Modeling SDG indicator 11.3.1

Ratio of land consumption rate to population growth rate

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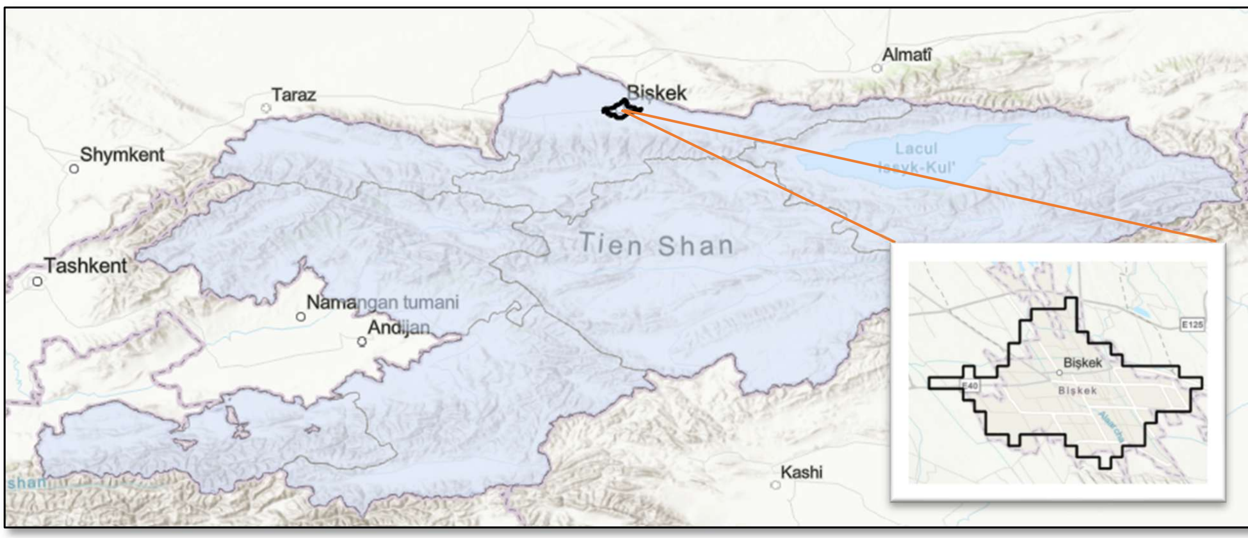
This guide provides step-by-step methodology for the estimation of SDG indicator 11.3.1 "Ratio of land consumption rate to population growth rate," using open-source data and national datasets for Kyrgyzstan.

For illustrative purposes, the guide focuses on the City of **Bishkek** in **Kyrgyzstan** as a practical case study. The methodology in this guide can be applied for any chosen urban area.

The DEGURBA methodology, which defines the urban territories used for analysis, is in line with global metadata standards, ensuring consistency and comparability across different regions.



Introduction to SDG Indicator 11.3.1

SDG indicator 11.3.1 aligns with **Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable**, and specifically **Target 11.3: By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries.**

This indicator is vital for understanding the efficiency of urban growth, comparing how quickly land is being consumed relative to population growth. A ratio greater than 1 suggests that land is being consumed faster than the population is growing, potentially indicating unsustainable sprawl. A ratio less than 1 suggests densification.

The calculation of this indicator requires high-resolution data on population (such as geocoded, gridded data, or population at small administrative units) and built-up area information for two or more distinct time periods. For calculating rates, it is suggested to use analysis periods of 3, 5, or 10 years apart,

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especially when built-up area analysis is conducted using medium to high-resolution satellite imagery (e.g., Landsat and Sentinel).

For this guide, the time period used in 2017 – 2020 using relevant datasets.

The Ratio of land consumption rate to population growth rate (LCR_PGR) is calculated using the following formula:

$$\mathbf{LCRPGR} = \left(\frac{\text{Vpresent} - \text{Vpast}}{\text{Vpast}} * \frac{1}{\text{T}}\right) \Bigg/ \left(\frac{\mathbf{LN}\left(\frac{\mathbf{Pop_{t+n}}}{\mathbf{Pop_t}}\right)}{\mathbf{y}}\right)$$

Ref: https://unstats.un.org/sdgs/metadata/files/Metadata-11-03-01.pdf

Where:

- $V_{present}$: Built-up area at the end of the analysis period (km^2)
- V_{past}: Built-up area at the beginning of the analysis period (km^2)
- T: Time in number of years in the analysis period (e.g., T=3 for 2017-2020)
- Pop_{t+n}: Total population at the end of the analysis period
- Pop_t: Total population at the beginning of the analysis period
- Y: Number of years in the analysis period (same as T)
- ln: Natural logarithm

(Reference: https://unstats.un.org/sdgs/metadata/files/Metadata-11-03-01.pdf)

Key Components of the Indicator:

- **Land Consumption Rate (LCR):** This is the rate at which urbanized land, or land occupied by a city/urban area, changes during a period of time (usually one year), expressed as a percentage of the land occupied by the city/urban area at the start of that time.
- **Population Growth Rate (PGR):** This represents the change of a population in a defined urban area (city, etc.) during a specific period, usually annualized. It reflects the number of births and

deaths during a period and the number of people migrating to and from the focus area. For SDG 11.3.1, this is computed for the area defined as urban/city.

Key Data Inputs and Considerations:

Input datasets used in this guide combine raster (grid) and vector geospatial formats. The methodology is comprehensive and can be applied with national proprietary (public or private access) geospatial datasets, or with the global open sources used in this guide.

1. **Analytical Geography – DEGURBA Urban Areas:**

- **Definition:** The Degree of Urbanisation (DEGURBA) is a classification that indicates the character of an area by classifying the territory of a country along an urban-rural continuum. It defines the specific urban/city boundaries for which both Land Consumption Rate and Population Growth Rate are calculated.

- **Considerations:** For this guide, the DEGURBA Bishkek dataset (for 2020) was derived using automated tools offered at the official Copernicus data portal. It used the WorldPop global population data (resampled from 100x100 m to meet 1 km resolution requirements) and Esri Living Atlas built-up data. These were processed and referenced into a common coordinate system (UTM 44N). The resulting dataset of Bishkek urban areas for 2020 serves as the analytical geography for this guide.

  NOTE: There is information provided on datasets for other major cities, in this guide. The download section of this guide also offers DEGURBA delimitation for other major cities, if available.

2. **Land Consumption Rate Data – Built-up Area Information:**

- **Source:** Esri Living Atlas Land Use Land Cover data. This data is available from the official webpage for years 2017-2022, both as a downloadable raster and a GIS web service.

- **Considerations:** For this guide, datasets for 2017 and 2020 were used. These were accessed from the Esri open GIS portal, which offers an annual 10-meter resolution map of Earth's land surface from 2017-2022. Other global alternatives for Land Use Land Cover, such as Dynamic World Global 10-m Land Cover Data or GlobeLand30 30-meter Global Land Cover, could serve the purpose of incorporating longer time series. Alternatively, national Land Use Land Cover datasets may be available, developed using machine learning (ML) algorithms over high-resolution imagery (e.g., using QGIS add-on instruments from Copernicus – Sentinel Hub, or UN-Habitat tutorials using Google Earth Engine).

3. **Population Growth Rate Data – Population Estimates:**

- **Source:** Kyrgyzstan population estimates for 2017 and 2020, available via the WorldPop data hub. This data, in raster format, provides the spatial distribution of the population (total number of people per grid cell, e.g., 100x100 m) for the relevant time periods.

- **Considerations:** The Population Growth Rate will be calculated as an annualized value for the specified time period (e.g., 3 years for 2017-2020). The use of national geocoded population datasets of high accuracy (e.g., to building level) is recommended to obtain more accurate index values. Creating population spatial grids based on national census data and adopting this methodology can yield advanced spatial insights and facilitate further in-depth analysis related to land consumption and population dynamics in urban areas.

Spatial Reference System

All datasets utilized in this guide are assumed to share a common spatial reference system (e.g., WGS 1984 UTM Zone 44N for the Kyrgyzstan example). When using alternative data sources, it is critically important to ensure all datasets are projected to a consistent and appropriate spatial reference system relevant to your country or region for accurate geospatial processing.

Input Geodata Sources (Examples)

The table below provides examples of the input geodata used in this guide. Users are expected to identify and procure equivalent open or national authoritative datasets for their specific region. For the Kyrgyzstan case study, example data links are provided.

System recommendations and considerations

Software: QGIS 3.28.11

Recommended Hardware for data analytics and processing:

Intel i5/i7, RAM minimum 8 GB/recommended 16 GB, dedicated GPU

Year of analysis: 2017/2020

Please use the table below for the sources of the input geodata:

Geodata	Name of geodata	national/ open-source data	Link
Administrative			
DEGURBA Bishkek urban area 2020 (derived as a part of the educational module using step-by step Guide on DEGURBA)	GHS-DUG_URBAN_CENTRE_UTM 44N.shp	national	geospatialSDGs/data/SDG1131 at main · ESCAP-SD/geospatialSDGs
DEGURBA urban areas for 7 cities of Kyrgyzstan 2020 (derived as a part of the educational module using step-by step Guide on DEGURBA)	DEGURBA_all_43UTM_final 7.shp	national	geospatialSDGs/data/SDG1131 at main · ESCAP-SD/geospatialSDGs
Chuy region	Chuy_UTM44N.shp	national	geospatialSDGs/data/SDG1131 at main · ESCAP-SD/geospatialSDGs
Land consumption			
Land Use Land Cover dataset of Esri for 2017 – mosaic raster dataset	LULC_2017_mozaica.tif	open	geospatialSDGs/data/SDG1131 at main · ESCAP-SD/geospatialSDGs
Land Use Land Cover dataset of Esri for 2020 – mosaic raster dataset	LULC_2020_Mozaica.tif	open	geospatialSDGs/data/SDG1131 at main · ESCAP-SD/geospatialSDGs
Population growth			
WorldPop Population (100 x 100 m.) for Kyrgyzstan 2017, Chuy region	Population2017_Chuy.tif	open	geospatialSDGs/data/SDG1131 at main · ESCAP-SD/geospatialSDGs
WorldPop Population (100 x 100 m.) for Kyrgyzstan 2020, Chuy region	Population2020_Chuy.tif	open	geospatialSDGs/data/SDG1131 at main · ESCAP-SD/geospatialSDGs

NOTE: Upon completion of the guide you can assess your results against the Final project with all deliverables and geospatial datasets via this link

geospatialSDGs/data/SDG1131/SDG 1131 ResultData.zip at main · ESCAP-SD/geospatialSDGs

Methodology for obtaining SDG 11.3.1 based on open and national datasets

Methodology for Estimating SDG 11.3.1 Based on Open and National Datasets

The guide is divided into data processing and analytics, primarily using QGIS.

Step 0: Preprocessing data

This initial step ensures all necessary data is organized and easily accessible

1. **Create a Dedicated Project Folder:** Create a new folder on your local drive (For example: D:/SDG_1131_Project, or a name of your choosing).

   This folder will hold all your input and output data.

2. **Download and Unzip Data:** Download all required spatial datasets (identifying relevant national or open global sources for your area, similar to the examples referenced above). Unzip all downloaded files into the dedicated data folder.

3. **Launch QGIS:** Open the QGIS Desktop application.

4. **Start a New Empty Project:** Choose (double-click) "New Empty Project" from the QGIS initial screen or navigate to Project > New Empty Project.

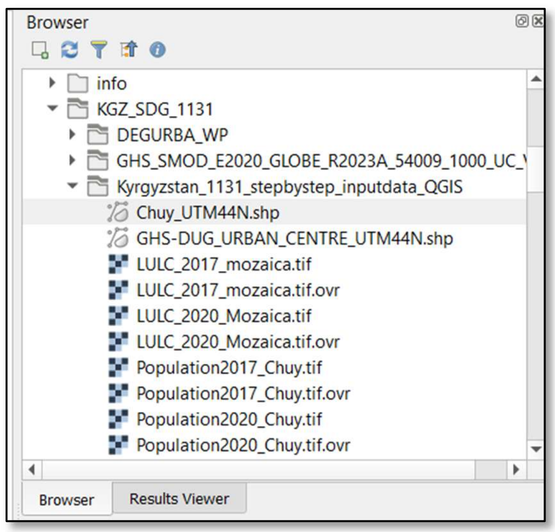
   NOTE: Be aware that all geospatial datasets used in the project should ideally have a common geographic reference system for accurate processing. If they don't, QGIS will often reproject them on-the-fly, but it's best practice to ensure consistency beforehand.

Step I: Calculating Land Consumption Rate

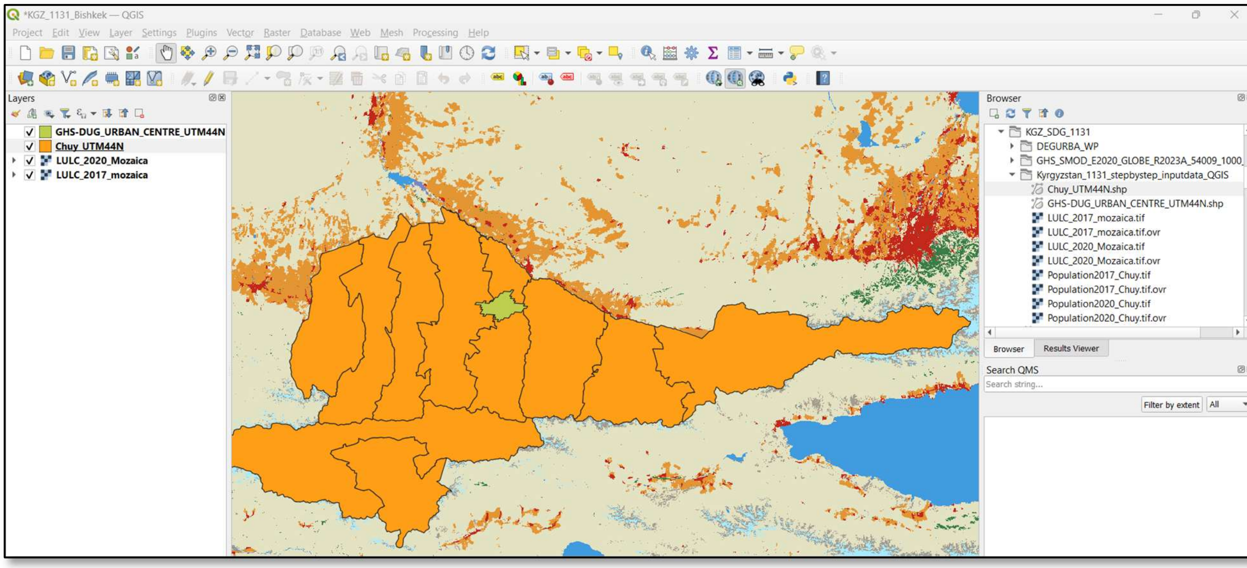
This section focuses on preparing land use/land cover data to derive built-up area statistics for different time periods.

5. **Navigate to Project Folder in QGIS Browser:** In the 'Browser' panel (typically on the left), navigate to your newly created project folder (For example: D:/SDG_1131_Project).

6. **Add Vector and Raster Layers to Map:** Select (click) and drag-and-drop the relevant shapefiles and rasters from your project folder into the QGIS map canvas. For the Kyrgyzstan example, these would include the following files (as in the picture below):
   GHS-DUG_URBAN_CENTRE_UTM44N.shp (DEGURBA urban areas for selected city, e.g., Bishkek)
   Chuy_UTM44N.shp (Chuy region boundary)
   LULC_2017_Mozaica.tif (Esri LULC for 2017)
   LULC_2020_Mozaica.tif (Esri LULC for 2020)

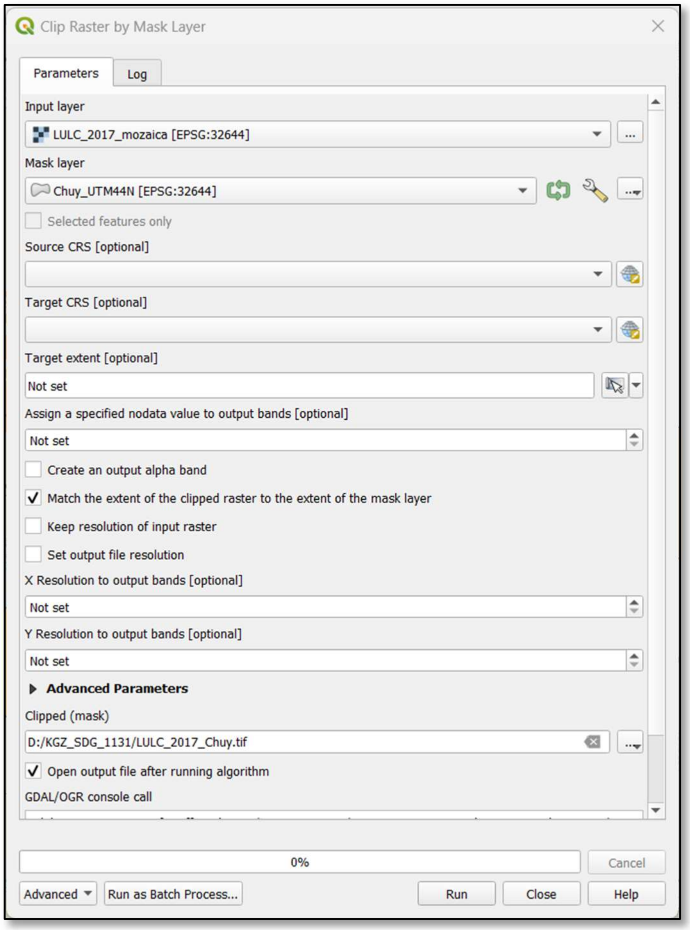


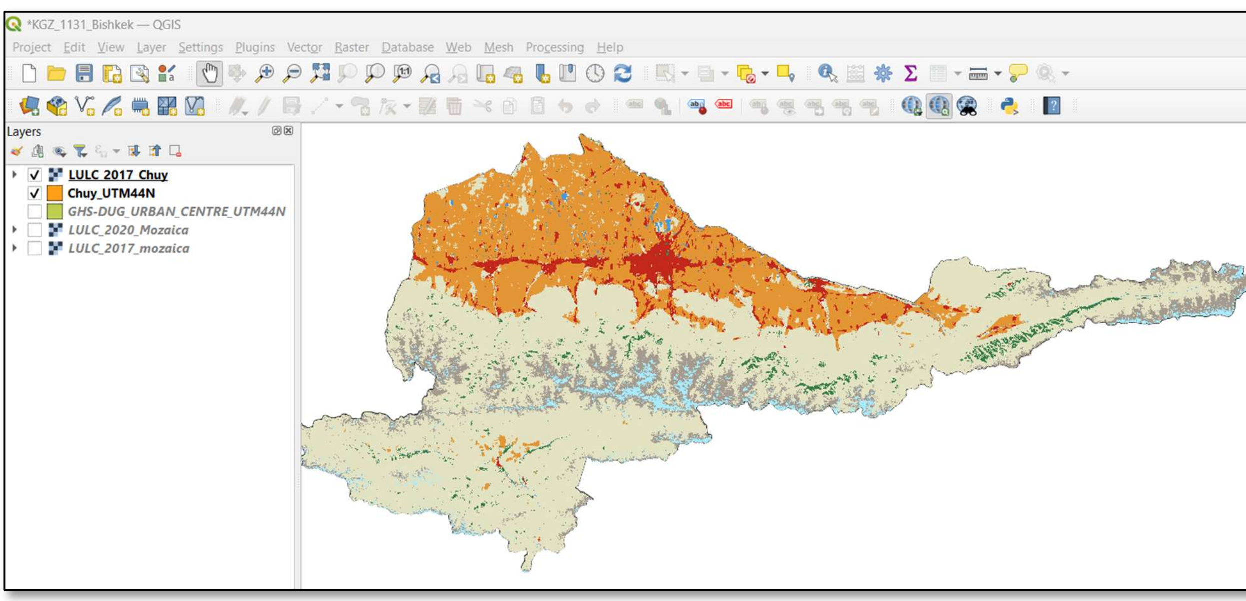
7. **Save QGIS Project:** Save your QGIS project (For example: as SDG_1131_Analysis.qgz) in your project folder (For example: D:/SDG_1131_Project, or the name of your choosing).



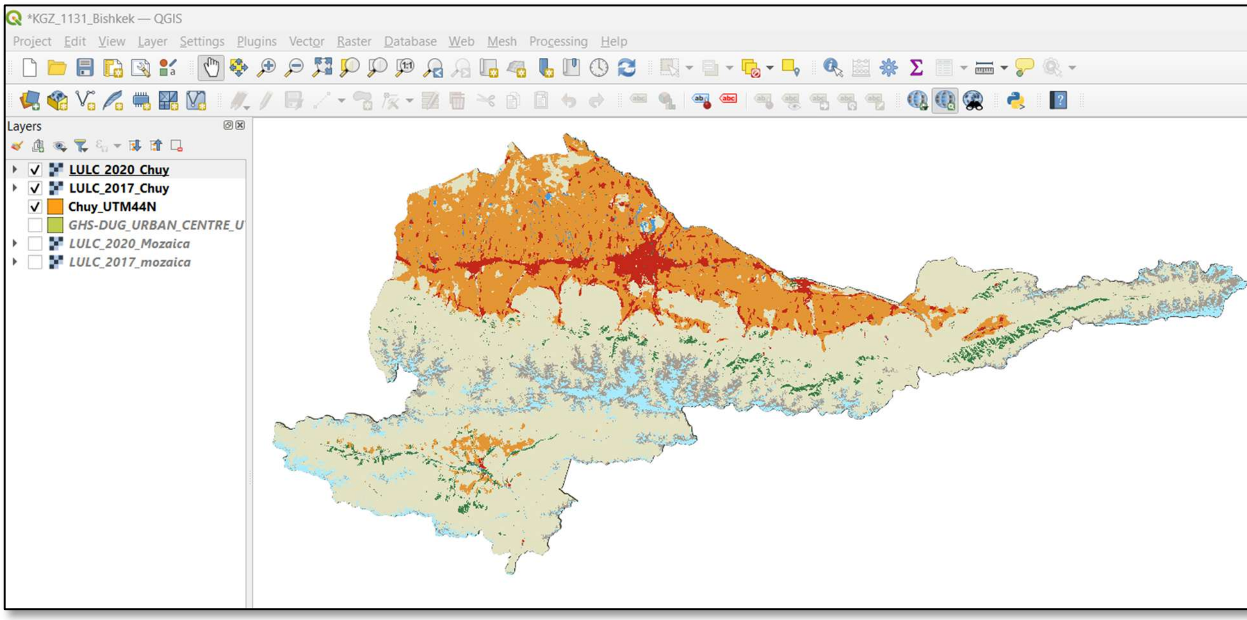
8. **Clip Land Use Land Cover (LULC) for 2017 to Region Extent:** To focus the analysis on your specific region, clip the broader LULC grid for 2017 to the extent of your chosen administrative boundary (e.g., Chuy region).

- Choose Raster > Extraction > Clip Raster by Mask Layer.
- Set 'Input layer' to LULC_2017_Mozaica.tif.
- Set 'Mask layer' to your regional boundary (e.g., Chuy_UTM44N).
- Ensure 'Match the extent of the clipped raster to the extent of the mask layer' is checked.
- Specify an 'Output file' path and name (e.g., D:/SDG_1131_Project/LULC_2017_Chuy.tif).
- Click 'Run'.


Clip Raster by Mask Layer
Parameters
Log
Input layer
LULC_2017_mozaica [EPSG:32644]
Mask layer
Chuy_UTM44N [EPSG:32644]
Selected features only
Source CRS [optional]
Target CRS [optional]
Target extent [optional]
Not set
Assign a specified nodata value to output bands [optional]
Not set
Create an output alpha band
Match the extent of the clipped raster to the extent of the mask layer
Keep resolution of input raster
Set output file resolution
X Resolution to output bands [optional]
Not set
Y Resolution to output bands [optional]
Not set
Advanced Parameters
Clipped (mask)
D:/KGZ_SDG_1131/LULC_2017_Chuy.tif
Open output file after running algorithm
GDAL/OGR console call
0%
Cancel
Advanced
Run as Batch Process...
Run
Close
Help


*KGZ_1131_Bishkek — QGIS
Project Edit View Layer Settings Plugins Vector Raster Database Web Mesh Processing Help
Layers
LULC 2017 Chuy
Chuy_UTM44N
GHS-DUG_URBAN_CENTRE_UTM44N
LULC_2020_Mozaica
LULC_2017_mozaica

9. **Clip Land Use Land Cover (LULC) for 2020 to Region Extent**: Repeat step 8 for the LULC_2020_Mozaica.tif dataset to generate a clipped raster named LULC_2020_Chuy.tif (or similar, reflecting your region).



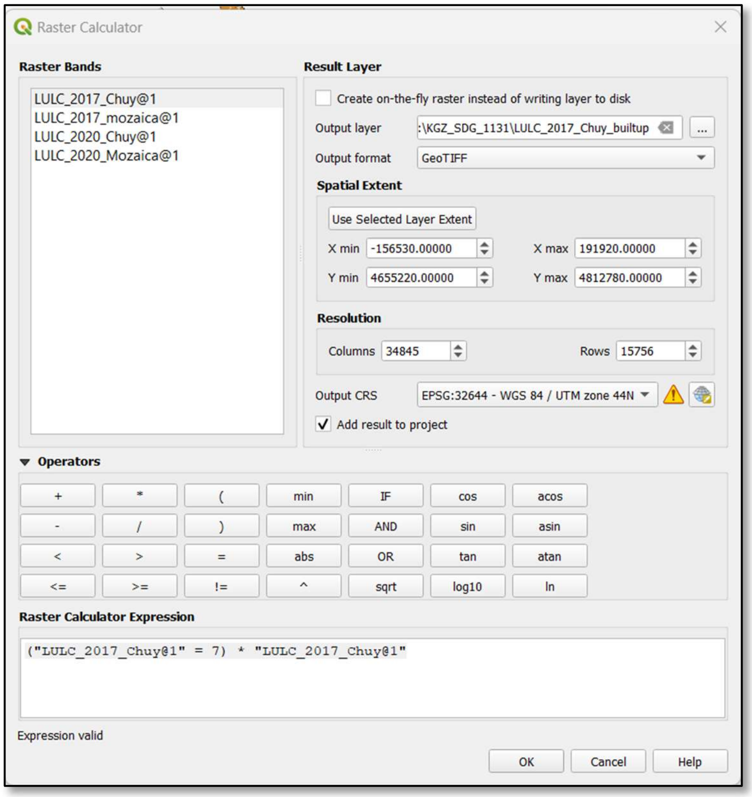
10. **Isolate Built-up Areas using Raster Calculator:** For each clipped LULC raster (2017 and 2020), select only the built-up areas. Esri Land Use Land Cover data typically assigns a specific class value to built-up areas (e.g., class 7).

- Launch Raster > Raster Calculator.
- **For 2017:**
  - Enter the expression: ("LULC_2017_Chuy@1" = 7) * "LULC_2017_Chuy@1"
  - This expression creates a new raster where only pixels with a value of 7 (built-up areas) retain their value, and all other values become 0.
  - Specify an 'Output layer' path and name (e.g., D:/SDG_1131_Project/LULC_2017_Chuy_builtup.tif).

Please note that this output layer is used as an input layer in the methodology fto produce DEGURBA. More guidance is provided in the series of guides published by ESCAP.

  - **IMPORTANT NOTE:** To produce accurate results and ensure the output is a permanent file, **ALWAYS create a physical raster dataset** by specifying an output file path. Do not leave the 'Create on-the-fly raster instead of writing layer to disk' option selected.
  - Click 'OK'.

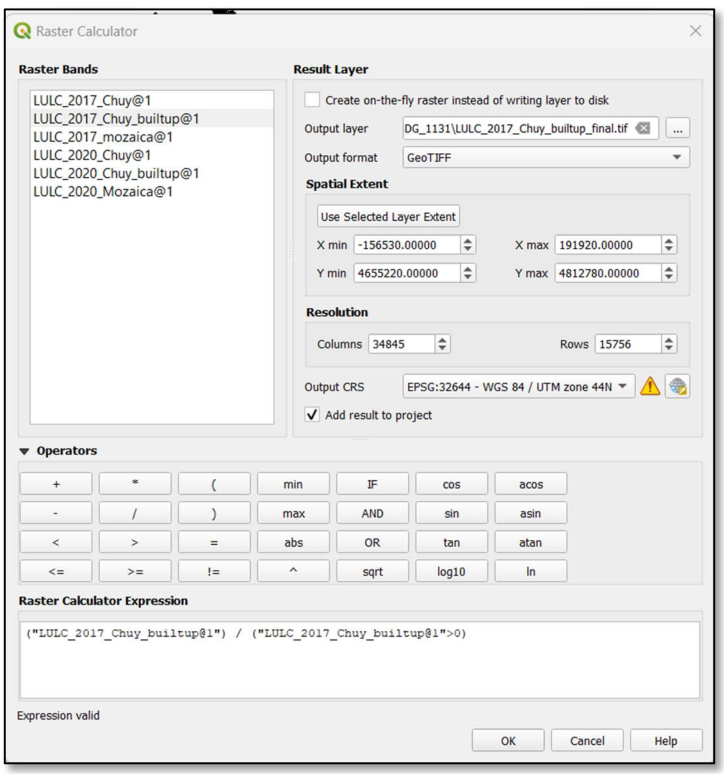
- **For 2020:**
  - Repeat the process with the expression: ("LULC_2020_Chuy@1" = 7) * "LULC_2020_Chuy@1"
  - Specify the output as D:/SDG_1131_Project/LULC_2020_Chuy_builtup.tif.
  - Click 'OK'.



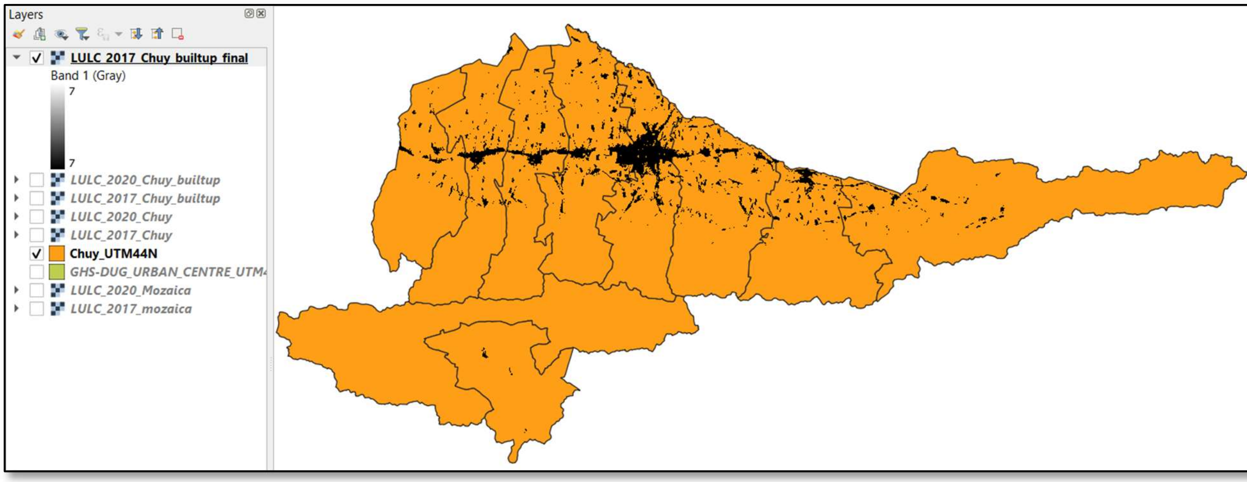
NOTE: Built-up areas are in white. To produce accurate results ALWAYS create physical raster dataset within the Raster Calculator!! Do not leave set up properties to create on-the-fly raster.

11. **Remove Zero Values (Prepare for Analysis):** To ensure only built-up areas are considered and to prepare the grids for accurate area calculation, remove zero-value cells from the built-up rasters obtained in the previous step. This effectively creates a binary mask where built-up areas have a value (e.g., 7) and non-built-up areas are null or ignored.

- Launch Raster > Raster Calculator.
- **For 2017:**
  - Enter the expression: ("LULC_2017_Chuy_builtup@1") / ("LULC_2017_Chuy_builtup@1" > 0)
  - Specify the output as D:/SDG_1131_Project/LULC_2017_Chuy_builtup_final.tif.
  - Click 'OK'.
- **For 2020:**
  - Repeat the process with the expression: ("LULC_2020_Chuy_builtup@1") / ("LULC_2020_Chuy_builtup@1" > 0)
  - Specify the output as D:/SDG_1131_Project/LULC_2020_Chuy_builtup_final.tif.
  - Click 'OK'.

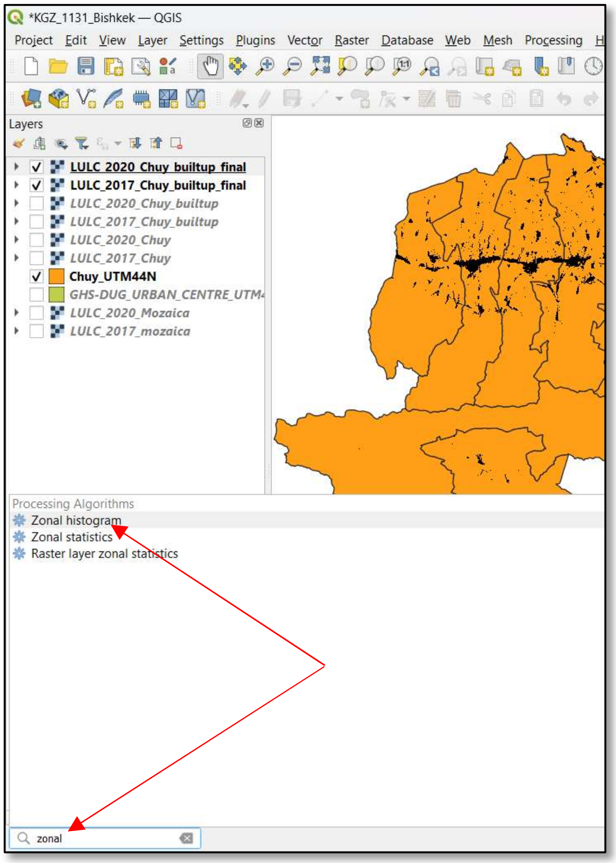


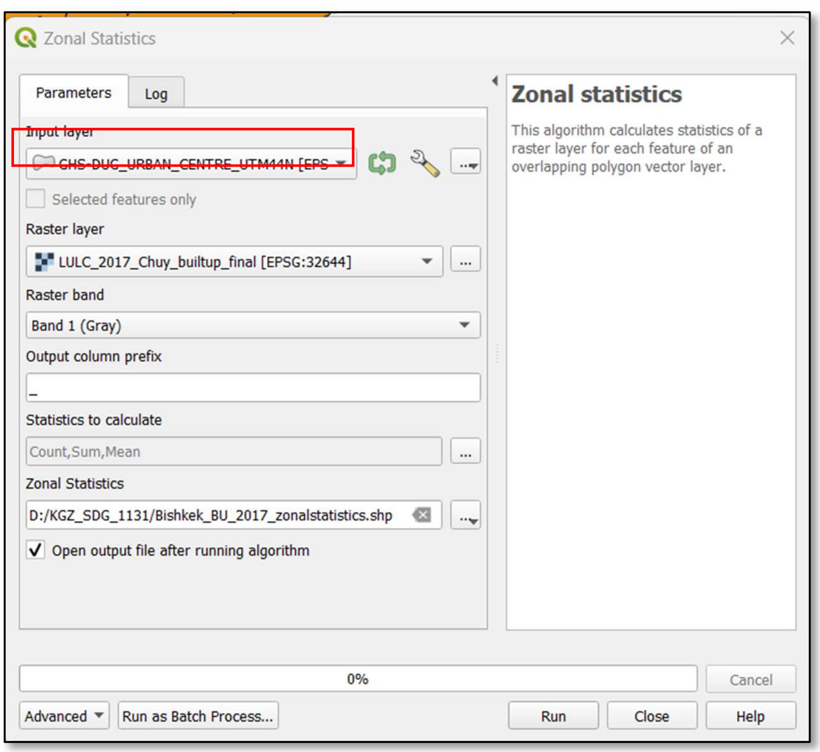
NOTE: You can use a variety of data sources for Built-up areas. It is essential to analyze the data and its quality. For example, upon validation, GHS (Global Human Settlement) datasets from the Copernicus data portal could be used. Specialists could also generate their own Built-up areas using the Sentinel Hub Plugin in QGIS or via Google Earth Engine (refer to materials from UN-Habitat).



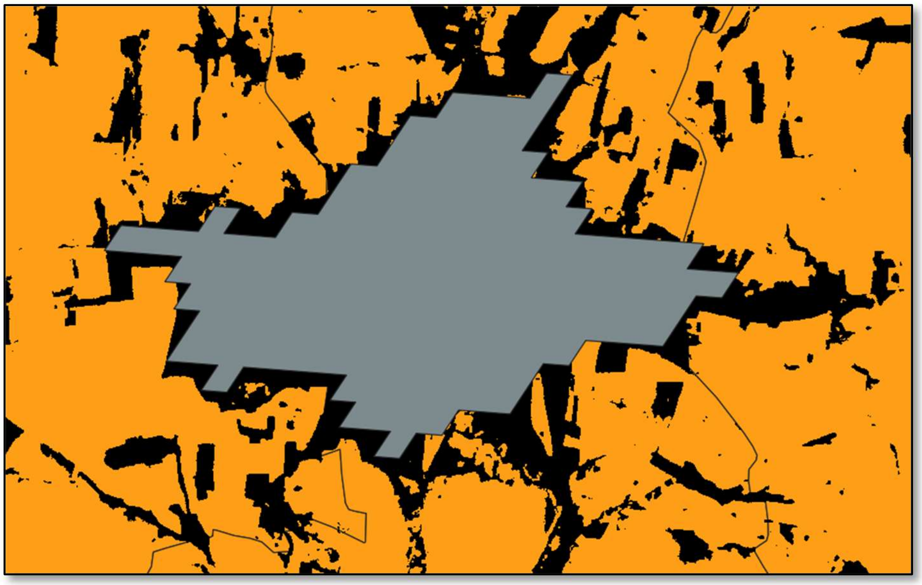
12. **Calculate Built-up Area (m²) for 2017 within Urban Boundaries:** Identify the total area (in square meters) covered by built-up areas within the boundaries of your defined urban zones (DEGURBA areas) for the year 2017.

- In the 'Processing Toolbox' (accessible via Processing > Toolbox), search for "Zonal statistics" and choose Raster analysis > Zonal statistics.
- Set 'Input layer' to your DEGURBA urban area shapefile (e.g., GHS-DUG_URBAN_CENTRE_UTM44N).
- Set 'Raster layer' to your final 2017 built-up raster (e.g., LULC_2017_Chuy_builtup_final).
- Set 'Raster band' to Band 1 (Gray).
- Under 'Statistics to calculate', ensure 'Count' and 'Sum' are selected. (The original document also shows 'Mean', but 'Count' and 'Sum' are most relevant for total area calculation in a binary raster).
- Specify an 'Output column prefix' (e.g., BU_2017_).
- Specify an 'Output file' path and name for the new shapefile (e.g., D:/SDG_1131_Project/Bishkek_BU_2017_zonalstatistics.shp).
- Click 'Run'.

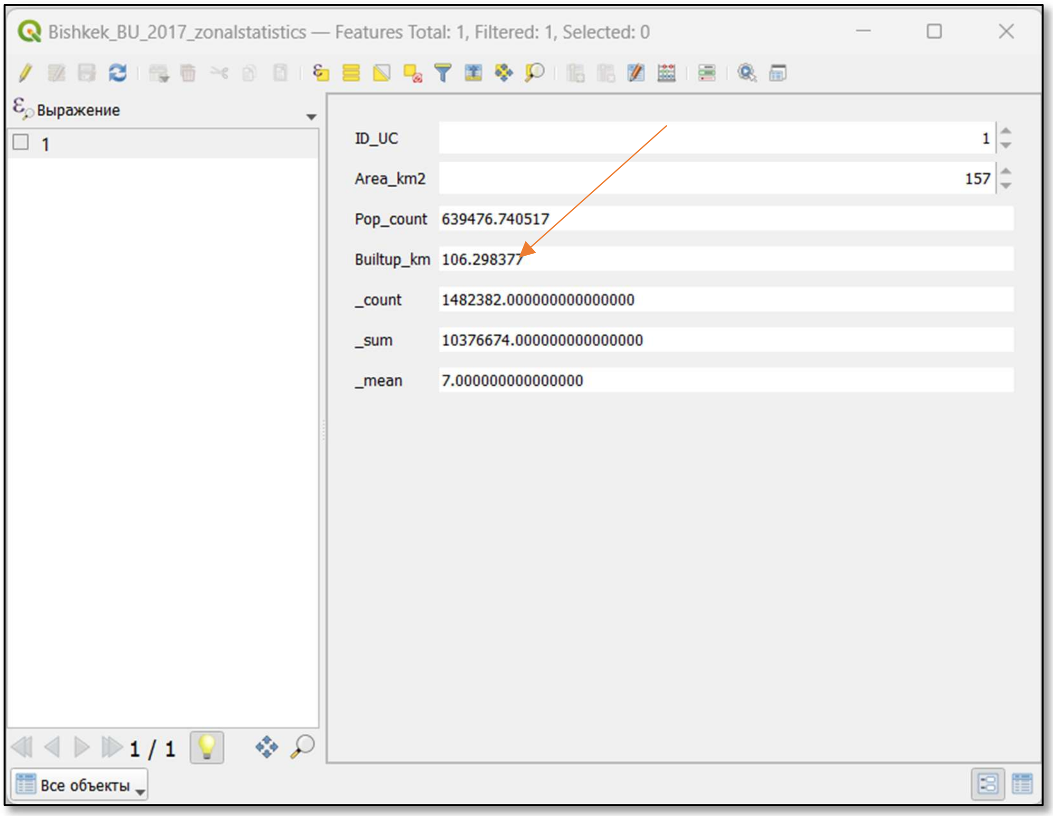

*KGZ_1131_Bishkek — QGIS
Project Edit View Layer Settings Plugins Vector Raster Database Web Mesh Processing
Layers
LULC 2020 Chuy builtup final
LULC_2017_Chuy_builtup_final
LULC_2020_Chuy_builtup
LULC_2017_Chuy_builtup
LULC_2020_Chuy
LULC_2017_Chuy
Chuy_UTM44N
LULC_2020_Mozaica
LULC_2017_mozaica
Processing Algorithms
Zonal histogram
Zonal statistics
Raster layer zonal statistics
zonal


Zonal Statistics
Parameters
Log
Input layer
GHS-DUG_URBAN_CENTRE_UTM44N [EPS
Selected features only
Raster layer
LULC_2017_Chuy_builtup_final [EPSG:32644]
Raster band
Band 1 (Gray)
Output column prefix
_
Statistics to calculate
Count,Sum,Mean
Zonal Statistics
D:/KGZ_SDG_1131/Bishkek_BU_2017_zonalstatistics.shp
Open output file after running algorithm
Zonal statistics
This algorithm calculates statistics of a raster layer for each feature of an overlapping polygon vector layer.
0%
Cancel
Advanced
Run as Batch Process...
Run
Close
Help

Below is a zoomed-in view of the built-up areas and DEGURBA boundary.

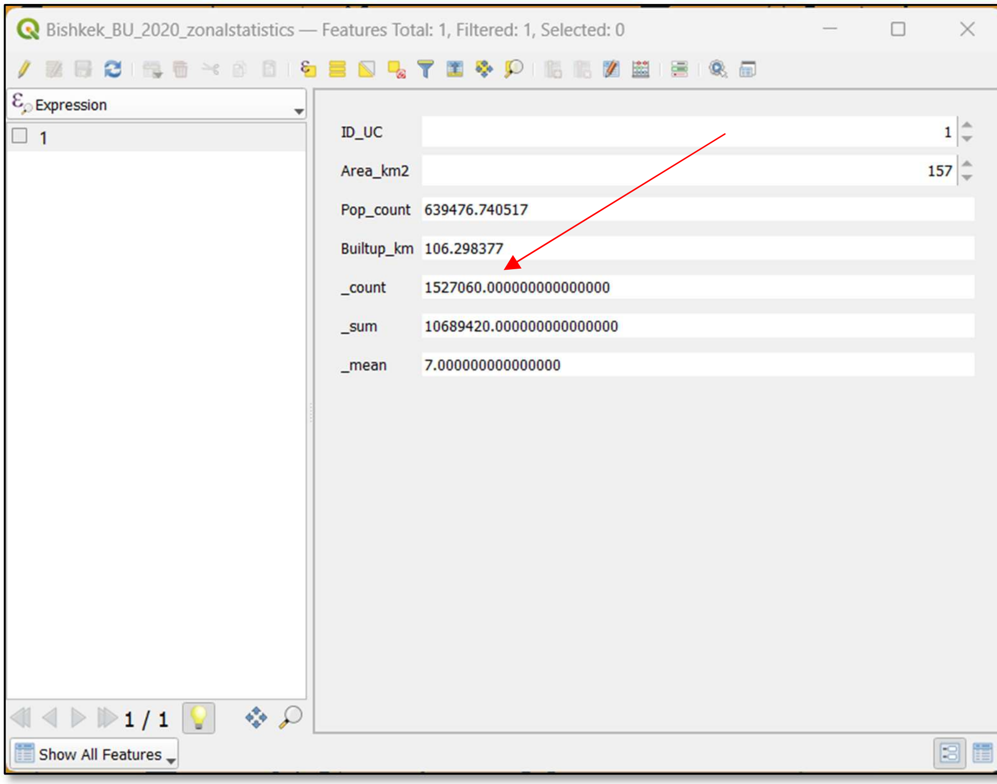


13. **Review 2017 Built-up Area Statistics:** Right-click on the newly created Bishkek_BU_2017_zonalstatistics layer in the 'Layers' panel and select 'Open Attribute Table'.
   - The 'count' field in the attribute table represents the number of built-up raster cells within your DEGURBA urban area. Given that the Esri LULC data is at 10x10 m resolution, each cell represents 100 m2.
   - Multiply the 'count' value by 100 to get the total built-up area in square meters. For example, if the count is 1482382, the area is 1482382 * 100 = 148,238,200 m^2, or 148.2382 km^2. This is the total built-up area for Bishkek in 2017.



14. **Calculate Built-up Area (m^2) for 2020 within Urban Boundaries:** Repeat steps 12 and 13 to calculate the built-up area statistics for Bishkek in 2020.

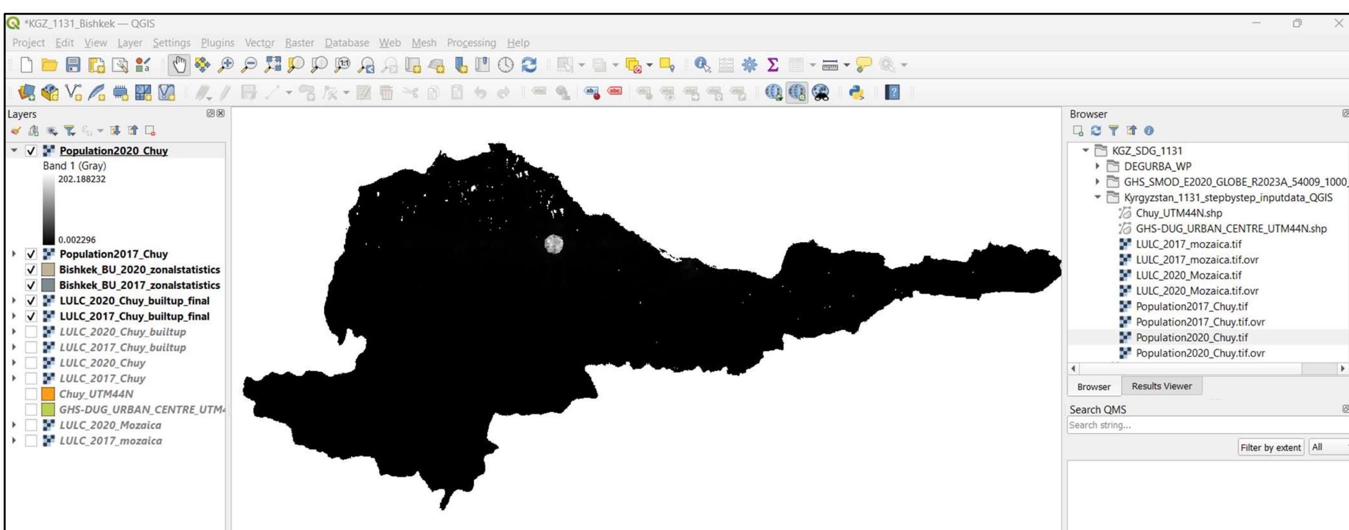
- Use LULC_2020_Chuy_builtup_final as the 'Raster layer'.
- Specify a new output shapefile (e.g., D:/SDG_1131_Project/Bishkek_BU_2020_zonalstatistics.shp).
- Review the attribute table. The example shows a value of 1527060 for the count, resulting in 152,706,000 m^2 or 152.7060 km^2 of built-up areas in Bishkek in 2020.



Step II: Calculating Population Growth Rate (PGR)

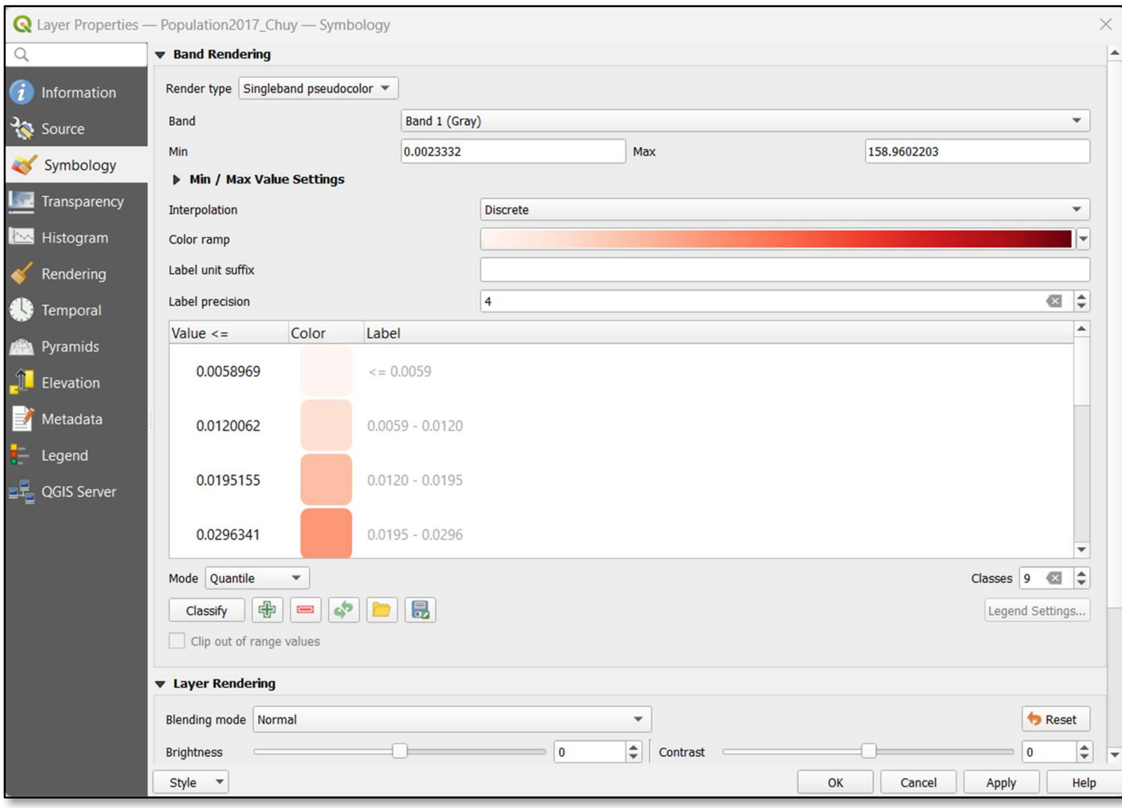
This section focuses on preparing population grid data to derive population statistics for different time periods within your urban areas.

15. **Add WorldPop Raster Datasets to Map:** Add the WorldPop raster datasets for 2017 and 2020 to your QGIS map canvas (e.g., drag-and-drop Population2017_Chuy.tif and Population2020_Chuy.tif).

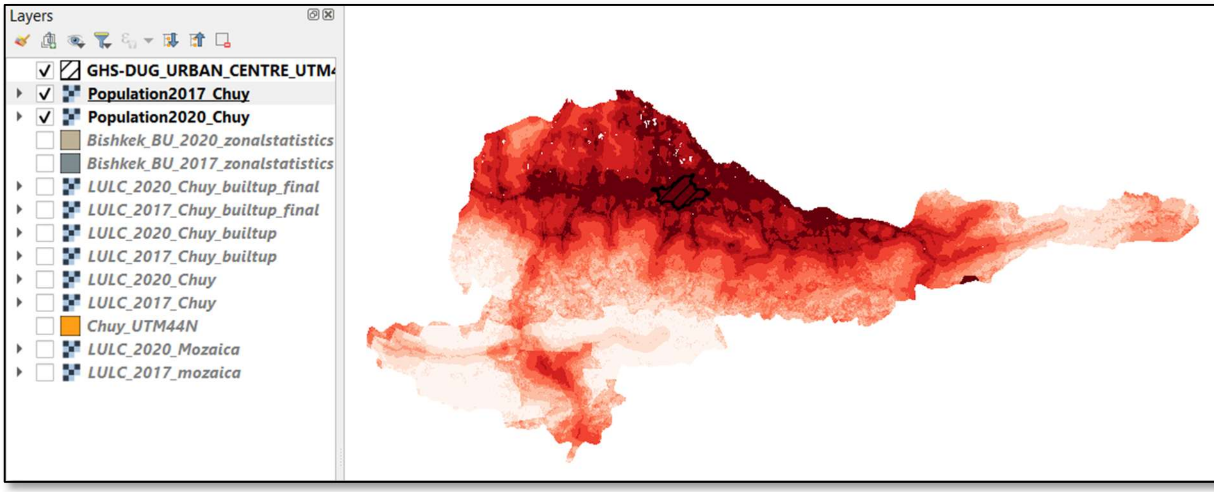


16. **Enhance Population Grid Visualization (Symbology):** To better understand the population distribution within the grids, change the symbology for both raster layers.

- Right-click each population layer in the 'Layers' panel and select Properties > Symbology.
- Set 'Render type' to 'Singleband pseudocolor'.
- Under 'Min / Max Value Settings', choose an appropriate 'Interpolation' (e.g., 'Discrete' or 'Linear') and 'Color ramp' (e.g., 'Reds' for population density).
- Adjust 'Mode' (e.g., 'Quantile' or 'Equal Interval') and 'Classes' to define visual ranges.
- Click 'Apply' then 'OK'.

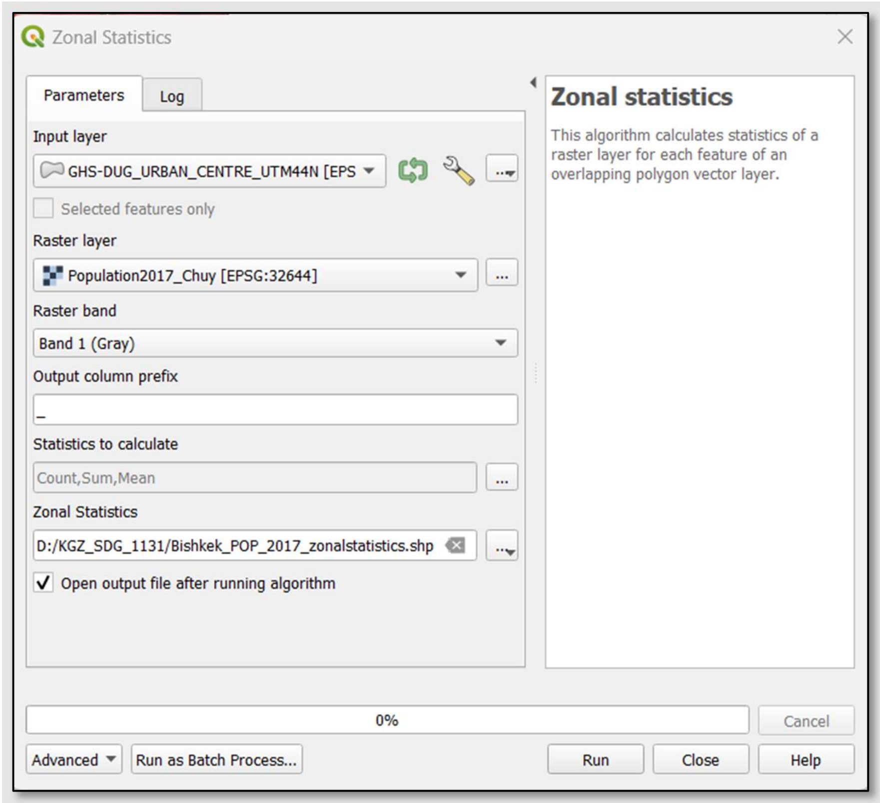


The image below shows the visualized population grid:



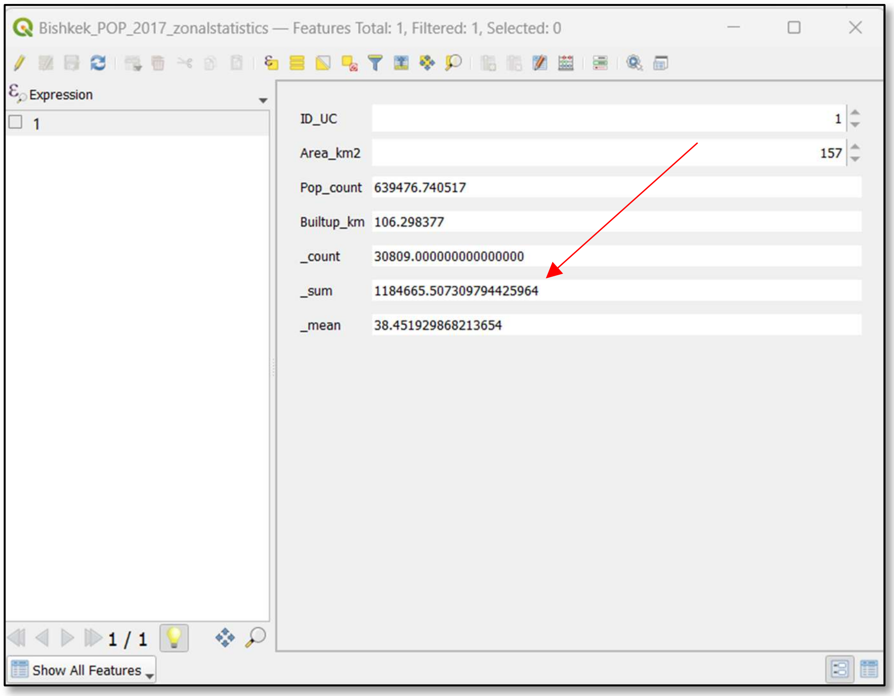
17. **Calculate Population Statistics for 2017 and 2020 within Urban Boundaries:** Run the Zonal statistics tool for both Population2017_Chuy.tif and Population2020_Chuy.tif rasters. This will sum the population values within your DEGURBA urban areas for each year.

- In the 'Processing Toolbox', search for "Zonal statistics" and choose Raster analysis > Zonal statistics.
- **For 2017:**
  - Set 'Input layer' to your DEGURBA urban area shapefile (e.g., GHS-DUG_URBAN_CENTRE_UTM44N).
  - Set 'Raster layer' to Population2017_Chuy.tif.
  - Under 'Statistics to calculate', ensure 'Sum' is selected.
  - Specify the output shapefile as D:/SDG_1131_Project/Bishkek_POP_2017_zonalstatistics.shp.
  - Click 'Run'.
- **For 2020:**
  - Repeat the process with 'Raster layer' set to Population2020_Chuy.tif.
  - Specify the output shapefile as D:/SDG_1131_Project/Bishkek_POP_2020_zonalstatistics.shp.
  - Click 'Run'.

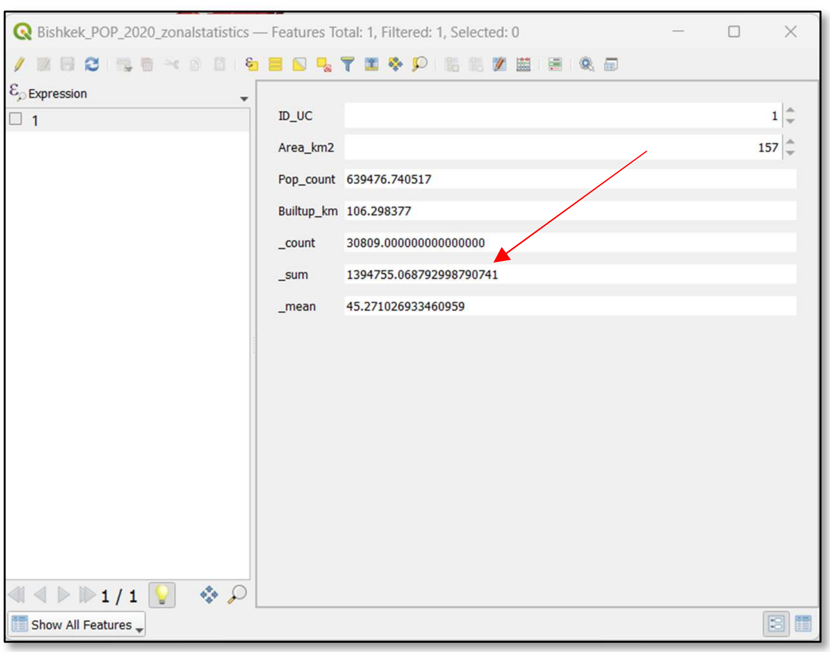


18. **Review Population Statistics for 2017 and 2020:** Open the attribute tables for the layers Bishkek_POP_2017_zonalstatistics and Bishkek_POP_2020_zonalstatistics to obtain the total population values for Bishkek in 2017 and 2020, respectively.

- For 2017, the example shows a sum of 1184665.50..., which translates to approximately 1,184,665 inhabitants.



- For 2020, the example shows a sum of 1394755.06..., which translates to approximately 1,394,755 inhabitants.



NOTE: Creating a population spatial grid based on national census data and adopting this methodology can result in advanced spatial insights and further in-depth analysis related to land consumption and population dynamics in urban areas.

Step III: Calculation of SDG 11.3.1 “Ratio of land consumption rate to population growth rate”
To calculate SDG 11.3.1 for your urban area (e.g., Bishkek), it is highly recommended to use the official SDG 11.3.1 Reporting Template provided by the custodian agency, UN-Habitat.

19. **Download SDG 11.3.1 Reporting Template:** Obtain the Excel file from the official sources (e.g., https://unhabitat.org/guidance-urban-indicators-database). Search for "SDG 11.3.1 Reporting Template." Download and save the Excel file with your preferred name.

20. **Input Data into Reporting Template:** In the Excel file, navigate to the Tab: 2-Indicator 11.3.1 data inputs. Introduce the numbers obtained from the previous steps into the corresponding cells to calculate SDG 11.3.1:
    - **Built up area within T3 urban area boundaries (km²):**
        - T1 (2017): Input the value from Step 14 (e.g., 148.2382).
        - T2 (2020): Input the value from Step 14 (e.g., 152.7060).
    - **Total population within T3 urban area boundaries for each analysis year:**
        - T1 (2017): Input the value from Step 18 (e.g., 1184665).
        - T2 (2020): Input the value from Step 18 (e.g., 1394755).
    - **T (Number of years between analysis cycles):** Input the number of years between T1 and T2 (e.g., 3 for 2017-2020).

The Excel template will automatically calculate the Land Consumption Rate, Population Growth Rate, and the final Ratio of land consumption rate to population growth rate.

City name	Analysis Years (Advisable to keep similar months between years)			Built up area within T3 urban area boundaries (Km2)			Total population within T3 urban area boundaries for each analysis year			*t* (Number of years between analysis cycles)		Land consumption rate (Locked cell, including formula)		Population growth rate (Locked cell, including formula)		Ratio of land consumption rate to population growth rate (Locked cell, including formula)	
	T1	T2	T3	T1	T2	T3	T1	T2	T3	t (T1-T2)	t (T2-T3)	T1 - T2	T2 - T3	T1 - T2	T2 - T3	T1 - T2	T2 - T3
Bishkek	2017	2020		148.2382	152.7060		1184665	1394755		3	-2020	0.01005	0.00	0.05442	#NUM!	0.1846	#NUM!

Step IV: Calculation of Secondary Indicators

There are two important secondary indicators that help interpret the value of the main SDG 11.3.1 indicator, providing a better understanding of the nature of urban growth in each urban area. Both indicators use the same input and output data as the main indicator and thus will not require additional geospatial processing.

1. **Built-up Area Per Capita:**
   - **Definition:** This measures the average amount of built-up area available to each person in an urban area during each analysis year. This indicator can help identify when urban areas become too dense or too sparsely populated.
   - **Formula:**
     Built-up area per capita(m^2/person)=$Pop_t UrBU_t$
     Where:
     - UrBUt: The total built-up area in the urban area at time t (in square meters)
     - Popt: The population in the urban area at time t
   - **Calculation using input data (Example):**
     - 2017 Bishkek built-up area: 148.2382 km^2 = 148,238,200 m^2
     - 2020 Bishkek built-up area: 152.7060 km^2 = 152,706,000 m^2
     - 2017 Bishkek population: 1,184,665
     - 2020 Bishkek population: 1,394,755
     - **Built-up area per capita (2017)** = 148,238,200 m^2 / 1,184,665 = **125.13** m^2**/person**
     - **Built-up area per capita (2020)** = 152,706,000 m^2 / 1,394,755 = **109.49** m^2**/person**
2. **Total Change in Built-up Area (%):**
   - **Definition:** This measures the total increase in built-up areas within the urban area over time. When applied to a smaller part of an urban area (e.g., the core city), this indicator can be used to understand densification trends. It uses the same inputs as the Land Consumption Rate.
   - **Formula:**

{Total change in built-up area (%)} = \frac{UrBU_{t+n} - UrBU_t}{UrBU_t}

     Where:
     - UrBUt+n: Total built-up area in the urban area at the current/end year
     - UrBUt: Total built-up area in the urban area at the past/initial year
   - **Calculation using input data (Example):**
     - 2017 Bishkek built-up area: 148,238,200 m^2
     - 2020 Bishkek built-up area: 152,706,000 m^2
     - **Total change in built-up area (%)** = (152,706,000 m^2 - 148,238,200 m^2) / 148,238,200 m^2 = 0.03 or **3%**

Following these calculations, it would be beneficial to utilize advanced Map Algebra instruments within QGIS or other GIS software for more in-depth spatial analysis and visualization of land consumption and population dynamics.

Conclusion and Recommendations

This guide provides a comprehensive and replicable methodology for modeling SDG indicator 11.3.1 using readily available open-source GIS software (QGIS) and global/national geospatial datasets. By following these steps, National Statistics Offices and GIS professionals can effectively assess the ratio of land consumption rate to population growth rate within their urban areas and contribute to global monitoring efforts.

Key Recommendations for Global Implementation:

- **Data Consistency:** Ensure that land use/land cover and population datasets are consistent in terms of methodology, spatial resolution, and temporal coverage across different time periods.
- **Definition of Urban Area:** Consistently apply a robust methodology, such as DEGURBA, to delineate urban areas for analysis. This ensures that the indicator reflects actual urban dynamics rather than administrative boundaries alone.
- **Spatial Reference Systems:** Always maintain consistency in spatial reference systems across all input datasets to prevent projection errors during geospatial operations.
- **Data Validation:** Regularly validate your derived built-up area and population estimates against other reliable sources or ground truth data to ensure accuracy.
- **Longer Time Series:** Where possible, utilize longer time series (e.g., 5 or 10-year intervals) for more robust trend analysis of land consumption and population growth rates, especially when relying on satellite imagery.
- **Custom Tool Development:** For repetitive tasks or national-scale reporting, consider developing custom scripts or models within QGIS (e.g., using Python/PyQGIS) to automate the workflow.
- **Capacity Building:** Continuous training and knowledge sharing in geospatial data processing and analysis are crucial for NSOs to effectively implement and report on complex geospatial indicators like SDG 11.3.1.

By adopting this systematic approach, countries can gain valuable insights into their urban development patterns, inform sustainable urbanization policies, and contribute to achieving SDG 11.3.1 targets.

Additional Information

The guide was developed by Elena Hristev, ESCAP Consultant. For more details, please contact directly at lena.hristev@gmail.com or contact ESCAP-Statistics at stat.unescap@un.org

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