

Spatial Data Visualization and Analytics

Learn techniques for working with all types of spatial datasets.

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This course is also offered as an in-person class. If you would like to attend one of my workshops, visit www.spatialthoughts.com/events to know details of upcoming classes. You may also sign up for my mailing list to know when new sessions are scheduled.

Introduction

Why do we care about location?

“Everything is related to everything else, but near things are more related than distant things.” - Waldo Tobler’s First Law of Geography

When modeling and analyzing our world, location is a critical factor. A non-spatial model cannot accurately reflect the processes and interactions happening in our world. Take this example - predicting housing prices - where a spatial prediction model performed much better than a purely non-spatial one.

Location data is everywhere

Today the availability of location data - both for individuals and businesses - has exploded. Spatial data adds another dimension to data, and reveals patterns that are otherwise not obvious.

Individuals - with GPS sensors on their smartphones - have the ability to tag their data with location. Photos taken with smartphones have the location embedded in it. If opted-in, one can store and access their location history on an ongoing basis.

Most businesses have location data in one form or the other. Customer addresses, IP-locations of website visitors, sales territories, supply chain routes and so on. For other businesses - such as taxi aggregators, food delivery, logistics - generate huge amounts of location data that can be mined for intelligence.

IoT (Internet-Of-Things) devices are collecting location data continuously alongside with sensor data.

Governments are also increasing collecting and sharing location based data. Data relating to urban infrastructure, census, LIDAR and aerial imagery etc. are being collected at massive scale. Many governments have implemented open data sharing policies - making this data available to individuals and businesses to use.

Spatial Data Model

geometry + properties

shape + table

geometry = coordinates + reference properties = type + data

A GeoJSON representation

```
{  
  "type": "Feature",  
  "geometry": {  
    "type": "Point",  
    "coordinates": [ 77.58270263671875, 12.963074139604124]  
  },  
  "properties": {
```

```

        "name": "Bengaluru"
    }
}

```

Spatial Data Formats

Type	Non-Spatial Data	Spatial Data
Text	csv, json, xml	csv, geojson, gml, kml
Binary/Compressed	xlsx, zip	shapefile, geopackage
Images	tiff, jpg, png	geotiff, jpeg2000
Databases	SQLite, PostgreSQL, Oracle	Spatialite, PostGIS, Oracle Spatial

Spatial Data Types

Type	Sub Types	Examples
Vector	Point	
	Line	
	Polygons	
	Point Cloud	LIDAR surveys
Raster	Photos	Aerial and Drone Photos
	Grids	Satellite Imagery, Elevation Data, Thematic Data
Mesh	Mesh	
Tiles	Raster Tile Layers	TMS / WMS
	Vector Tile Layers	

Introduction to QGIS

Plugins

Points

The simplest representation of spatial data can be done using a table. A place can be represented using a pair of coordinates - Latitude and Longitude - with other attribute information about the place. Many spatial data source come in this form. Excel sheets, CSV files, database tables etc.

Exercise: Mapping Air Quality

Worsening air quality is a severe problem in many countries around the world. India - particularly - Delhi suffers from acute problems of high pollution levels. One of the first steps to better understand the problem, is to have continuous monitoring of air quality across the cities. Many organizations have stepped up and setup such sensors that collect air quality data and make it publicly available. OpenAQ is a platform that collects this data from all public sources and makes it available in an easy to use form.

If you are interested in this topic, Urban Emissions has a lot of relevant information and datasets for India.

We will take the sensor data for PM2.5 concentrations 1 day and map it. The aim is to turn this tabular data info an informative spatial data visualization.

For this exercise, we are using daily average data for Delhi, India for February 15, 2020. This data was downloaded from OpenAQ Data Download

The screenshot shows the 'Data Download' interface for OpenAQ. The main title is 'Data Download'. Below it, there are sections for 'Guatemala', 'Hong Kong', and 'Ireland'. The 'Guatemala' section is active, showing a message: 'Customize the data you want to download. Currently, only the last 90 days is available from this form. Realtime and daily archives of all 529,373,956 are also available. More'.

LOCATIONS: 42

Country: India | **Area**: Delhi | **Location**: Select a Location

START DATE: Year: 2020, Month: February, Day: 15

END DATE: Year: 2020, Month: February, Day: 15

PARAMETERS: BC, CO, NO2, O3, PM10, **PM2.5** (selected), SO2

Download Selection (CSV)

Hong Kong: MEASUREMENTS: 1,489,382 LOCATIONS: 16

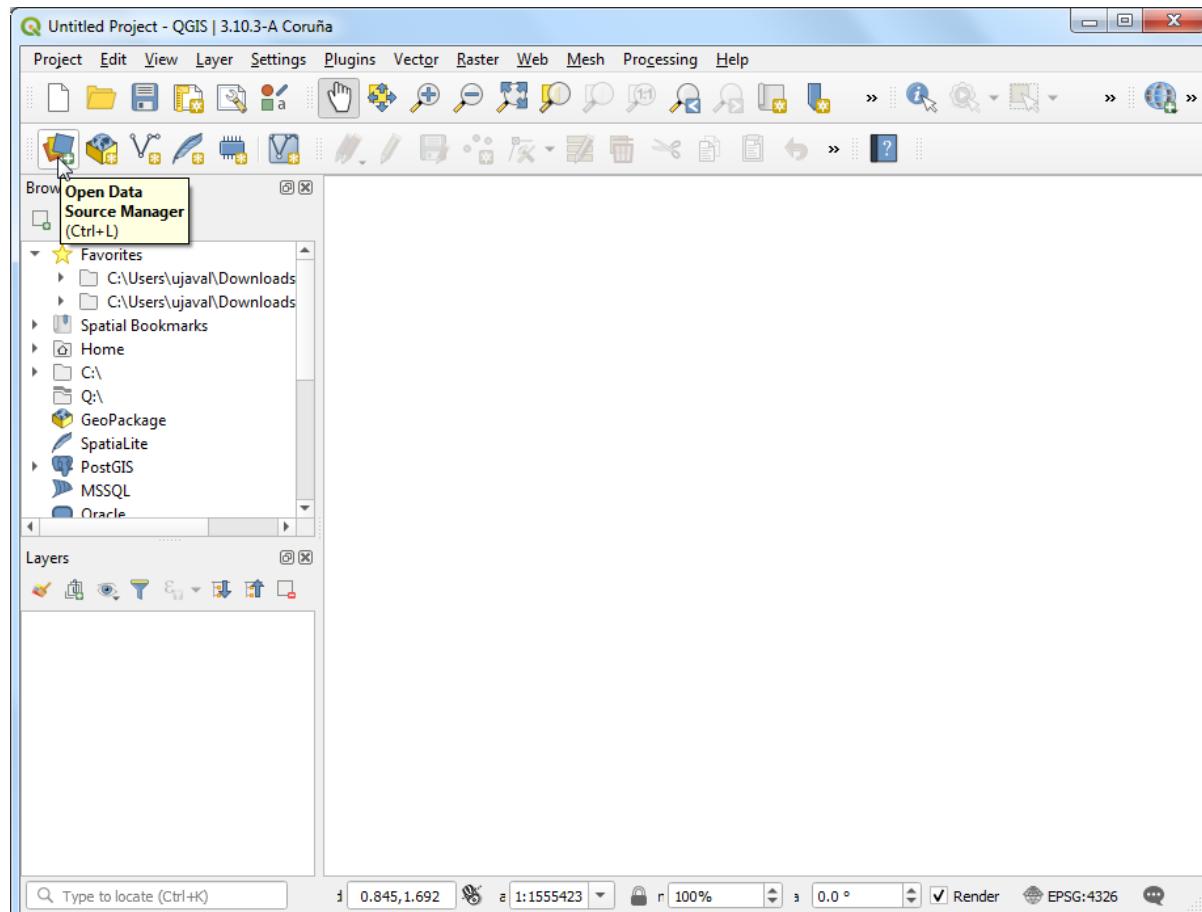
Ireland: MEASUREMENTS: 75,895 LOCATIONS: 5

Israel: MEASUREMENTS: 173,130,367 LOCATIONS: 2,041

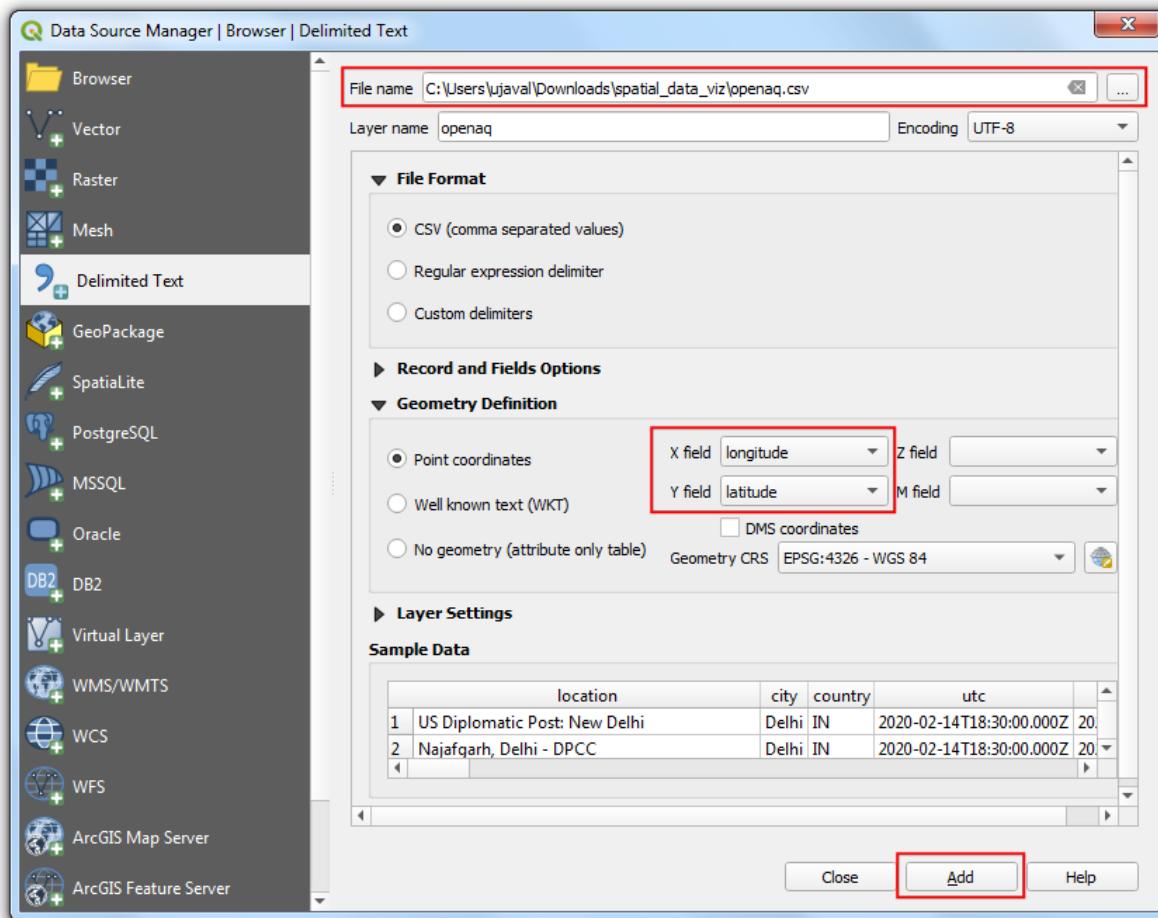
Open the `openaq.csv` file in a text editor and examine it. Each row of data contains data from 1 monitoring station. The `latitude` and `longitude` column contain the coordinates of the station and the `value` contains the daily average PM2.5 concentration

location	city	country	utc	local	parameter	value	unit	latitude	longitude	Attribution
US Diplomatic Post: New Delhi	Delhi	IN	2020-02-14T18:30:00.000Z	2020-02-15T00:00:00+05:30	pm25	67	µg/m³	28.63576	77.22445	{"name": "EPA AirNow I"}
Najafgarh, Delhi - DPCC	Delhi	IN	2020-02-14T18:30:00.000Z	2020-02-15T00:00:00+05:30	pm25	195	µg/m³	28.570173	76.933762	{"name": "Central Pollu"}
Alipur, Delhi - DPCC	Delhi	IN	2020-02-14T18:30:00.000Z	2020-02-15T00:00:00+05:30	pm25	85	µg/m³	28.815329	77.15301	{"name": "Central Pollu"}
Mundka, Delhi - DPCC	Delhi	IN	2020-02-14T18:30:00.000Z	2020-02-15T00:00:00+05:30	pm25	68	µg/m³	28.684678	77.076574	{"name": "Central Pollu"}
Sri Aurobindo Marg, Delhi - DPCC	Delhi	IN	2020-02-14T18:30:00.000Z	2020-02-15T00:00:00+05:30	pm25	85	µg/m³	28.531346	77.190156	{"name": "Central Pollu"}
Narela, Delhi - DPCC	Delhi	IN	2020-02-14T18:30:00.000Z	2020-02-15T00:00:00+05:30	pm25	101	µg/m³	28.822836	77.101981	{"name": "Central Pollu"}
Vivek Vihar, Delhi - DPCC	Delhi	IN	2020-02-14T18:30:00.000Z	2020-02-15T00:00:00+05:30	pm25	84	µg/m³	28.672342	77.31526	{"name": "Central Pollu"}
Okhla Phase-2, Delhi - DPCC	Delhi	IN	2020-02-14T18:30:00.000Z	2020-02-15T00:00:00+05:30	pm25	102	µg/m³	28.530785	77.271255	{"name": "Central Pollu"}
Ashok Vihar, Delhi - DPCC	Delhi	IN	2020-02-14T18:30:00.000Z	2020-02-15T00:00:00+05:30	pm25	74	µg/m³	28.695381	77.181665	{"name": "Central Pollu"}
Dr. Karni Singh Shooting Range, Delhi - DPCC	Delhi	IN	2020-02-14T18:30:00.000Z	2020-02-15T00:00:00+05:30	pm25	68	µg/m³	28.498571	77.26484	{"name": "Central Pollu"}
Punjabi Bagh, Delhi - DPCC	Delhi	IN	2020-02-14T18:30:00.000Z	2020-02-15T00:00:00+05:30	pm25	63	µg/m³	28.674045	77.131023	{"name": "Central Pollu"}
R K Puram, Delhi - DPCC	Delhi	IN	2020-02-14T18:30:00.000Z	2020-02-15T00:00:00+05:30	pm25	72	µg/m³	28.563262	77.186937	{"name": "Central Pollu"}
Mandir Marg, Delhi - DPCC	Delhi	IN	2020-02-14T18:30:00.000Z	2020-02-15T00:00:00+05:30	pm25	70	µg/m³	28.636429	77.201067	{"name": "Central Pollu"}
Bawana, Delhi - DPCC	Delhi	IN	2020-02-14T18:30:00.000Z	2020-02-15T00:00:00+05:30	pm25	150	µg/m³	28.7762	77.051074	{"name": "Central Pollu"}
Sonia Vihar, Delhi - DPCC	Delhi	IN	2020-02-14T18:30:00.000Z	2020-02-15T00:00:00+05:30	pm25	77	µg/m³	28.710508	77.249485	{"name": "Central Pollu"}
Patparganj, Delhi - DPCC	Delhi	IN	2020-02-14T18:30:00.000Z	2020-02-15T00:00:00+05:30	pm25	52	µg/m³	28.623748	77.287205	{"name": "Central Pollu"}
Nehru Nagar, Delhi - DPCC	Delhi	IN	2020-02-14T18:30:00.000Z	2020-02-15T00:00:00+05:30	pm25	59	µg/m³	28.56789	77.250515	{"name": "Central Pollu"}
Jawaharlal Nehru Stadium, Delhi - DPCC	Delhi	IN	2020-02-14T18:30:00.000Z	2020-02-15T00:00:00+05:30	pm25	57	µg/m³	28.58028	77.233829	{"name": "Central Pollu"}
Jahangirpuri, Delhi - DPCC	Delhi	IN	2020-02-14T18:30:00.000Z	2020-02-15T00:00:00+05:30	pm25	106	µg/m³	28.73282	77.170633	{"name": "Central Pollu"}
Dwarka-Sector 8, Delhi - DPCC	Delhi	IN	2020-02-14T18:30:00.000Z	2020-02-15T00:00:00+05:30	pm25	103	µg/m³	28.5710274	77.0719006	{"name": "Central Pollu"}
NSIT Dwarka, Delhi - CPCB	Delhi	IN	2020-02-14T18:30:00.000Z	2020-02-15T00:00:00+05:30	pm25	118.51	µg/m³	28.60909	77.0325413	{"name": "Central Pollu"}
ITO, Delhi - CPCB	Delhi	IN	2020-02-14T18:30:00.000Z	2020-02-15T00:00:00+05:30	pm25	53	µg/m³	28.628624	77.24106	{"name": "Central Pollu"}
DTU, Delhi - CPCB	Delhi	IN	2020-02-14T18:30:00.000Z	2020-02-15T00:00:00+05:30	pm25	133.45	µg/m³	28.7500499	77.1112615	{"name": "Central Pollu"}
Shadipur, Delhi - CPCB	Delhi	IN	2020-02-14T18:30:00.000Z	2020-02-15T00:00:00+05:30	pm25	63.41	µg/m³	28.6514781	77.1473105	{"name": "Central Pollu"}
IHBAS, Dilshad Garden, Delhi - CPCB	Delhi	IN	2020-02-14T18:30:00.000Z	2020-02-15T00:00:00+05:30	pm25	52.4	µg/m³	28.6811736	77.3025234	{"name": "Central Pollu"}
North Campus, DU, Delhi - IMD	Delhi	IN	2020-02-14T18:30:00.000Z	2020-02-15T00:00:00+05:30	pm25	37.95	µg/m³	28.6573814	77.1585447	{"name": "Central Pollu"}

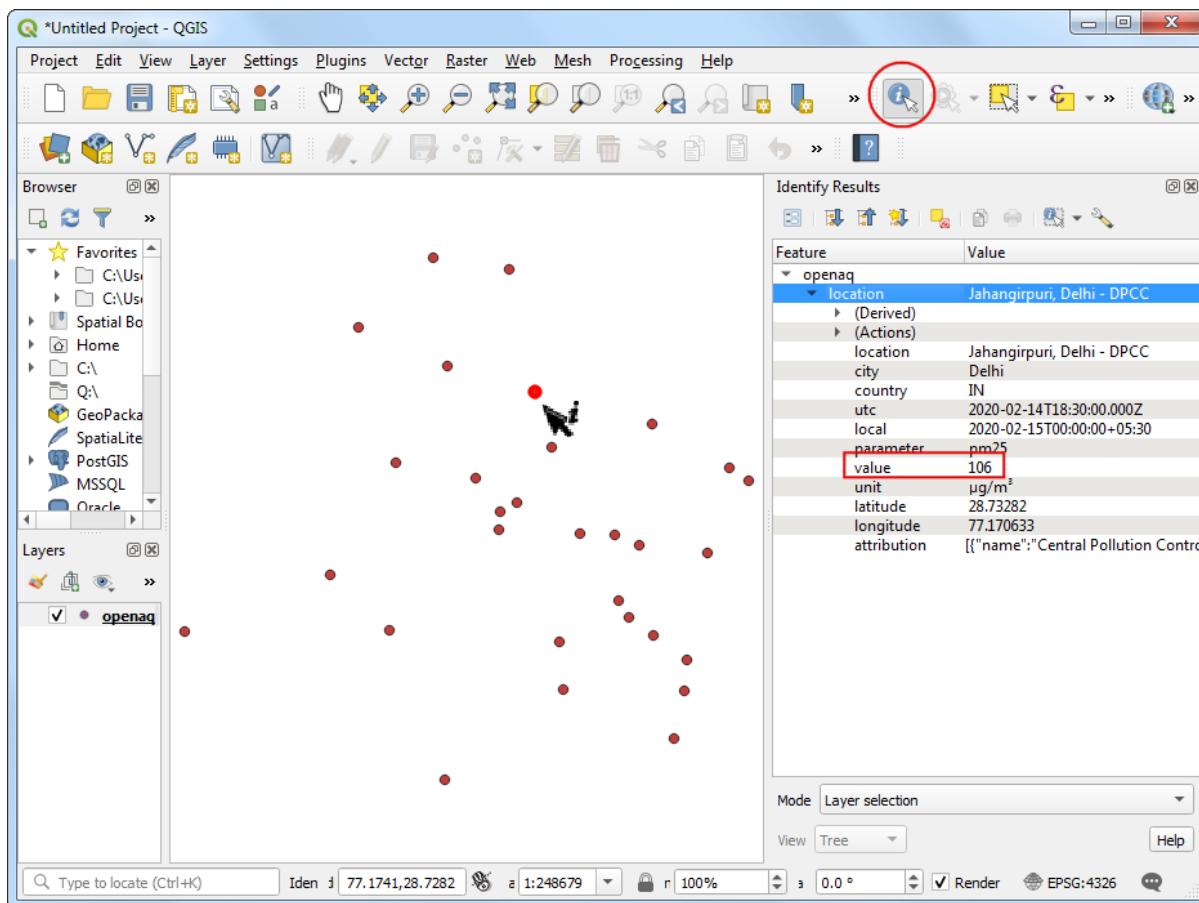
Tabular data in text files fall into the category of **Delimited Text** files, such as this can be imported in QGIS via *Data Source Manager*. Click *Open Data Source Manager* button.



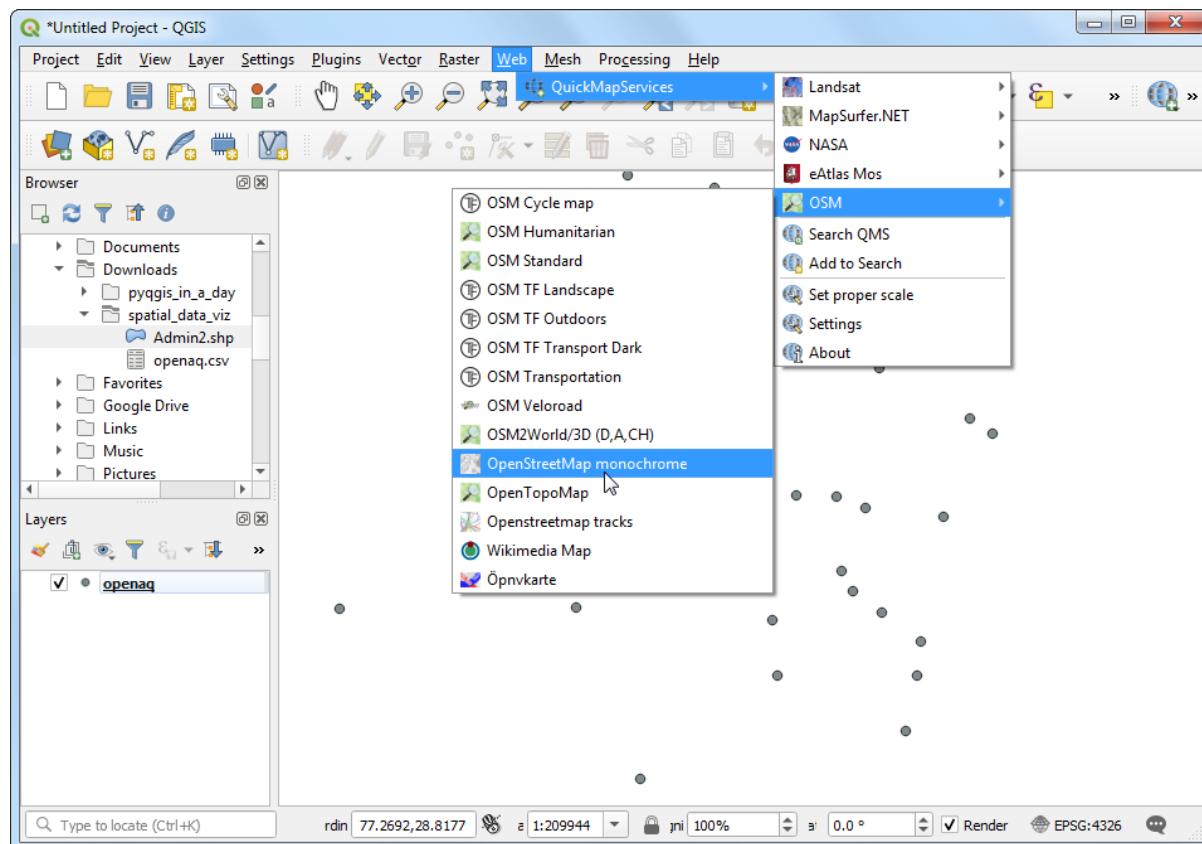
Browse to the `openaq.csv` file and open it. As we want to import this file as points, select *Point coordinates*. Choose *longitude* as *X Field* and *latitude* as *Y Field*. Click *Add*.



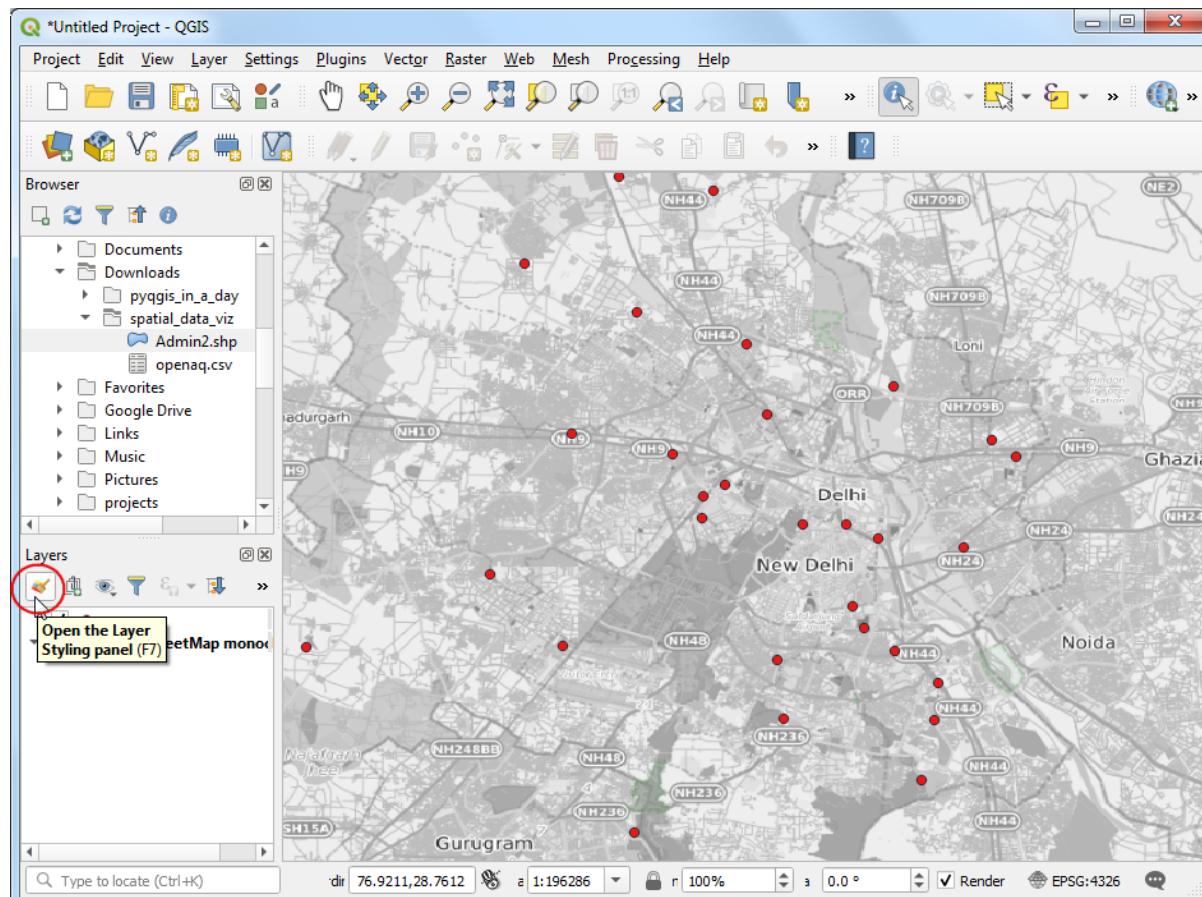
You will see the tabular data now loaded in QGIS canvas as a spatial data layer. Use the *Identify* button and click on any of the point. You will see the attribute data that is attached to each point.



Through we can see the point distribution is across the city of Delhi, we are missing the context on where is point is located. A base-map layer will help us understand this data better. The **QuickMapServices** plugin gives us ready access to many different types of base-maps. Go to **Web** → **QuickMapServices** → **OSM** → **OpenStreetMap monochrome** layer.

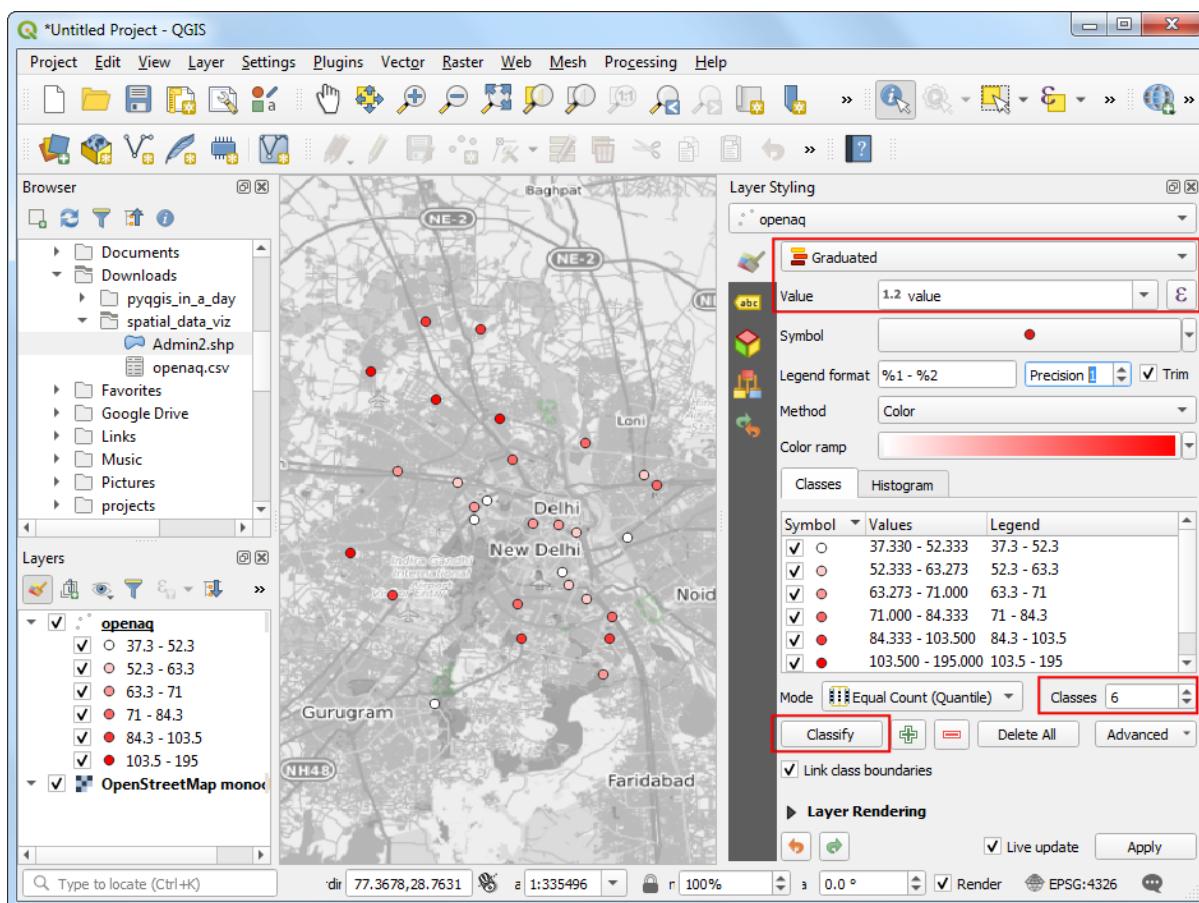


A new layer will get added to the *Layers* panel and the *Canvas*. Now you can see the points in the context of the city and surroundings. Let's style the point layer better now. Click *Open the Layer Styling Panel*.



We will color each point according to the observed PM2.5 value. Choose **Graduated**

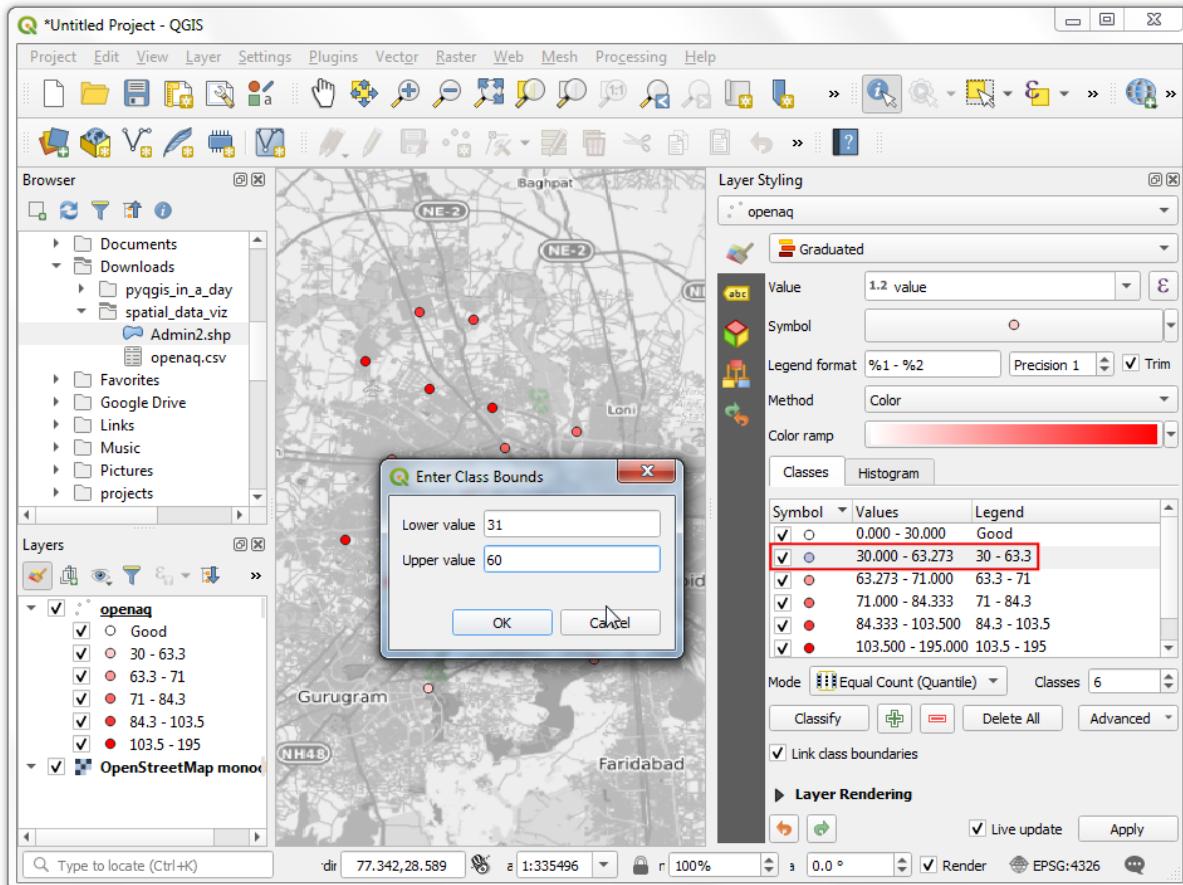
renderer and value as the *Value* column. Set the number of *Classes* to 6 and click *Classify*.



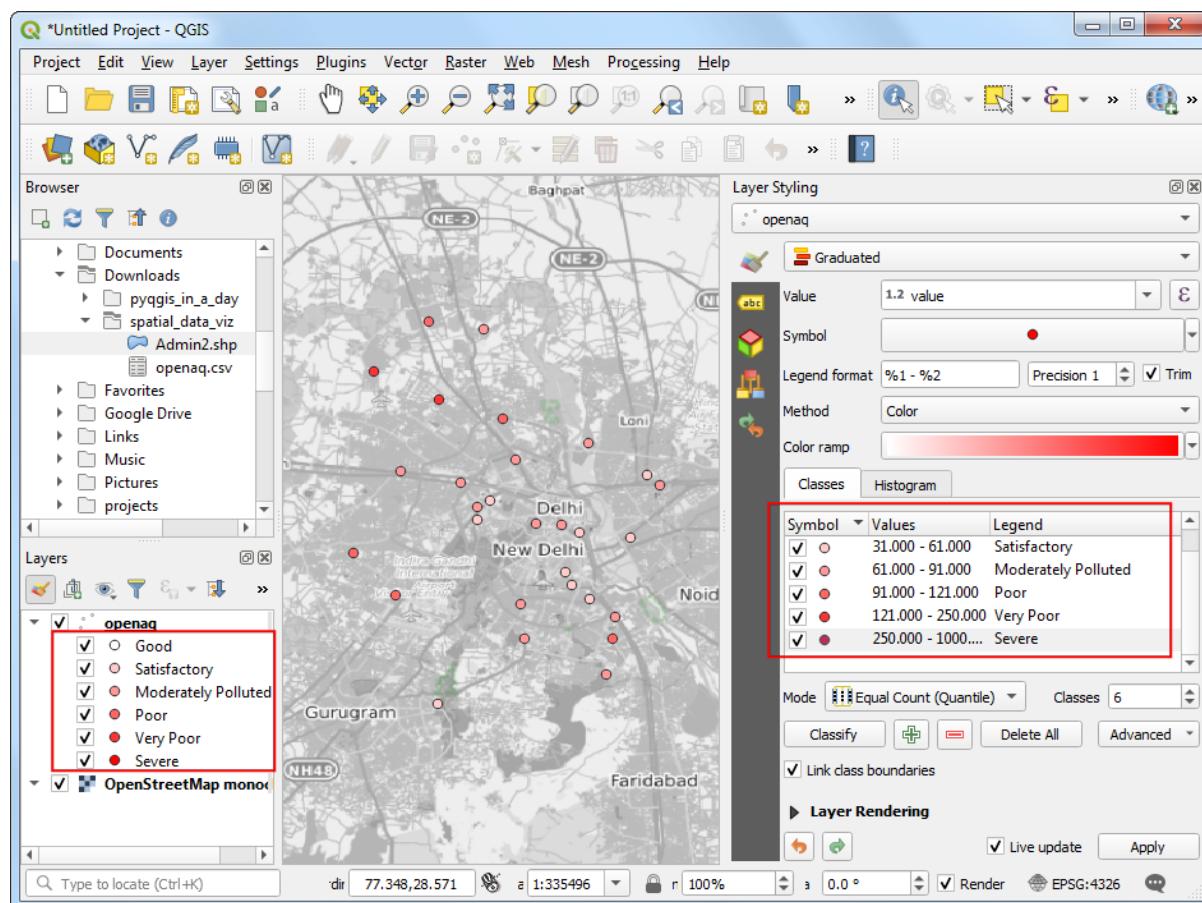
For the class ranges to have some meaning, we need to link them to the commonly used scale. India has adopted National Air Quality Index with the following definitions.

AQI Category, Pollutants and Health Breakpoints								
AQI Category (Range)	PM ₁₀ 24-hr	PM _{2.5} 24-hr	NO ₂ 24-hr	O ₃ 8-hr	CO 8-hr (mg/m ³)	SO ₂ 24-hr	NH ₃ 24-hr	Pb 24-hr
Good (0-50)	0-50	0-30	0-40	0-50	0-1.0	0-40	0-200	0-0.5
Satisfactory (51-100)	51-100	31-60	41-80	51-100	1.1-2.0	41-80	201-400	0.5 – 1.0
Moderately polluted (101-200)	101-250	61-90	81-180	101-168	2.1- 10	81-380	401-800	1.1-2.0
Poor (201-300)	251-350	91-120	181-280	169-208	10-17	381-800	801-1200	2.1-3.0
Very poor (301-400)	351-430	121-250	281-400	209-748*	17-34	801-1600	1200-1800	3.1-3.5
Severe (401-500)	430 +	250+	400+	748+*	34+	1600+	1800+	3.5+

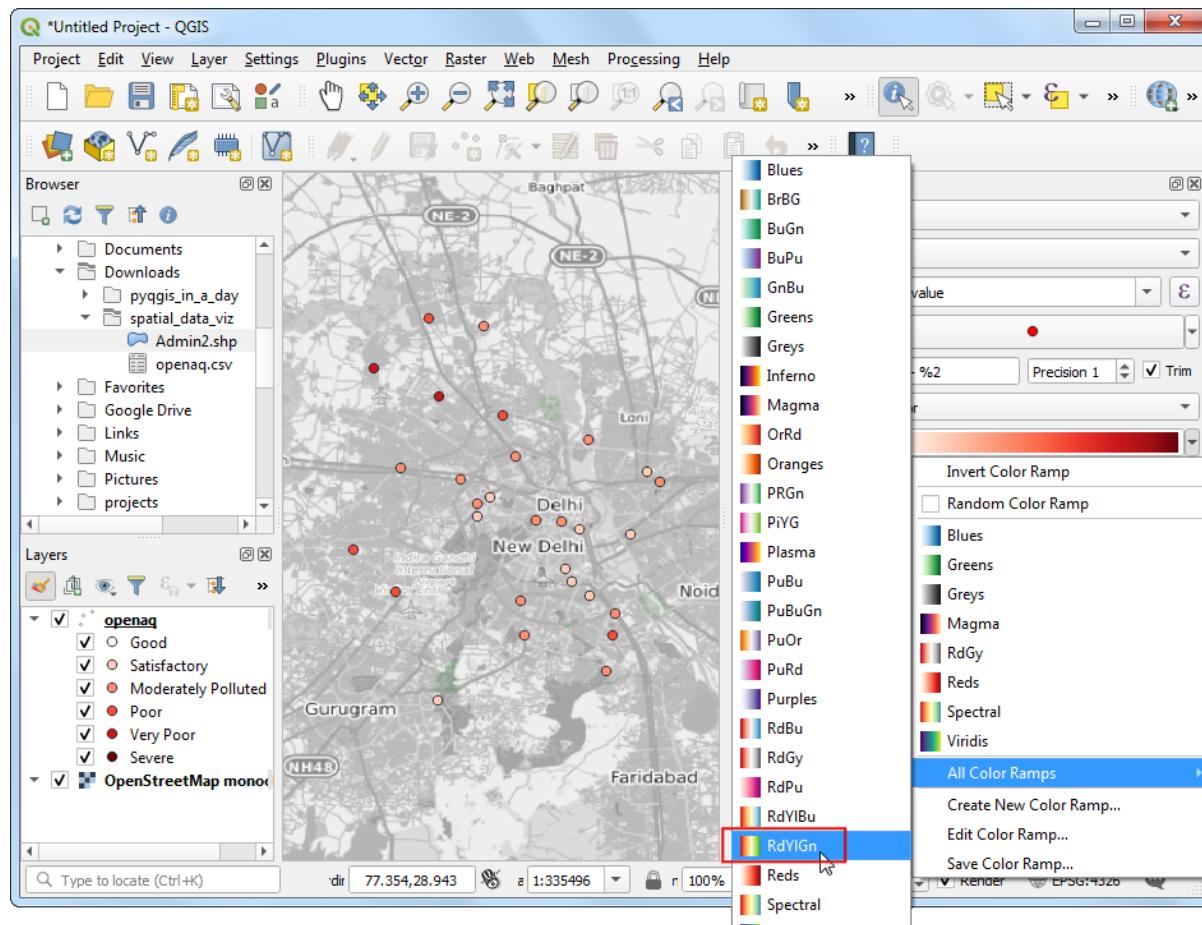
Let's adjust the class values to match those defined in the National Air Quality Index. We can also change the *Legend* labels to the human-readable category names. You can double-click each class range and edit it.



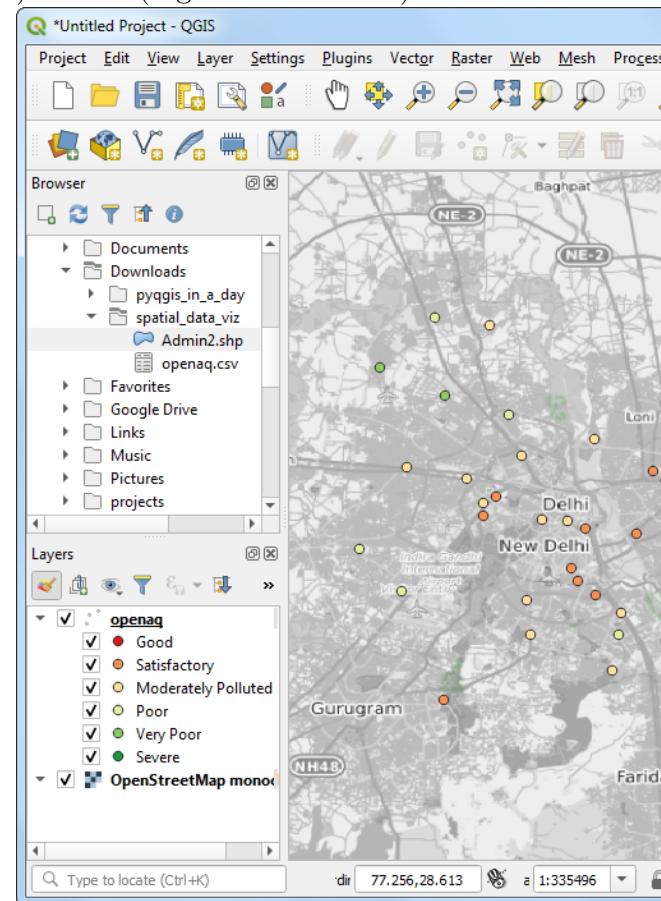
As you edit the categories, the map visualization will change accordingly. The layer legend will also show the legend labels now.



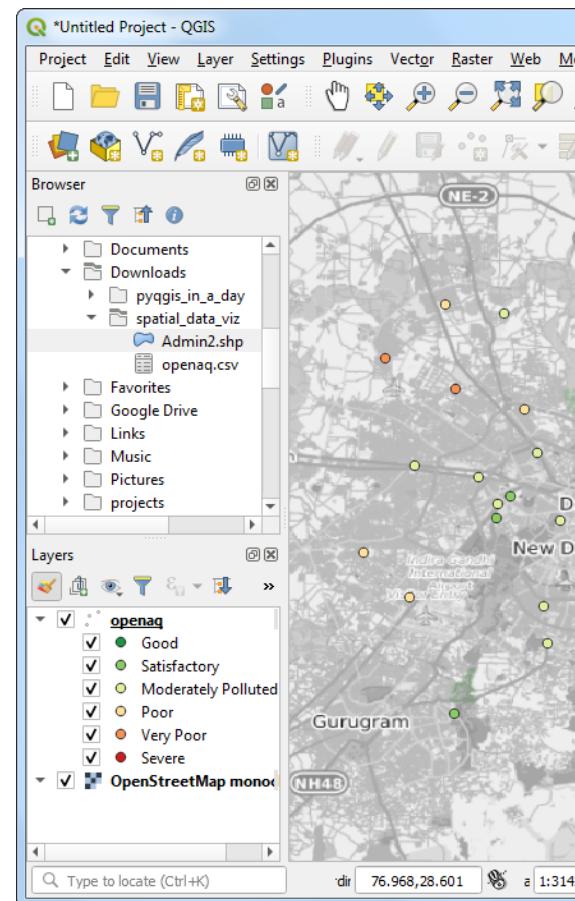
We can change the color also to match those defined in the index. Select the dropdown next to the color ramp and select the RdYlGn (Red-Yellow-Green) ramp.



We want the ramp to go from Green (low PM2.5 values) to Red (high PM2.5 values) - so

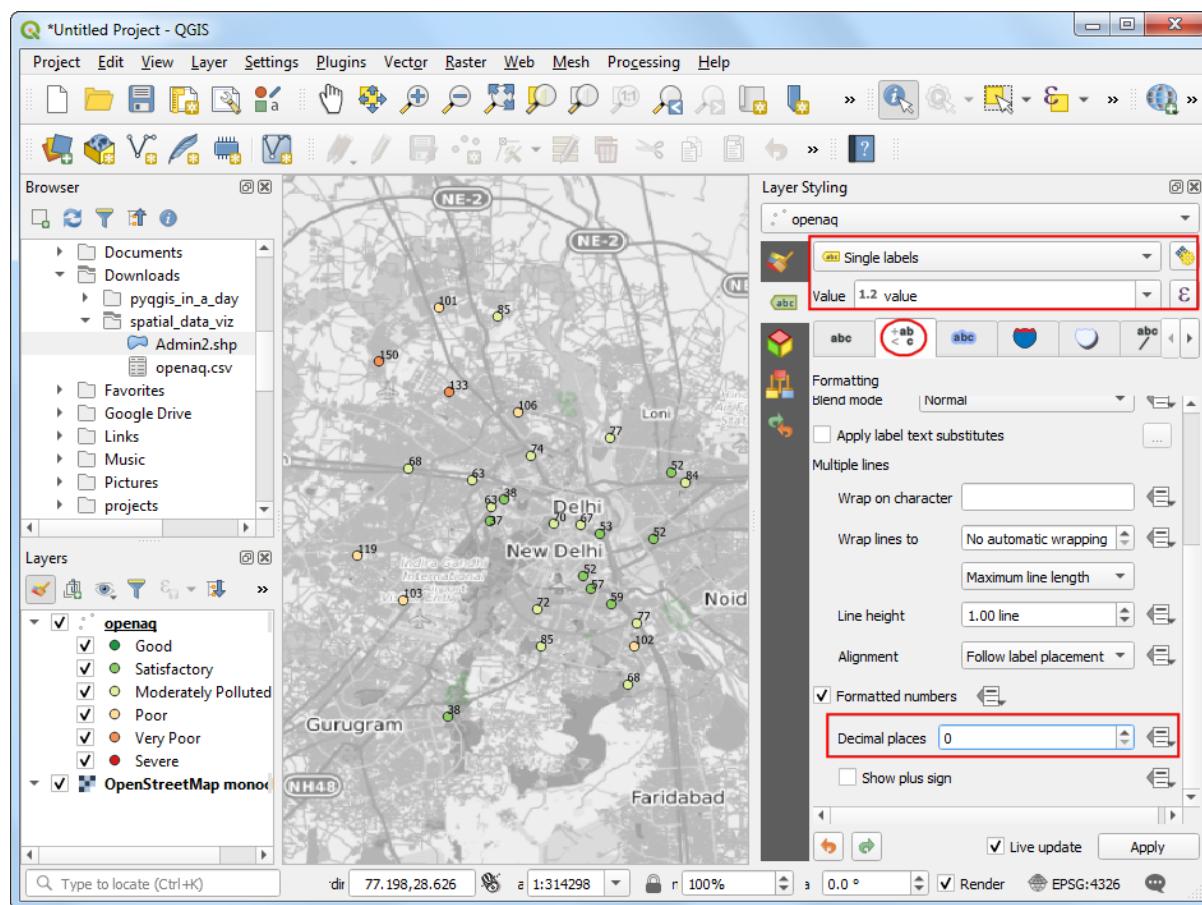


click the dropdown again and select *Invert Color Ramp*.

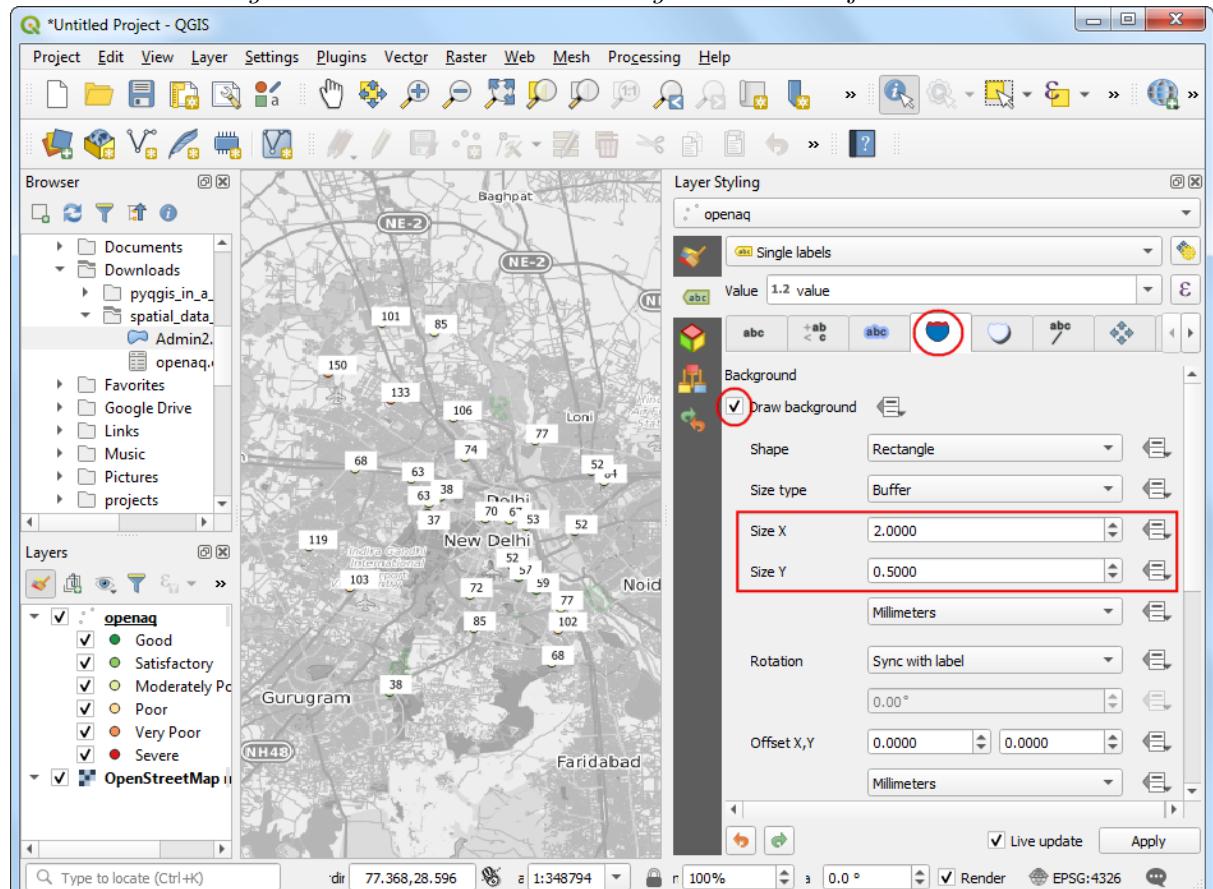


We will add labels to the points now. Switch to the *Labels* tab.

Choose **Single labels** and **value** as **Value**. Scroll down and check **Formatted numbers** and change the **Decimal places** to 0.

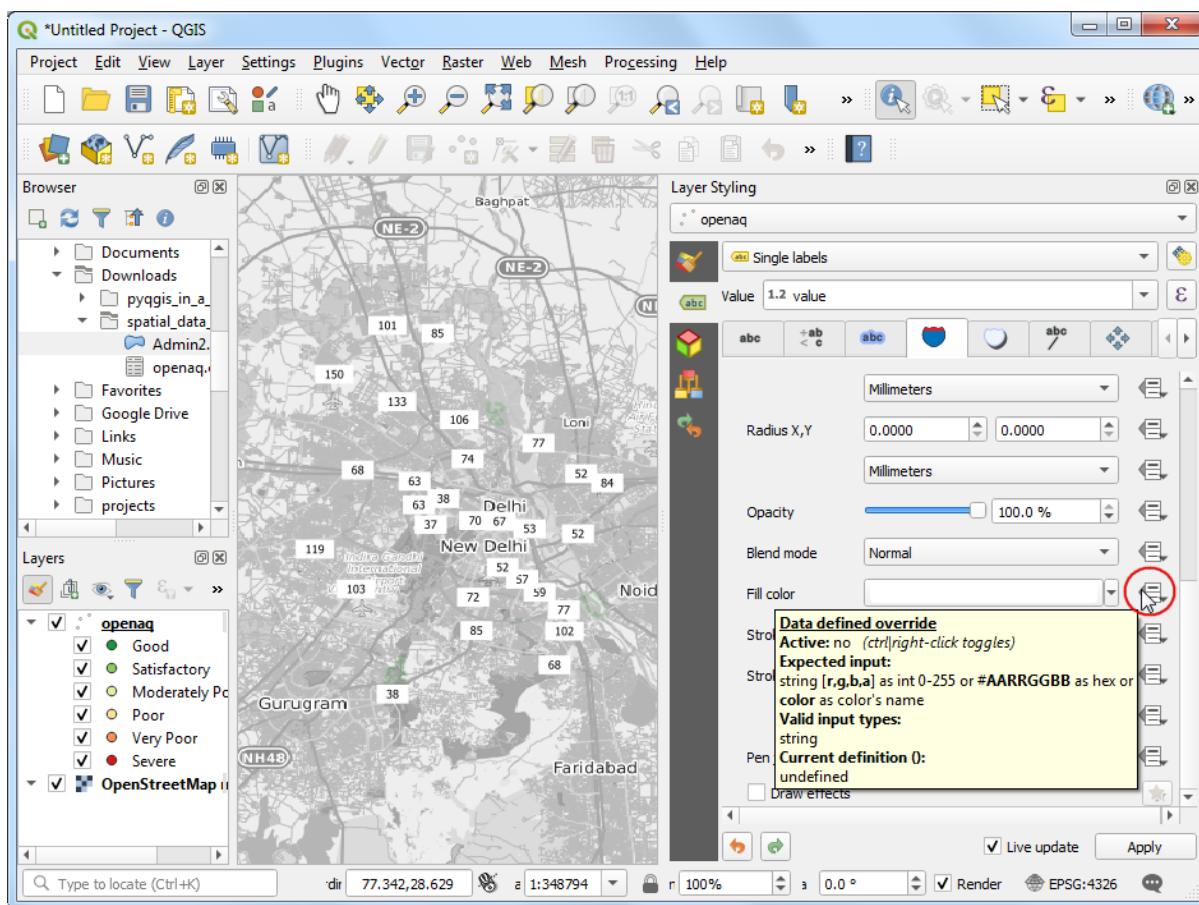


Next, switch to the *Background* tab. Check *Draw background* and adjust the *Size X* and

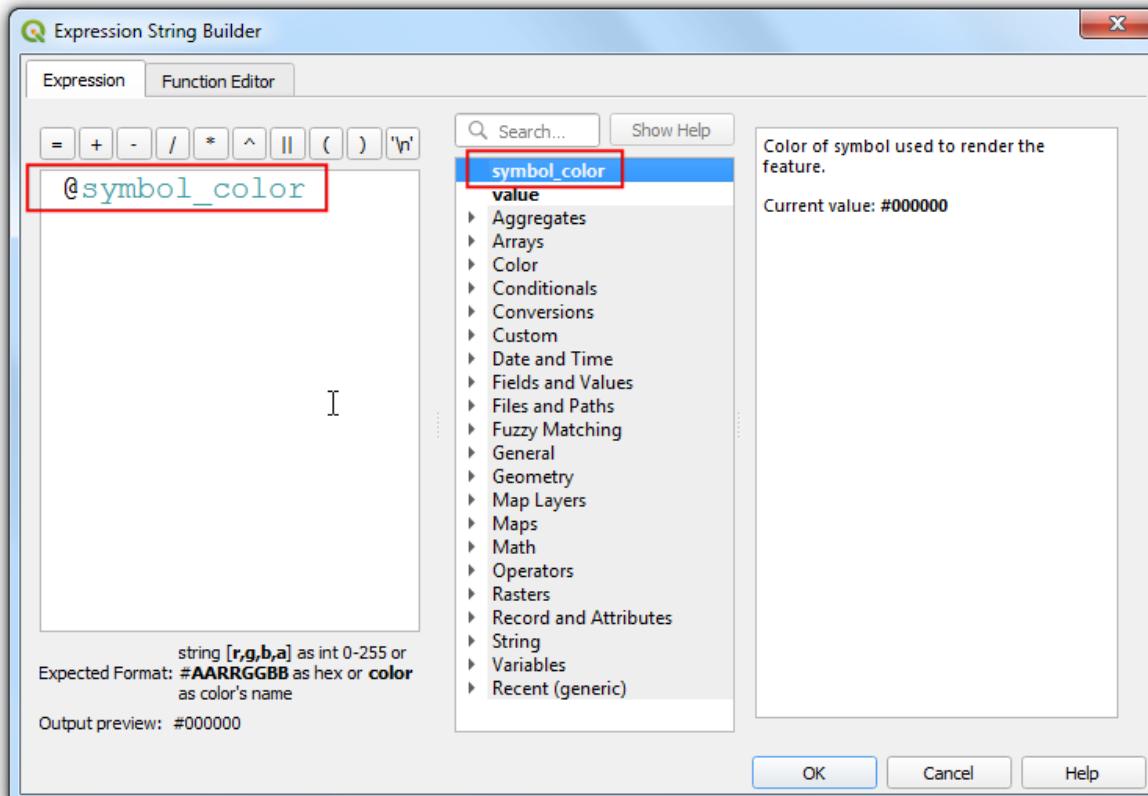


Size Y.

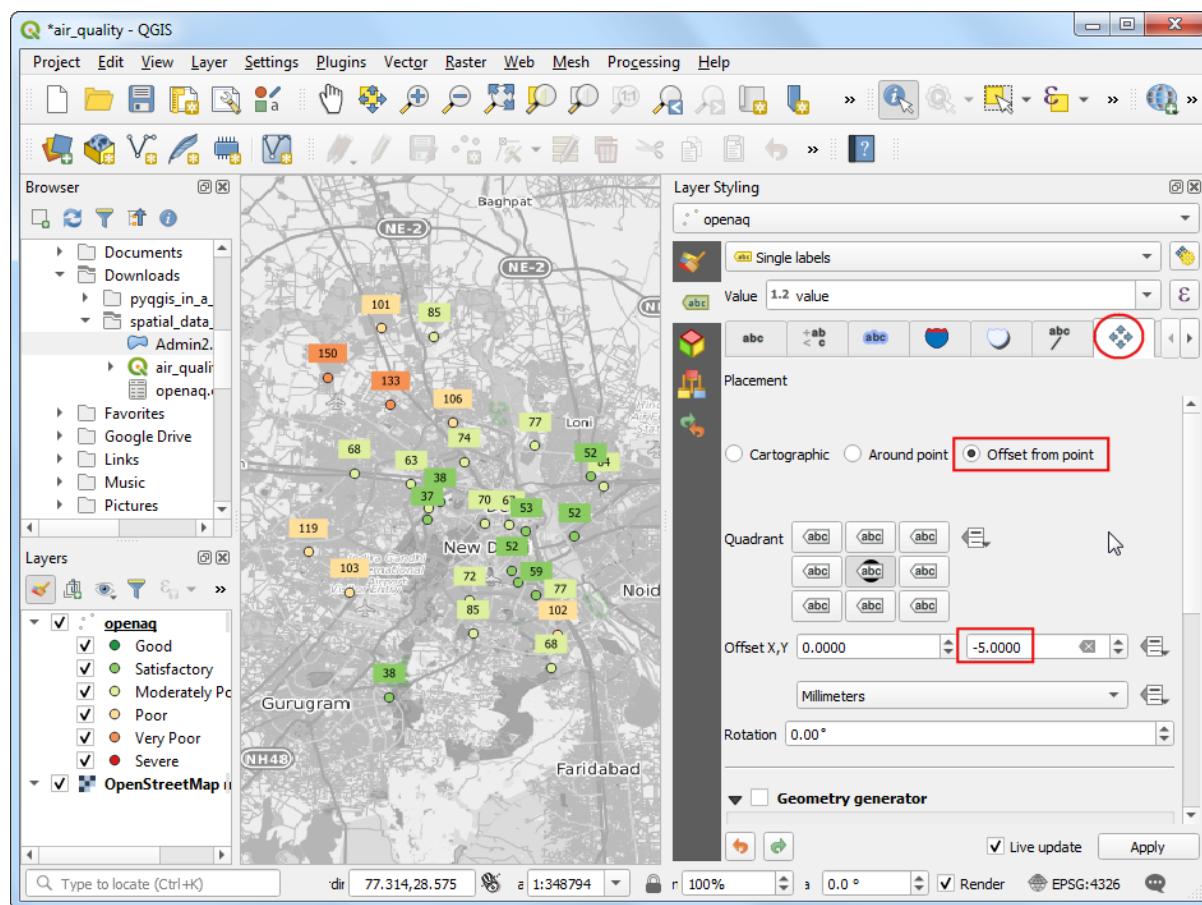
Scroll down to the *Fill color* section. We want the fill color for each box to match the color of the associated point. Click the *Data defined override* button and choose *Edit*.



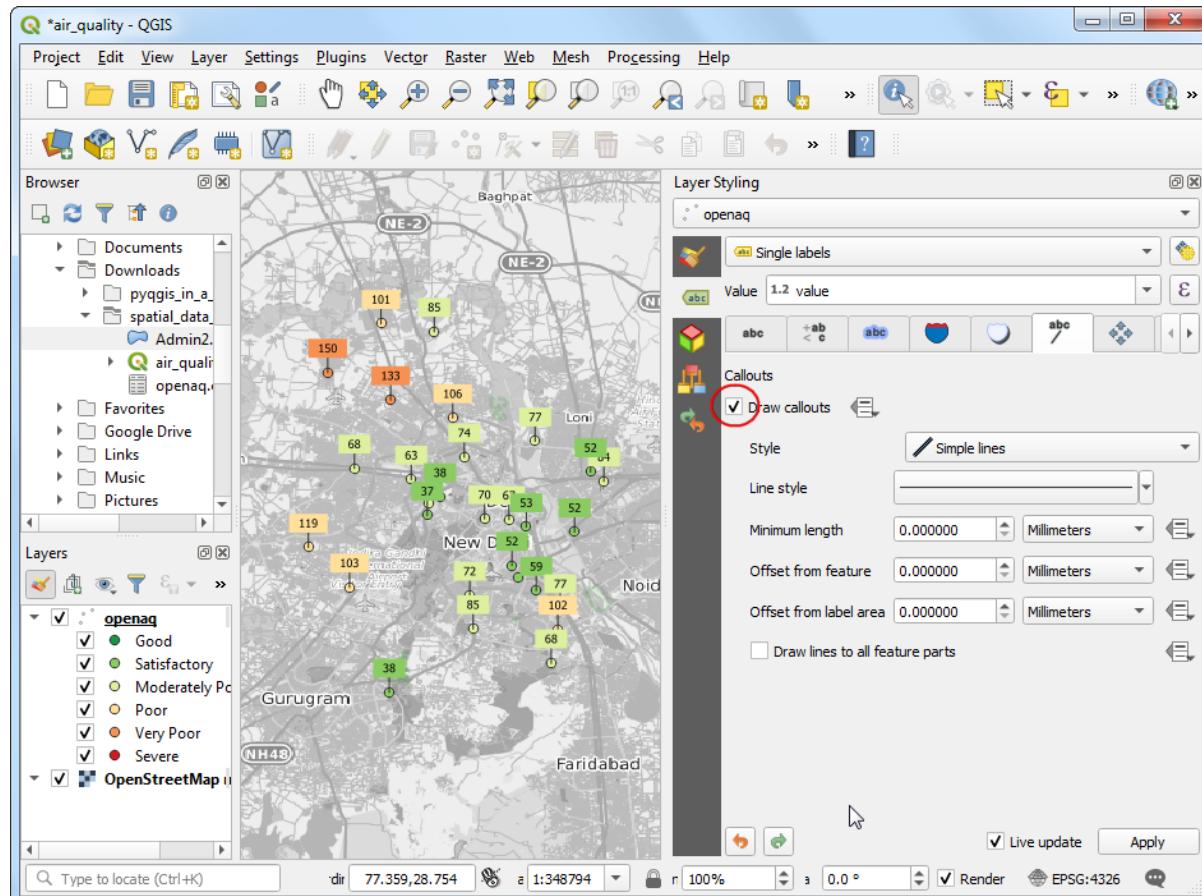
Double-click the `@symbol_color` variable to add it to the expression. Click OK.



You will see the map change and the label shields will have the color matching the category based on the values. We will move the labels slightly above so the points are also seen. Switch to the *Placement* tab and select *Offset from point*. Check the *Offset Y* to *-5*.

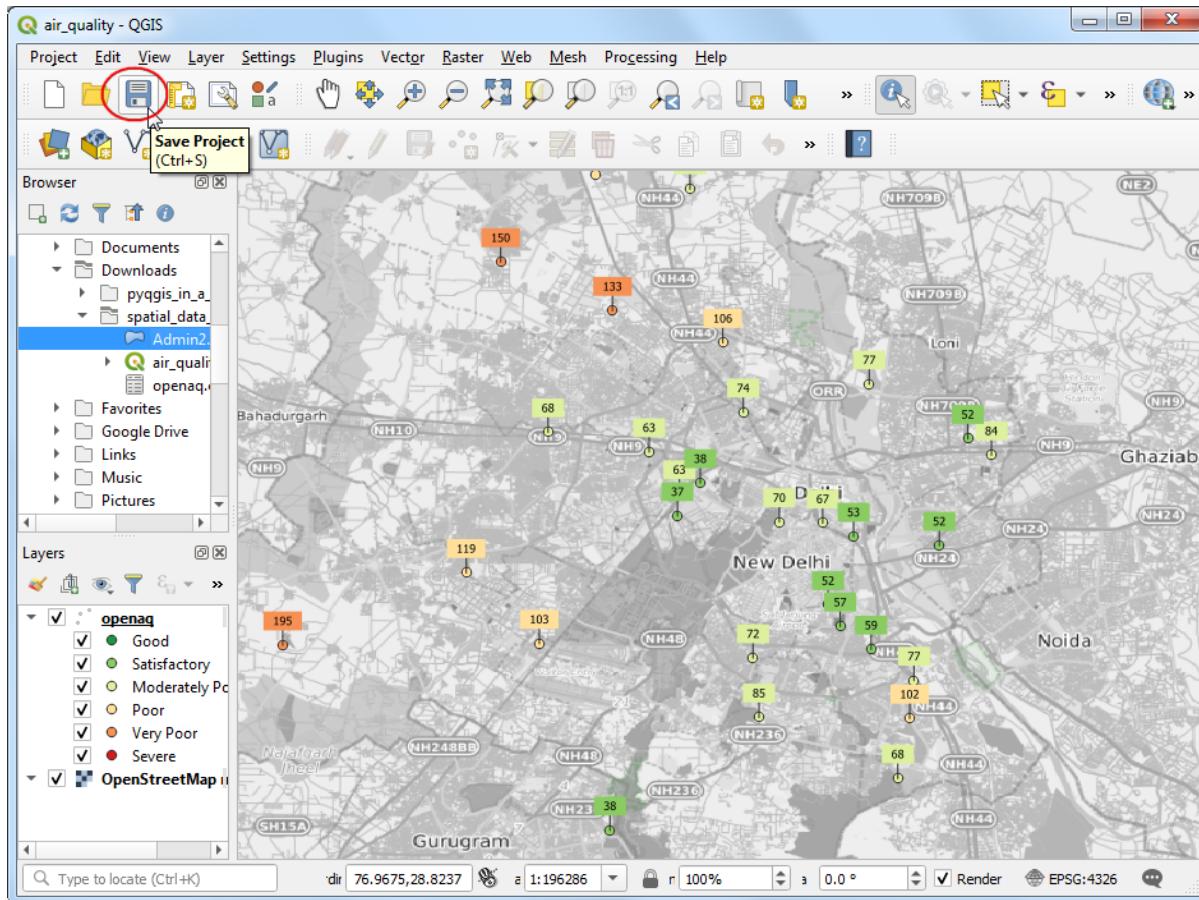


Lastly, go to the *Callouts* tab and check *Draw callouts* to make it easy to see which labels belong to which point.

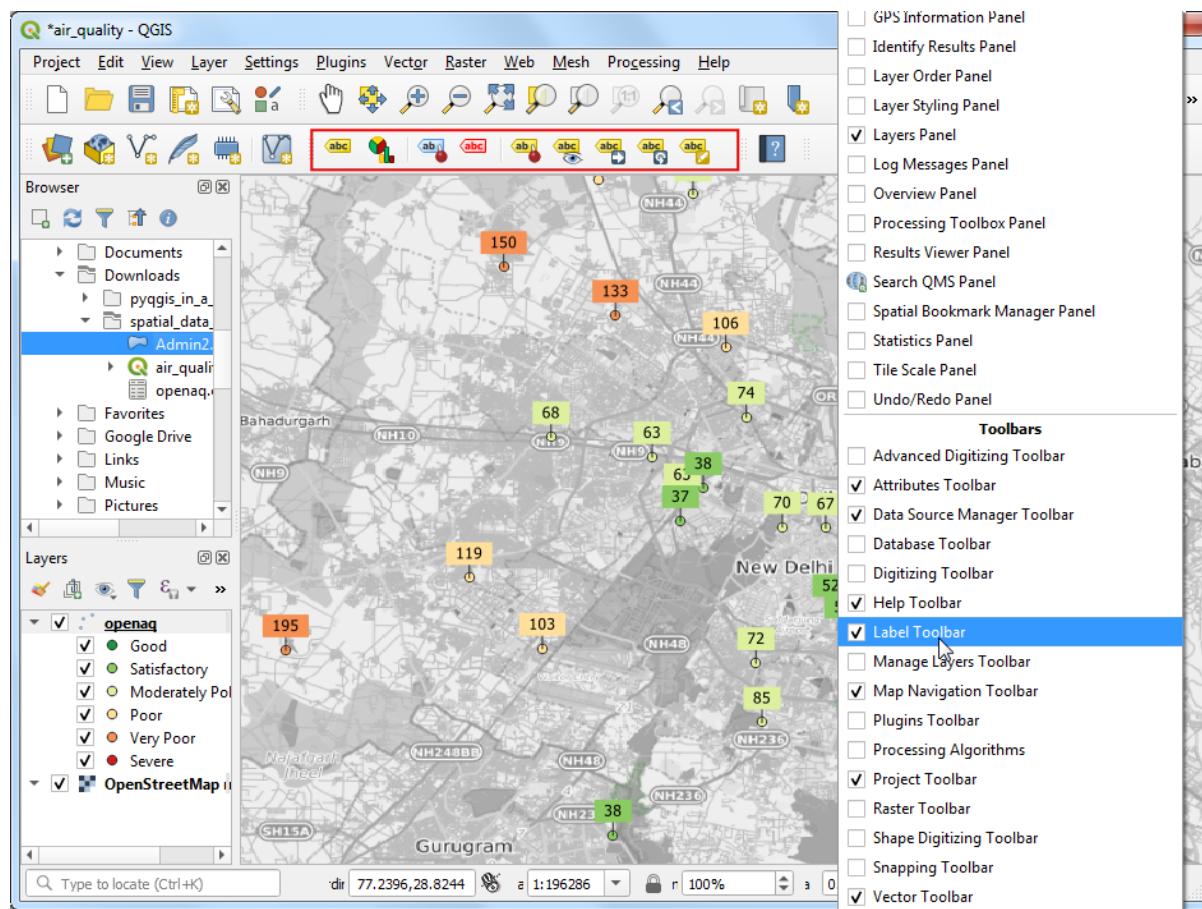


It is a good idea to save our work. Click the *Save Project* button and save it as

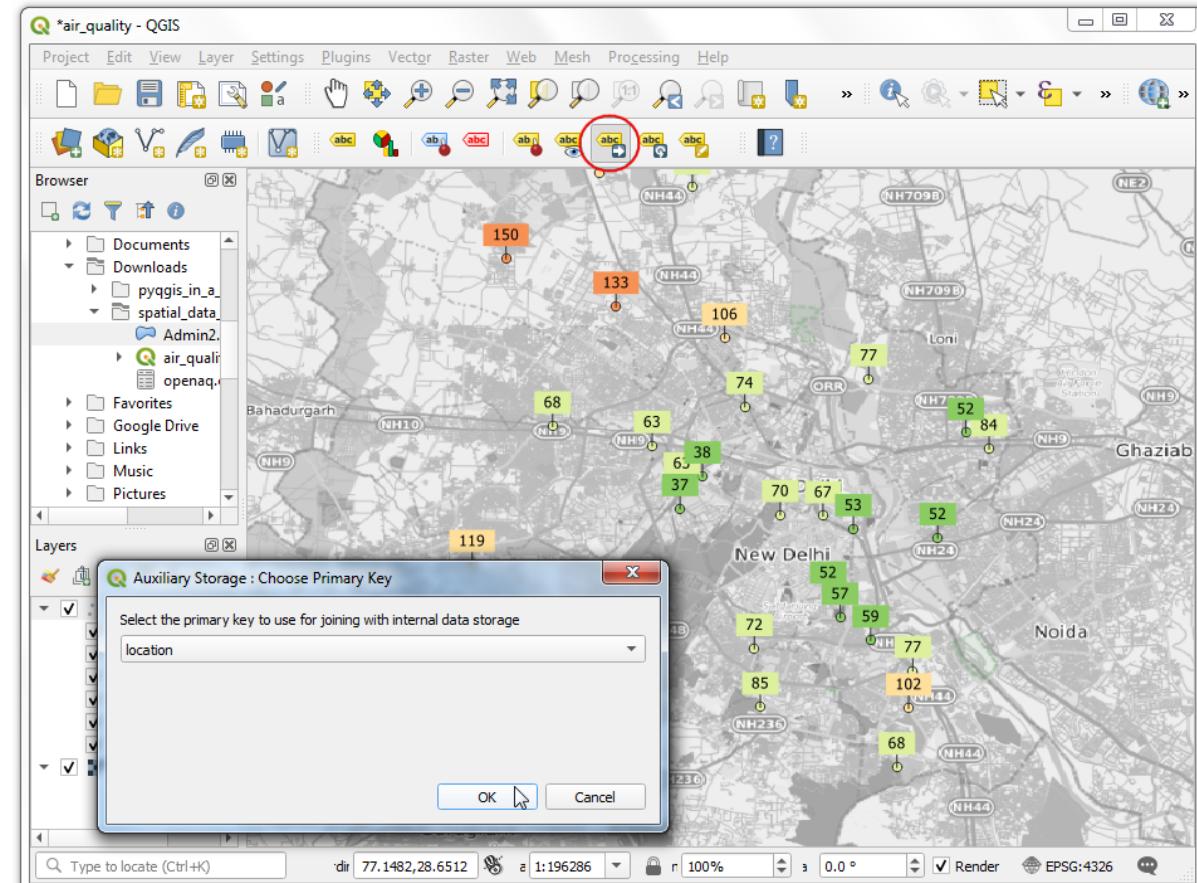
air_quality.qgz.



You can see most of the labels are legible, but some are too close and feel a bit cluttered. We can fix them by manually adjusting the placement. Right-click anywhere on the toolbar area and enable the *Label Toolbar*.

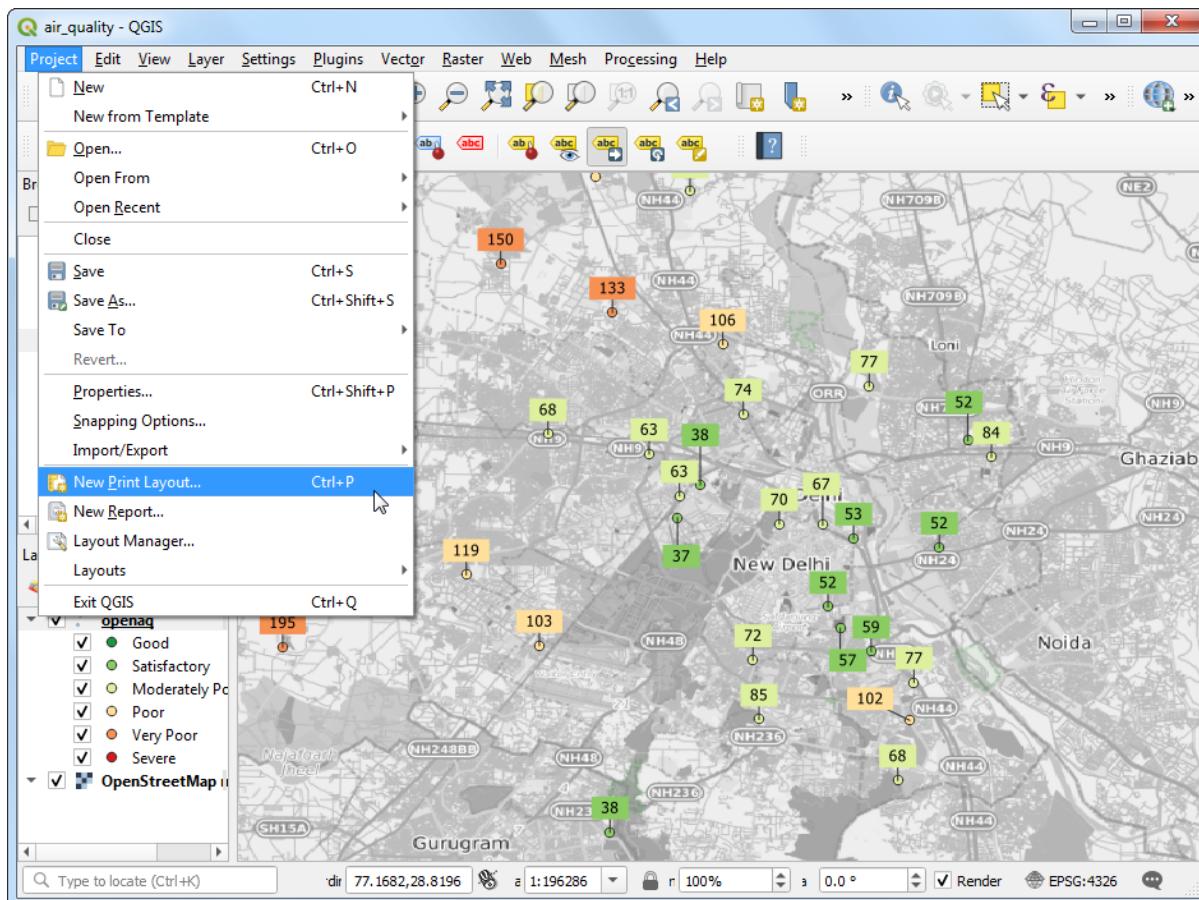


Click the *Move a Label* button. Click *OK* on the *Auxiliary Storage* prompt.

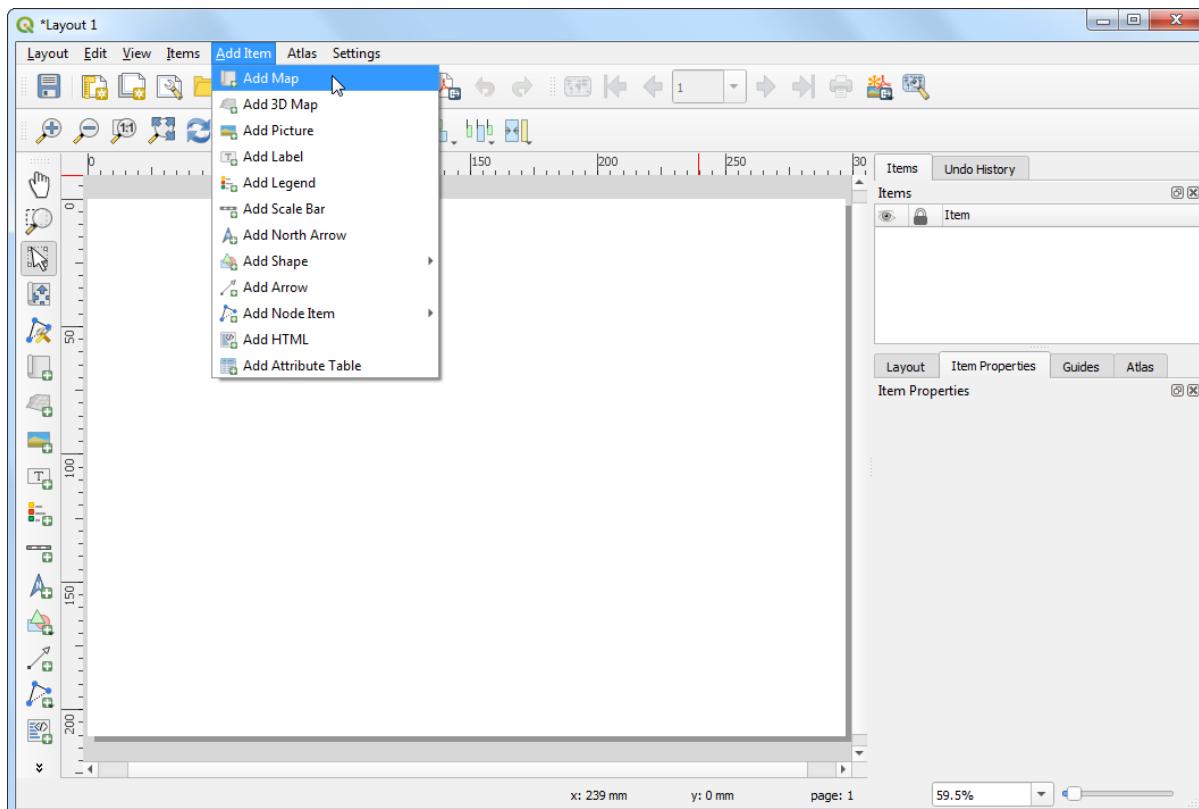


With the *Move a Label* button active, click on a any label to select it. Click at the place you want to move it to, and it will be placed there. Once you are satisfied, save the

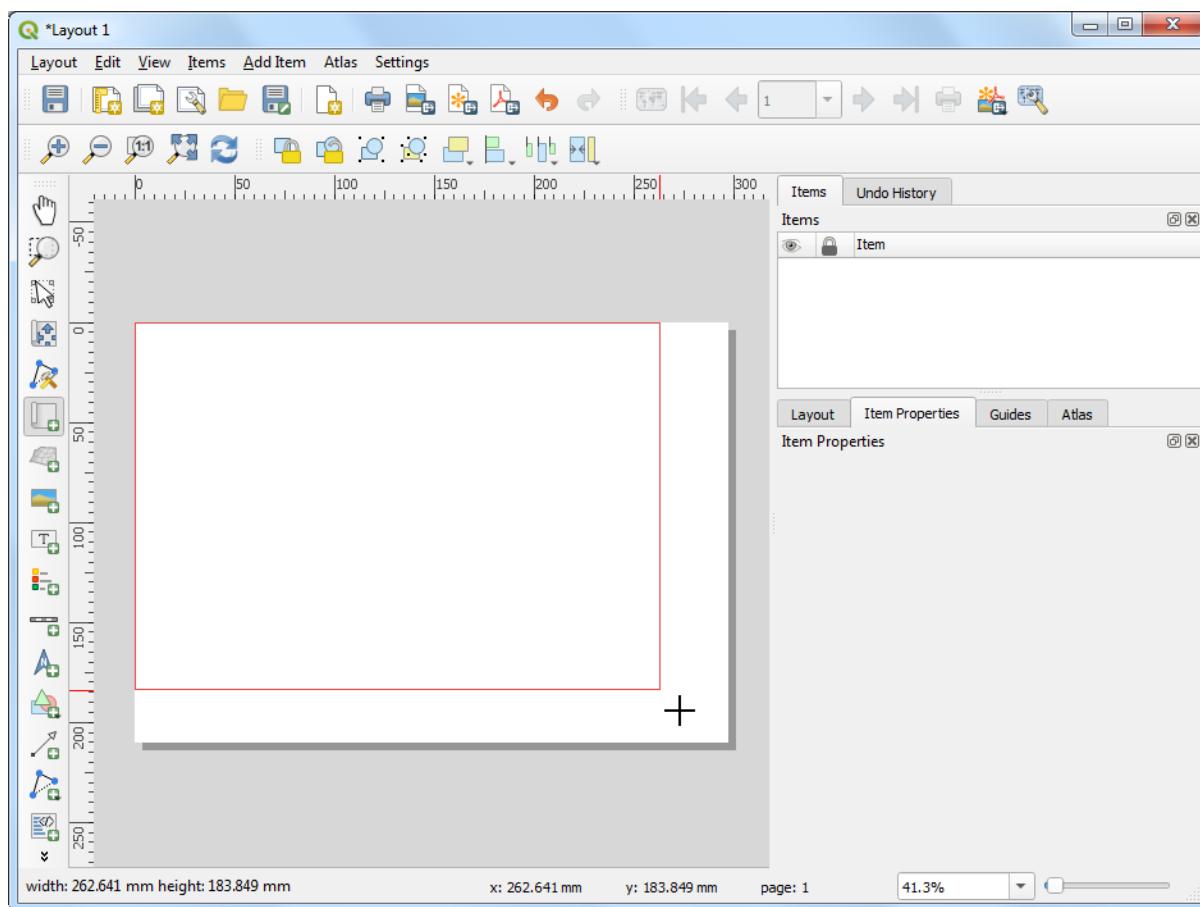
project. It is time to export our map. Go to **Project → New Print Layout....**. Leave the name empty and click *OK*.



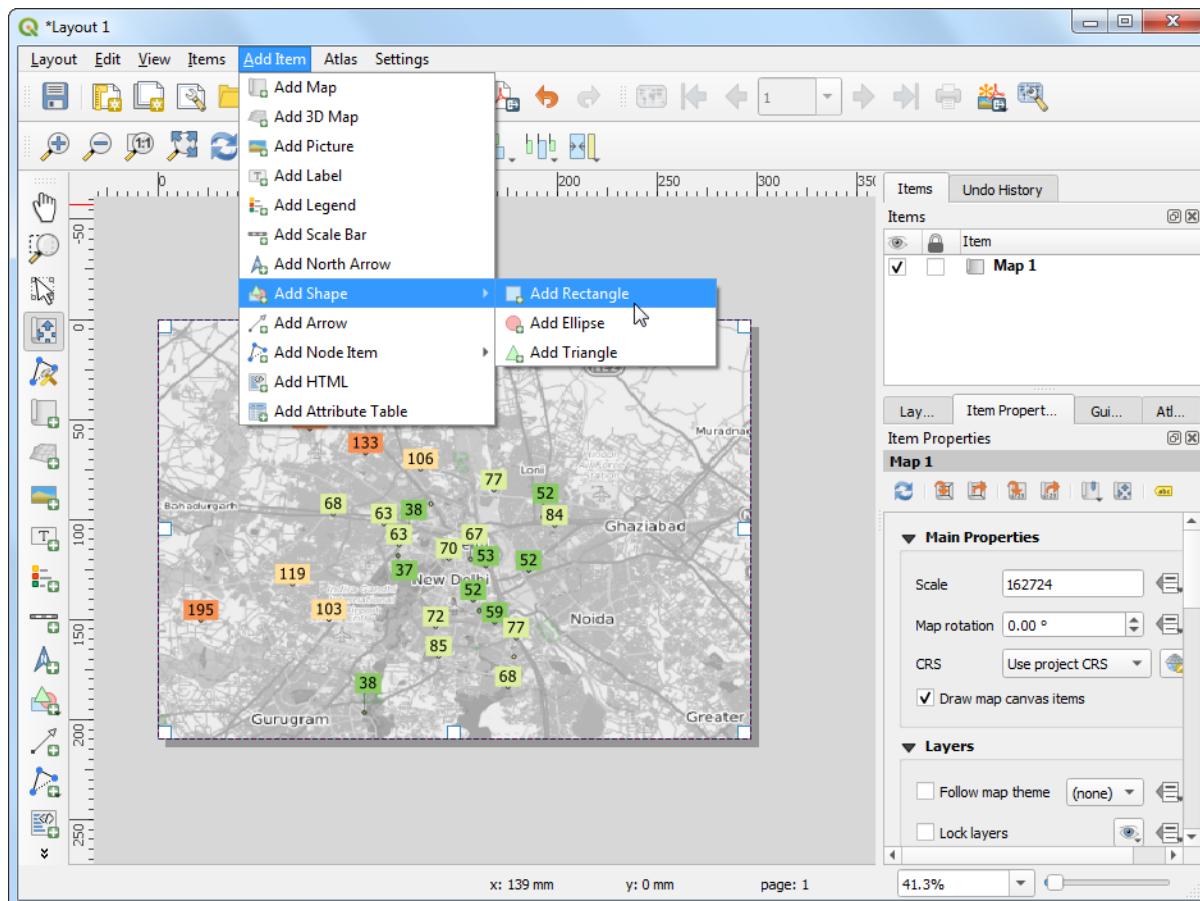
Print Layouts are a way to compose a static map with various elements such as labels, legends, north arrow, scale bar etc. Go to **Add Item → Add Map**.



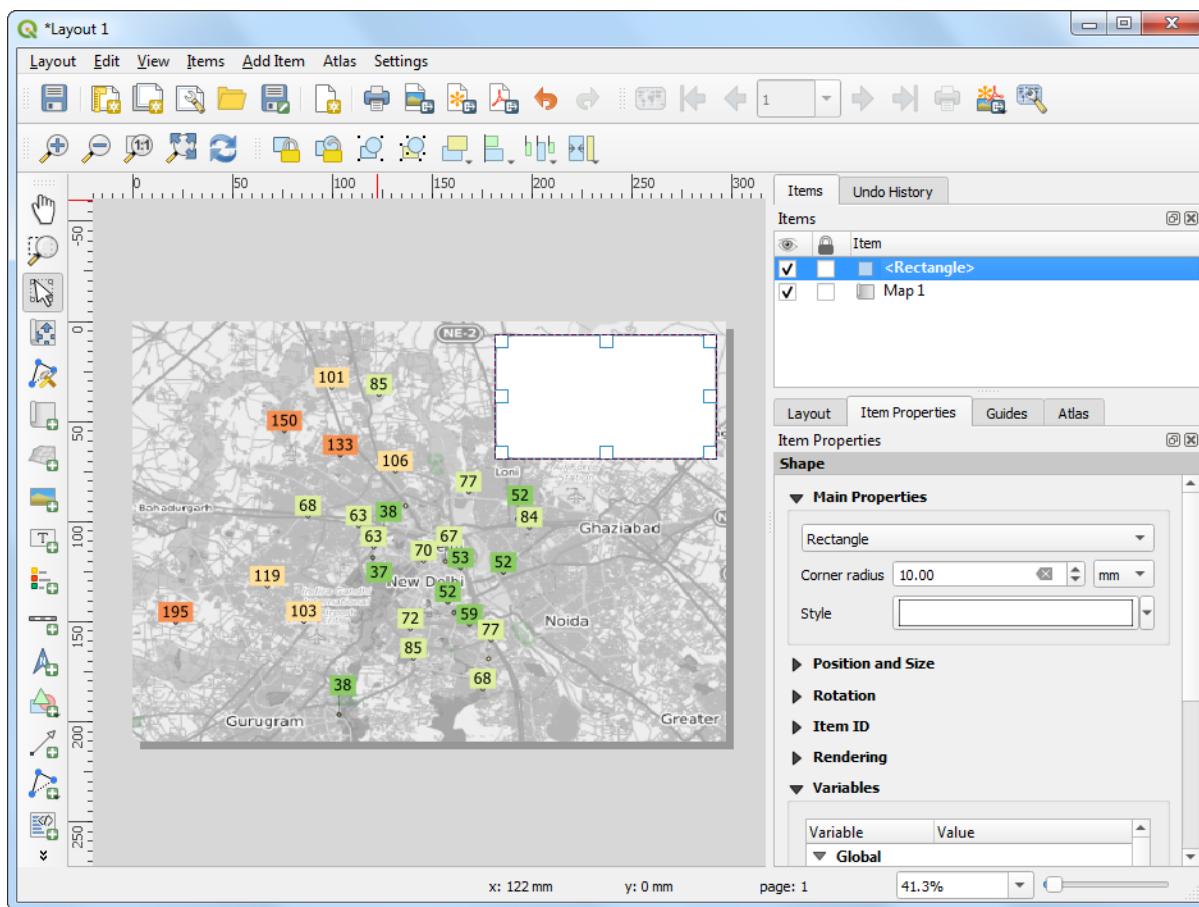
Drag a rectangle where you want the map to be rendered. Once you let go of your mouse button, the map from the main canvas will be loaded in the region.



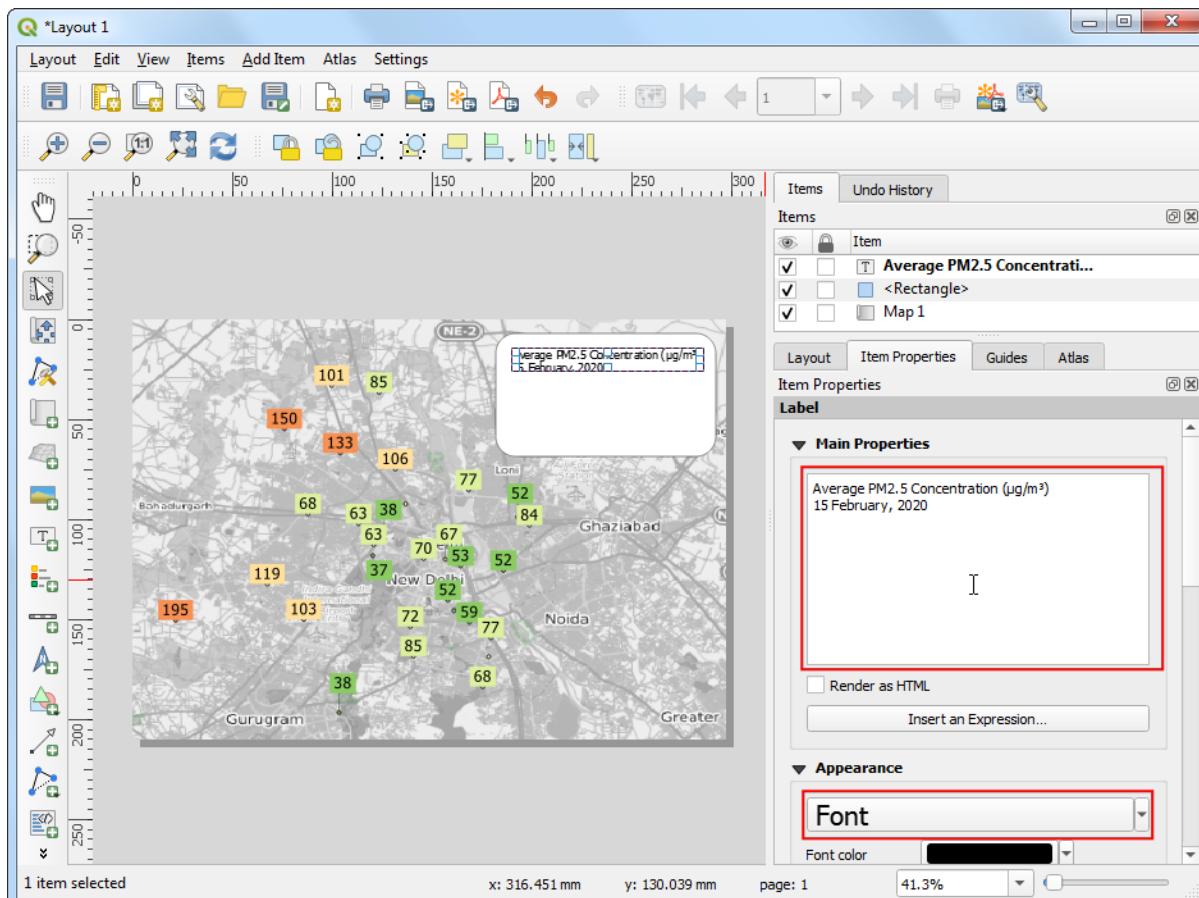
Next, we will add a *Rectangle* which will hold the tile, legend and attribution.



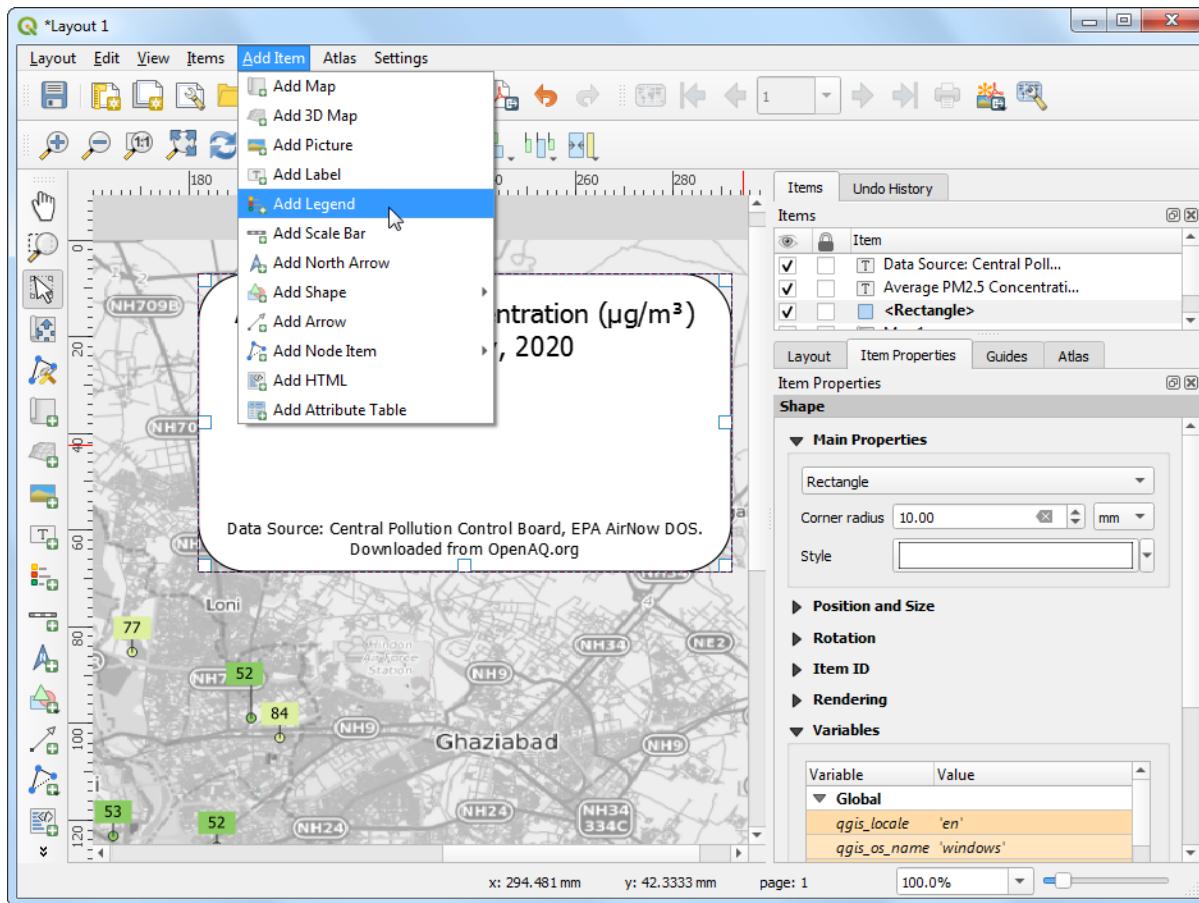
Place the rectangle on the top-right hand corner and change the *Corner radius* to 10.



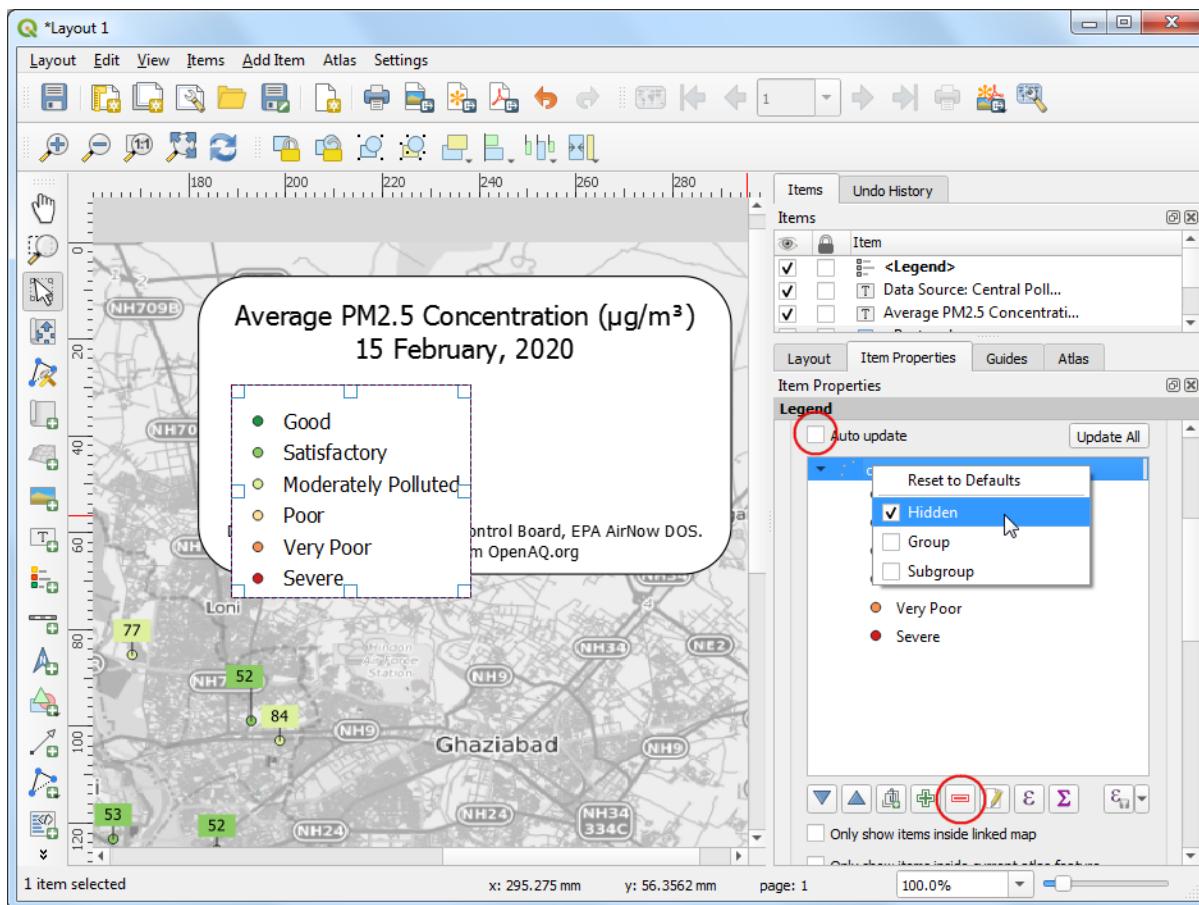
Next, add a *Label* with the title **Average PM2.5 Concentration ($\mu\text{g}/\text{m}^3$)** and date **15 February, 2020**.



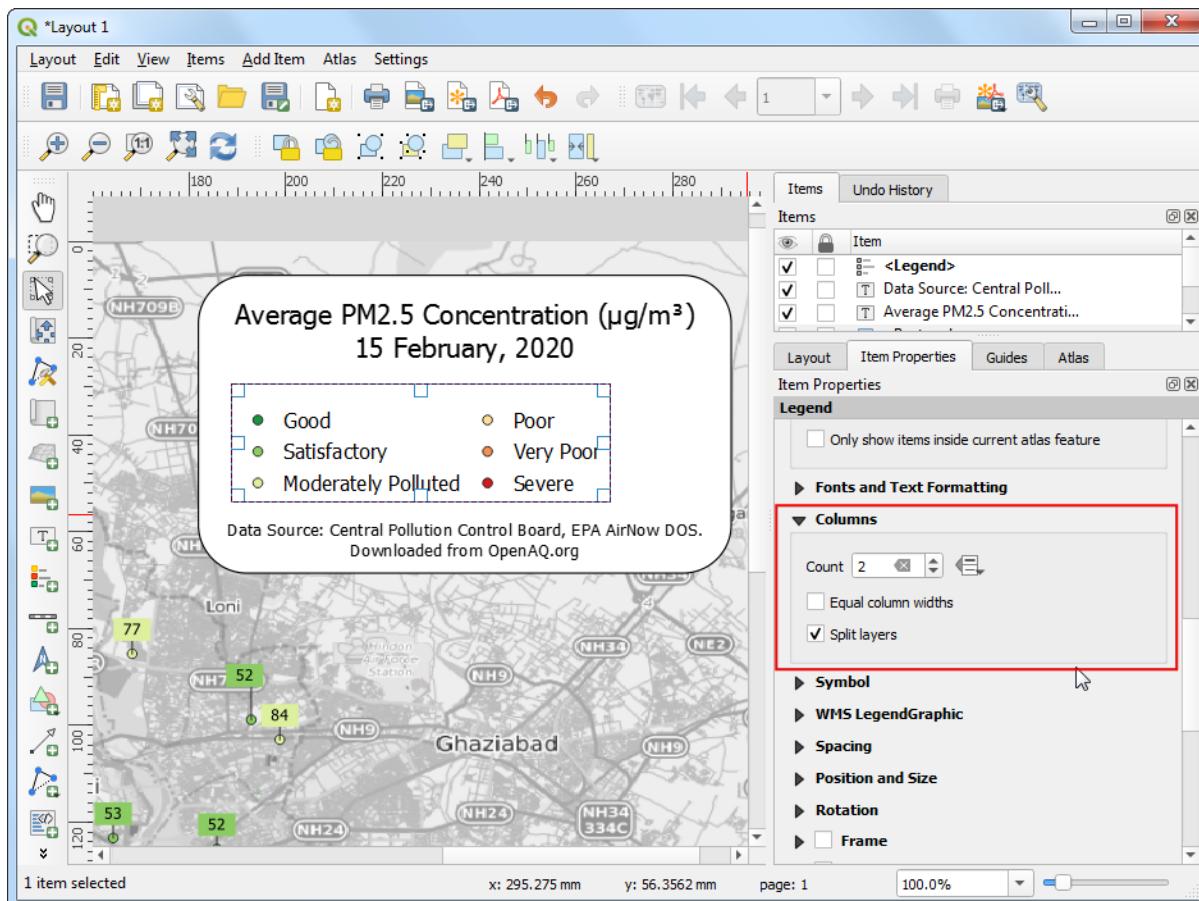
Add another *Label* with the attribution text Data Source: Central Pollution Control Board, EPA AirNow DOS. Downloaded from OpenAQ.org. Now we will add a legend, so our users know how to interpret various colors on the map. Go to Add Item → Add Legend



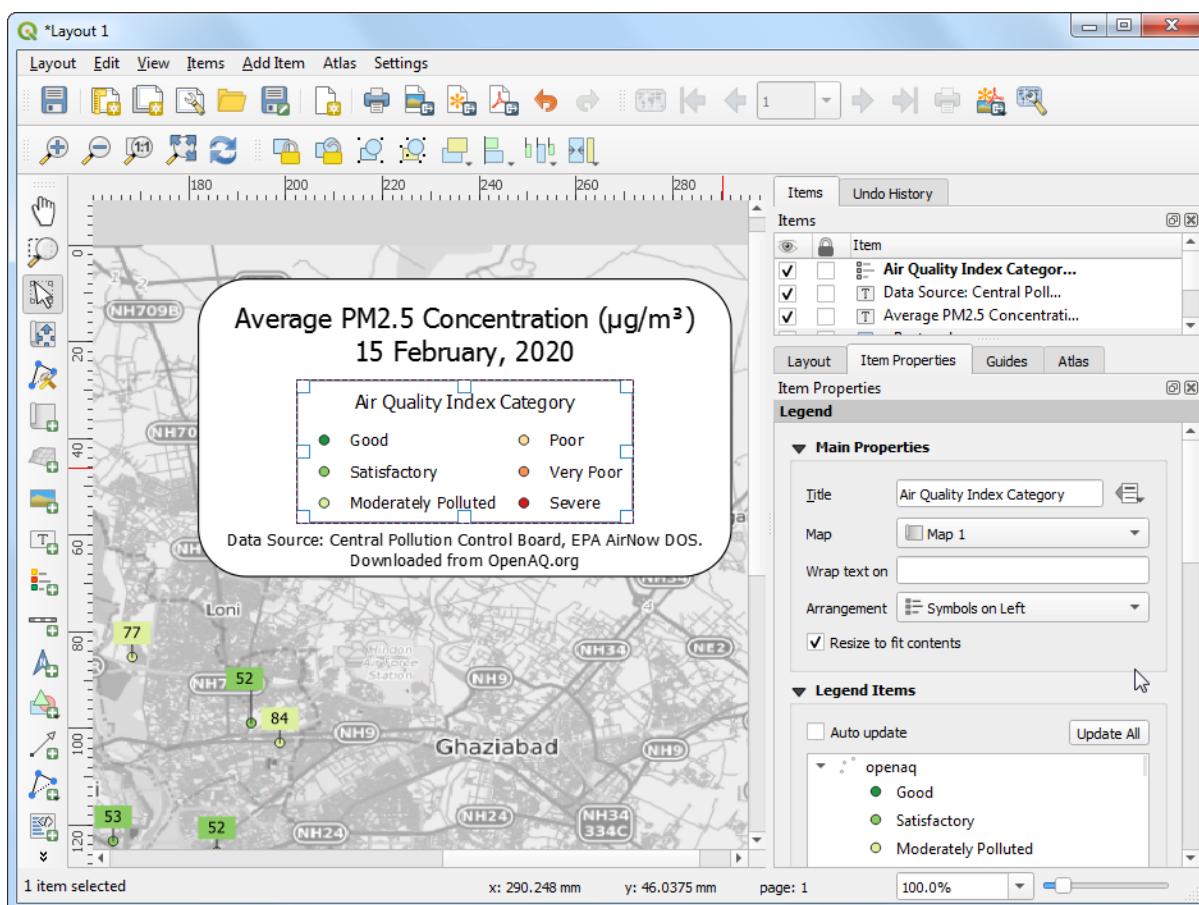
Drag a box to insert the legend. Go to the *Item Properties* tab and turn-off *Auto update*. Remove the OpenStreetMap monochrome layer and set the `openaq` group label to *Hidden*.



The default legend placement is vertical - in a single column. We can change it to be in multiple columns to make it span horizontal. Scroll down to the *Columns* section and change the *Count* to 2 and check *Split layers*.



In the *Main Properties* section, enter a *Title* for the legend as **Air Quality Index Category**.



Once you are satisfied with the map, we can export the map. You can export the composition as an **Image** if you wanted to use it in a website, email, slideshow etc. You can also export it to as an **SVG** so it can be further edited in a graphics program such as InkScape. But the most common format for maps is still a **PDF**.

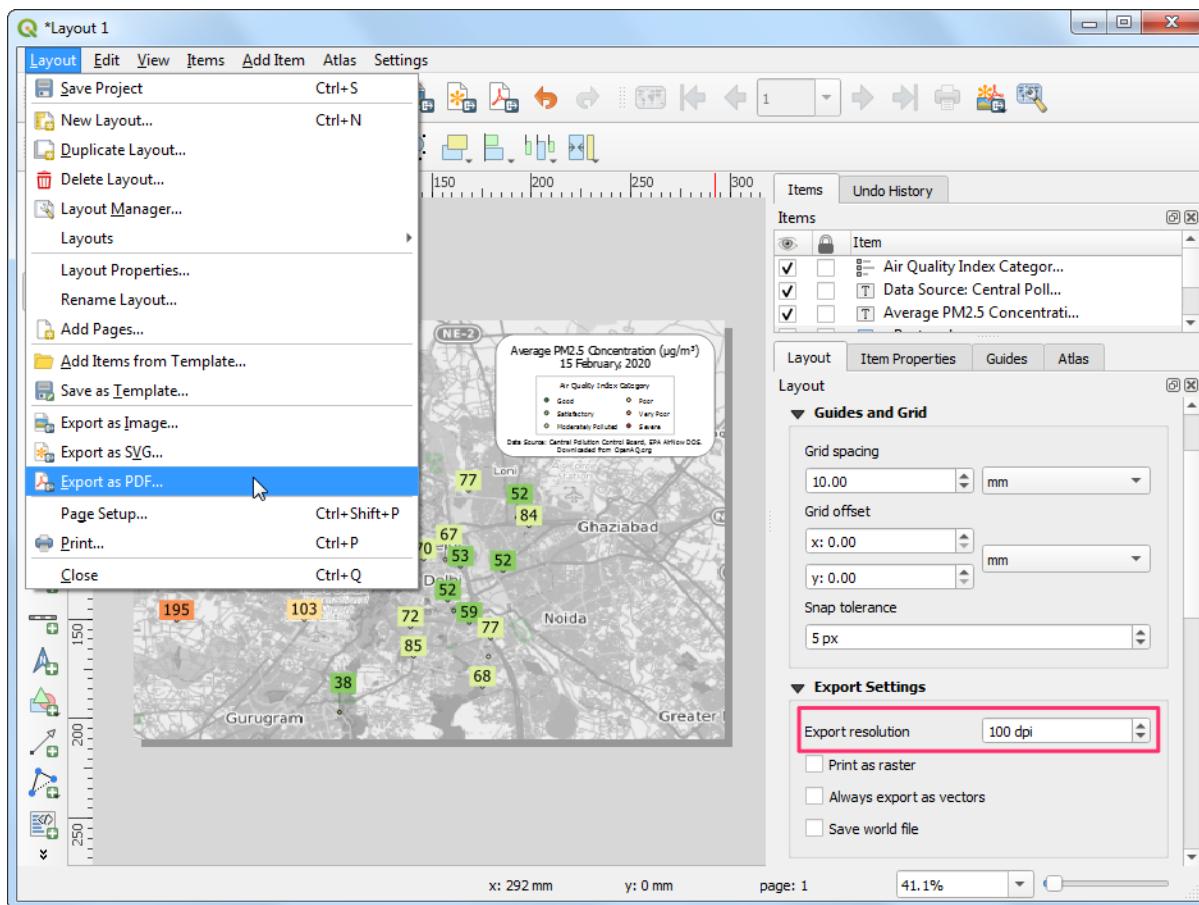
Atanas Entchev
@atanas

Replies to [@awoodruff](#)

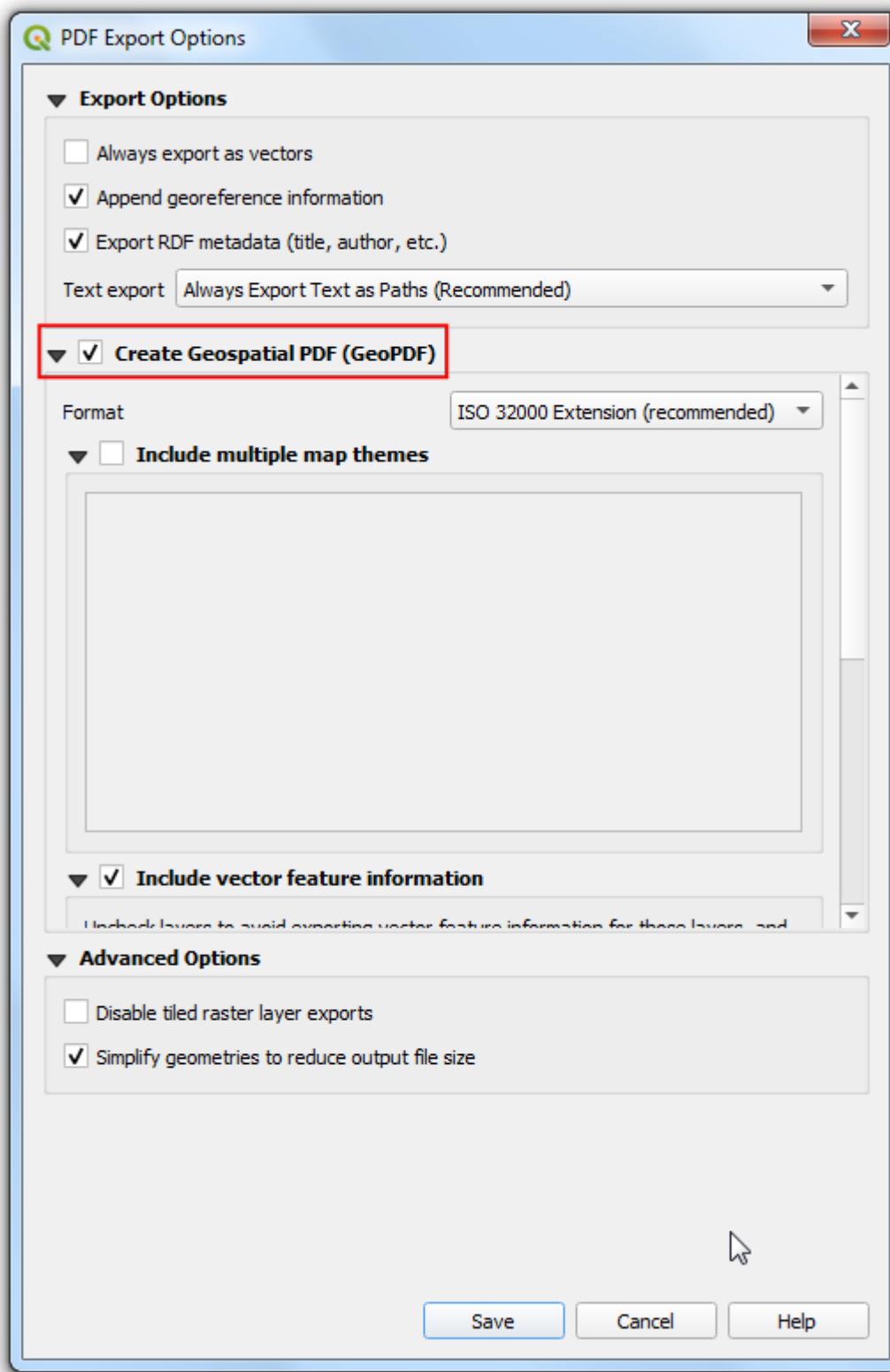
80% of GIS is converting SHP to PDF, no matter what ppl on this here platform say.

8:18 PM · Oct 9, 2019 · [Twitter Web App](#)

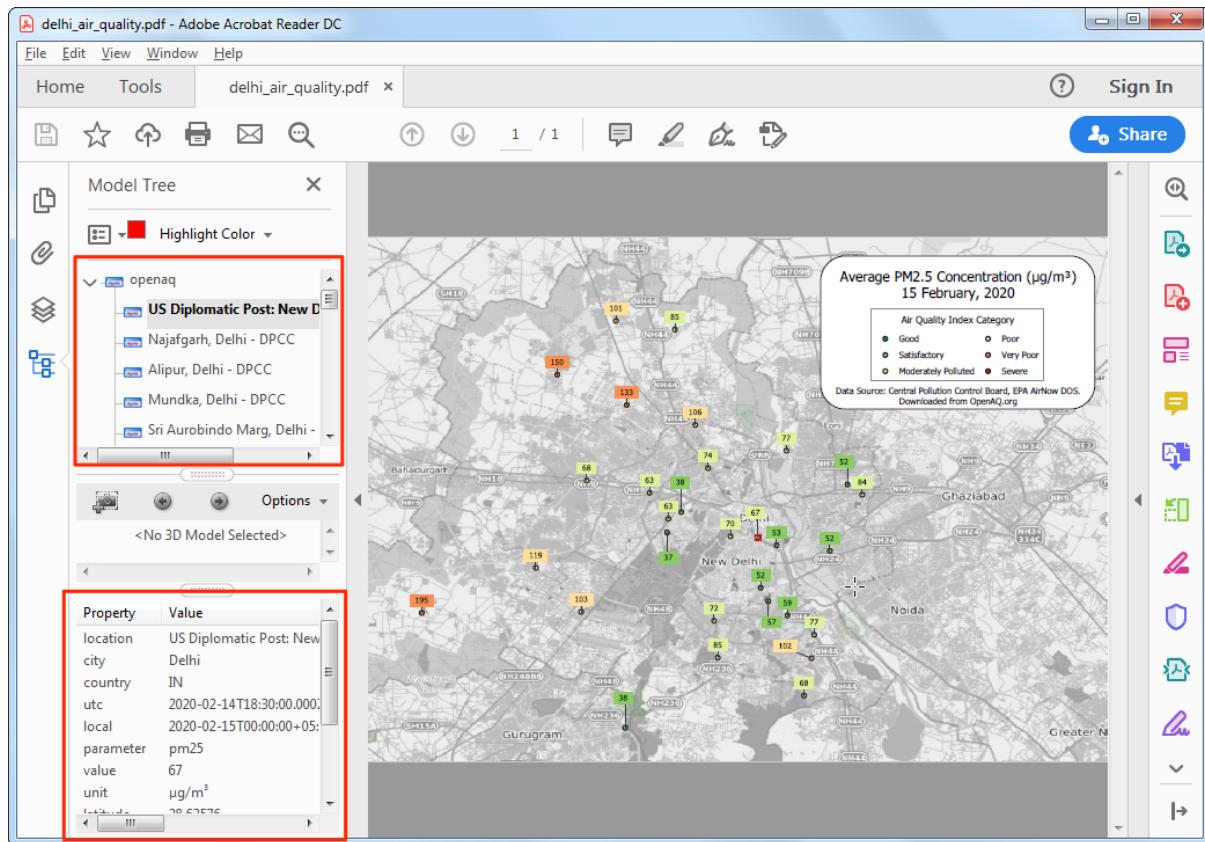
So let's export our map to a PDF. Before exporting, switch to the *Layout* tab and set the *Export resolution* to 100 dpi. Go to **Layout → Export as PDF**.



In the *PDF Export Options*, you can check *Create Geospatial PDF (GeoPDF)*. GeoPDF is an enhanced PDF format that is spatially aware and preserves layer and attribute information. Click *Save* and save the output as `delhi_air_quality.pdf`.



If you open the resulting PDF in a compatible reader such as Adobe Acrobat, you can toggle layer visibility, query attributes by features, measure distances and so on.



Polygons

Regions are modeled as polygons. Polygons are most commonly used to model administrative areas, buildings, land parcels etc. Polygon geometry is represented as a series of coordinates. Since the shapes can be complex, polygons have a more verbose geometry descriptions and seldom come in a CSV files. GeoJSON and shapefile are the most commonly used file formats for storing polygon datasets.

Exercise: Mapping Census Data

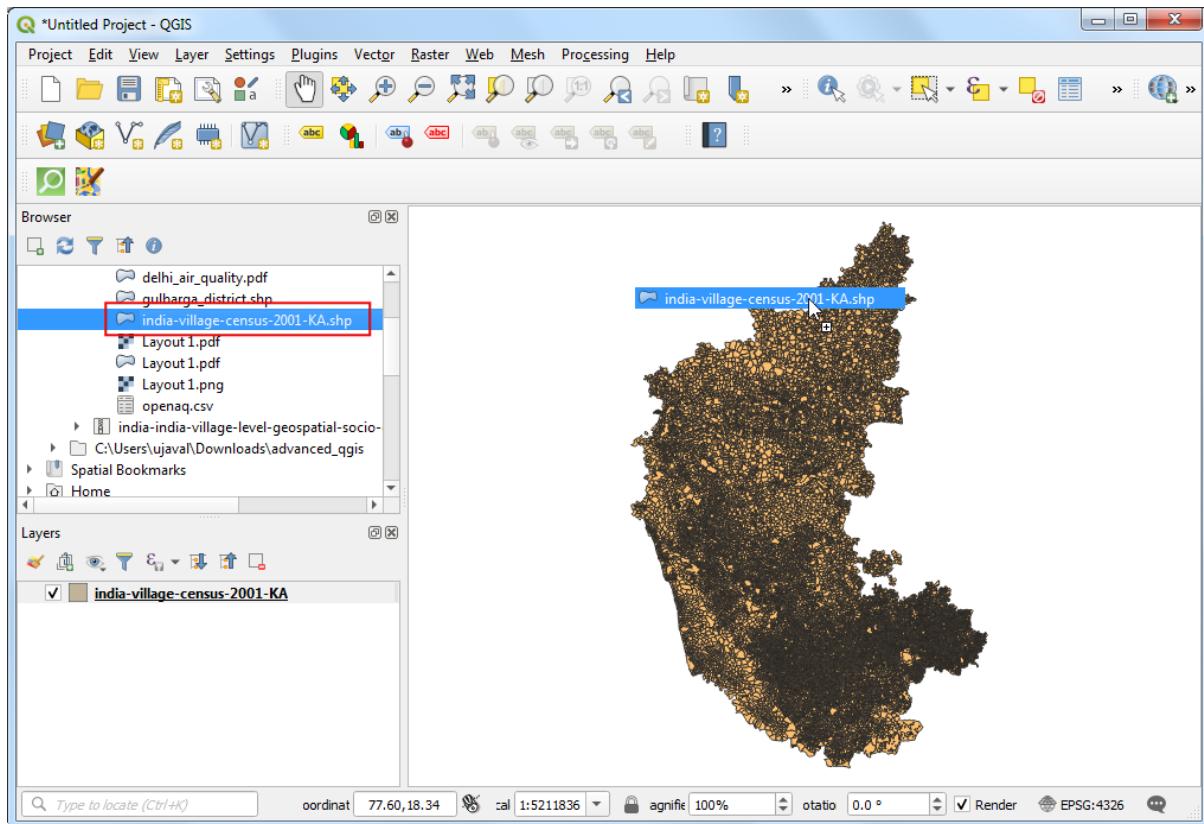
Census data is one of the major sources of secondary data available in a country. Many types of spatial analysis requires detailed demographic information that is available from the census data.

Census data is usually published as tables by aggregating the raw numbers to an administrative region - typically a *census block*. To map these tables, one needs to know the *geometry* of these regions - which are supplied separately as boundary files. Both of these can be joined to create a polygon layer that can be visualized and mapped. See this tutorial on how this process is carried out in QGIS.

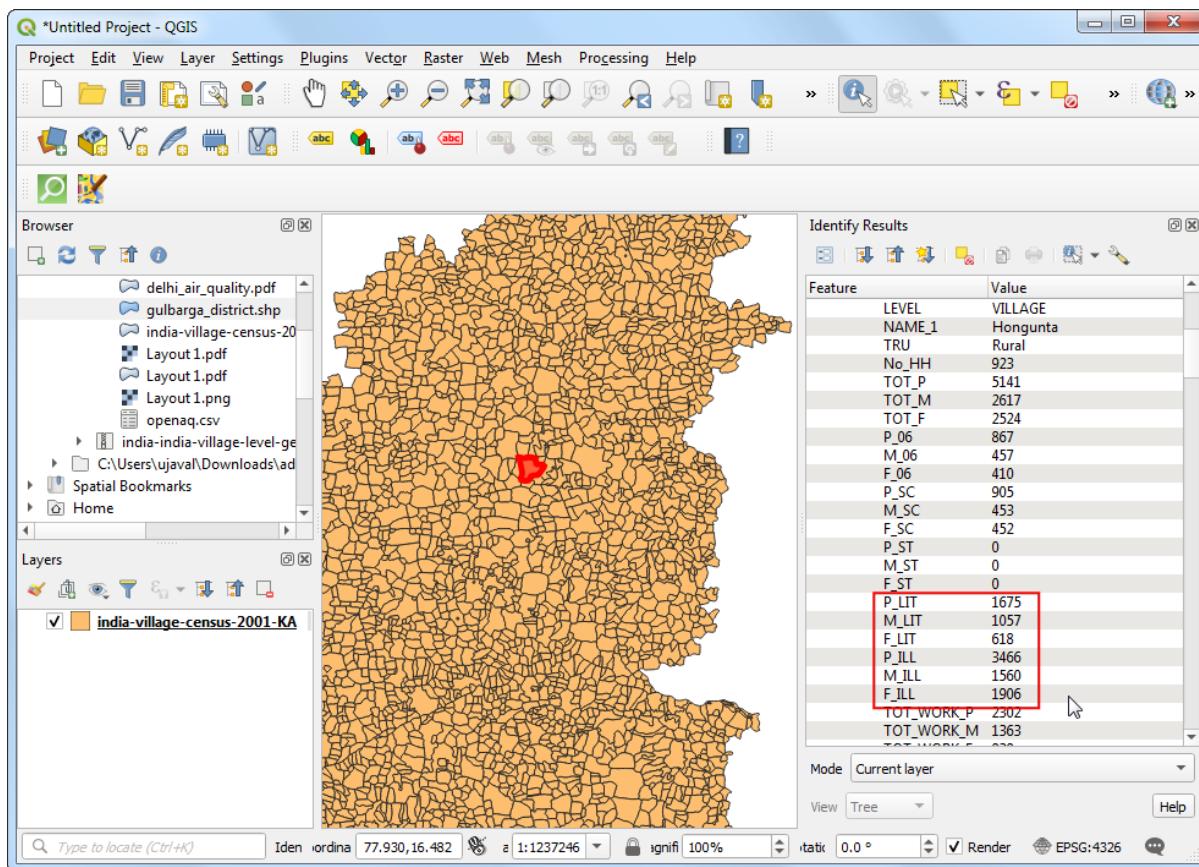
We will use India Village-Level Geospatial Socio-Economic Data Set published by NASA Socioeconomic Data and Applications Center (SEDAC). This dataset combines the village/town level boundaries with Primary Census Abstract (PCA) and Village Directory (VD) data series of the Indian census. It is distributed as shapefiles.

For this exercise, we will be using the shapefile for the state of Karnataka and map the literacy rate in the Gulbarga district.

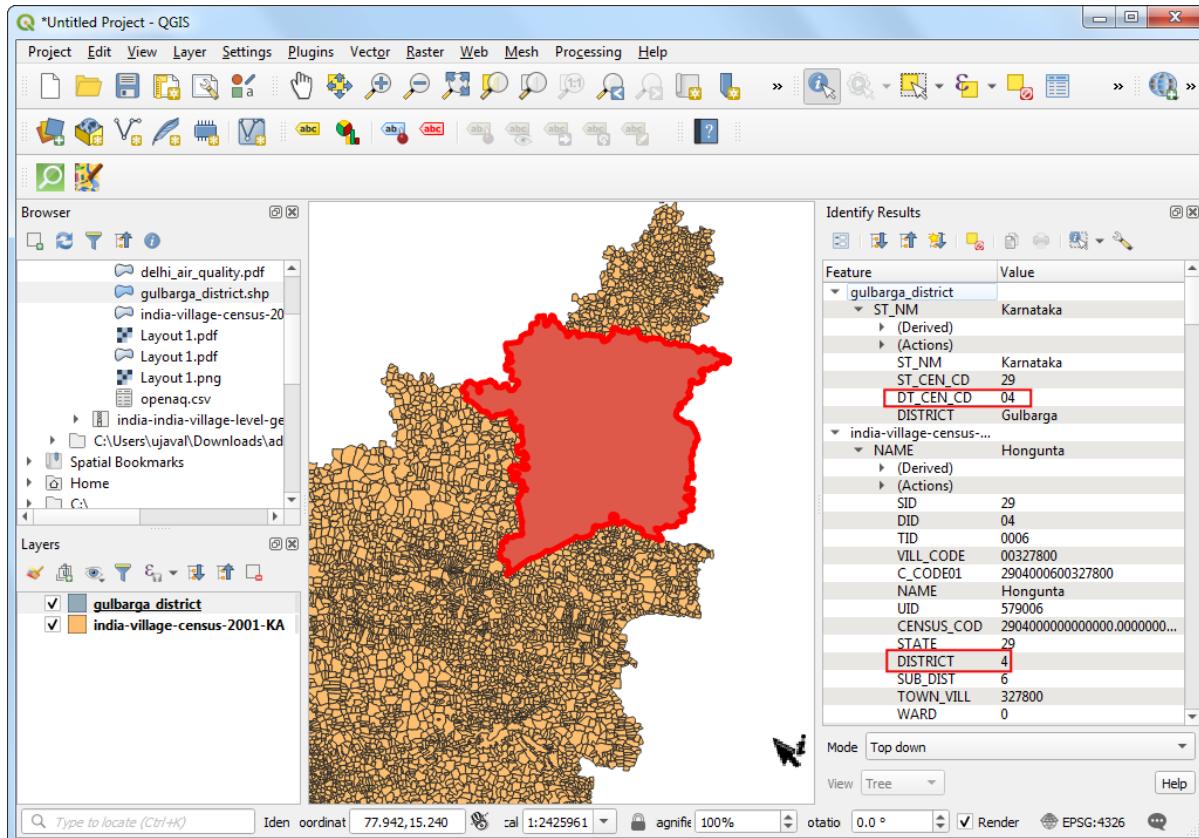
Locate the `india-village-census-2001-KA.shp` file in the *Browser* panel and drag it to QGIS canvas.



A new layer `india-village-census-2001-KA` will be added to the *Layers* panel. Use the *Identify* tool to click on any polygon and explore the attributes. The definitions of each column is contained in the documentation that is supplied with the data. As we are looking to map the literacy levels, the attributes with `_LIT` suffix are useful for our purpose. The `P_LIT` column refers to *Person Literates* and `TOT_P` refers to *Total Population* that we will use to calculate and map literacy rate.

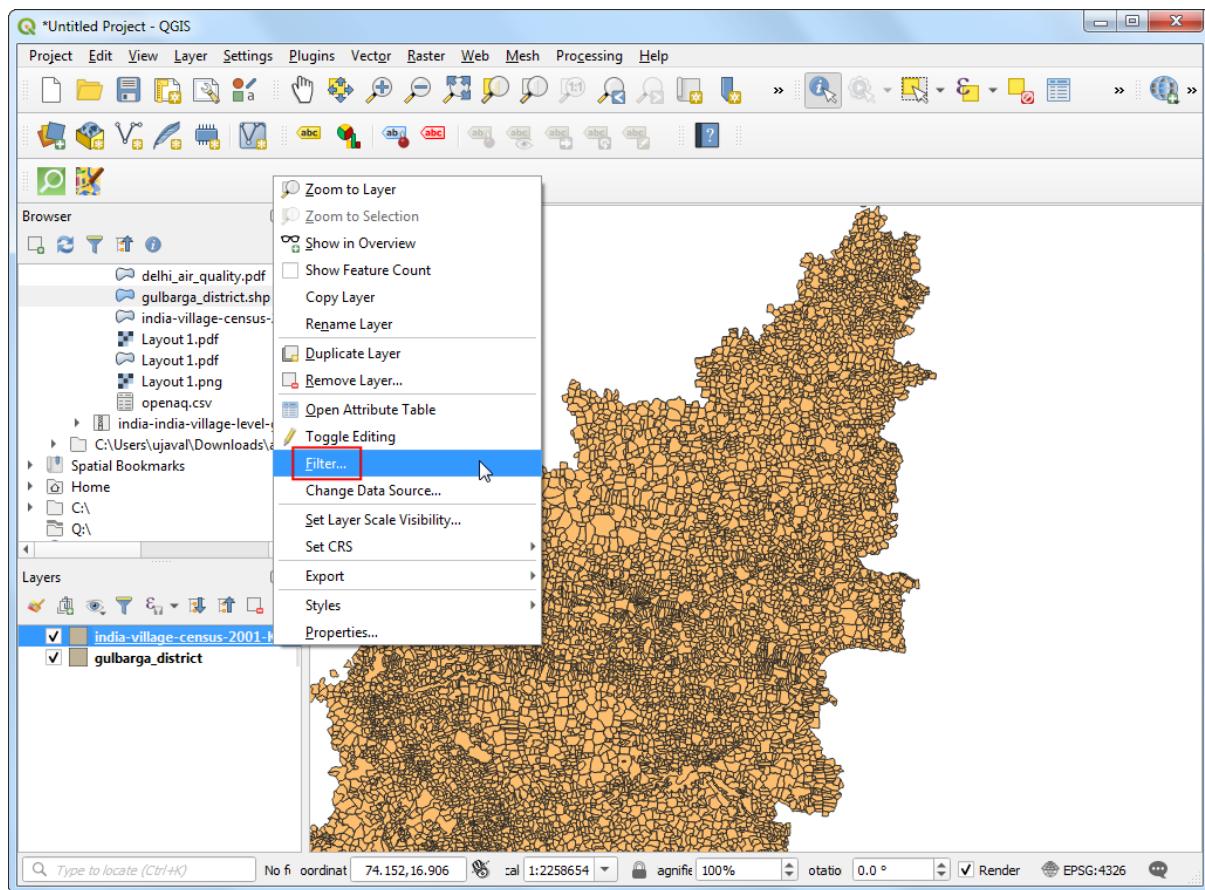


We want to select a subset of polygons from this layer belonging to the *Gulbarga* district. Load the *gulbarga_district.shp* layer that has been extracted from the Districts shapefile supplied by DataMeet. The column DT_CEN_CD contains the district id for this particular district. We can use this to filter the polygon layer.

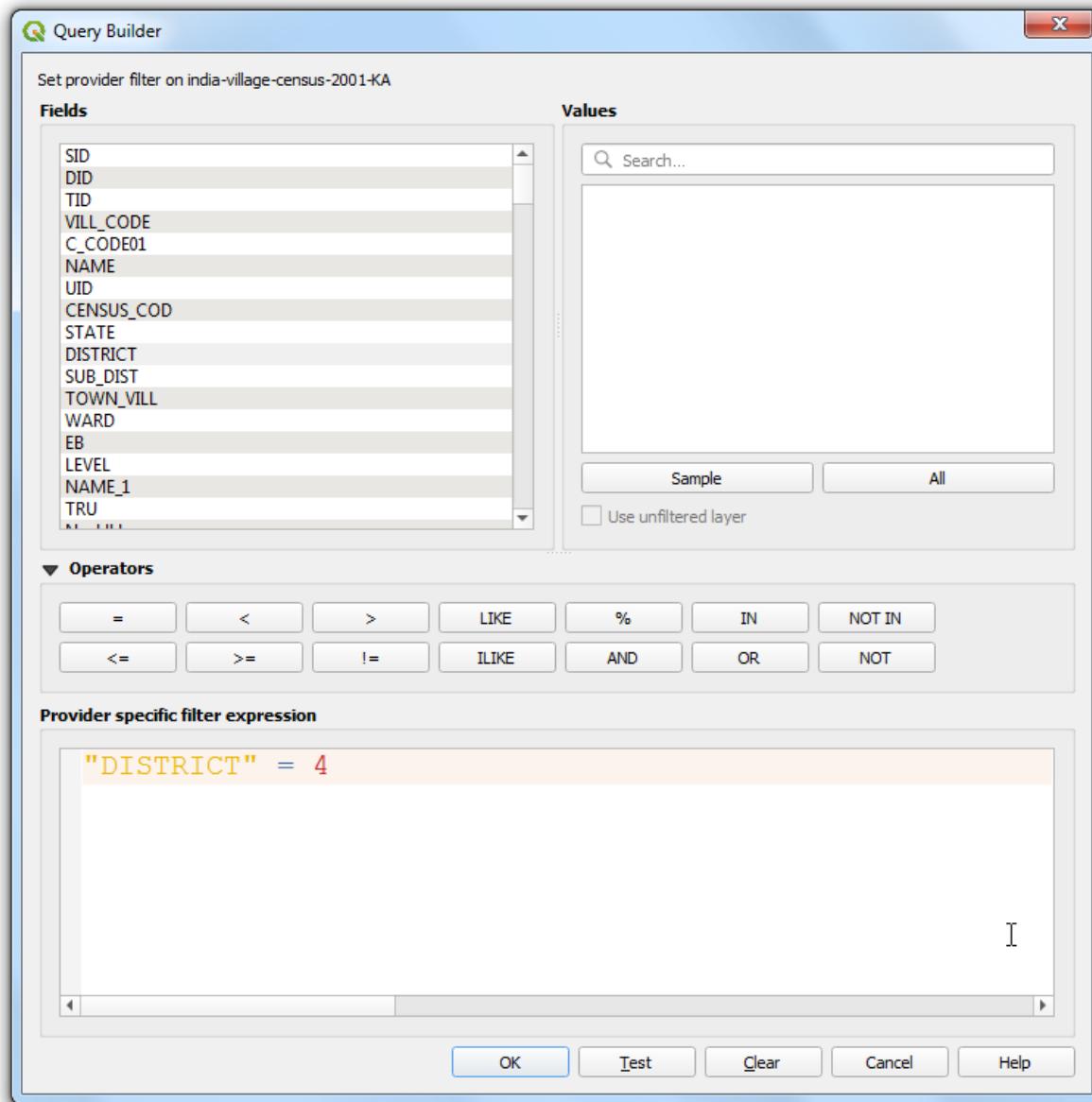


In the *Layers* panel, drag the *gulbarga_district* layer below the *india-village-census-2001-KA*

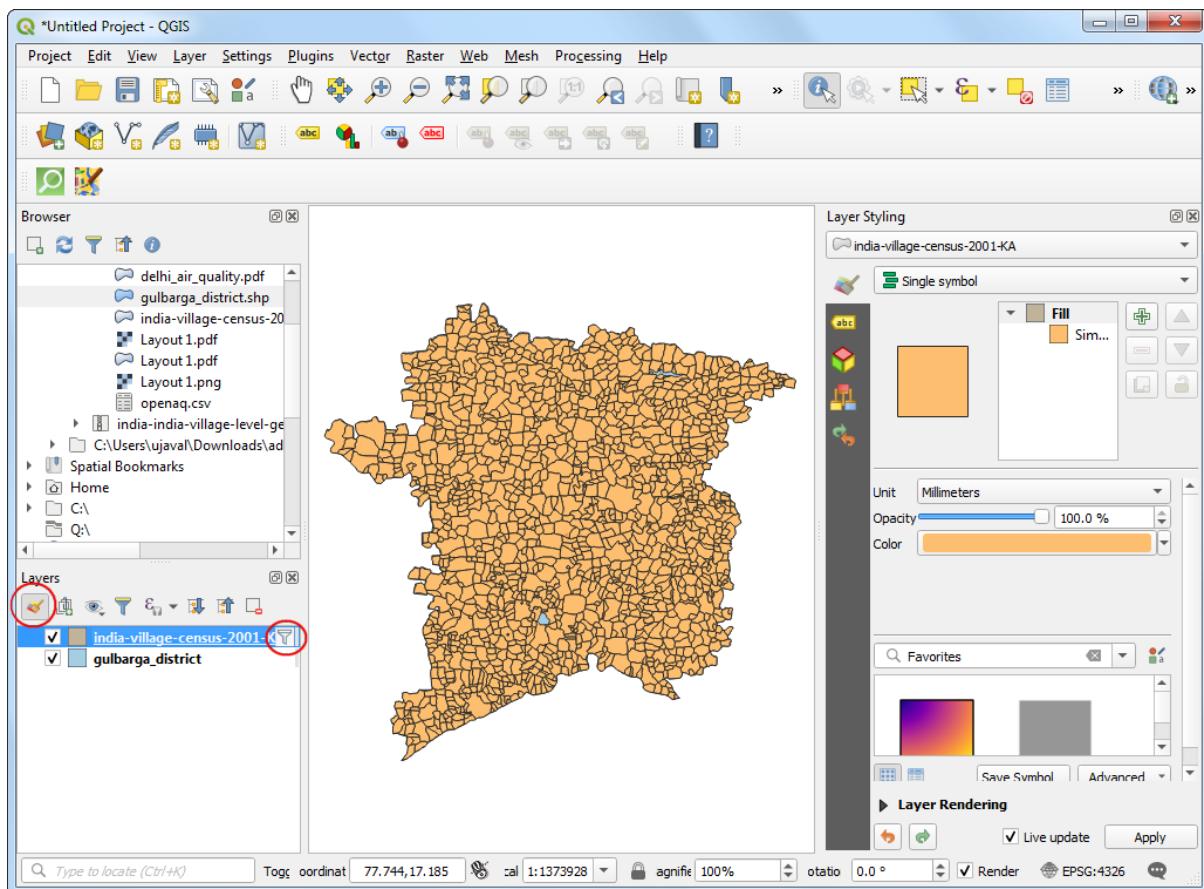
layer. Right-click the `india-village-census-2001-KA` layer and select *Filter*.



Enter the expression `DISTRICT = 4` to select all villages and towns from our chosen district. Click *OK*.



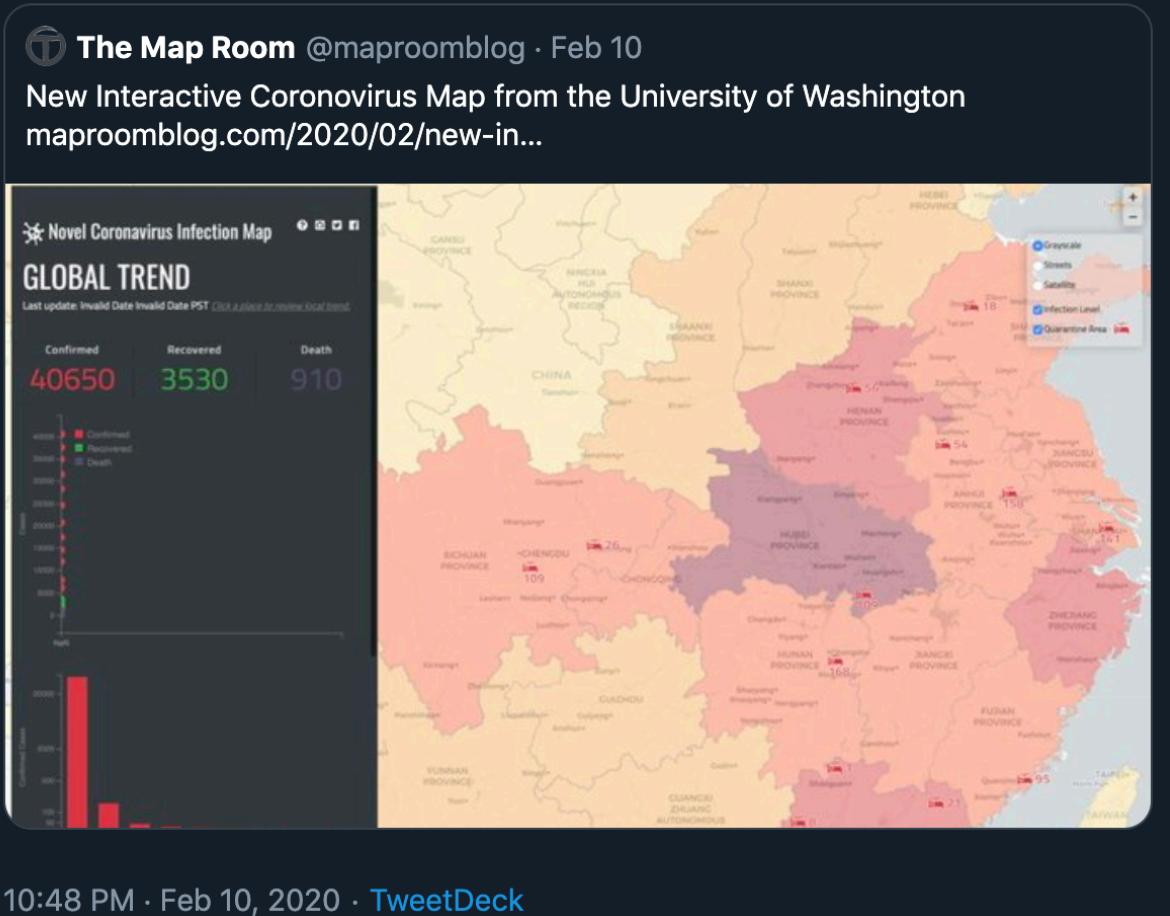
You will see a filter icon next to the `india-village-census-2001-KA` layer indicating that a filter is applied to the layer. The map canvas will update to show only the polygons belonging to the district.

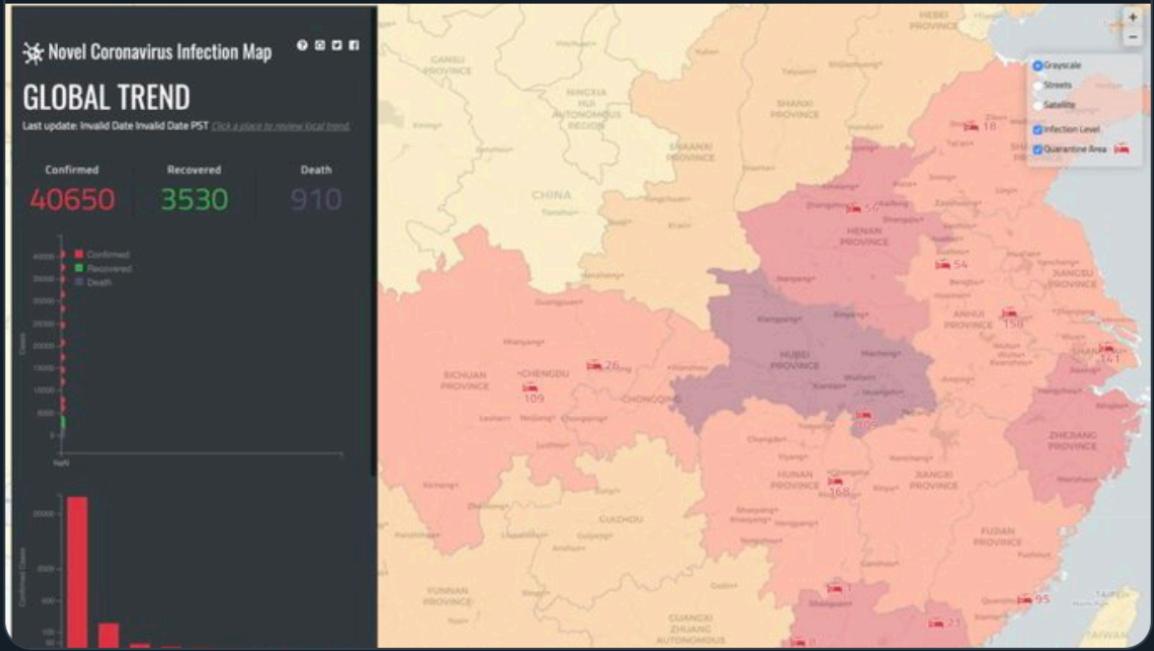


Now we will create a *thematic* map showing the literacy rate in the district. When creating a thematic (choropleth) map such as this, it is important to normalize the values you are mapping. A common mistake is to use totals instead of rates in such map.

 **Kenneth Field** @kennethfield

And yet another that uses totals, not rates, on a choropleth rendering it utterly useless as a way to compare the incidence & prevalence across the map. Normalize the damn thing. Per capita is a simple calculation.


The Map Room @maproomblog · Feb 10
New Interactive Coronavirus Map from the University of Washington
maproomblog.com/2020/02/new-in...

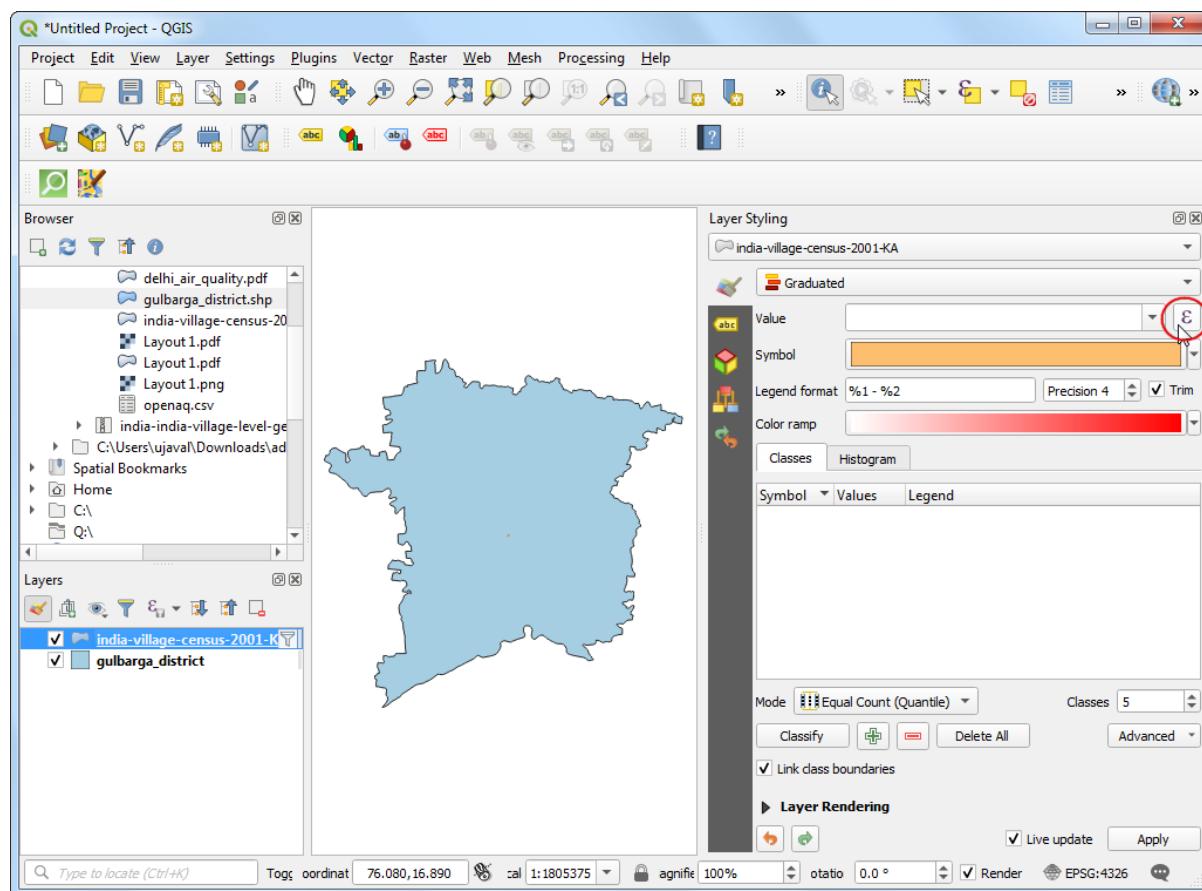


The figure consists of two panels. The left panel is a bar chart titled "GLOBAL TREND" showing the number of confirmed cases, recoveries, and deaths. The right panel is a choropleth map of China where provinces are colored according to their infection level. A legend on the map indicates that darker shades of red represent higher infection levels.

Confirmed: 40650 | Recovered: 3530 | Death: 910

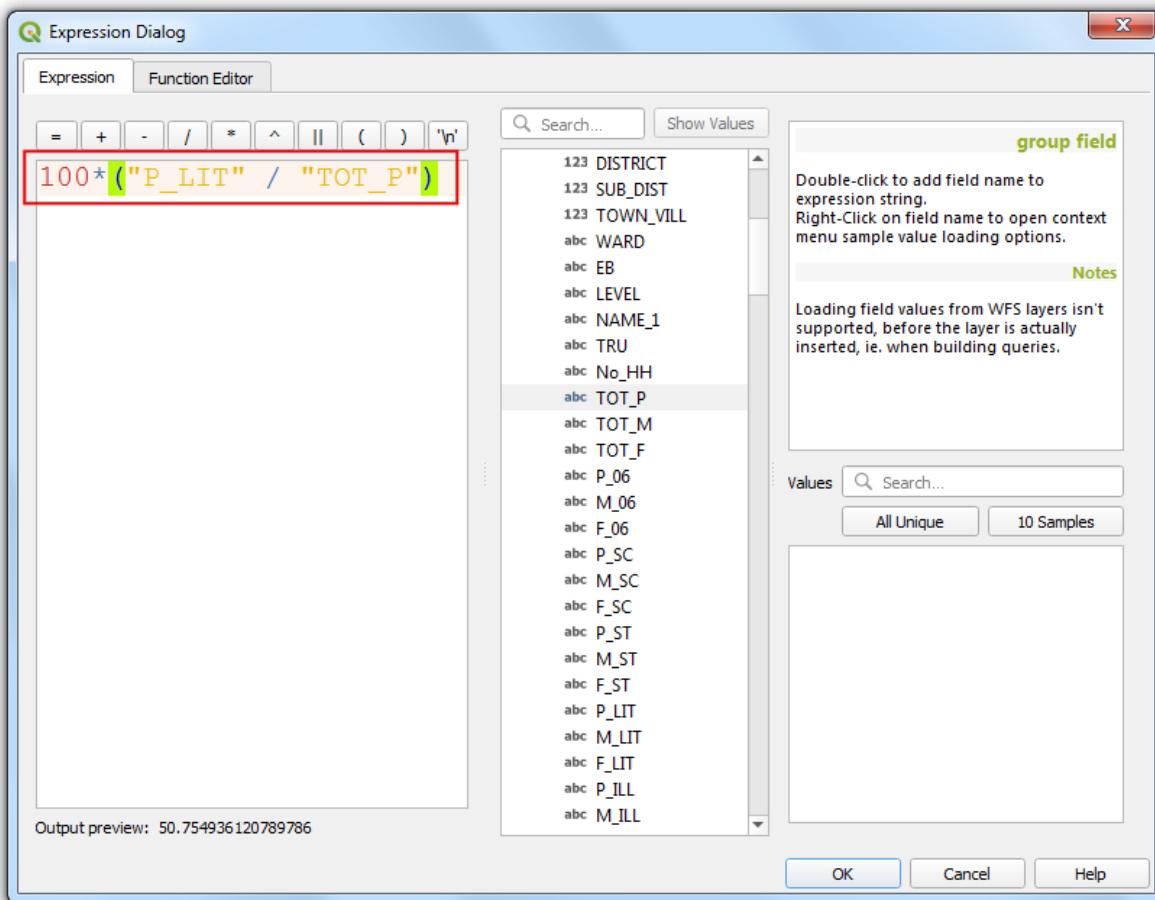
10:48 PM · Feb 10, 2020 · TweetDeck

Click *Open the Layer Styling Panel*. Select *Graduated renderer*. In the *Value* column, click the *Expression* button.

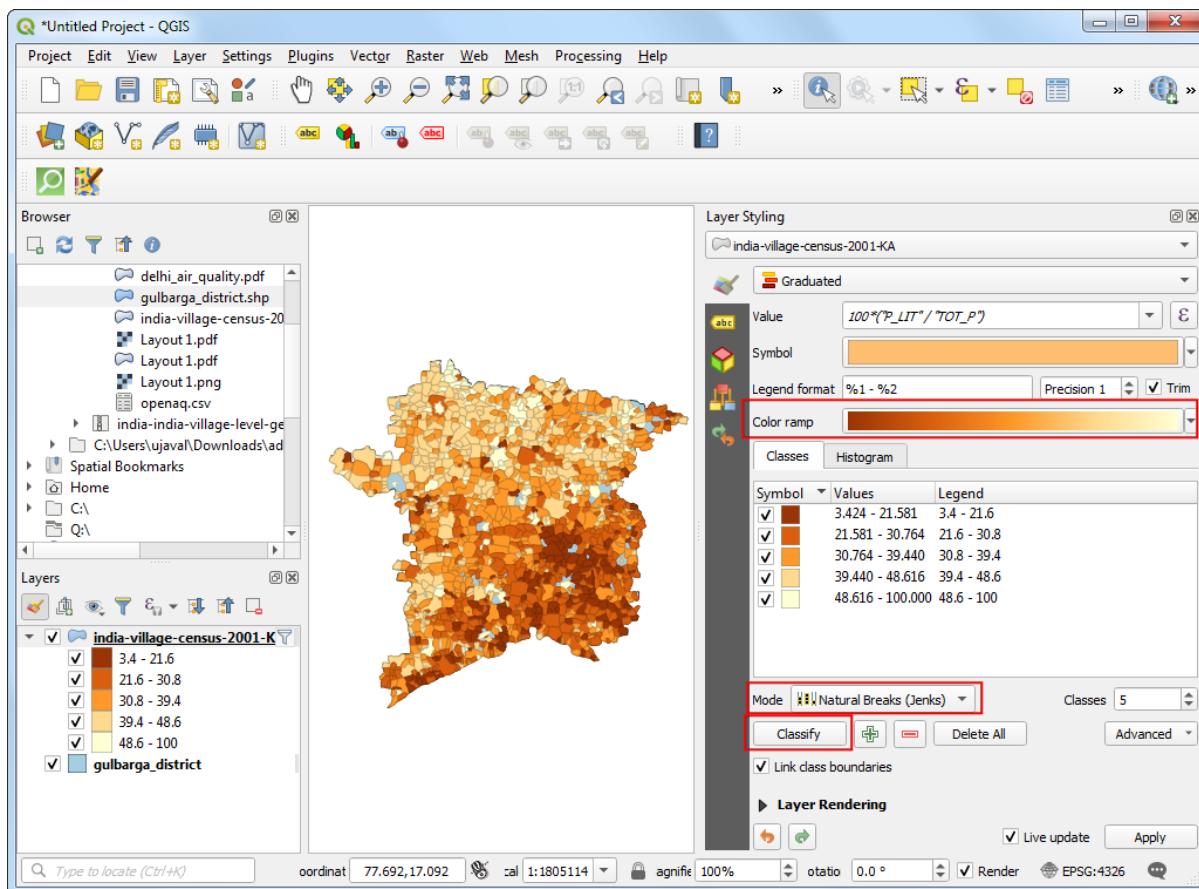


Enter the following expression. As we want to map literacy rate, we can normalize the total literate persons by dividing with the total population.

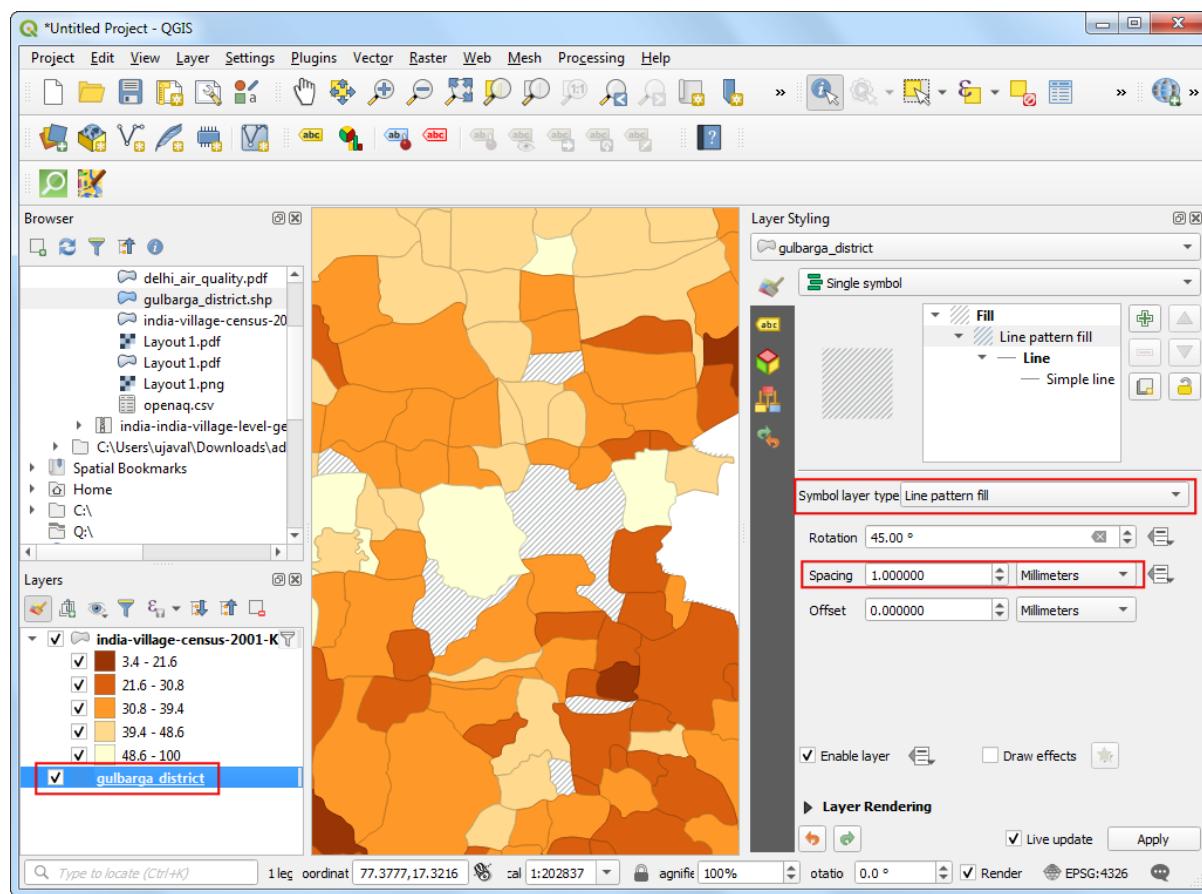
`100 * ("P_LIT" / "TOT_P")`



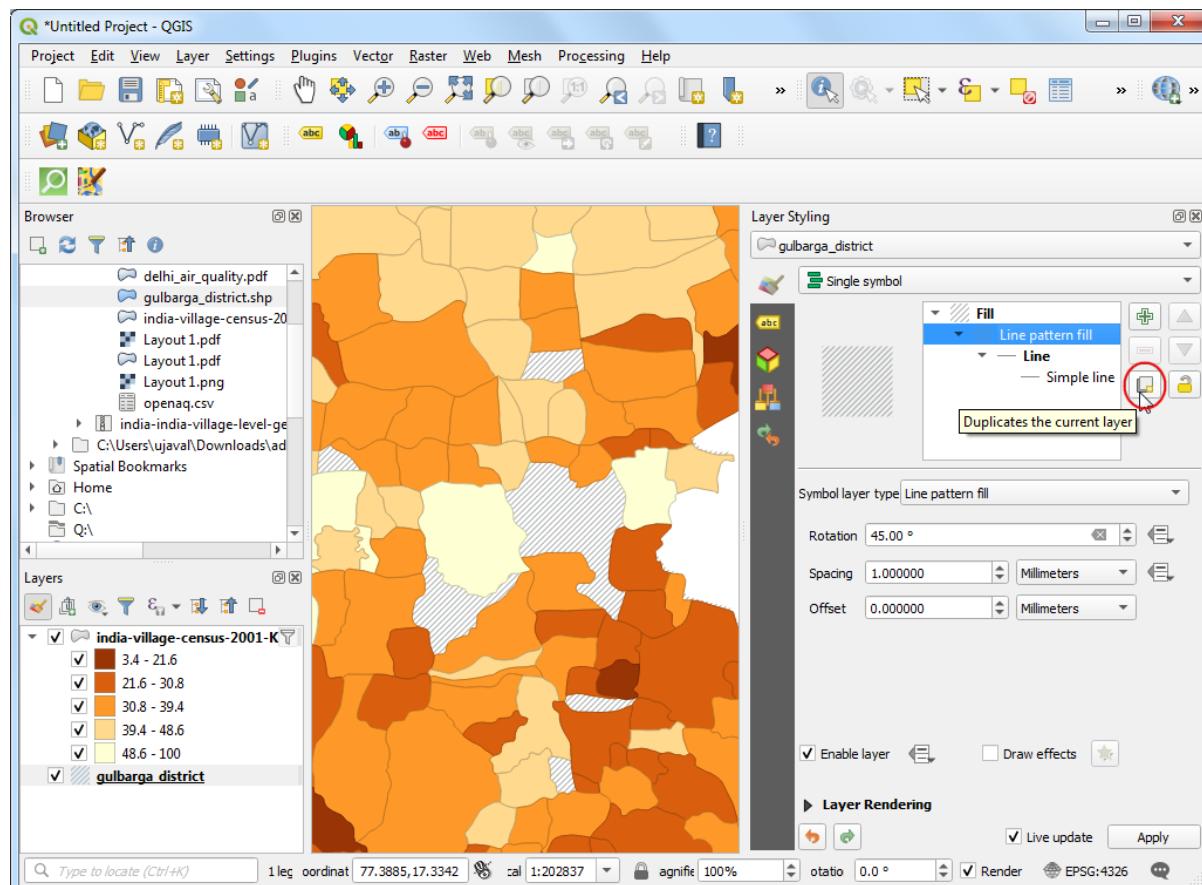
Choose a color ramp and the *Mode* of your choice and click *Classify*. You will see the polygons colored according to the literacy rates. Mapping this makes it much easier to see the pattern that villages to the south of the district have much lower literacy rates than their northern counterparts.



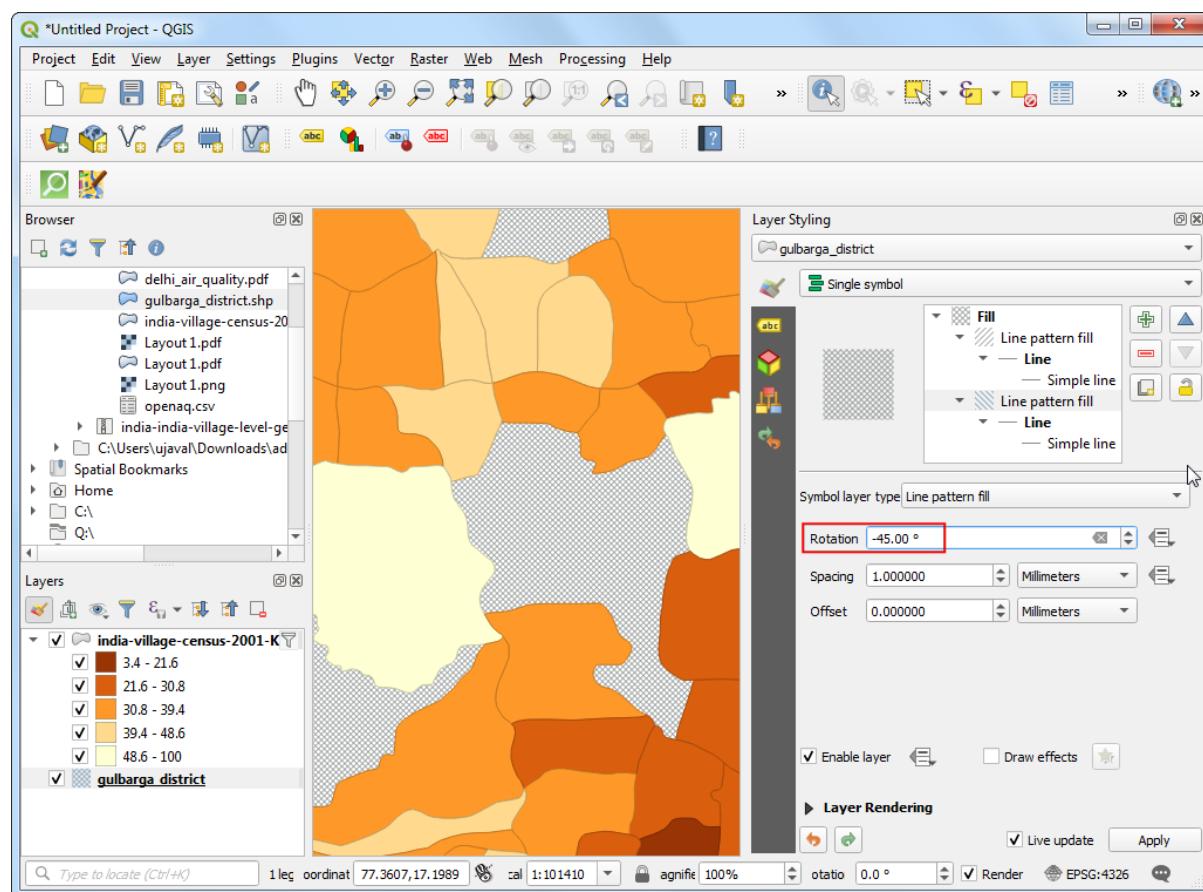
If you zoom in - you will notice gaps in the polygon layer. These are the areas with cities which do not have Village Directory (VD) data tables and thus excluded in this data layer. Instead of a hole, we can style it better to indicate no-data values. Select the `gulbarga_district` layer. Change the *Symbol layer type* to be Line pattern fill. Change the spacing as per your liking.



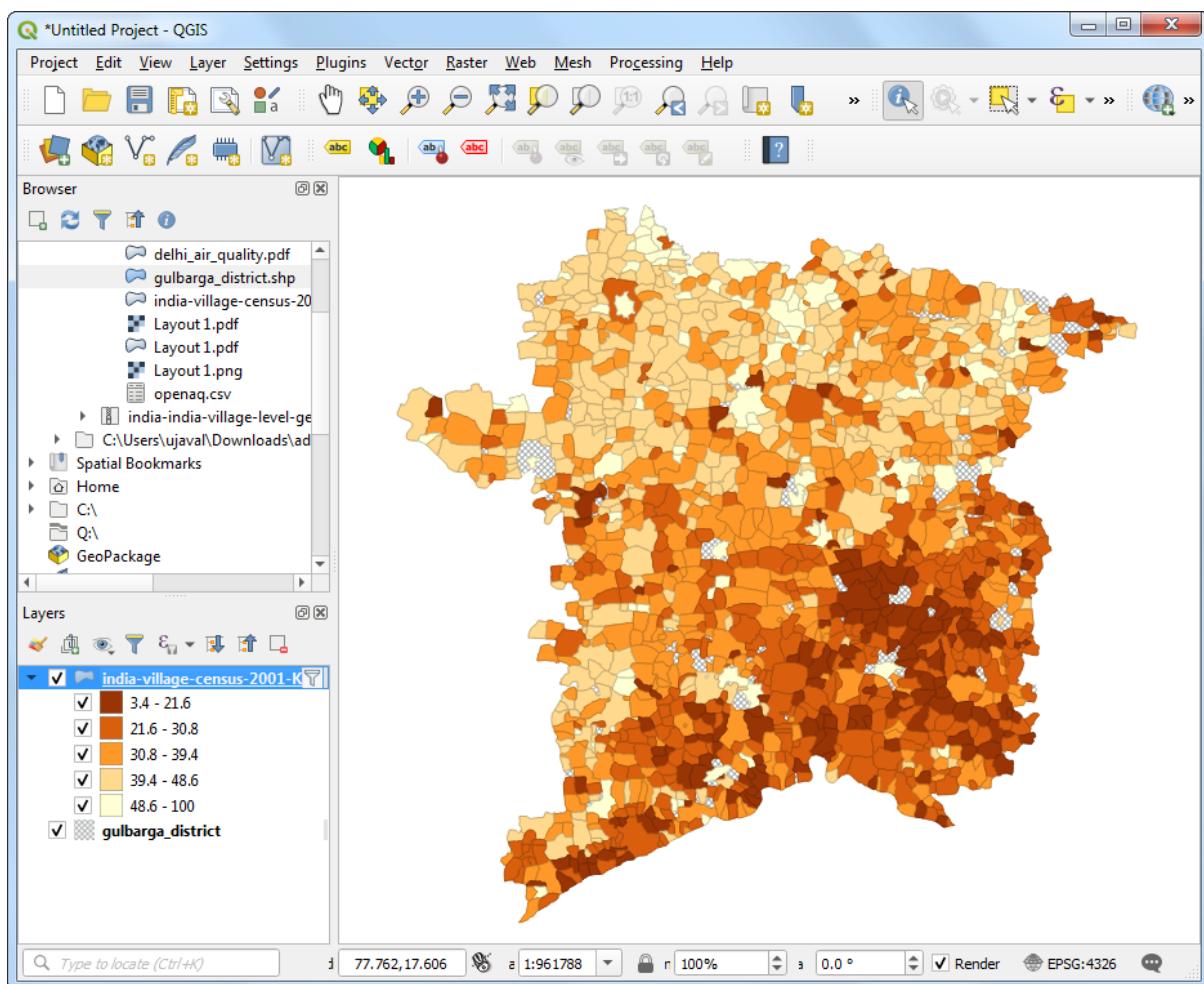
You will notice that the options for fill do not have a cross pattern fill. That is because it can be easily created by combining 2 line pattern fills of opposite direction. Click the *Duplicate the current layer* button in the *Layer Styling Panel*.



Change the *Rotation* value to -45.00 degrees. You will see the gaps now rendered with a cross-pattern fill.



You have a visualization of the literacy rate in the district.



Raster - Photos

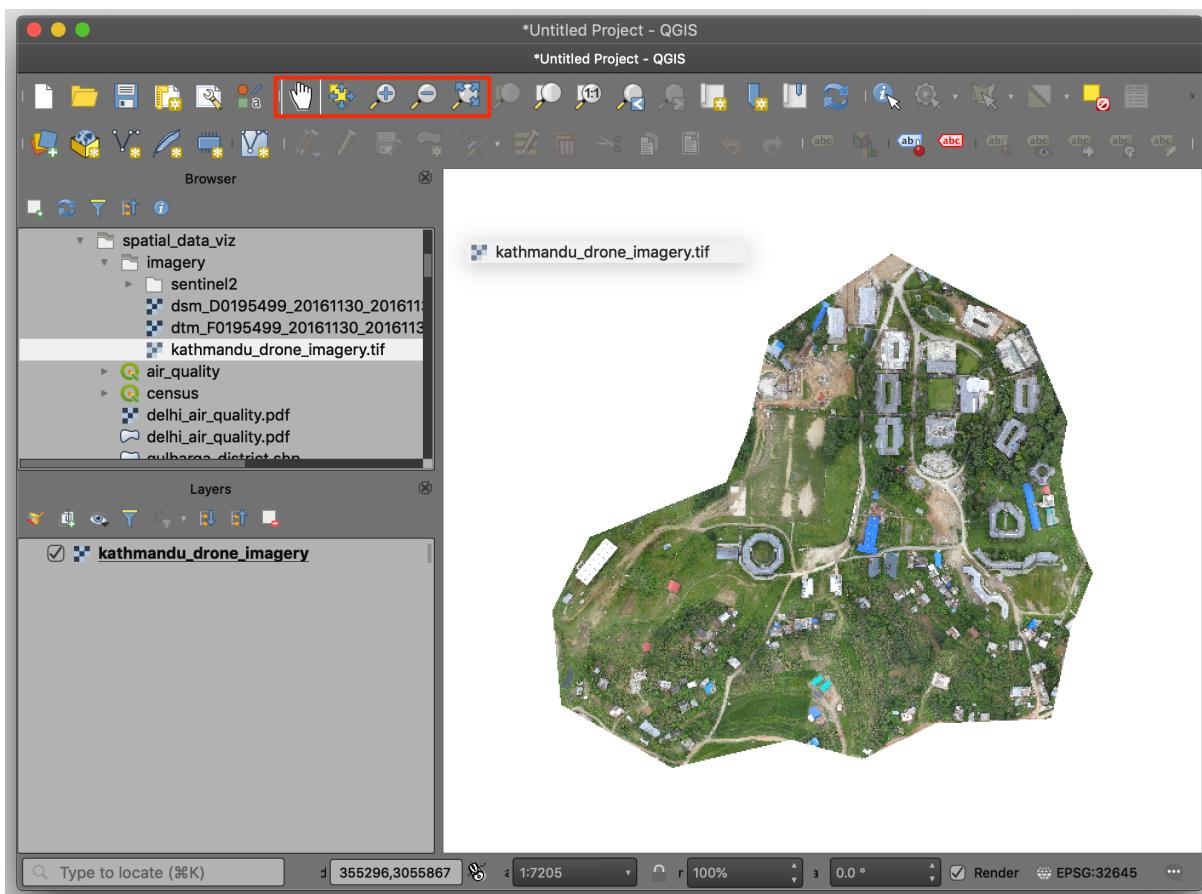
Photos collected from airborne sensors - such as kites, hot-air balloons, planes, helicopters and more recently UAVs - are useful source of information for mapping. They often act as a basemap - providing context for other spatial data. They are also used to extract feature information that are modeled as vector data.

The most common format for imagery is GeoTiff. A geotiff file contains additional metadata that allow us to convert pixel location (row/column) to a real-world location (latitude/longitude). A regular photo can be converted to a spatially-aware raster through a process known as GeoReferencing.

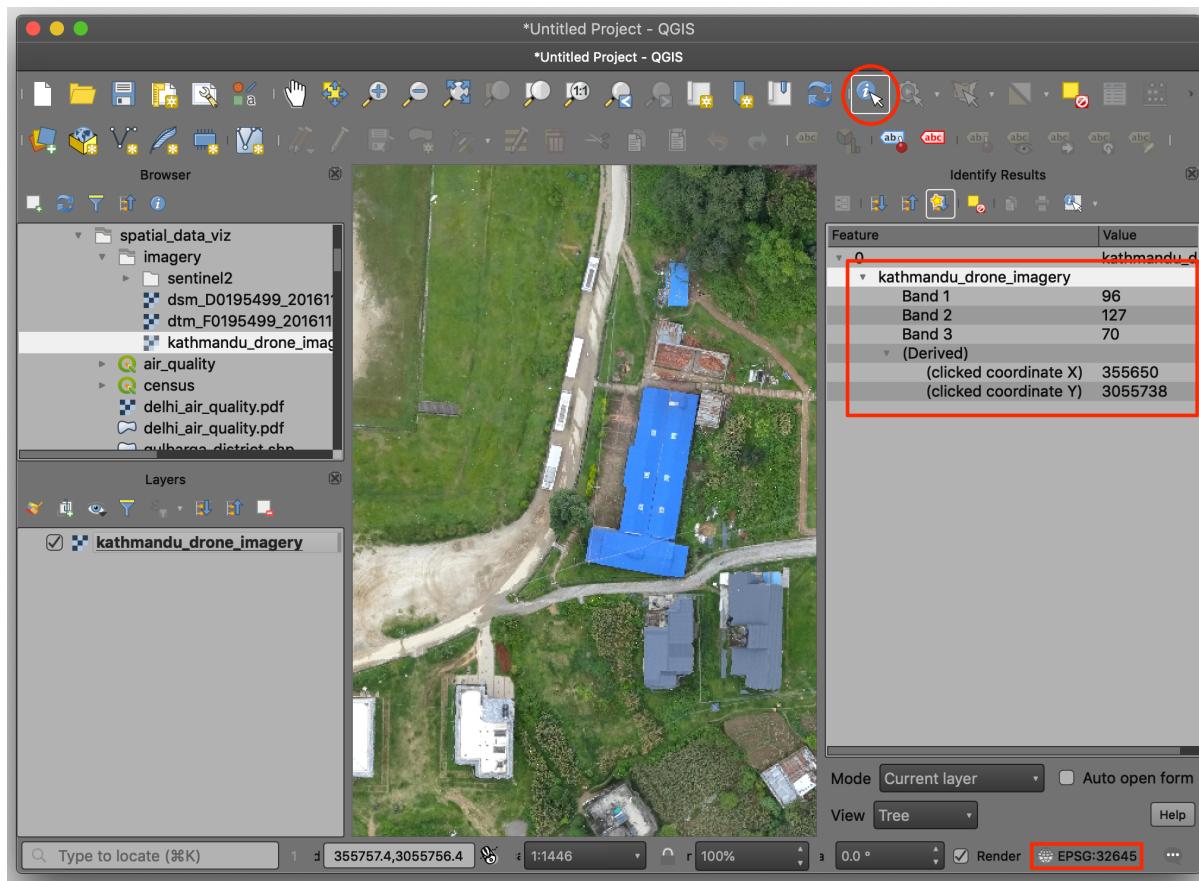
Exercise: View Drone Imagery

OpenAerialMap is an open service to share and download overhead imagery. We will use an image of Kathmandu University Grounds shared by WeRobotics.

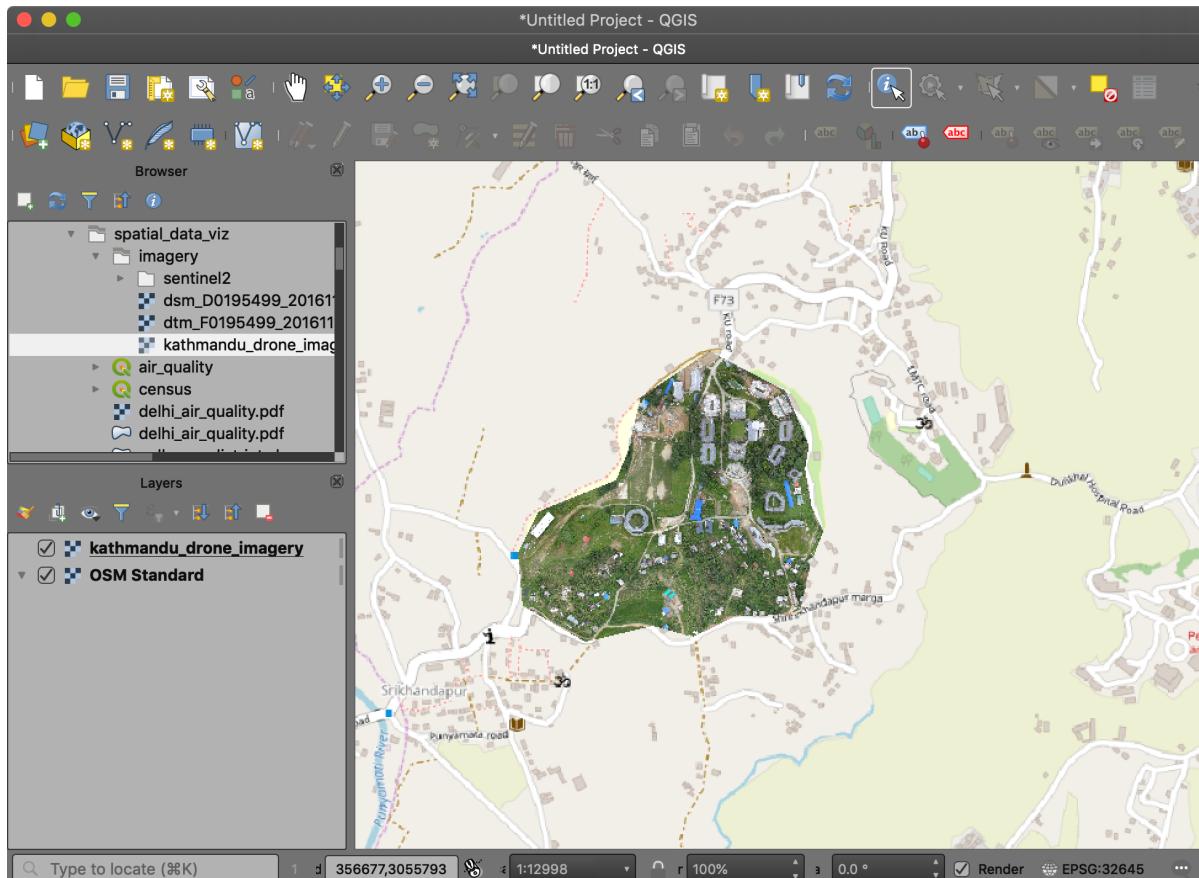
Browse to the `kathmandu_drone_imagery.tif` file and drag it to QGIS. Use the Zoom/Pan tools to explore the imagery.



At the bottom right, notice that the CRS is EPSG:32645 which refers to the UTM Zone 45N. Select the *Identify* tool and click anywhere on the image. You will see that the image contains 3 bands - one each for Red, Green and Blue. The coordinates are projected coordinates - not geographic coordinates. These are referred as *X (Easting)* and *Y (Northing)*.



As the image is also georeferenced, we can see it in context of other spatial layers. Go to **Web → QuickMapServices → OSM → OSM Standard**. A tile layer will be added to the *Layers* panel and you can see both line up with each other since both layers are spatially aware.



Raster - Satellite Images

There are hundreds of Earth Observation Satellites in space continuously capturing images of the earth. Many space agencies around the world make this data available freely. These datasets are immensely valuable to scientists, researchers, governments and businesses.

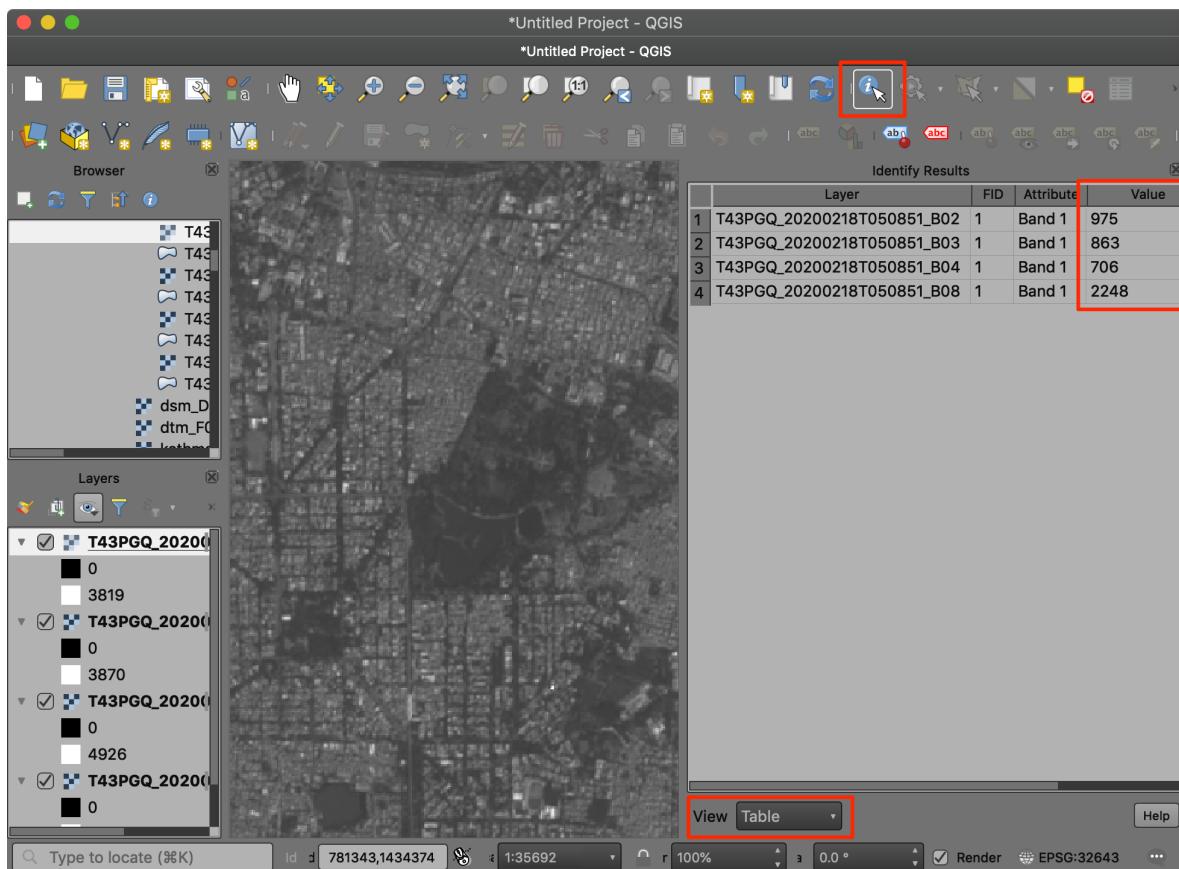
The satellite images are different than regular photos because they contain information in across many bands of wavelengths - not just - Red, Green and Blue. This rich information allows machine learning models to easily distinguish different objects. For example, an astroturf and real lawn may both look green, but reflect the infrared light very differently. So one can easily differentiate between these using the additional information contained in a multi-spectral image.

Exercise: View Sentinel-2 Image and Create Composites

Sentinel-2 is a European Space Agency (ESA) mission with 2 satellites. The resolution of each pixel in the image is 10 meters. This is lower than drone or aerial imagery resolution, but still good enough for city and region level analysis. More importantly, the data is captured in 12 different bands - making it very useful for scientific applications. These mission capture every location on the earth every 5 days, allowing for continuous monitoring of the whole earth. ESA also makes all the data from this mission freely available.

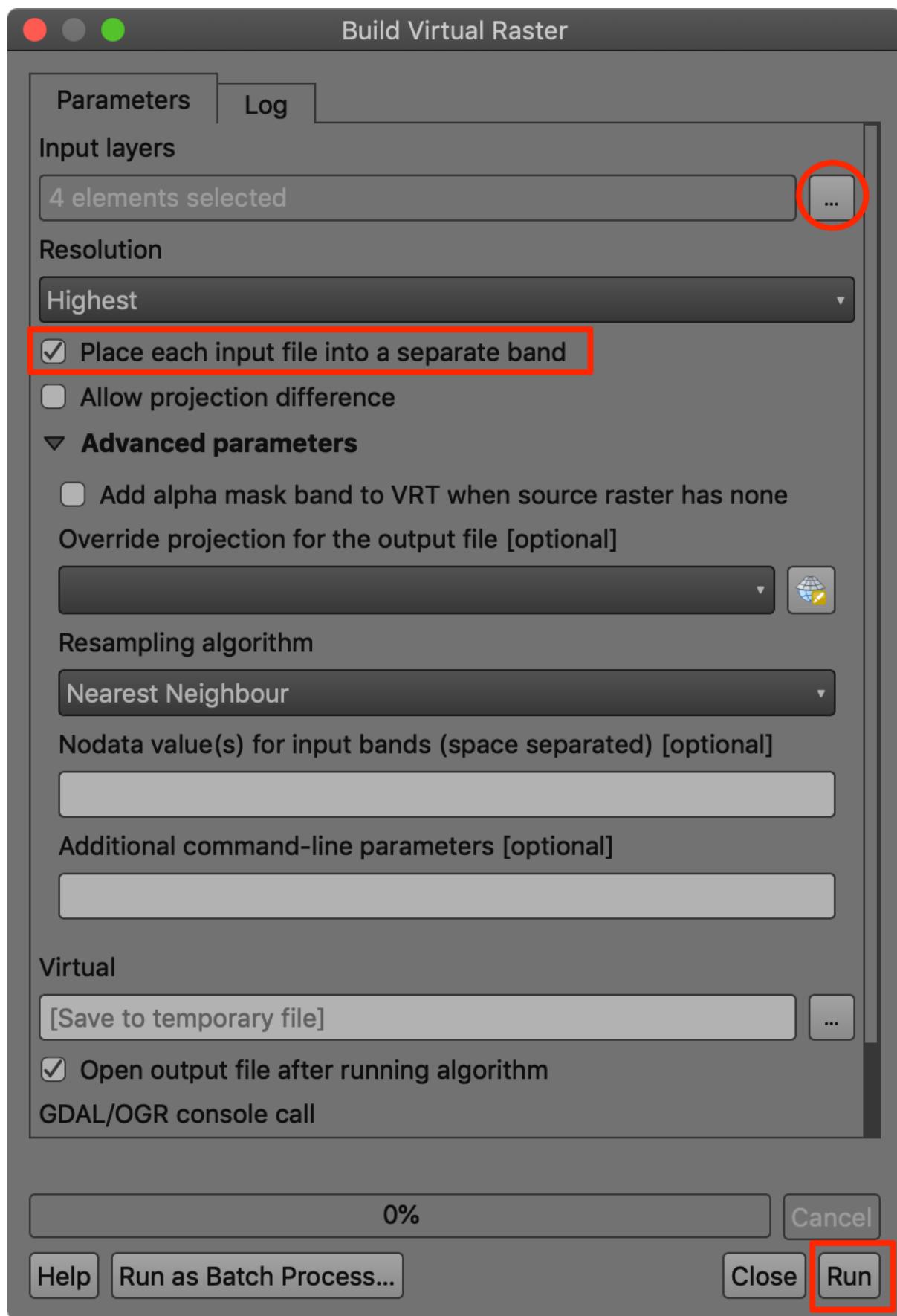
We will load a Sentinel-2 image for Bangalore, India captured on 18 February, 2020. The data package directory `imagery/sentinel-2` 4 files in JPEG2000 format. The 4 files are for bands Red (B4), Green (B3), Blue (B2) and Near Infrared (B8).

Drag all 4 images to the QGIS canvas. Zoom in to any area and explore how the same object has different reflectance in different bands.



We can combine multiple bands into a single image and visualize it. These are called *Color Composites*. To merge individual images to a single one, go to **Processing → Toolbox** and find **GDAL → Raster miscellaneous → Build virtual raster**. Double-click to launch the tool.

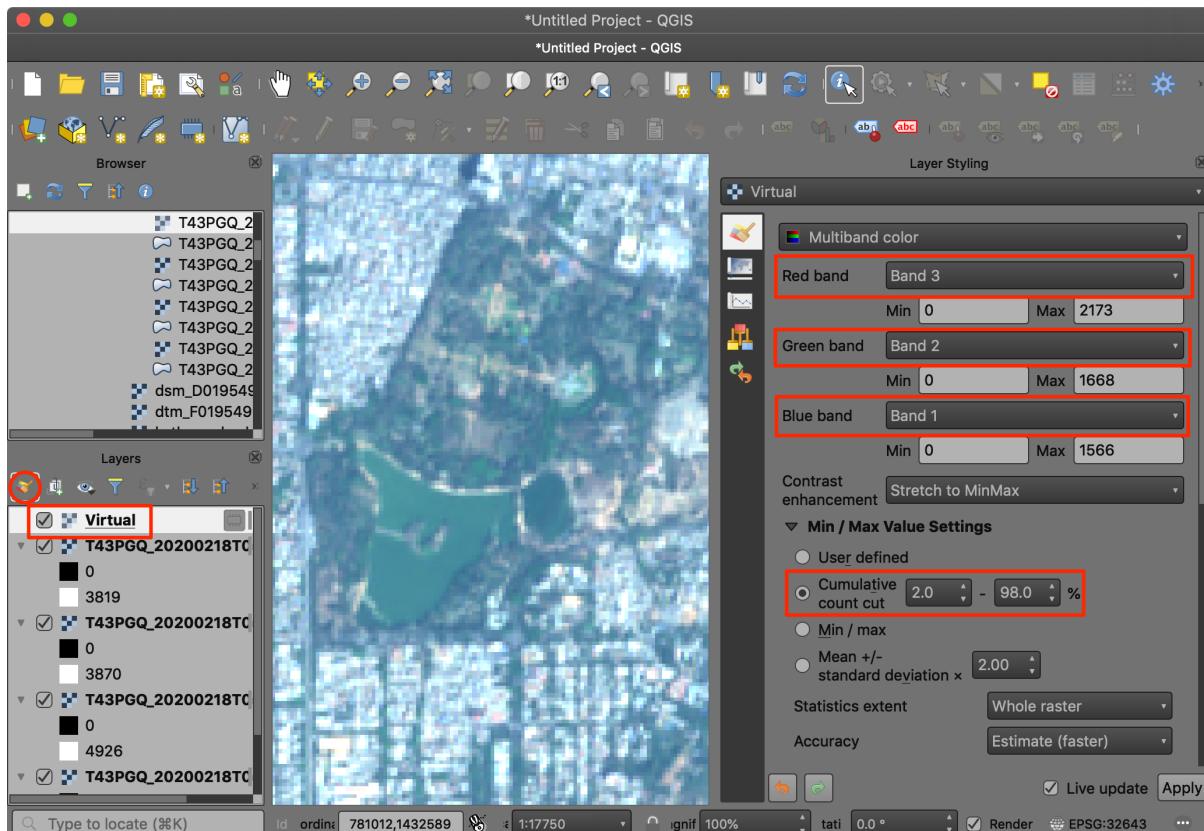
Select all 4 layers as *Input layers* and check *Place each input file into a separate band*. Next click *Run*.



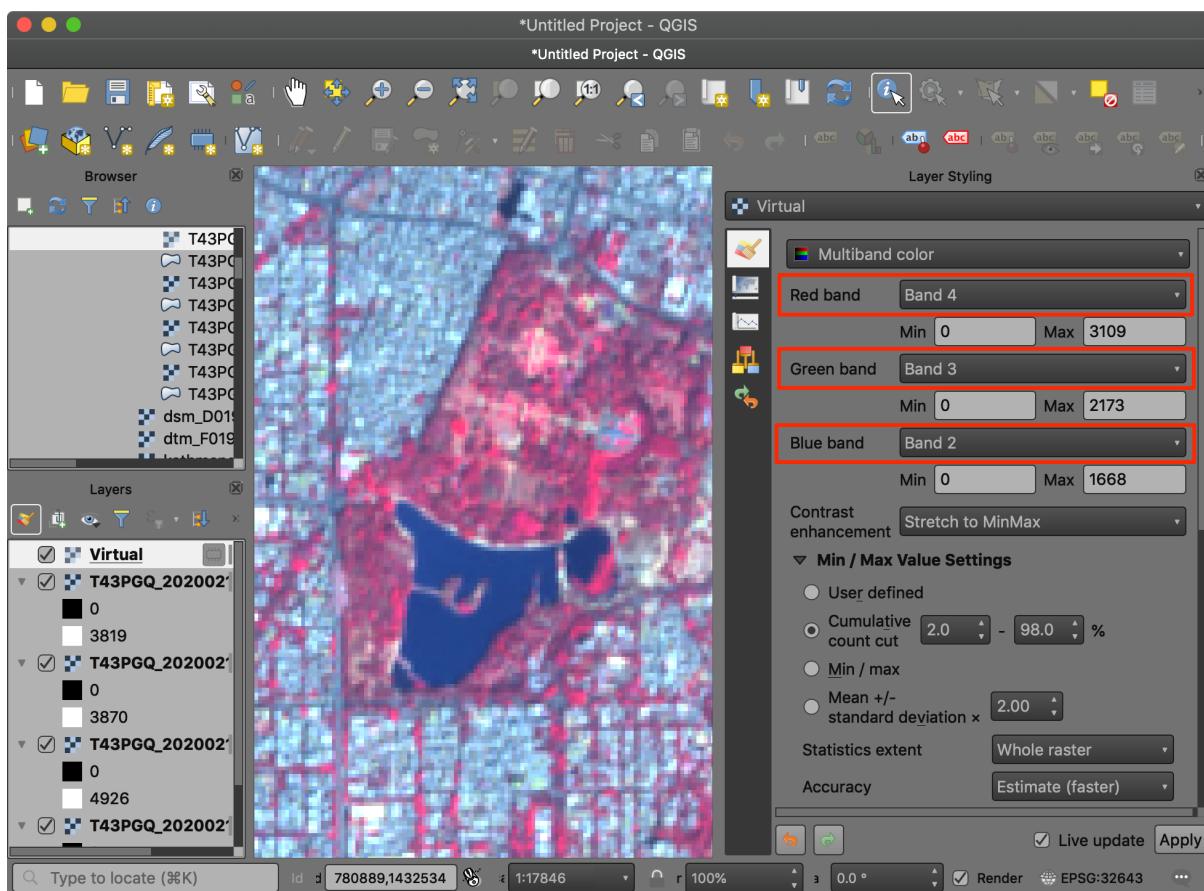
A new layer **Virtual** will be added to the *Layers* panel. This layer contains references to the 4 different images. Note that the order of the bands in alphabetical, so the mapping in the virtual raster is as follows:

Virtual Raster Band	Image
Band 1	B02 (Blue)
Band 2	B03 (Green)
Band 3	B04 (Red)
Band 4	B08 (NIR)

We will first visualize a *RGB Color Composite*. This is also referred as a *Natural Color Composite* since it is how the image would be perceived by the human eye. Place **Band 3**, **Band 2** and **Band 1** as *Red*, *Green* and *Blue* bands. Change the *Min/Max Value Settings* to *Cumulative count cut*. You will see the image now appears in natural colors.



Let's create a different type of visualization, known as *False Color Composite*. Here we want to create a *NRG Color Composite* where we put Near Infrared band in Red channel, Red band in green channel and Green band in blue channel. This visualization highlights the vegetation in red color and allows for easy visual interpretation of vegetation. Note how the water body and vegetation appeared almost the same color in the RGB composite, but are easy to separate in the NRG composite.



Data Credits

- Delhi PM2.5 concentrations. Downloaded from OpenAQ data download service. Source data from Central Pollution Control Board (CPCB) India and EPAAirNow DOC.
- India Village-Level Geospatial Socio-Economic Data Set. Meiyappan, P., P. S. Roy, A. Soliman, T. Li, P. Mondal, S. Wang, and A. K. Jain. 2018. India Village-Level Geospatial Socio-Economic Data Set: 1991, 2001. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). <https://doi.org/10.7927/H4CN71ZJ>. Accessed 15 February 2020.
- Census 2001 Districts: Downloaded from Datameet Spatial Data repository.
- Oxford Point Cloud. DTM, and DSM. Downloaded from Defra Data Services Platform. Crown Copyright 2019
- Kathmandu University Ground Drone Imagery. Downloaded from OpenAerialMap. Captured by WeRobotics
- Bangalore Sentinel-2 Imagery. Downloaded from Copernicus Open Access Hub. Copyright European Space Agency - ESA.

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