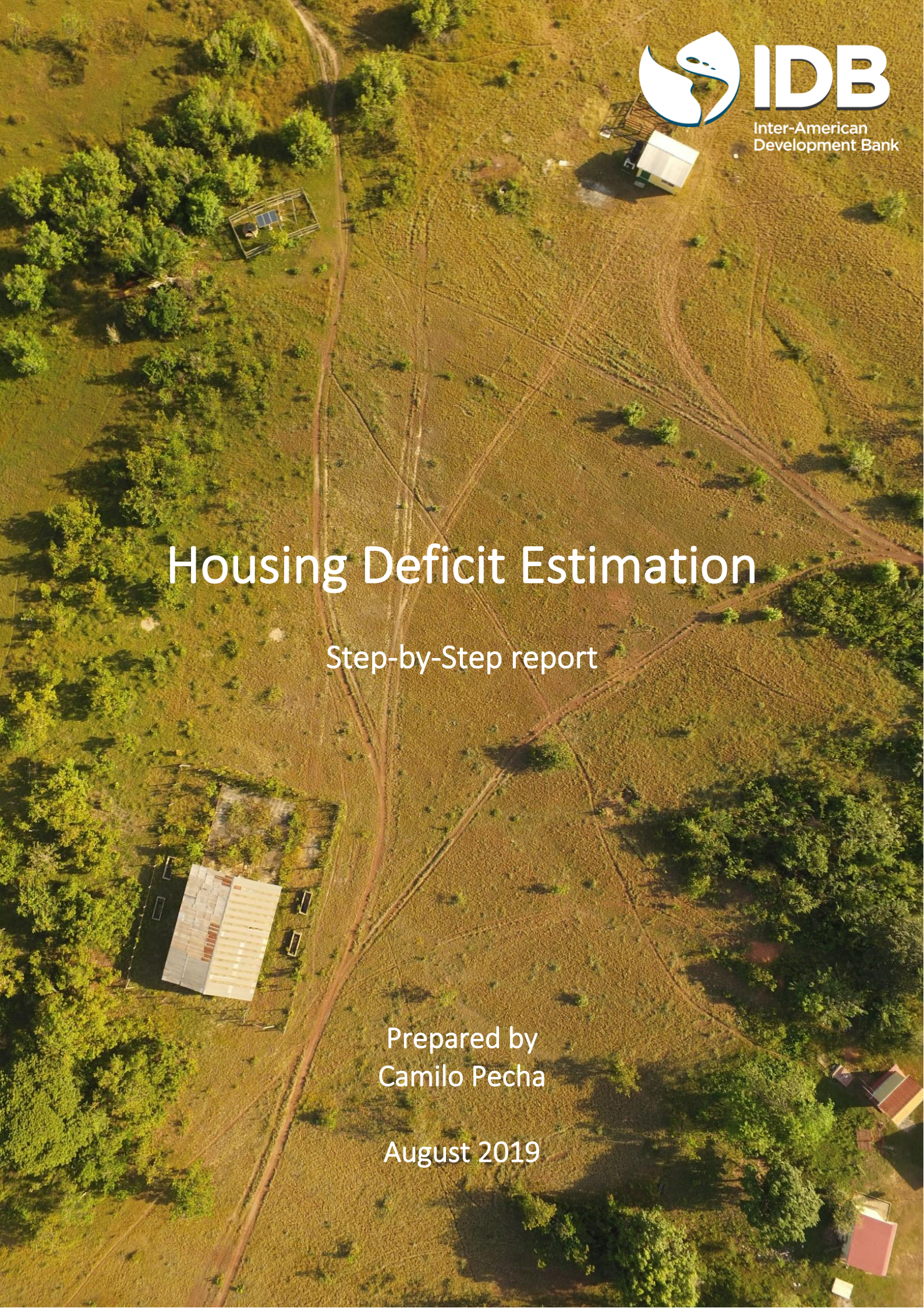


IDB
Inter-American Development Bank

Housing Deficit Estimation

Step-by-Step report

Prepared by
Camilo Pecha

August 2019

Acknowledgment

This report is presented as second deliverable for the consultancy on Housing and Urban Development Small Area Estimation. I want to thank to Jordan Fischer and Patricio Zambrano for their support.

I. INTRODUCTION

Guyana is home to close to 750,000 people, of which more than 90% lives on a semi-continuous urban coastal strip that represents only 5% of total land area. The country is divided into 10 regions, each is composed of local Neighborhood Democratic Councils—the smallest local-level administrative unit. On the coastal strip, Region 4 alone, which includes the capital and primary city of Georgetown and its low-density peri-urban areas, contains over 40% of the country's population. The urban coastal region and the rural hinterland each present unique challenges for housing policy.

The Government of Guyana (GoG), through the Central Planning and Housing Authority (CHPA), is committed to the long-standing goals of expanding the supply of housing, improving affordability, and ensuring access to housing and infrastructure for poor households—and

doing so in the context of the development of sustainable and resilient communities. Over the last five years, HUD has worked closely with CHPA in this mission, primarily through loan operations and technical assistance. As part of HUD's support for the development of a Housing Strategy, CHPA requested support for improved data gathering, management, and analysis, in support of improved and transparent policy design and implementation. Over the last year, HUD has focused on improving the agency's integrated territorial/geospatial data management system, through the collection and clean-up of a variety of GIS datasets.

However, the agency still lacks a comprehensive understanding of housing deficits in the country, crucial for prioritizing projects and resource allocation. To date, HUD and CHPA have based their program design primarily on 1) relevant information extracted from the 2012 census and 2) internal data about housing demand from CHPA, which is gathered through their applications and associated waiting lists for households interested in the agency's programs.

This scattered data on housing conditions suggest that Guyana primarily has quantitative housing deficits. In addition, Guyana is one of a few developing countries that saw a decline in its population in the 2002-2012 inter-census period—though the recent discovery of vast offshore oil reserves may alter this pattern and affect future housing demand and overall land markets. Given this information, to date, HUD and CHPA believe the current approach is effective, but still require more granular and more up to date information to better carry out program and policy design.

Updated and granular housing deficit information are crucial to inform major elements of a National Housing Strategy, including resource allocation and program design. This information can be obtained with a housing deficit estimation, using the following inputs:

1. Most recent census data
2. Nationwide shapefiles at the most granular level available
3. Satellite images of nocturnal luminosity

These inputs can be used to estimate housing deficit in the most recent year for which satellite images are available in the following 4-part process:

1. A decisive methodology is used to determine levels of quantitative, qualitative, and total housing deficit based on the 2012 census data (code in R).
2. Nocturnal luminosity (night lights) raster data are extracted from Satellite imagery of the country (using QGIS or Python).
3. A simple regression is used to the predict calculated housing deficit based on the average luminosity of each administrative division (code in R).
4. The predictions resulting from the regression can be visualized in an easy-to-understand map (using QGIS, Python, or Tableau)

This document will serve as a how-to guide for the above process, supplemented by additional documents where necessary.

II. HOUSING DEFICIT DEFINITION AND CALCULATION

The details of housing deficit definition can be found in a separate document: the Methodological Report. This report includes definitions and calculations of quantitative and qualitative housing deficits – specifically in sections III and IV. Furthermore, the deficit calculations can be run using the relevant census data and the R scripts “Data_prep.R” and “Indicators.R”.

III. OBTAINING NIGHTTIME LUMINOSITY DATA FROM SATELLITE IMAGERY

In order to predict levels of qualitative housing deficit, this project utilizes nightlight data extracted from satellite imagery. This section will explain the procedure to obtain, extract, and process satellite imagery information to produce the statistical data used in the estimation of housing deficit. At the end of this section the user should be able to obtain information in numerical format to be used in statistical packages in combination with other information, like census microdata, to do estimations.

Accessing the satellite imagery

The data used for this project was obtained from the Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band. The VIRSS is a sensor designed by Raytheon Company and it has been installed in two satellites: Suomi NPP and National Oceanographic and Atmospheric Administration (NOAA)-20.[1] The VIIRS project cleans the imagery by filtering lights from lunar reflectance, clouds, etc. The data is then averaged monthly and annually, and the resolution is 15 arc-seconds (approximately 450 meters per pixel).[2]

The following are the steps to download the data from NOAA's National Centers for Environmental Information.

[1] https://en.wikipedia.org/wiki/Visible_Infrared_Imaging_Radiometer_Suite
[2] For more information, please visit: https://ngdc.noaa.gov/eog/viirs/download_dnb_composites.html

First, visit https://ngdc.noaa.gov/eog/viirs/download_dnb_composites.html and scroll down to find the download site as shown in figure 1. This data is stored in a panel structure with the world divided in 6 tiles, each tile with information from March 2012 to present.

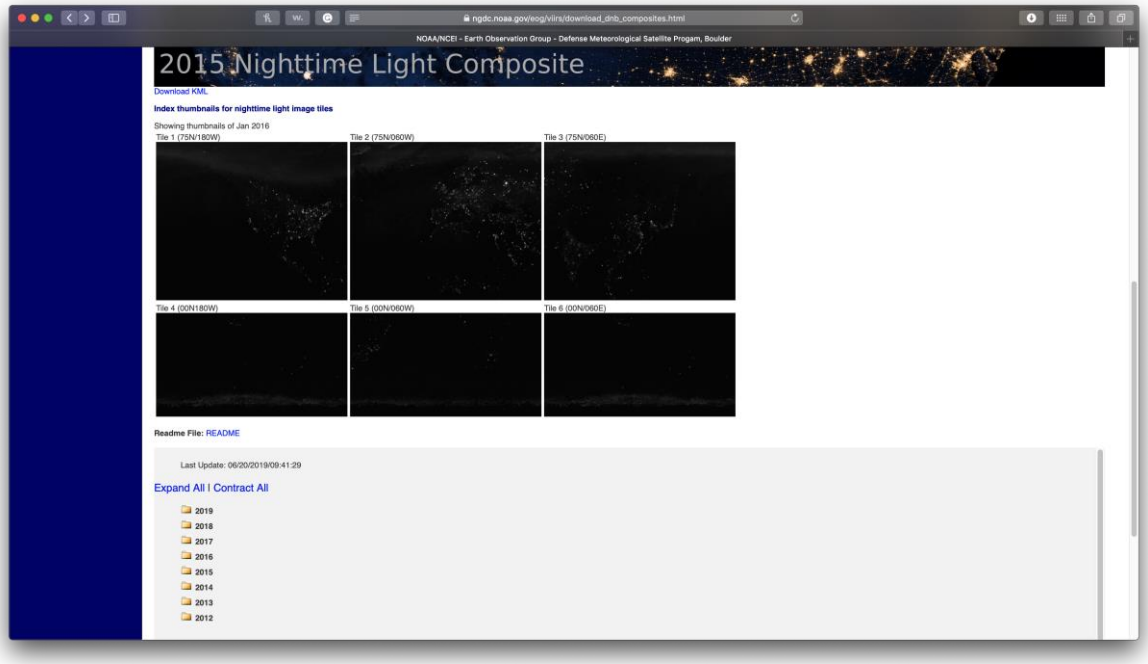


Figure 1: NOAA's download site for VIIRS data

For this project, the tiles selected where tiles 1 and 2 since Guyana is partitioned in these two in the NOAA's data format. From the menu located in the lower-left corner, select the 2012 folder by clicking on it. Select "Monthly", and then "201211" (November). For Tiles 1 and 2, the files named "VCMCFG" contain zipped folders with the tiff images, as shown in figure 2. The same process is followed for April 2019.

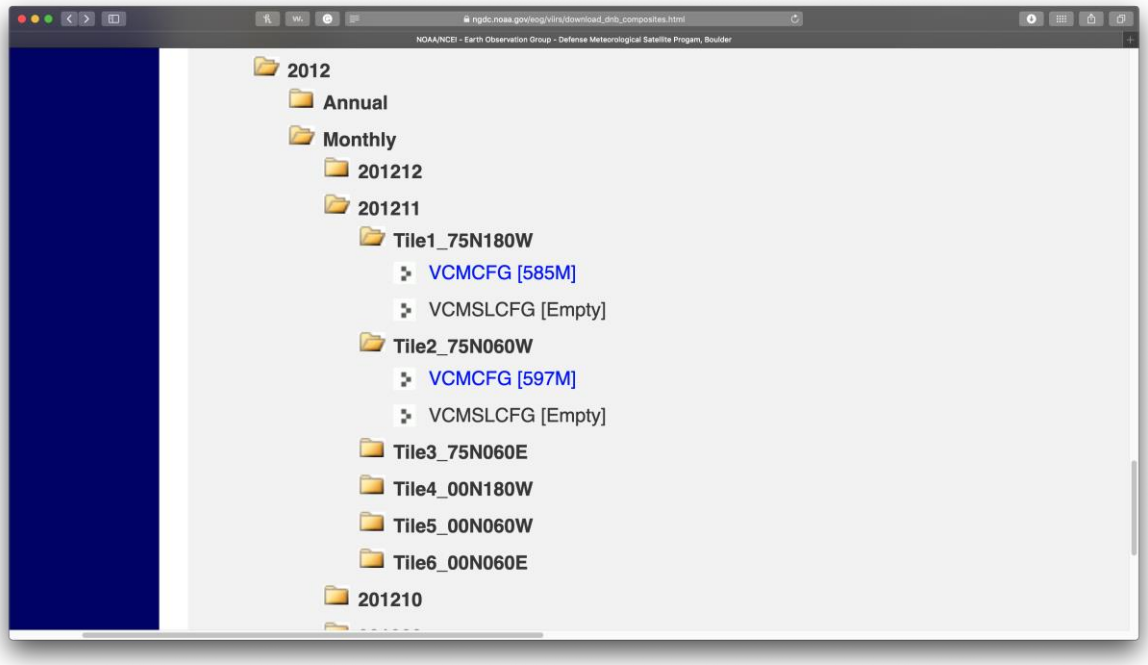


Figure 2: Files selection in NOAA VIIRS' site

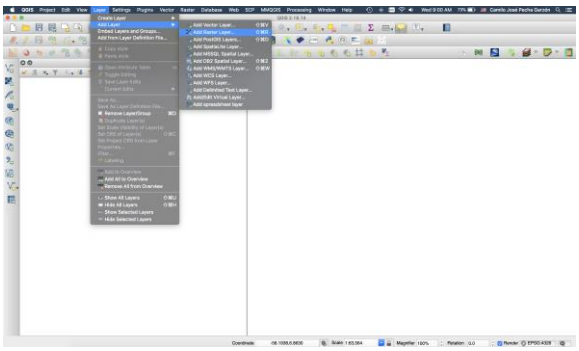
Each zipped file is greater than 0.5 Gb, with a total size for 2012 and 2019 greater than 2 Gb. When unzipped, the total file size is around 8.3 Gb of disc space, so it is important to have in mind the hard disc drive size needed for processing.

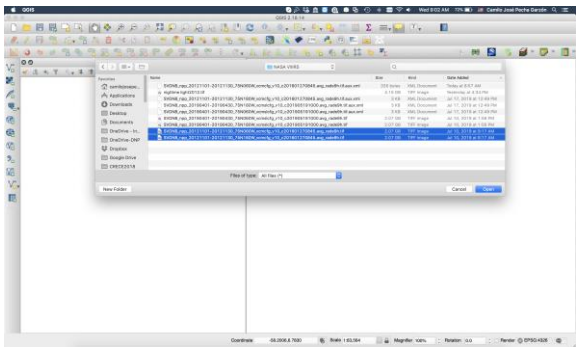
The following sections (Opening data in QGIS, Merging geotiffs, Clipping the merged geotiff, and Converting the raster data to numerical data), should be carried out first on the 2012 files, and then on the 2019 files. The end result for all of Section III should be two .csv files – one for 2012 luminosity data and one for 2019 luminosity data.

Opening data in QGIS

Once the data is downloaded, it is time to open it in QGIS to process it. The idea in this step is to show the steps to convert raster data into information compatible with other datasets like census microdata.

The first step is to open the data in QGIS, to do that select the "Layer -> add new -> Add raster layer" from the menu, or simply press the icon from the left side of the main window.[3] Each downloaded folder should contain 2 .tif files – select the file ending in '…avg_rade9h.tif' for each tile since this is the file corrected by radiation. Select the files to be open in the main window as shown in figure 3. Second, we need only the data for Guyana, so we use the shapefile for the country boundaries to extract that information. To do that, open the shapefile for the level 0 of administrative division selecting "Layer -> add new -> Add vector layer" from the menu, or simply press icon.[4]





[3] This tutorial is based on the QGIS 2.18.14, the most stable version of the software for Mac-OS users.
[4] To download shapefiles for administrative division of Guyana and other countries, please visit http://www.diva-gis.org/gdata where you can select the country and download various type of GIS data.

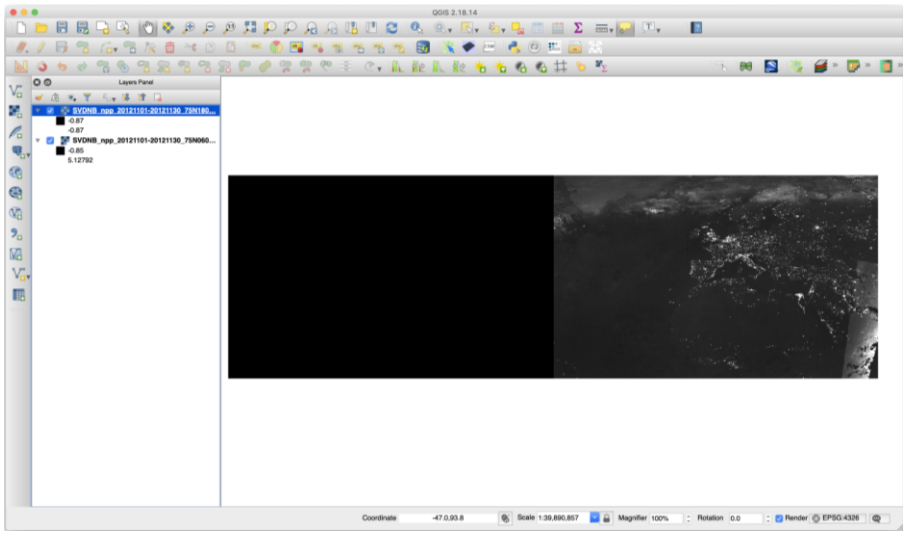
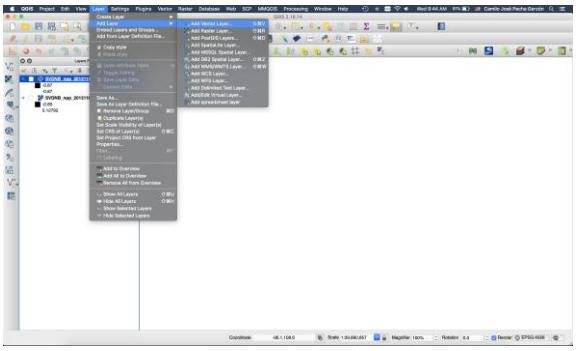
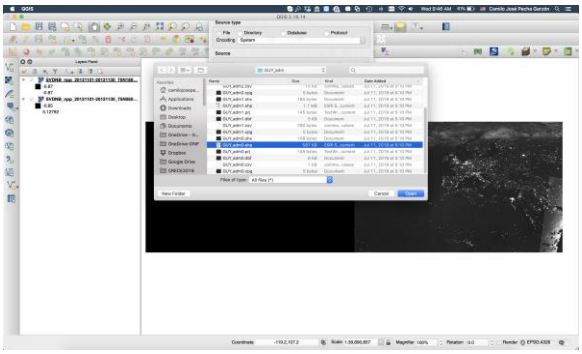


Figure 3: Opening raster files in QGIS

Figure 4 presents how to open the Guyana's level 0 of administrative division shapefile (country boundaries).





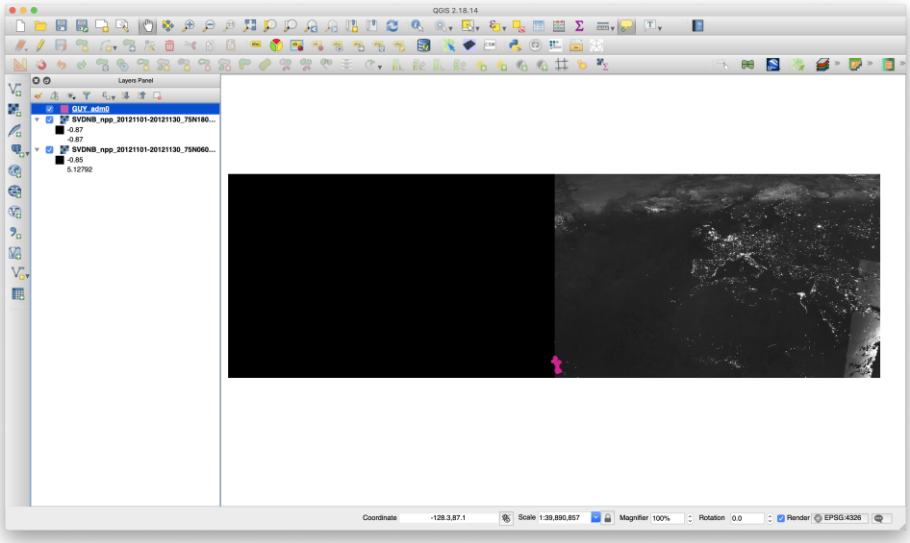
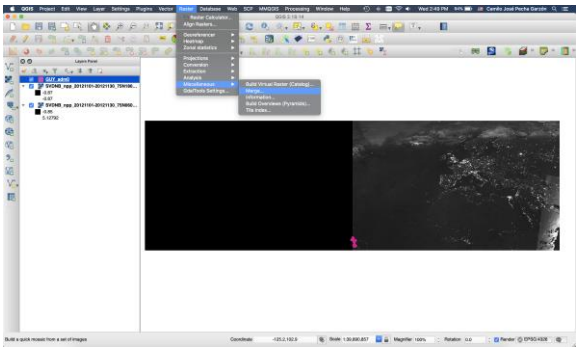
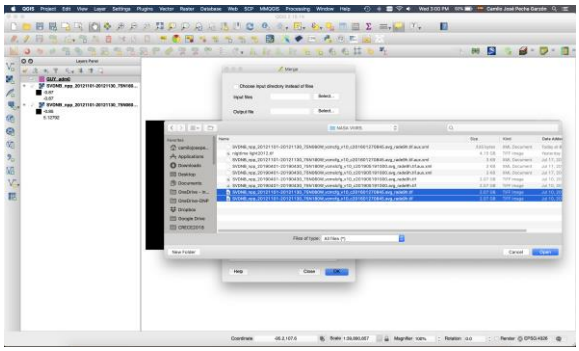


Figure 4: Opening vector files (shapefiles) in QGIS

Merging geotiffs

The next step is to "cut" only the information relevant for Guyana since we only need to process the lights in the country and processing the whole dataset could be computationally demanding. To "cut" or select only the information for Guyana the first thing to do is to merge the two original tiles into a single Raster file. To do that, select "Raster -> Miscellaneous -> Merge…", then in the prompted window select the raster files for tiles 1 and 2 in the "input files" field and set the output file's name and location, then click "OK". A new raster file is produced and loaded into the canvas as shown in figure 5.





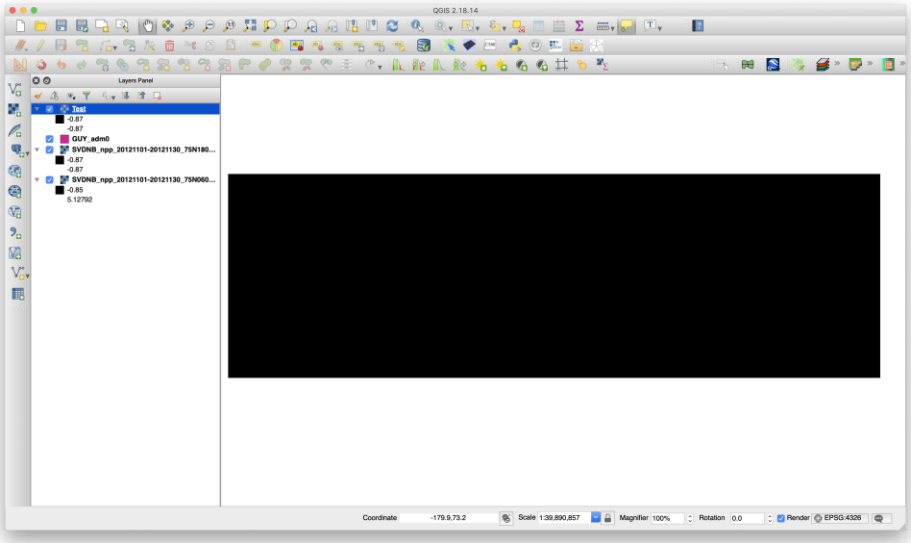


Figure 5: Merging Raster files in QGIS

If there are errors, check the box at the bottom of the prompt window. This box will show the python code that is used to run this function within QGIS. The code used in this case is shown in the box below:

```
gdal_merge.py -of GTiff -o /Users/…/Downloads/merged.tif /Users/…/Downloads/ SVDNB_npp_20121101-20121130_75N180W_vcmcfg_v10_c201601270845\SVDNB_npp_20121101-20121130_75N060W_vcmcfg_v10_c201601270845.avg_rade9h.tif /Users/…/Downloads/transaccion-7.pdf
```

Clipping the merged geotiff

Once the merged file is built, only the portion corresponding to Guyana's country boundaries is selected. To do that, select "Raster -> Extractions -> Clipper…" from menu. In the prompted window, select the merged file in the "Input file (raster)" field, define an "Output file" that will be the file containing the information for only Guyana. In the "Clipping mode" section, select "Mask layer" and select Guyana's administrative shapefile as "Mask layer", and finally, check mark "Crop the extent of the target dataset to the extent of the cutline" and click ok. The process is shown in figure 6.

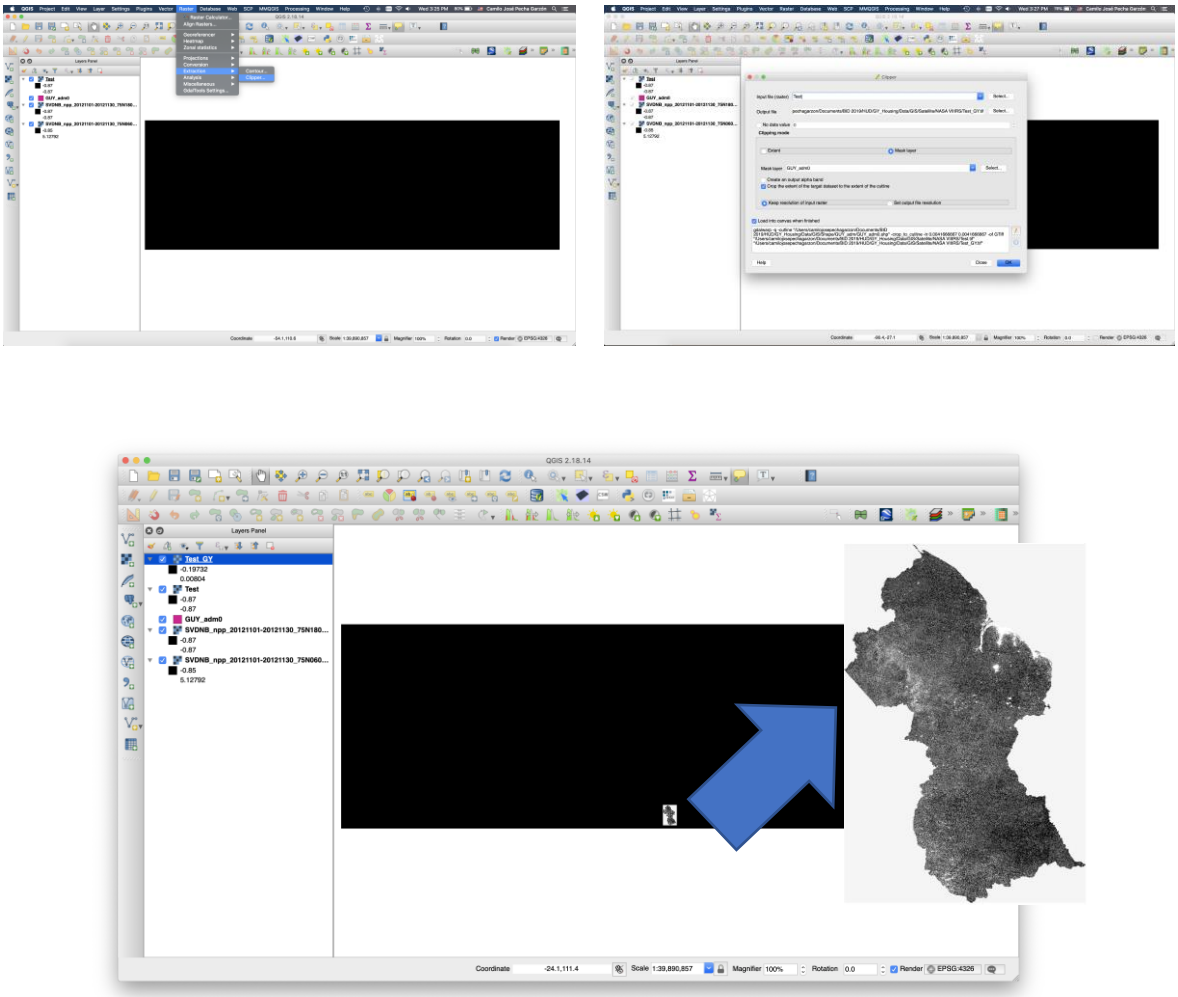


Figure 6: Extracting nighttime light information from raster file and shape file

If there are errors, check the box at the bottom of the prompt window. This box will show the python code that is used to run this function within QGIS. The code used in this case is shown in the box below:

```
gdalwarp -q -cutline "/Users/.../Data/GIS/Shape/GUY_adm/GUY_adm2.shp" -crop_to_cutline -tr 0.0041666667 0.0041666667 -of GTiff "/Users/.../Test.tif" "/Users/.../Test_GY.tif"
```

Converting the raster data to numerical data

The final step is to convert this raster data into numerical data that can be used in a statistical software. This step includes three sub-steps:

1. convert the raster data into vector data (polygonize);
2. combine the new vector data with the shapefile of Guyana's NDCs or level 2 of administrative division (spatial join);
3. convert the new shapefile resulted from previous step into a tabular data version.

Polygonization

To convert raster to vector, select "Raster -> Conversion -> Poligonize" from menu. In the prompted window, select as "Input file (raster)" the raster file containing the information extracted in the previous step (figure 6), set the "Output file for polygons (shapefile)", define the name of the field containing the nighttime light data, and checkmark "Load into canvas when finished". Finally, click "OK" as shown in figure 7.

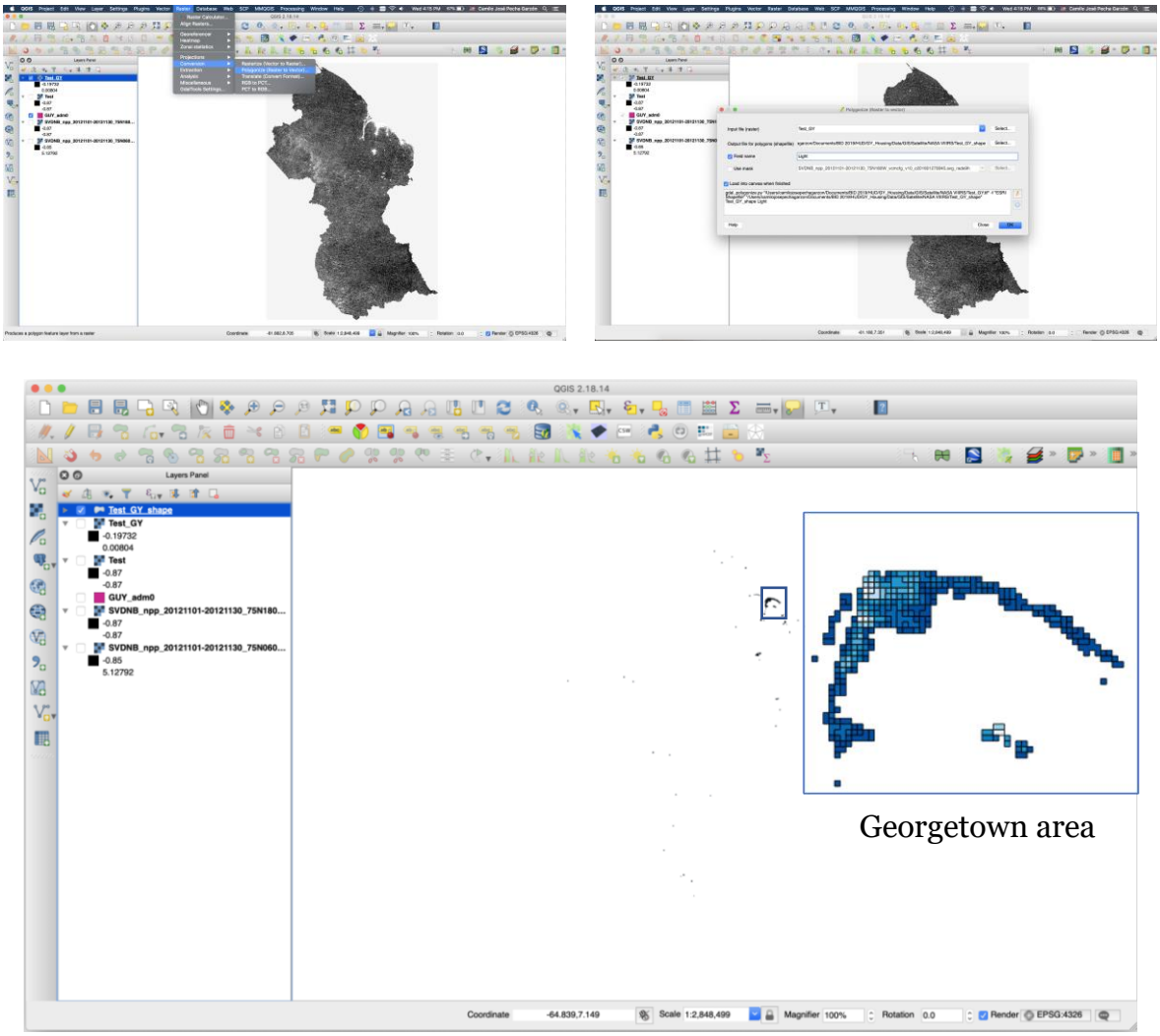


Figure 7: Converting nighttime light information from raster file to shape file[5]

Spatial join

The next step is to combine the new nighttime light shapefile with the level 2 of administrative division of Guyana. To do that, first, open the level 2 administrative shapefile. To combine datasets, select "Vector -> Data Management Tools -> Join attributes by location" form menu.

[5] To obtain the shaded version of the map, select the shapefile with double click, "Properties" window will appear. In the left window, select "Style" and in the first dropdown menu select "Graduated". In the dropdown menu select the variable you want to show and in the "Color ramp" chose one of your interest. Select the number of classes you want to plot from the selector at the right-hand side under the "Classes" window. Click on "Classify" under the "Mode" dropdown menu. Finally, click "OK at the bottom left corner. You should obtain a graduated version of the map. This process will be explained in the following section.

In the prompted window, select the administrative division as “Target vector layer”, and select the nighttime light shapefile as “Join vector layer”, checkmark all the “Geographic predicate” options, in the “Attribute summary” chose “Takes summary of intersecting features”, define the output “Joined layer” and click “Run” as shown in figure 8.

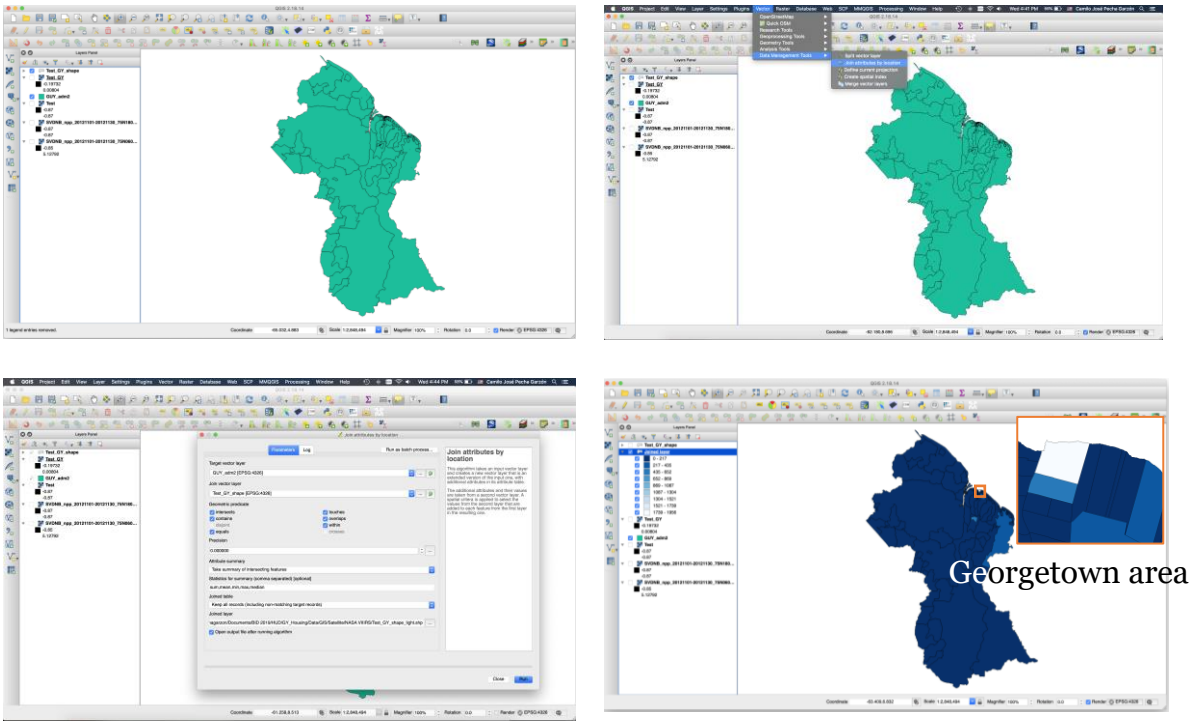


Figure 8: Combining nighttime light shapefile with administrative division shapefile

To check that this step was completed successfully, right click on the joined layer, select “open attribute table” and verify that new columns have been added as seen in the figure below.

sumDN	meanDN	minDN	maxDN	medianDN	count
0.00000	0.00000	0.00000	0.00000	0.00000	1.00000
0.00000	0.00000	0.00000	0.00000	0.00000	1.00000
3.00000	1.00000	0.00000	2.00000	1.00000	3.00000
1.00000	0.00000	0.00000	1.00000	0.50000	2.00000
18.00000	3.00000	0.00000	6.00000	3.00000	6.00000
61.00000	2.00000	0.00000	7.00000	2.00000	25.00000
47.00000	3.00000	0.00000	17.00000	1.50000	14.00000
5.00000	1.00000	0.00000	3.00000	1.00000	4.00000
2.00000	0.00000	0.00000	1.00000	1.00000	3.00000
15.00000	1.00000	0.00000	3.00000	1.00000	11.00000
7.00000	1.00000	0.00000	3.00000	1.00000	5.00000
12.00000	1.00000	0.00000	4.00000	2.00000	7.00000

Figure 9: Example of shapefile's "attribute table"

Tabularization

The final step is to export the information stored into the shapefile to a tabular format. This can be done using a plugin called "MMQGIS". To install the MMQGIS plugin:

1. Go to menu "Plugins" > "Manage and Install Plugins…", and a window will appear
2. Using the **search** field in the window, type **mmqgis** and press install as shown in the following figures:

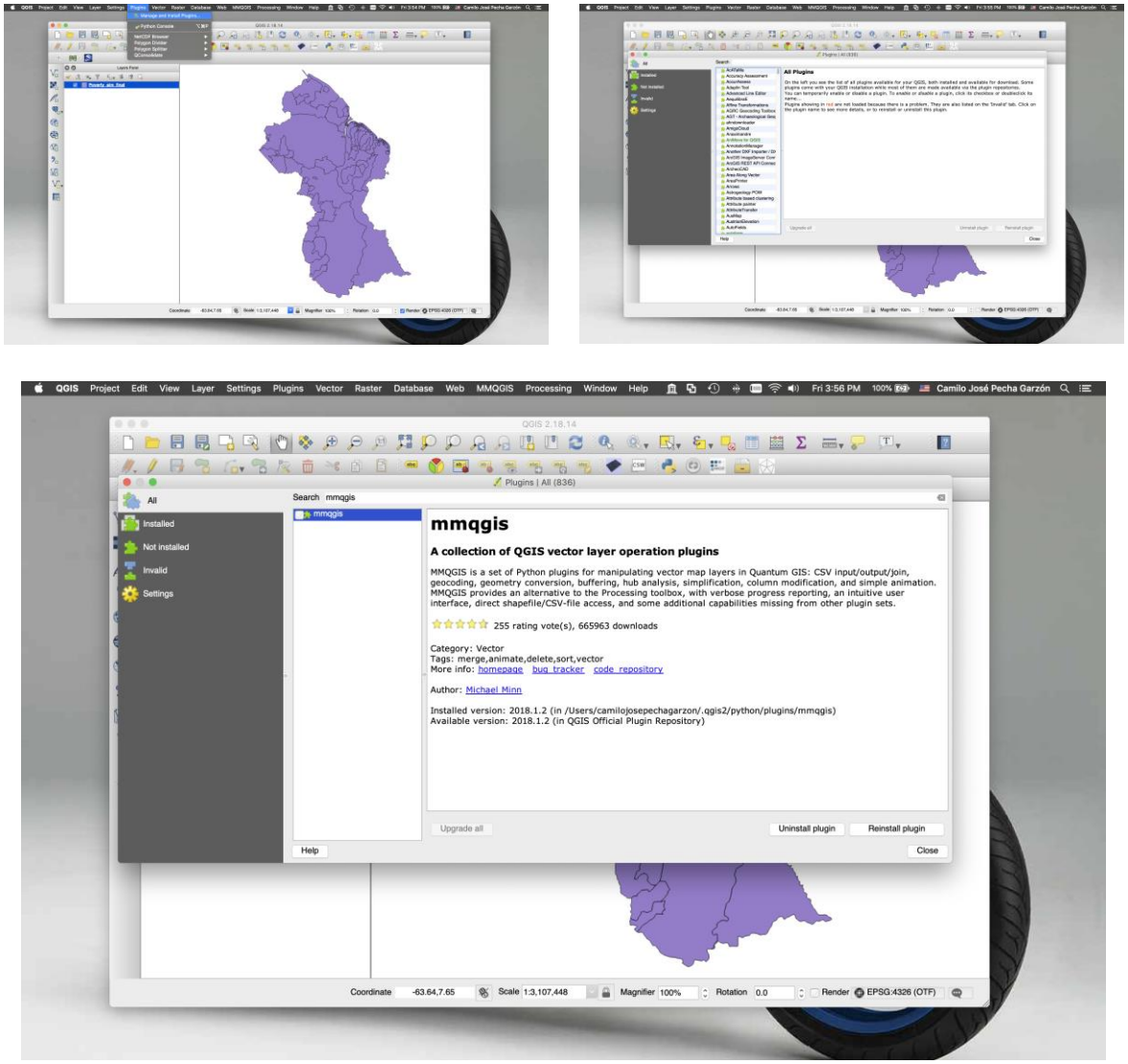


Figure 10. Installing MMQGIS plugin

Once MMQGIS is installed, it will appear as one of the options on the toolbar. Select “MMQGIS -> Import/Export -> Attributes Export to CSV file” in the menu. In the prompted window, select the desired attributes, define the name and path and click “OK”. Figure 9 presents the process and an excerpt of the csv file opened in excel that contains the NDC id and the summary statistics of the nighttime light data. From here, loading the resulting dataset in a statistical package can be done directly from the software of preference: R, Stata, etc.

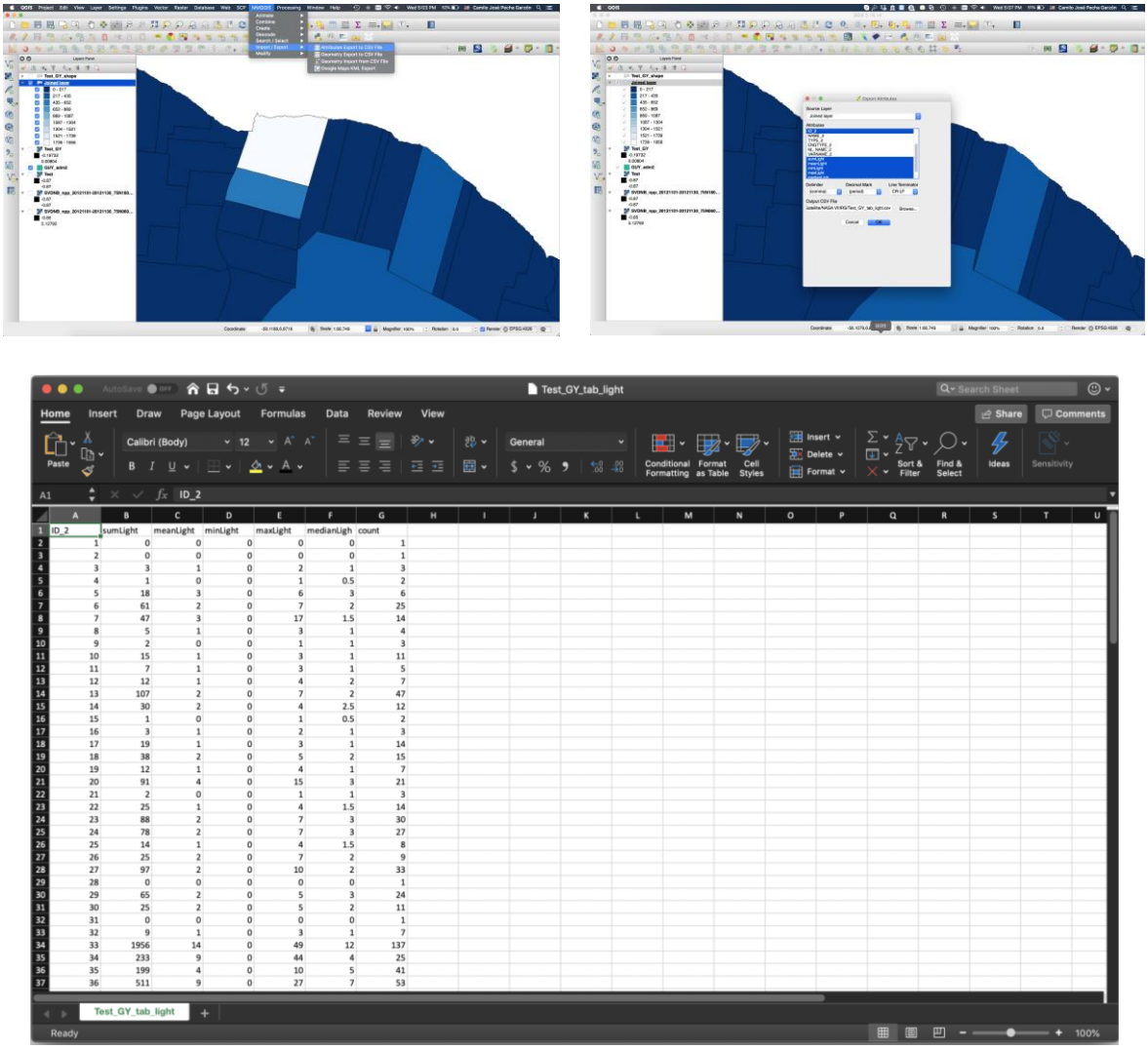


Figure 10: Example of final shapefile and exported attribute table

As explained above, once all luminosity data processing steps have been completed for 2012, the same steps should be repeated for 2019, to produce one CSV file for each year.

Functional code

Throughout this process, the prompt windows will include a box at the bottom with the python code used to run the various functions within QGIS. For the most part, users do not need to work with this box, however, if there are errors, the code contained therein can provide insight into what went wrong. The code used in this section is shown below:

Merging Geotiffs

gdal_merge.py -of GTiff -o /Users/…/ SVDNB_npp_20121101-20121130_75N180W_vcmcfg_v10_c201601270845\SVDNB_npp_20121101-20121130_75N060W_vcmcfg_v10_c201601270845.avg_rade9h.tif /Users/…/ SVDNB_npp_20121101-20121130_75N180W_vcmcfg_v10_c201601270845\SVDNB_npp_20121101-20121130_75N180W_vcmcfg_v10_c201601270845.avg_rade9h.tif

Clipping the merged geotiff

gdalwarp -q -cutline "/Users/…/Data/GIS/Shape/GUY_adm2.shp" -crop_to_cutline -tr 0.0041666667 0.0041666667 -of GTiff "/Users/…/Test.tif" "/Users/…/Test_GY.tif"

Polygonizing

gdal_polygonize.py "/Users/…/Test_GY.tif" -f "ESRI Shapefile" "/Users/…/Test_GY_shape_light.shp" Test_GY_shape_light Light

IV. REGRESSION TO PREDICT HOUSING DEFICIT FROM NOCTURNAL LUMINOSITY

A detailed explanation of how to use simple regression to predict housing deficit based on nocturnal luminosity can be found in the Methodological Report. Section V of the report includes theory, formulas and example results of deficit estimation. The regression can be run using the output of the R script “Indicators.R” (see section II of this guide), and the R script “Prediction.R”. This will produce 1 qualitative housing deficit value, and 1 total housing deficit value for each administrative division (in the case of Guyana, 116 values each for 116 NDCs).

V. MAP GRAPHING USING QGIS AND TABLEAU

A map is created using the Table of 116 housing deficit values (one per each NDC) and the GIS *shape-file* for NDCs. The process incorporates the use of ***QGIS (https://www.qgis.org/en/site/)***, a free open source tool for GIS data processing. This tool, as well as ArcGIS, is based on ArcPy, a toolset designed in Python to process data from the Geographical Information System as well as satellite imagery. The use of this software will permit not only the construction of the housing deficit map but also the incorporation of additional data from different institutions/Ministries, thereby allowing for improved programming of interventions.

This section will include instructions on shape-file loading and visualization, merging attributes from .csv data, extracting data from OpenStreetMap (OSM) using the plugin, and finally exporting the map to pdf. Visualizing the resulting map using Tableau public ***(https://public.tableau.com/)*** will also be covered.

Opening data in QGIS

As before, **shape-file data (.shp)** can be opened by going to menu "Layer">"Add layer">"Add Vector Layer", as shown in figure 11:

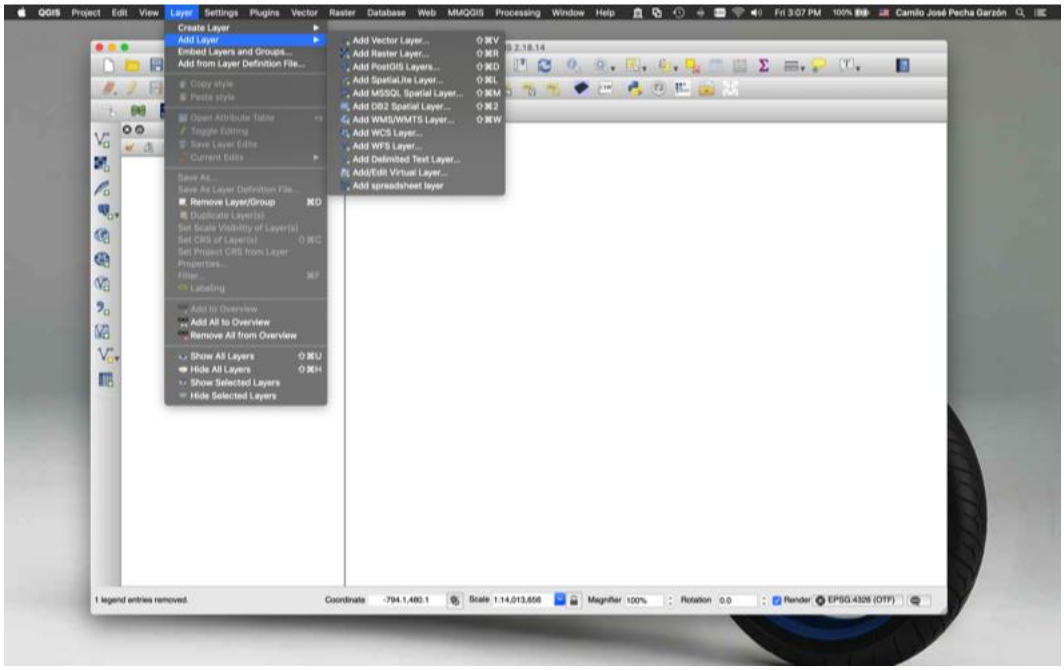


Figure 11: Opening shapefile

You may also use the button 

Once the menu is selected, a window is prompted where you will look for your **.shp file**[6] containing the administrative division of the Country and press "open". You should get the following:

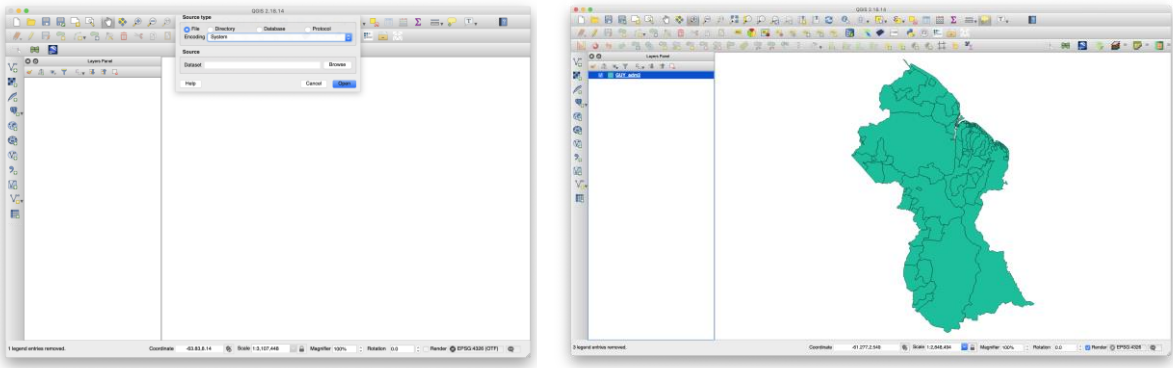


Figure 12: Opened shape-file

[6] This should be the same administrative divisions (of Guyana's NDCs or level 2 of administrative division) that was used in the spatial join in Section III.

Next, an attribute is needed so that the Map can be shown color coded by level of housing deficit. In this specific case, this attribute is levels of housing deficit, which was produced in the .csv output[7] of Section IV. The merging of data from a **.csv file** to a shape-file can be done in two ways:

1. Using a **plugin** (MMQGIS) or,

2. Joining the **.csv file** using the shape-file's properties menu window.

Using 'Plugin' to merge CSV file.

1. Go to **"MMQGIS">"Combine">"Attributes join from CSV file".** Use the **"input CSV file"** field to browse for the data you want to plot that should be in .CSV (you can convert any excel file to csv). Another important field that should be in the .CSV file is the **geographic code** that must match the corresponding geographic code in the Shape-file opened in QGIS. In the case of this Report, there are 116 NDCs and municipalities in the data, numbered 1 to 116.

[7] To map the predictions for 2019 in Guyana, the file would be *2019_precitions_by_NDC.csv*

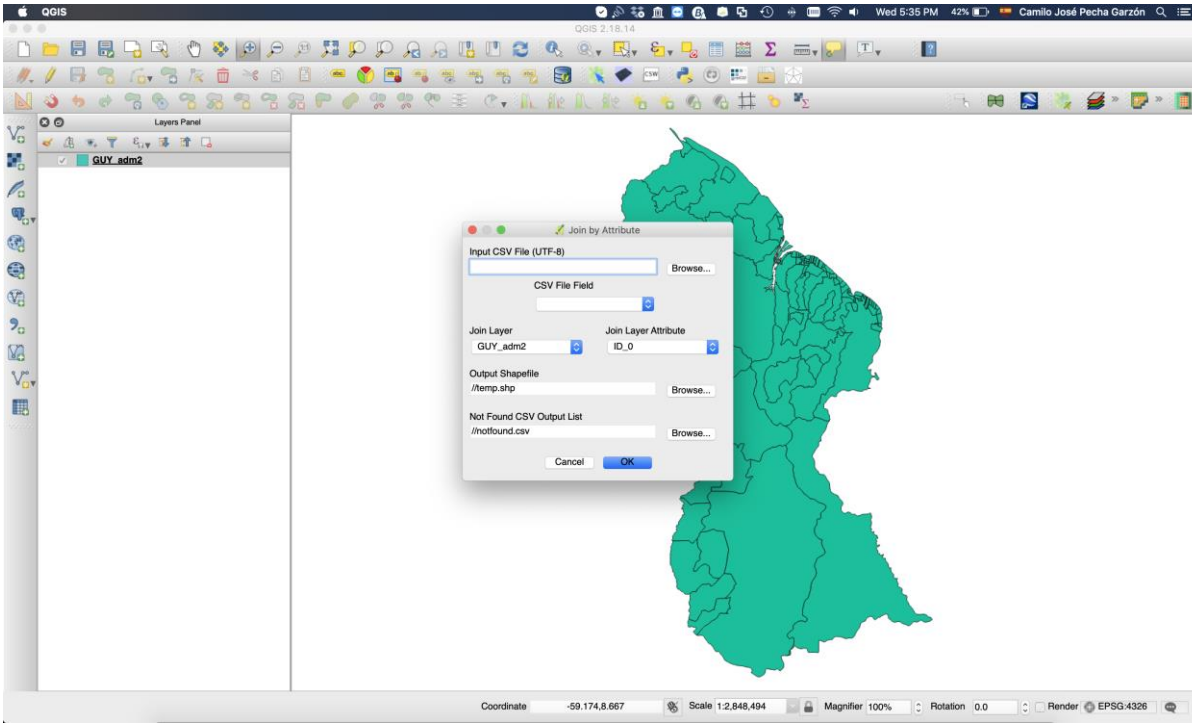


Figure 14: Merging data from .csv to shape-file in QGIS' memory.

Once the CSV data is merged with the shape-file, it is possible to use the data as attribute. For the present case, the housing deficit is defined by each one of the 116 geographic areas, where each location has its own value.

Using "Joins" to merge CSV file.

This process does not create a new map but uses the one stored in QGIS memory and joins a Table. To do this, the first step is to load the *csv* data into *QGIS* environment by clicking the "Big Comma" menu on the left hand side of the **main 'QGIS' window** (or simply looking for it in the Directory for Versions 3.X). A window is prompted with the title **"Create a Layer from a Delimited Text file**", browse for your file and in the section **"Geometry definition"** select **"No Geometry (attribute only table**). Finally, click **"Ok"** as shown in Figure 16.

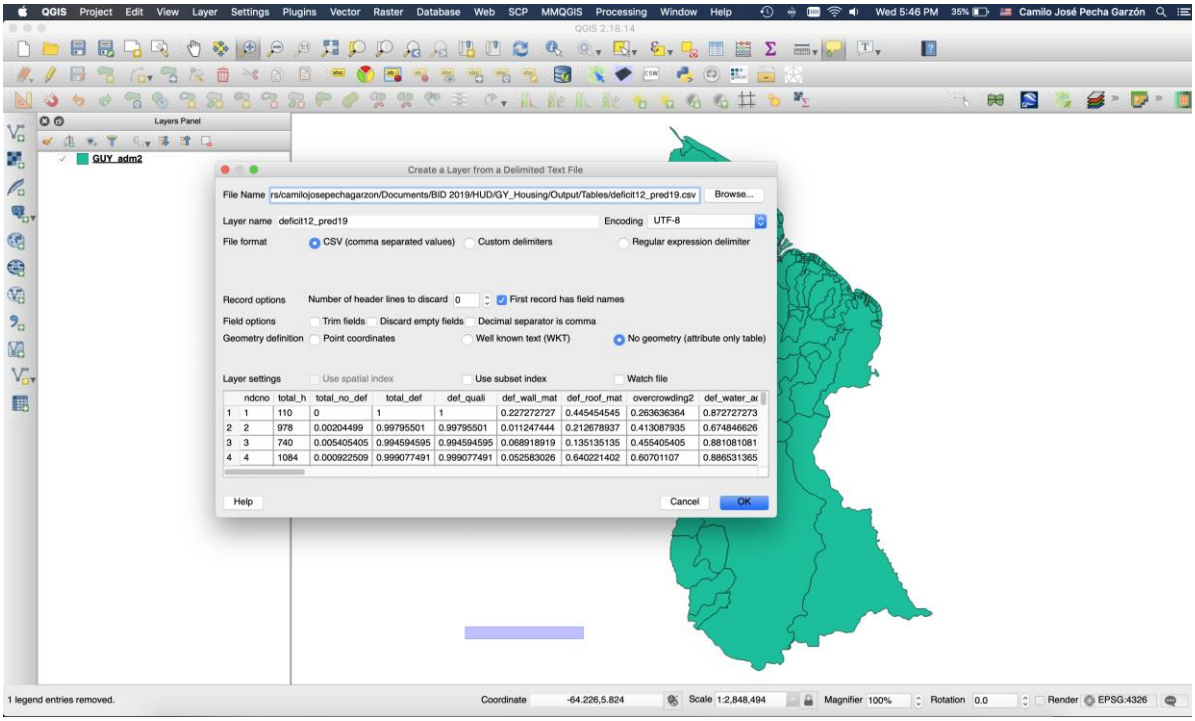


Figure 16: Load a *.CSV* file as attribute layer

Once the *csv* file is loaded, right-click on **shapefile** and select **"Properties">"Joins"**. From the **"plus"** sign at the window's bottom, a window is prompted where you can **"Add a vector join".** Select in the **"Join layer**" the csv file just loaded, in the join field select the one that corresponds to the geographical identifier. From the **"Target field"** select the variable that identifies the geographical location at the shapefile and click **"Ok".** From here, repeat the steps to put color in the map described in the last subsection.

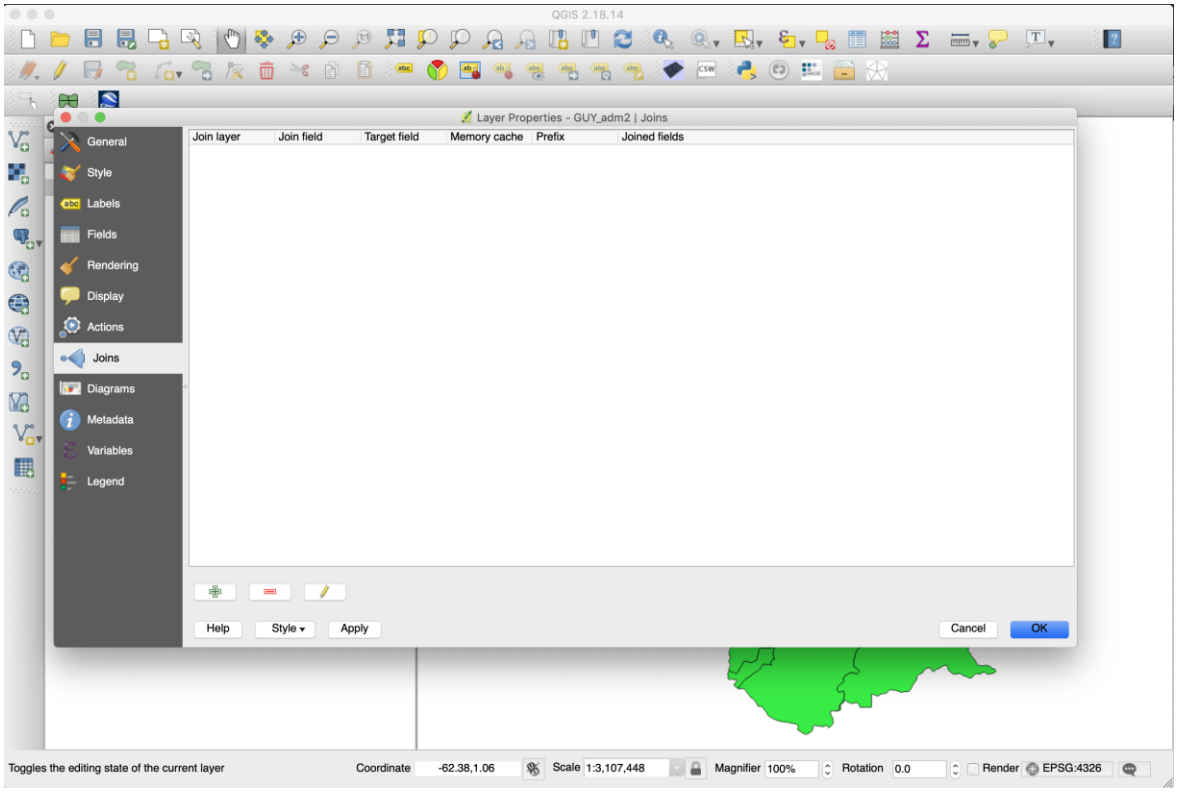
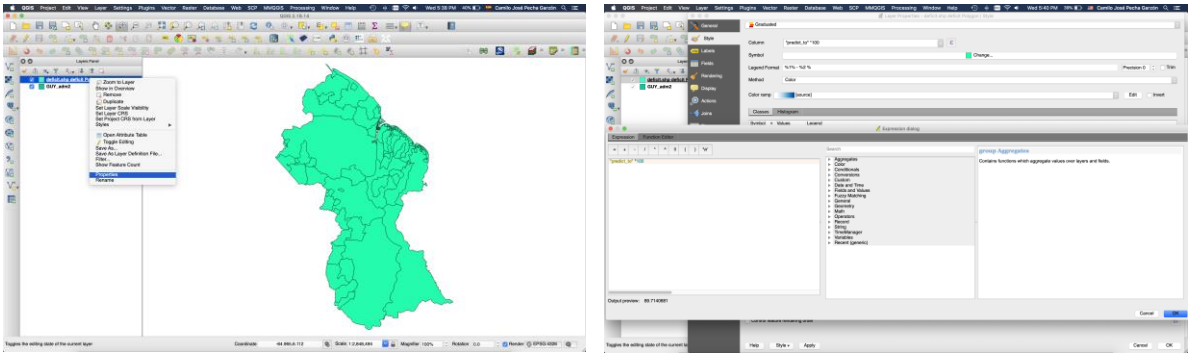


Figure 17: Joining a dataset to shapefile using geographic identifiers

Shading the map by attribute

Using the properties menu (right-click in the shapefile), select "Style">"Single symbol" and use the "Graduated" option from the drop-down menu. From the listing, select the variable/feature that will be depicted on the Map. Hit the button ε to create a formula so the numbers are expressed as percentages (the housing deficit variable X 100). Click on "Classify" to obtain the levels of deficit by ranges. The number of classes and the color ramp to be used can also be selected. Finally, click "Ok". Figure 15 shows the process.



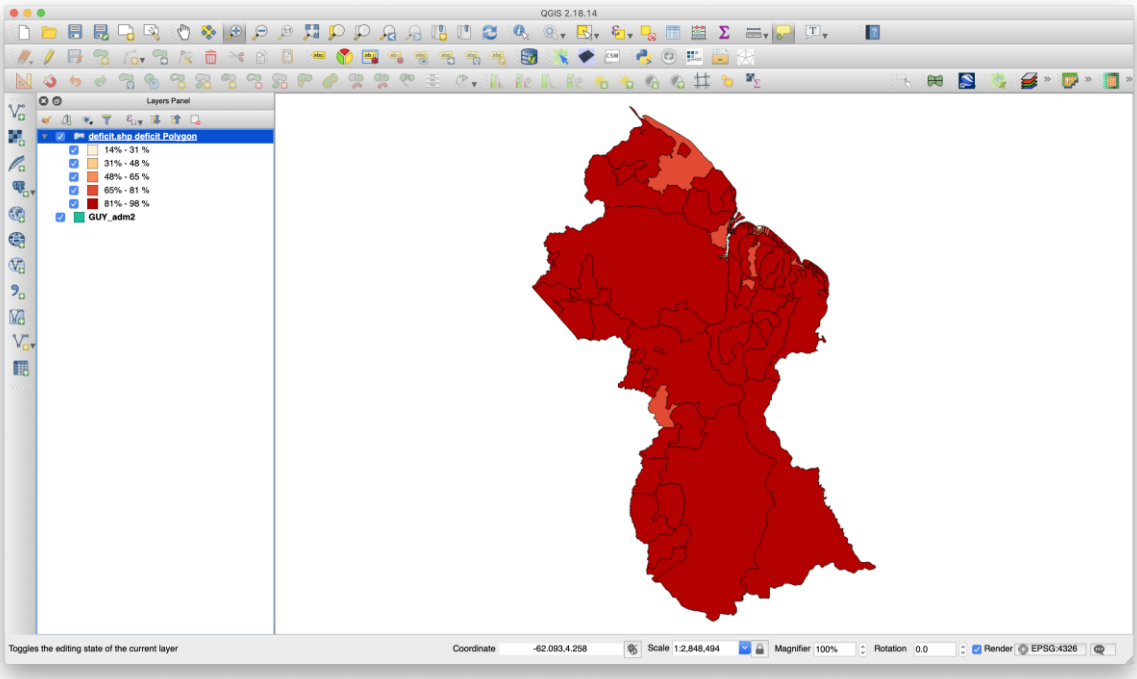


Figure 15: Map's color based on attribute coming from *.CSV file*

Extracting Information from 'OpenStreetMap'.

In addition to the statistical analysis explained above, supplementary data can be added to a visual analysis directly in QGIS. In order to visually study correlations of certain situations like housing deficit with neighborhood conditions, it is possible to use freely available information like **'OpenStreetMap' (OSM),** a free source of information that provides user-added data like

school locations[8]. OSM data can be downloaded by **installing the plugin "QuickOSM"** using the same steps that were used to install "MMQGIS." Once "QuickOSM" is installed, **open it**, and in the **"Key"** field, select the **type of information** that is of interest. For example, the extraction of school information starts by selecting "Key">"amenity", "Value">"School", and "Extent of a layer"> select the shapefile within whose boundaries the information should be added or just select the extent of the canvas. Finally, click "Run query" and close the window. The result is a Map that shows the location of schools in the country.

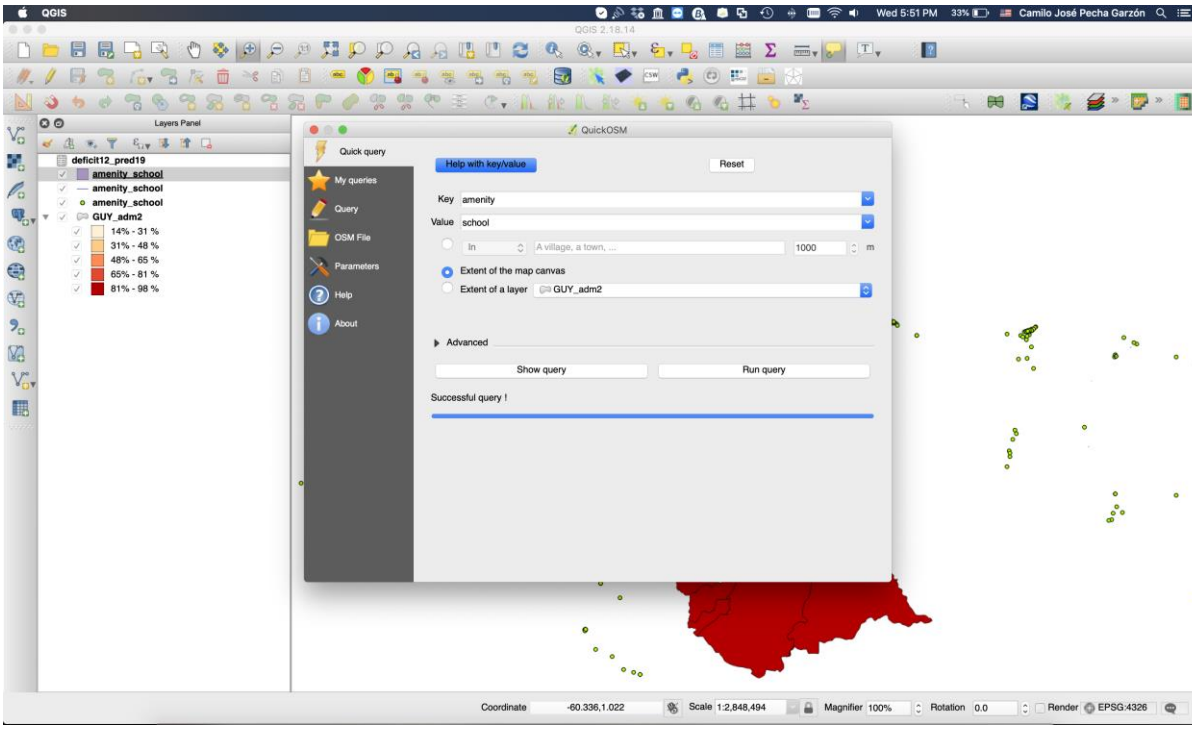


Figure 18: Using "QuickOSM" plugin to extract data from 'Open Street Maps'

[8] For more information, see www.openstreetmap.org and https://en.wikipedia.org/wiki/OpenStreetMap

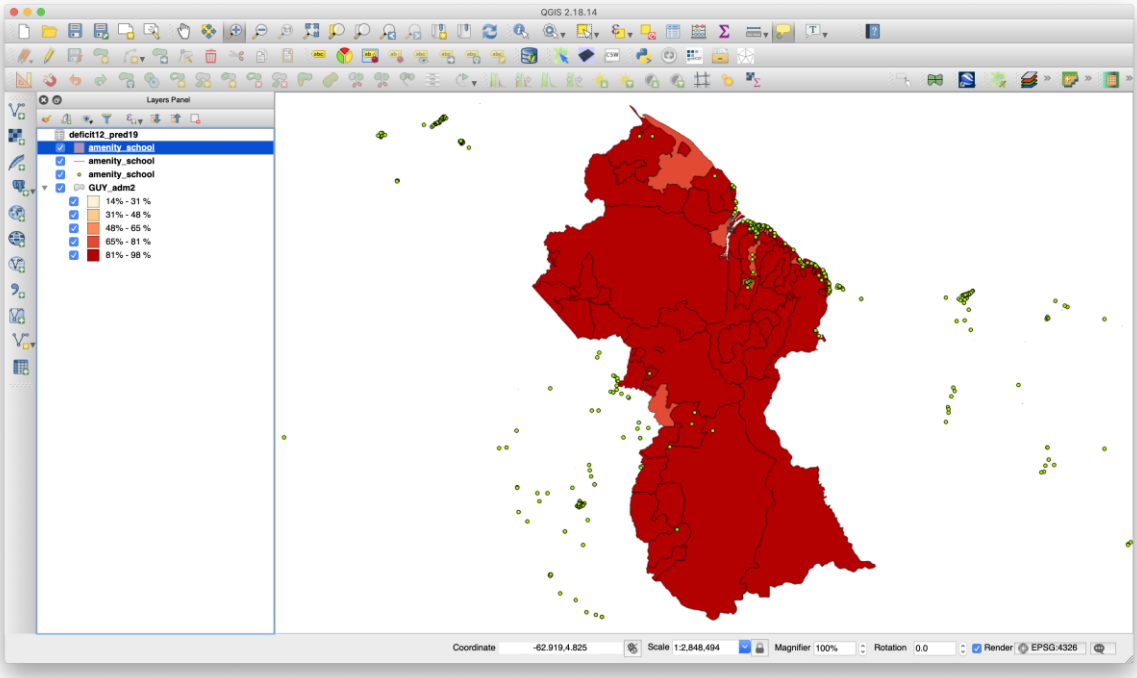


Figure 19: The location of schools across and nearby the country

The last figure shows that there is a concentration of schools in locations with low deficit figures in contrast with locations with large deficit issues. This exercise can be don with other information, also available in OSM, like hospitals, and other amenities.

Exporting a Map to pdf using "New Print Composer".

To export a map created in QGIS, the **print composer** uses the data and creates an image file. To do this, use the button  located in the upper side of the window. When the **"Composer Title"** appears, fill the field with the name of your preference, and click "Ok". A new window is prompted.

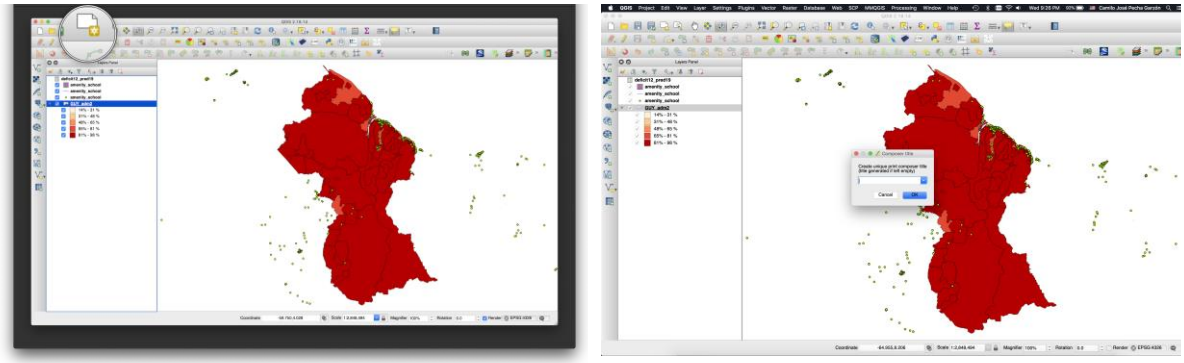


Figure 20: Opening Map Composer

In the **Composer window**, select the tool **"Layout">"Add map"**. Using the pointer **select the whole canvas** and the map will be displayed. Finally, click **"Composer">"Export PDF",** select the **location and set the file name** and click **save.**

Opening data in 'TABLEAU PUBLIC'.

It could be the case you want to share your map with others that may or may not use QGIS. For presentations and sharing purposes, ***Tableau*** is a good option since the software allows for saving of information and data **'into the Cloud'**. This process will create interactive visualizations of the data in a web-based environment, thereby allowing for sharing a **link to a web page** rather than the whole dataset. Documentation on and download options for installing the software - ***Tableau Public*** can be accessed at https://public.tableau.com.

Using the date generated in QGIS, simply **open Tableau and plot:**

- Open Tableau Public
- Select **"Spatial file"** from the menu to the left, under the title **"Connect"**. A window will open and prompt: **browse for the GIS file** that contains the *shapefile* with the housing

deficit levels as features, result of merging the administrative shapefile and the .csv file of 2019 predictions.

- **Open file.** A Table showing the GIS file's features will be displayed in the bottom-left corner.
- **Go to Sheet 1** for the Worksheet and **select.**

The advantage of **Tableau** is that it will automatically contextualize the data with the World Map.

- Select **"Geometry"**
- Select **"Measures",** located in the bottom-left panel
- Go to the largest panel located in the center of the window and click **"Drop field here"**. It will show the Map of Guyana in the context.

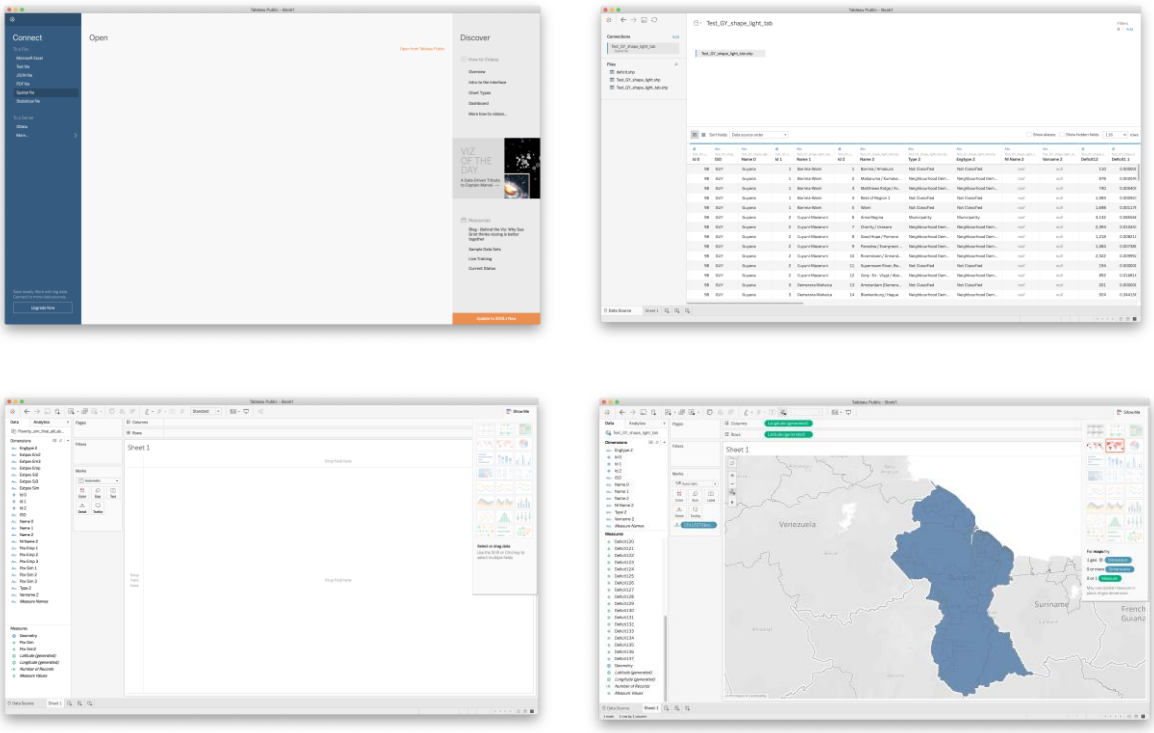


Figure 21: Opening Spatial Data in '*Tableau Public*'

Creating an Interactive Map.

To create an interactive map, use the features in the Map and the options in ***Tableau***.

The map shows the levels of housing deficit at the NDC, Municipality and hinterland community levels. Deficit data was used to plot the figure using **"Color", "Detail", and "Tooltip"** menus from the Panel **"Marks".**

- **Select the variable** with the dimension to be plotted and assign it to **"Color".** Select a 'set of shades' of one color rather than random individual colors. The set of shades will allow for easy detection of changes in the shade as the numbers (representing levels of deficit) increase/decrease.
- **Add names of locations:** Using the NDC name **"Name 2",** assign it to the "Tooltip" so it will appear also in the information pop-up when the mouse is passed over the area.

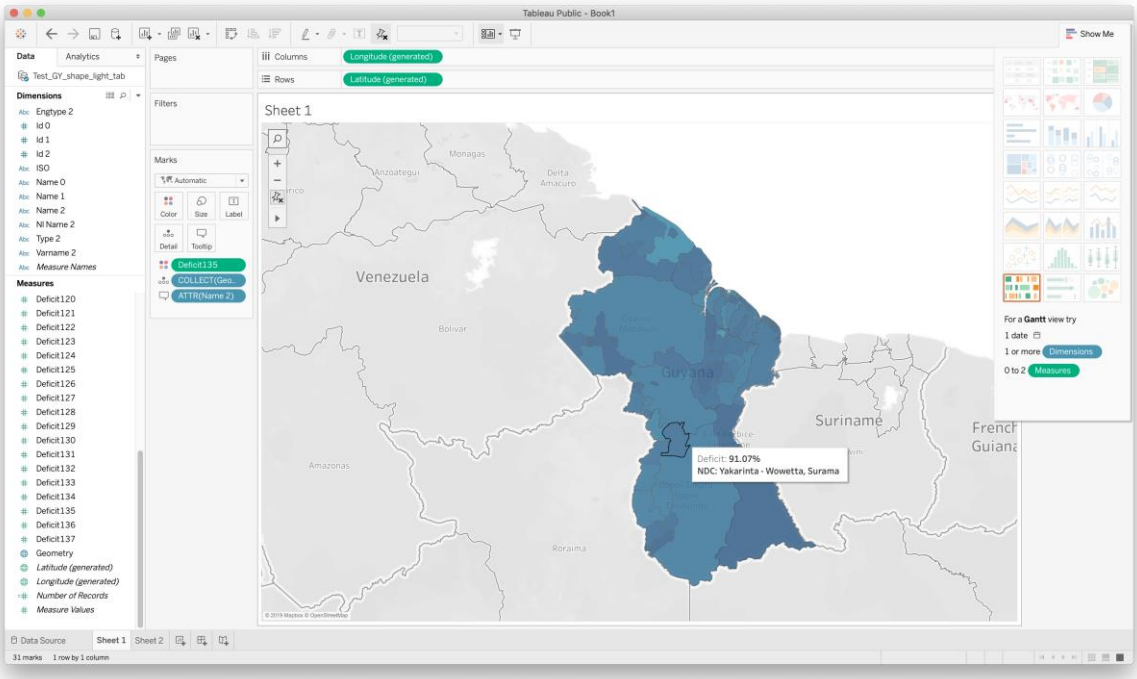


Figure 22: Plotting Data using '*Tableau Public*'

Aesthetic details of the map can be changed using the "Marks" panel and selecting "Map">"Map Layers" from the toolbar.

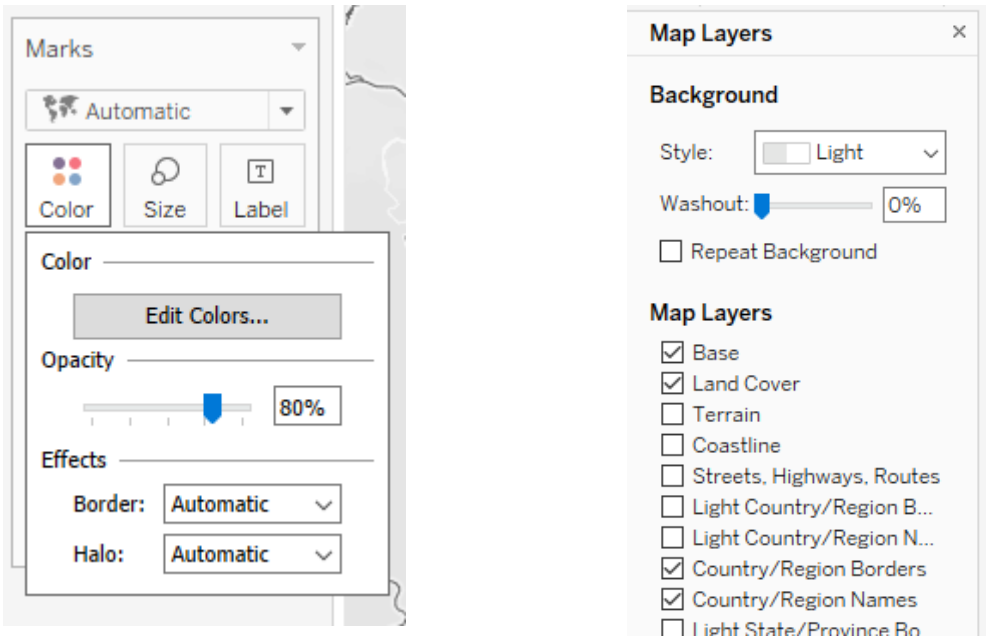


Figure 22: Adjusting map aesthetics in Tableau Public

Publishing and Sharing the Map with the World

- Go to **"File">"Save to Tableau Public As..."**. A window will prompt you to **sign in** to the Tableau system. Use login credentials to enter.
- Once the login is successful, a new window will ask for name of the workbook; then click save.
- Once the software communicates with server, a web browser page opens and the final product is visible.

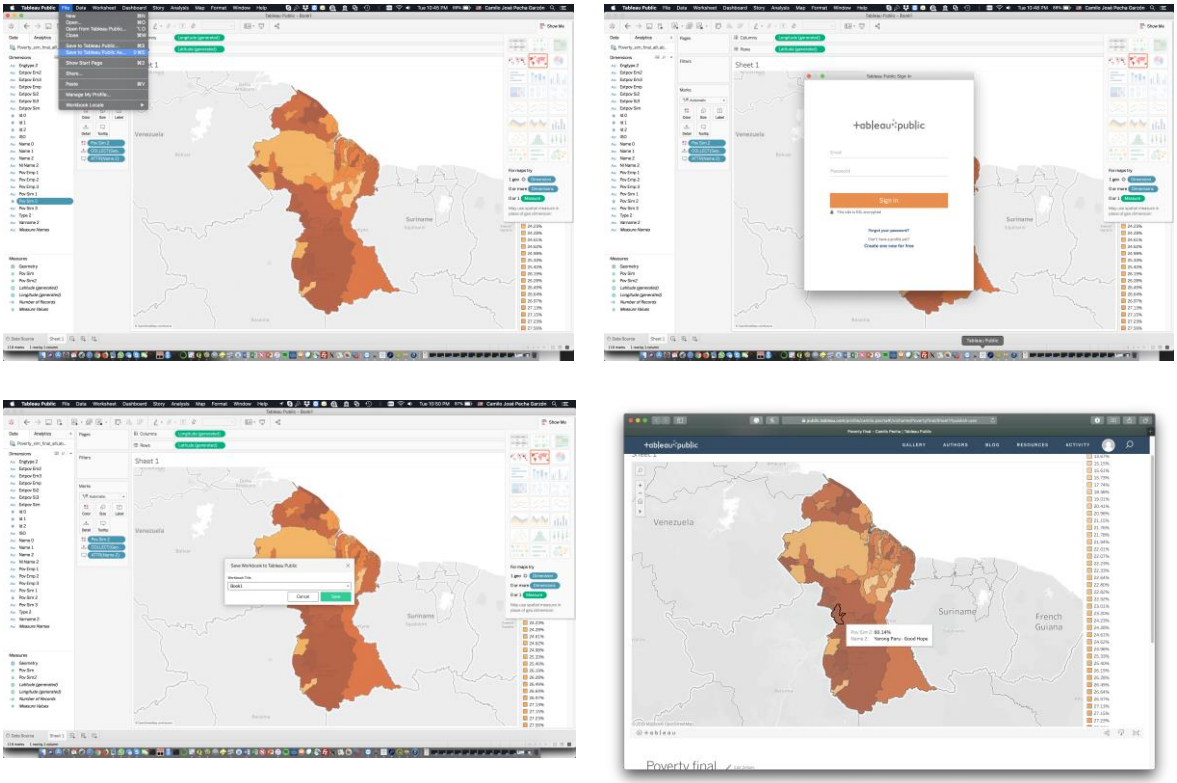


Figure 23: Publishing Data on Internet Using '*Tableau Public*'

VI. Bibliography

A. J. Bency, S. Rallapalli, R. K. Ganti, M. Srivatsa and B. S. Manjunath, "Beyond Spatial Auto-Regressive Models: Predicting Housing Prices with Satellite Imagery," 2017 IEEE Winter Conference on Applications of Computer Vision (WACV), Santa Rosa, CA, 2017, pp. 320-329. https://vision.ece.ucsb.edu/sites/default/files/publications/bency_wacv_17.pdf

Departamento Administrativo Nacional de Estadística. Metodología déficit de Vivienda. Bogotá, Colombia, 2009.

Divyani Kohli, Richard Sliuzas & Alfred Stein (2016) Urban slum detection using texture and spatial metrics derived from satellite imagery, Journal of Spatial Science, 61:2, 405-426, DOI: 10.1080/14498596.2016.1138247

Engstrom, Ryan; Hersh, Jonathan Samuel; Newhouse, David Locke. 2017. Poverty from space: using high-resolution satellite imagery for estimating economic well-being (English). Policy Research working paper; no. WPS 8284; Paper is funded by the Strategic Research Program (SRP). Washington, D.C. : World Bank Group.

NOAA, Ghosh, T., Powell, R., Elvidge, C. D., Baugh, K. E., Sutton, P. C., & Anderson, S. (2010)

ONU-Habitat. Déficit habitacional de América Latina y el Caribe: Una herramienta para el diagnóstico y el desarrollo de políticas efectivas en vivienda y hábitat. Programa de la Naciones

Unidas para los Asentamientos Humanos (ONU-Habitat) | P.O. Box 30030, GPO Nairobi 00100, Kenia. 2015