction, it was calculated the NDVI only in Bosa and Ciudad Bolivar clipping the result only to the borders defined by the previously selected parts of the feature collection.

## Image classification: Labeled Data

I use the composited images from the previous steps to create the labels for the image Classification. Knowing that Bosa has a more diverse built-up areas that can be helpful to classify the type of roofs in other boroughs, I identified 10 areas in this borough representing different types of cement, plastic roofs, and tin roofs. These areas were verified by using Google Street Maps visor that allowed me to identify if effectively the selected areas corresponded with a disadvantaged house or a new urban development. Once the areas were verified, more than 150 polygons were created in order to train the chosen labels for image classification algorithm. The used labels were:

- Tin oxidated roof surface: aluminum roofs tend to oxidate after 2 years of being exposed to the sun and water. In this sense, there were entire blocks of houses where the tin roofs' color was brown due to the oxidation. This label contained 50 polygons.
- Cement or plastic roofs: due to the limitations of the 30 meters images to classify roofs, surfaces that have a continuous color are a good proxy to classify roofs that are either made of cement or plastic. This label had 30 polygons.
- Forest and variations of forest: this refers to two labels with the same color. Using my personal knowledge of Bogota's streets, the urban limits of Bosa had several types of vegetation cover: parcels with bare vegetation, parts of urban areas with high trees (parks), and forests defining the limits of the city. This label was assigned 40 polygons.

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## Training and data classification

Three types of labels were created (cement/plastic roofs, tin roofs, and vegetation cover) and merged in a single variable to be used with the method “sampleRegions” that converts each pixel of contained in the labels into a feature collection. This sample Region feature collection are the image attributes used by the classification algorithm to

Using the method described by Lopez (2020), a Random Forest algorithm was used with 30 trees. In order to analyze test and validate the classification, the initial sample of 150 polygons was divided into two types feature collections: testing and training samples where the latter was assigned 70% of the labeled polygons and the testing uses 30% of the remaining labeled data by using a random number GEE method. Finally, in relation to the classification method, I consider that useful to classify roofs because every time that a new branch is created, a smaller set of the stronger predictors is consistently selected among all possible image attributes. In other words, the algorithm classifies roofs consistently by using the polygons initially selected which, in principle, would help to apply the image classification training in other boroughs.

### Results

The results are presented in figure 2 (Bosa) and figure 3 (Ciudad Bolivar) on page 6 and 7. The confusion matrix indicates an overall 87% of accuracy. Furthermore, the true-positive accuracy rate of 82% indicates that the algorithm is capable at distinguishing from a forest, a cement roof or an aluminum roof with a high level of accuracy. Complementarily, the true negative of 78% indicates that the algorithm confusing several streets without pavement with a roof. In synthesis, the model can distinguish with a limited level of accuracy the three types of defined land cover considering the limitation imposed by the created labels. Finally, by changing the number of trees, the accuracy of the model does not improve which indicates that the strongest predictors to distinguish tin and cement roofs from vegetated covered areas were already consistent in the initial classification. For Ciudad Bolivar, the overall accuracy was 85% which a priori might suggest a better model fit than Bosa. However, both true positive and negative accuracy are less promising than Bosa’s classification: 77% and 74% respectively- which shows the limitations of using Bosa’s labels to classify other boroughs.

### Discussion

The images provided by the NDVI analysis show that Bogota might be sacrificing important sources of vegetation given its accelerated urban growth. For Bosa, it is notorious the vegetation loss in the northern area in both northeast and northwest corners between 2014 and 2020. What was the nature of this vegetation loss? Based on the result of the image classification for Bosa, there was an expansion of “wealthier roofs” between the period of study which provides insights in relation to the urban expansion in one of the poorest boroughs of Bogota D.C.: more urbanizations with better material roofs were created in Bosa’s most recent urban expansion which probably indicates a positive influx of capital investment connected to the periods of economic growth.

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It is interesting how the classification for Bosa shows several cores where tin-roofs are clustered and several cement/plastic roofs surrounding these poorer areas; this result makes sense considering that the first migrants who arrive to Bosa probably constructed their homes having less resources. With the successive economic growth trends, new developers searched the cheapest land to build towers and urbanizations in order to not incur in extra costs derived from purchasing land from Bosa's first residents. Finally, the classification results in Bosa suggest a second question, will the arrival of a wealthier population to Bosa gentrify the "tin-roof" population living in the borough's center and other areas? This question is pertinent because even though the classification provides some insight on the improvement process per roof type, it is not clear if this can be explained due to a new inflow of wealthier residents. For Ciudad Bolivar's case, the vegetation loss between 2014 and 2020 shows an accelerated urbanization rate. It is important to acknowledge that Ciudad Bolivar (CB) has several economic actors beside its inhabitants competing for the borough's land: the cement and sand miners are responsible for the notorious reduction of vegetation in the southwest area of Ciudad Bolivar (NDVI 2020). This category was not included in the classification labels because it is not an unknown cover area and secondly is out of the main interest of the present study. Furthermore, CB's "wealthier roofs" (cement roofs) seem to be less available than Bosa's; this suggest that CB might not be receiving the dividends of the economic growth proportional to other regions with similar socioeconomic conditions like Bosa.

## Conclusion

This paper depicts a useful exploratory technique that informs urban planners about the urban expansions of perimetral boroughs and the type of building creating those urban expansions. However, considering the accuracy limitations in the image classification step, this methodology should be scaled, first, by increasing the quality of the imagery given it might offer valuable information about the variation of economic activity without using traditional expensive instruments as surveys. Other papers like Castagno & Atkins (2018) shows how LIDAR-derived imagery might be a suitable replacement for obtaining better images in comparison to LANDSAT 8 30-meter images. Secondly, applying a roof classification requires a more robust understanding of the types of materials used by Bogota's inhabitants; roofs in middle class boroughs like Chapinero are radically different from the wealthiest roofs in Usaquen. Therefore, it would be useful to improve labels by developing an accurate dataset containing a representative roof sample per borough. Finally, having clearer information regarding the roofs per borough would ultimately improve the accuracy of the classification at the moment of scaling this methodology in poor and rich neighborhoods; in other words, this would improve true-negative and true-positive accuracy rates. Finally, the present methodology should not replace a causal analysis assessing the relationship between economic variables that might explain the observed phenomenon. However, these results should motivate and support further research to understand how poverty changes over time and space in Bogota at the neighborhood level.

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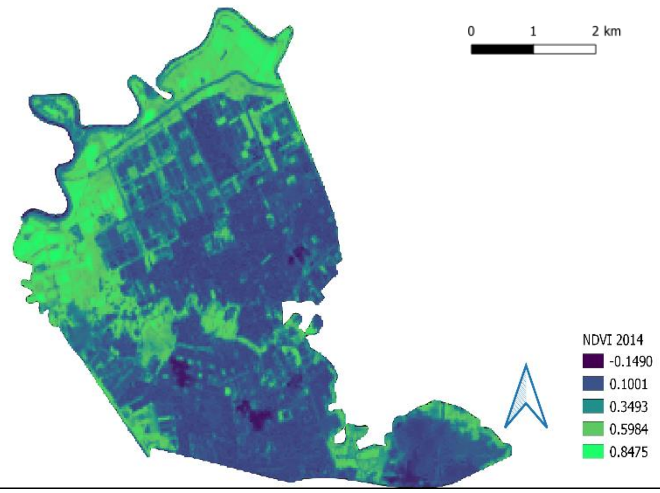
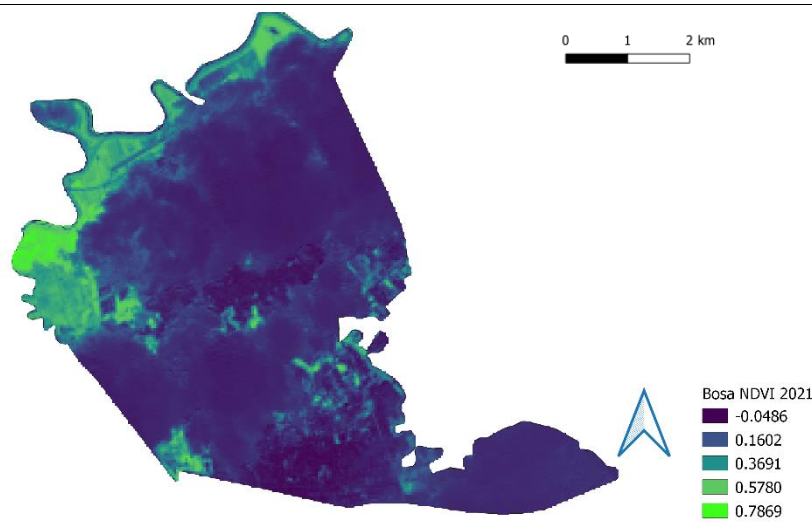
**Figure 2: Bosa panel**

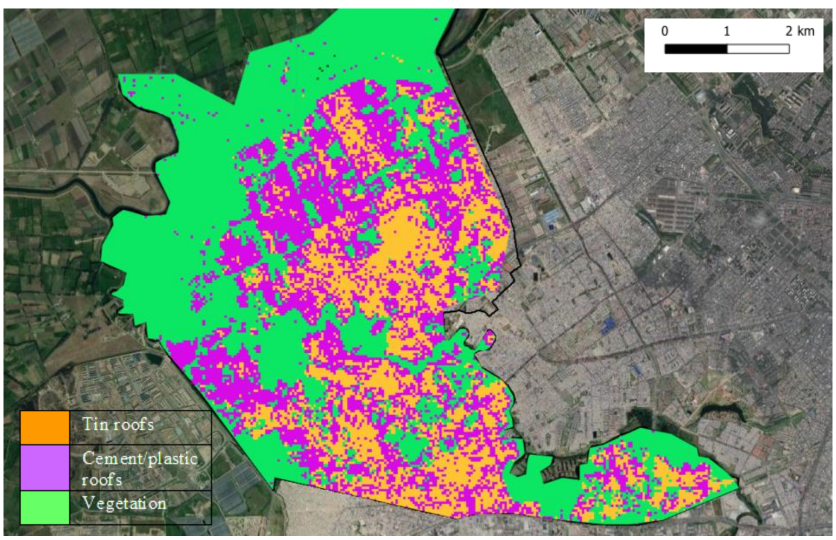
## NDVI 2014




## NDVI 2021




## IMAGE CLASSIFICATION 2021 FOR BOSA




For NDVI graphs above, the displayed index in the legend uses the NIR and red band to create an index that oscillates between -1 and 1. In this case, abundant vegetation areas are colored with a more intense version of green, whereas non-vegetated areas assume negative values or close to zero.

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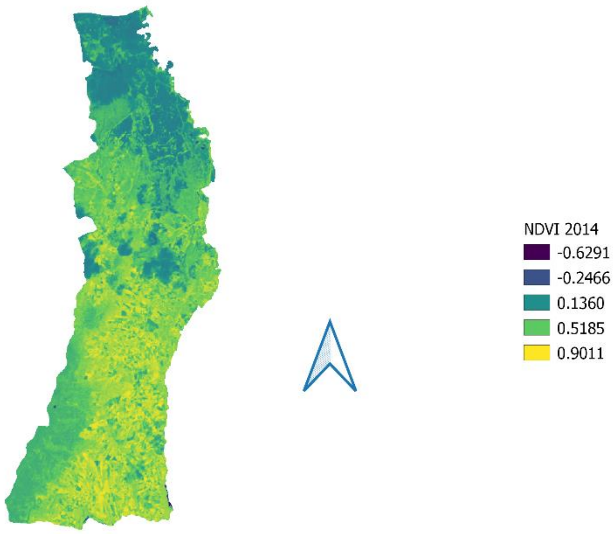
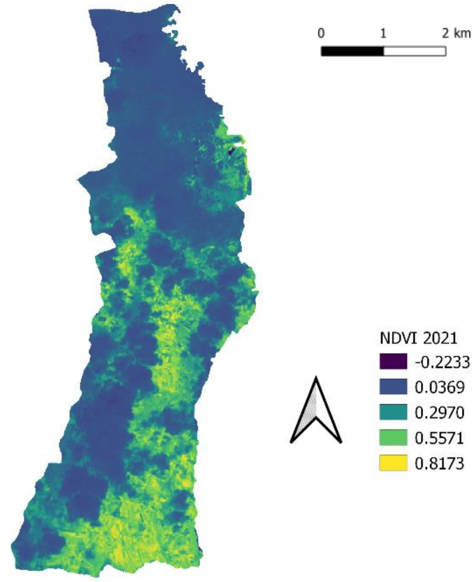
## Figure 3: Ciudad Bolivar panel

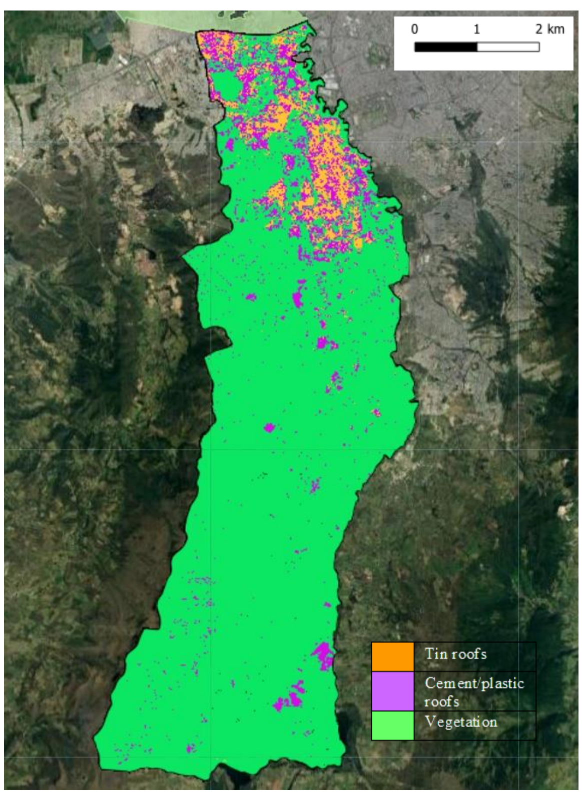
### NDVI 2014




### NDVI 2021




## IMAGE CLASSIFICATION 2021 FOR CIUDAD BOLIVAR

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