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LUE User Guide

A tool to calculate the Land Use Efficiency and the SDG 11.3 indicator with the Global Human Settlement Layer

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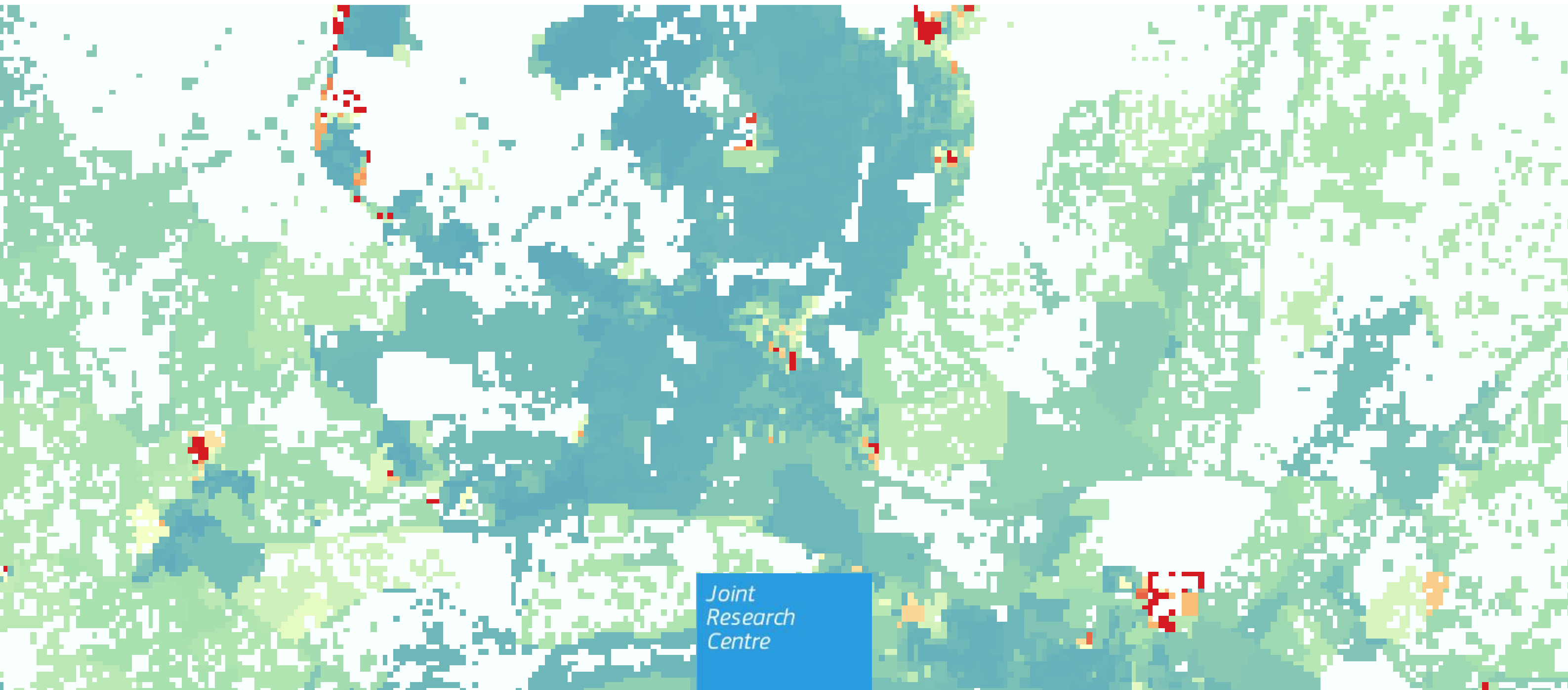

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Abstract

LUE tool stands for Land Use Efficiency tool and it is a tool developed by the Global Human Settlement Layer (GHSL) Team.

This tool, developed in Python language, allows user calculating easily and quickly some indicators on the change of land in an area of interest. The tool is designed to be use with GHS Layers on Built-up area and population, but it can be easily adapted also to other input data.

This guide provides instructions about installing and using the LUE tool in the open source software QGIS and provides suggestions for the output interpretation.

1) Introduction

With the adoption of the 2030 Agenda for Sustainable Development (New-York, 25 September 2015)[1], the country members are invited to measure, follow-up and achieve the 169 targets associated with the 17 Sustainable Development Goals (SDGs).

The success in achieving these goals relies on the provision of consistent, reliable and regularly updated data to measure the progress in the implementation of SDGs.

Currently, the Global Human Settlement Layer (GHSL) produced by the Joint Research Centre (JRC) of the European Commission represents on the best source of detailed and free data on human settlements and population on a global scale (Pesaresi et al. 2016). The characteristics and description of the GHSL data are presented in the following box:

Global Human Settlement Layer

The GHSL is a set of georeferenced layers that provides information on human settlements and population with global coverage.

It is produced elaborating historical satellite images and data from open sources. The main datasets consist in gridded layers of built-up area and number of inhabitants at a high resolution (38m and 250m respectively) for four dates: 1975, 1990, 2000, and 2015.

The GHSL allows measuring the growth of cities and towns over time, including information on population, urbanization rate and land consumption.

In the context of GHSL, a global layer on built-up surfaces (GHS-BU) was produced from Landsat image collections for four different periods (1975-1990-2000-2015).

The information generated with the GHS-BU was then used to downscale population and estimate population (GHS-POP) for the same years as the GHS-BU.

Data on built-up areas and population can be downloaded for free from the GHSL website: http://ghsl.jrc.ec.europa.eu/data.php

[1] http://www.un.org/sustainabledevelopment/

2) The Land Use Efficiency (LUE) and the SDG 11.3.1 indicator

The GHSL layer provides the baseline data to transform the challenges of implementing the SDGs into an opportunity, thanks to the possibility of estimating a series of indicators linked to the evolution of built-up surfaces and population.

In particular, the GHSL offers an interesting potential for monitoring the SDG 11.3[2] target that by 2030, aims to «enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries». To measure this target, the proposed indicator 11.3.1 is: **ratio between the land use growth rate and population growth rate (LCRPGR).**

Land Use growth includes: (a) The expansion of built-up area which can be directly measured; (b) the absolute extent of land that is subject to exploitation by agriculture, forestry or other economic activities; and (c) the over-intensive exploitation of land that is used for agriculture and forestry.
The *Land consumption rate (LCR)* is defined as:

$$LCR = \frac{LN\left(^{Urb_{t+n}}/_{Urb_t}\right)}{(y)} \qquad [1]$$

Where
Urb_{t+n} Total areal extent of the urban agglomeration in km^2 for past/initial year
Urb_t Total areal extent of the urban agglomeration in km^2 for current /final year
y The number of numbers between the two measurement periods

The *Population growth rate (PGR)* is the increase of a population in a country during a period, usually one year, expressed as a percentage of the population at the start of that period. It reflects the number of births and deaths during a period and the number of people migrating to and from a country.

$$PGR = \frac{LN\left(^{Pop_{t+n}}/_{Pop_t}\right)}{(y)} \qquad [2]$$

Where
Pop_{t+n} Total population within the city in the past/initial year
Pop_t Total population within the city in the current /final year
y The number of numbers between the two measurement periods

The formula to estimate the ratio of land consumption rate to population growth rate (LCRPGR) is provided as follows:

$$LCRPGR = \left(\frac{Land\ Consumption\ rate}{\text{Annual } Population\ growth\ rate}\right) \qquad [3]$$

And the overall formula can be summarized as:

[2] http://www.un.org/sustainabledevelopment/cities/

$$LCRPGR = \left(\frac{LN\,({}^{Urb_{t+n}}/_{Urb_t})}{(y)}\right) \Bigg/ \left(\frac{LN\,({}^{Pop_{t+n}}/_{Pop_t})}{(y)}\right) \qquad [4]$$

This indicator will hardly capture the dynamics of cities with negative a zero or negative growth of population or for those which lost part of its territories due to a natural catastrophe or a conflict. Moreover, the "urban area" is defined as the surface that includes the built-up area and the open urban space. A consensus on the definition of the urban area and its delimitation has still to be reached in order to define the indicator, due to the variety of the existing definitions and methods.

To overcome these difficulties, it has been proposed to adapt the formulation of the Land Use Efficiency (LUE) indicator in order to measure the «**change rate of the built-up are per capita**» (Corbane et al. 2016):

$$Idx_t = \frac{Y_t - Y_{t+n}}{Y_t} \qquad [5]$$

where $Y_t = \frac{BU_t}{POP_t}$ and BU_t et POP_t the built-up surface and the population at the time *t*.

The LUE indicator can be estimated with different time intervals (i.e. every 5, 10, 15 years) upon the availability of the observations. In order to ensure the comparability of the results at different times, it is recommended to normalise the values to obtain the variation a 10-year average change which divides the indicator by *n (the number of years that separate the observations)* and then multiply by 10. The formula of the normalised indicator is:

$$Idx_t = \frac{Y_t - Y_{t+n}}{Y_t} * \frac{10}{n} \qquad [6]$$

The availability of information on built-up surface and population with different dates offers an interesting case to test the proposed indicator and identify the factors of changes at different scales from the agglomeration to the regional scale. For this analysis we propose to use the GHSL layer (GHS-BU) and the associated population data (GHS-POP) at the 250 x 250 m resolution for the years: 1990-2000 and 2015.

The LUE tool allows to calculate the LUE indicator as defined in [5] but also the SDG11.3.1 indicator as in [4]. The tool produces a geoTIFF output file for the LUE indicator and the results of both indicators are summarized in a numerical form in a .csv file.

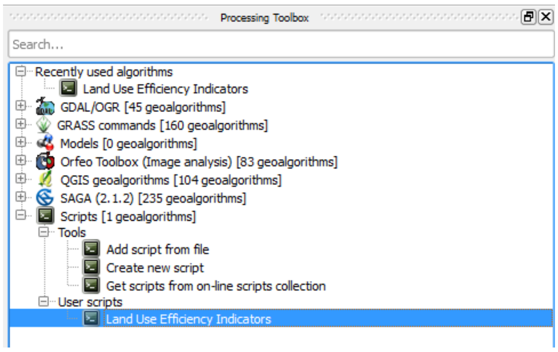
1.1 Installation of the LUE indicator calculation tool

The first step is to install the algorithm for calculating the LUE indicator, developed by the JRC team. This compiled script has to be installed in the toolbox of Quantum GIS (QGIS) only once.

This is compatible with QGIS v2.14 and following versions.

We will use the Toolbox, which is the main element of the QGIS processing module.. In the toolbox, we can find algorithms classified by category. These categories are classified under the *Geoalgorithms group*. There are also two other entries: *Templates and Scripts*. They contain user algorithms and define processing strings.

- To load the process of the LUE. Simply click on « Processing » in the main menu and the click « Processing toolbox »
- The dialogue window, go to « Script » → « Tools » → «Add a script from file »
- Load the python script supplied with the database of this application: **LUE.py**
- Once loaded, the Land Use Efficiency algorithm will appear in the "User Scripts" submenu



In the following sections, we will illustrate step by step the method for calculating the indicators and its direct implementation in the **LUE.py** tool.

1.2 Method to calculate the LUE indicator

The method of calculating the LUE indicator is based on a geospatial and temporal analysis of raster data. The calculation does not require any preliminary knowledge in remote sensing. However, basic knowledge in the handling and processing of geospatial data is required. The method developed is adapted to the free software QGIS so that any GIS anaysts, without any expertise in remote sensing, can use it. Figure 1 summarizes the succession of steps required for the calculation of the LUE indicator. To illustrate the method, an example of application on the city of Pretoria in South Africa is presented.

1. Download GHSL data: 1) raster data on built-up areas and 2) population raster data at 250 m resolution for the three dates analysed (1990, 2000 and 2014);
2. Delimitation of the area of interest and subsetting the input data.
3. Calculation of the built-up area per capita and estimation of the LUE indicator for two different periods (Id_{1990_2000} and Id_{2000_2014})
4. Visualization of the results including a classification of the LUE values and an attempt to interpretat and compare the results obtainted at the two dates.

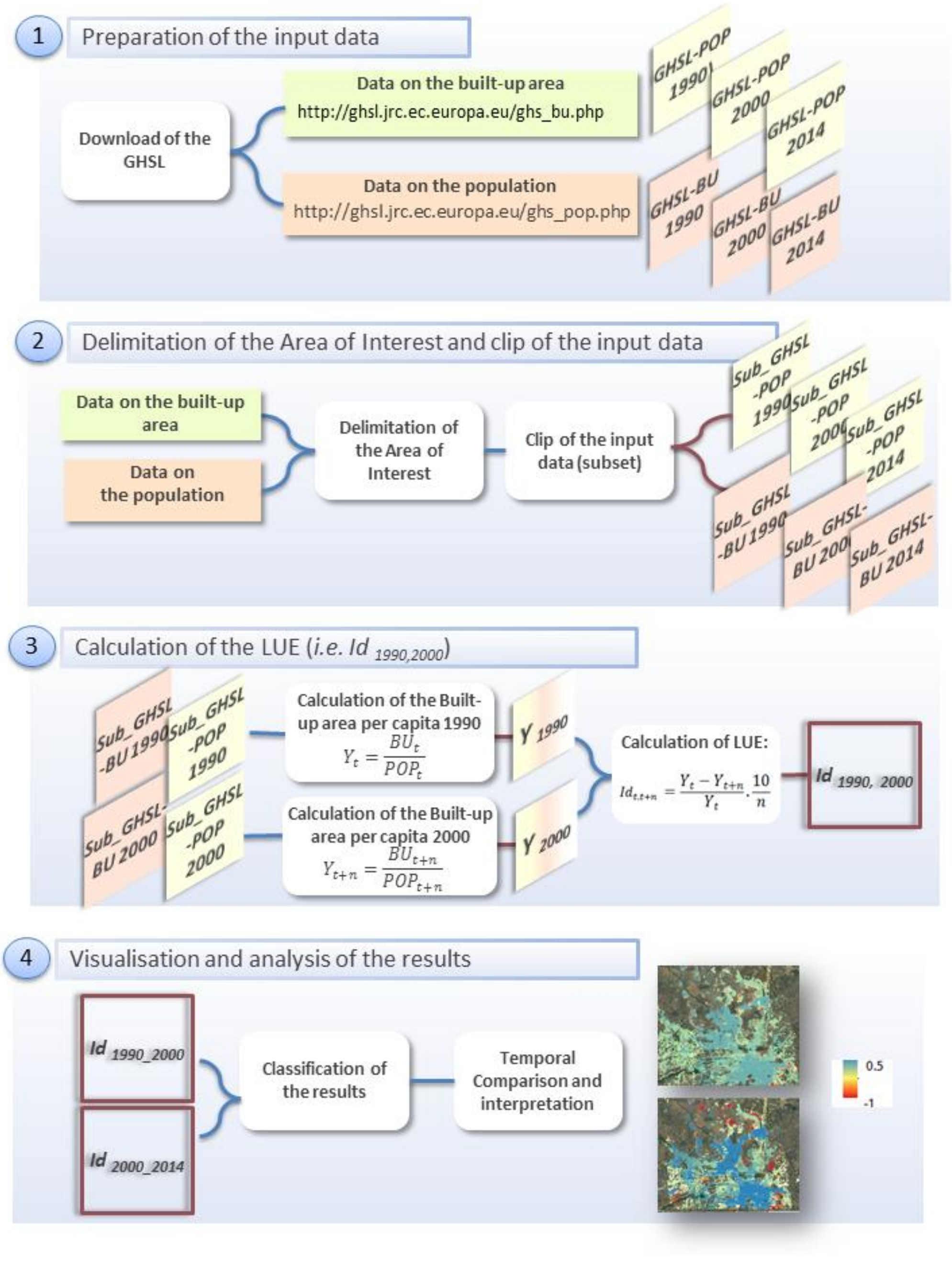
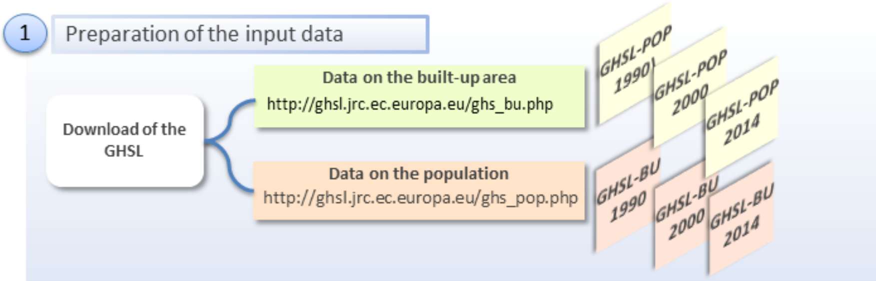


Figure 1 The four main steps for the calculation of the Land Use Efficiency

1.2.1 Preparation of the input layer

The first step is to download the raster data on built-up and population

from the GHSL website: http://ghsl.jrc.ec.europa.eu/data.php



These are the data for the built-up area and population produced at global scale with 250m resolution for the following dates: 1990, 2000 and 2014.

Download the data in .zip format in the same directory using the following links:

GHS-BU (250m) ***1990*** **–** ***2000*** **–** ***2014***

GHS_BUILT_LDS1990_GLOBE_R2016A_54009_250
GHS_BUILT_LDS2000_GLOBE_R2016A_54009_250
GHS_BUILT_LDS2014_GLOBE_R2016A_54009_250

GHS-POP (250m) ***1990 – 2000 – 2015***[3]

GHS_POP_GPW41990_GLOBE_R2015A_54009_250
GHS_POP_GPW42000_GLOBE_R2015A_54009_250
GHS_POP_GPW42015_GLOBE_R2015A_54009_250

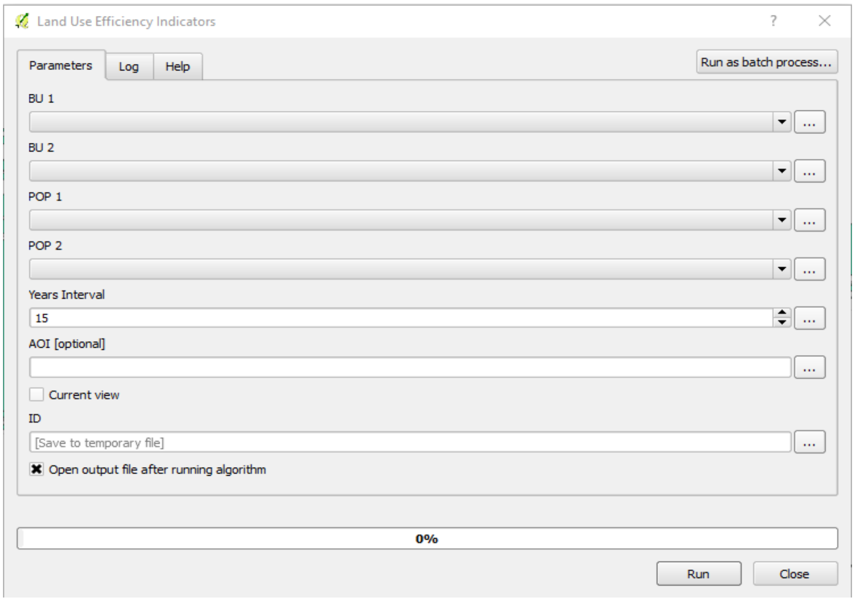
Unzip the file in the same folder preserving the structure of the original files (i.e. one directory per data).

[3] Since that the population layer for 2015 is produced from the built-up layer extracted from the Landsat 2014-2015 collection, for reason of simplification and consistency, we named the GHSP-POP 2014

1.2.2 Delineation of the area of interest and subsettingthe input data

Once the input data is available, it is possible to launch the Land Use Efficiency process by clicking on the tool previously loaded in the user scripts.

The following window appears:



- The step 2 of the process consists in the definition of the Area of Interest and in the subsetting of the input data on the Area of interest as defined. There are two available options:

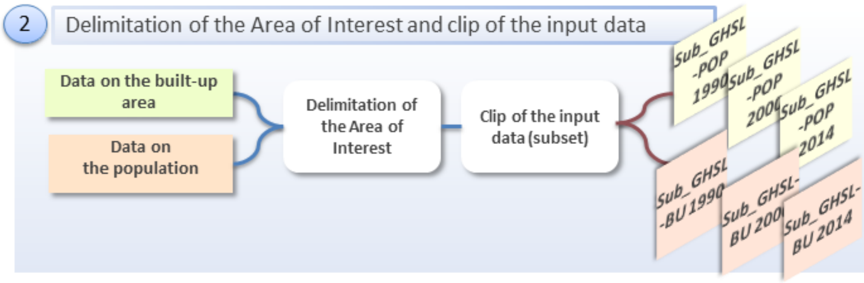
- **Option 1: AOI [Optional]**

  In this case, the Area of Interest is defined by a file in shapefile format (.shp). To illustrate this approach, a vector file is provided in the context of this application (*location: data/aoi/aoi.shp*). The file corresponds to an area of about 6.000 km^2 centered on the city of Pretoria in South Africa. Alternatively, the user can provide a vector file delimiting the chosen study area.

- **Option 2: Current extent**

  Another possibility is to use the current extent of the window as area of interest. To do so, simply check the box corresponding to Current Extent.

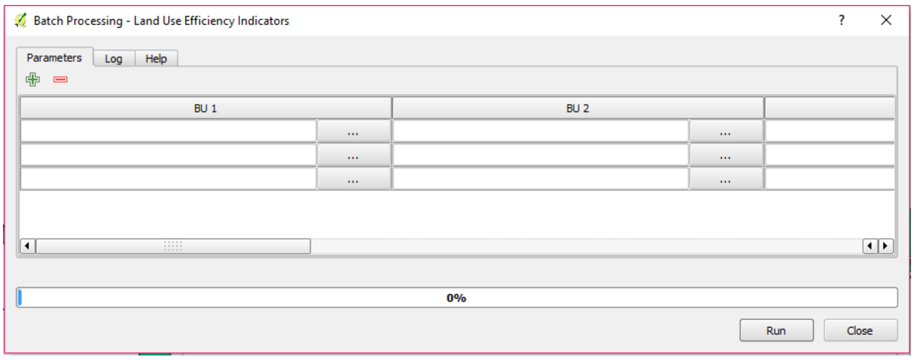
  Whichever option is chosen, the definition of the area of interest will be used to extract a subset of the data to be analyzed: all input raster images will be divided according to the same geographical extent.



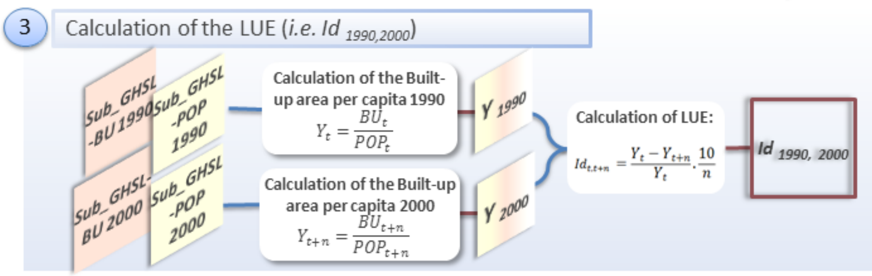
Afterwards, the user has to indicate the location of the input data file, namely the GHS-BU and GHS-POP raster images at two dates chosen for the calculation of the indicator. Alternatively, the user can load other data into the display window of the QGIS project and redefine the projection as follows:

- Double click on the raster layer in the property window of the layer.
- Choose the tab « General »
- Go to «Coordinate reference system (SCR)», click on the filter « 54009» to choose the EPSG: the number 54009 corresponds to the projection World Mollweide
- Click on OK

- The data used for the demo in this example corresponds to the following dates: 1990 and 2000. The processing can be automatically repeated for another time interval (i.e. 2000 and 2014 or 1975-1990) using the Option of batch processing. Click on the "Run as batch process" option on the top right. The following window will open; this allows choosing different combinations of GHS-BU and GHS-POP for the desired LUE indicator, as well as per different areas of interest.

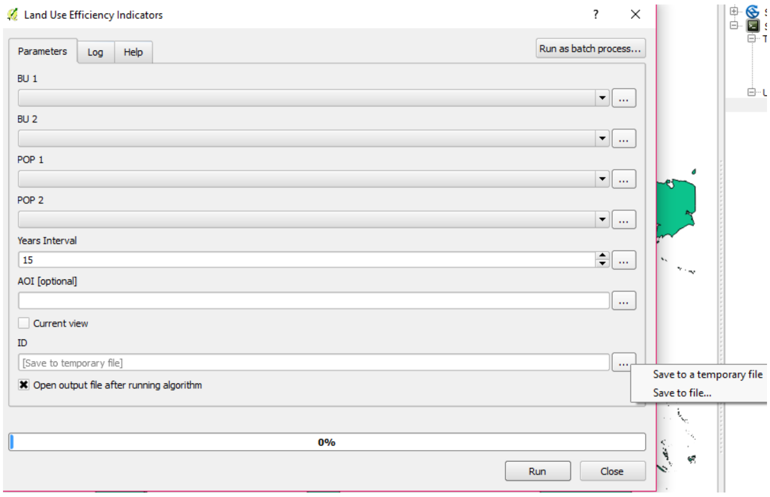


1.2.3 Calculation of the Land Use Efficiency indicator (LUE)



- The user can choose to save the output result either in a temporary file or locally, by choosing the location and format of the output file:

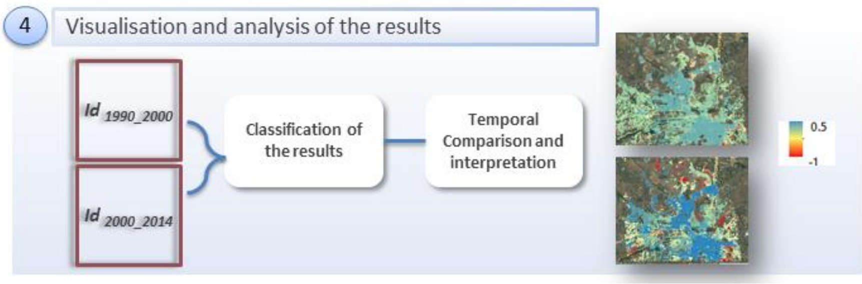
- Under the "LUE" option of the **Land Use Efficiency** user interface, click on the three points [...]
- Choose one of the two backup options that appear.



- Enter the "Number of Years" (n) separating the two dates of observations. By default, the value is n = 15.
- Press on the "Run" button.
- The algorithm will then calculate, for each of the dates, the built surface per capita $Y_t = \frac{BU_t}{POP_t}$ and $Y_{t+n} = \frac{BU_{t+n}}{POP_{t+n}}$. In a second step, the normalized indicator Idx_t is estimated according to equation [1.2].
- The side menu will be displayed in the window if the option "Open output file after running algorithm" is checked.
- We repeat steps 1, 2 and 3 for dates 2000 and 2014 to calculate indicator $Id_{2000-2014}$. Alternatively, it is possible to calculate the indicator for both time intervals simultaneously with the option "Run as batch process".

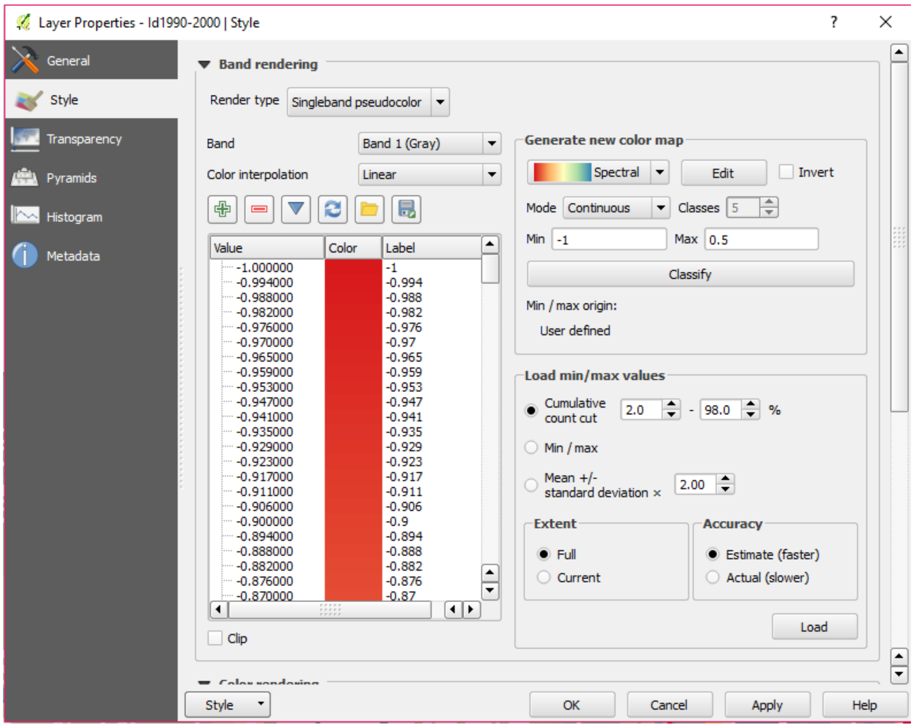
1.2.4 Visualisation and analysis of the results

Once the results of the indicator are ready and displayed in the QGIS project, it is time to visualise them and try to interpret the values of the indicator.



In order to facilitate the interpretation of the values, one style of visualization and classification is proposed. We suggest to change the style in the following way:

- Double-click on the name of the raster file corresponding to the indicator (i.e. *Id*$_{2000\text{-}2014}$) in the legend or right-click on the name and choose "Properties" from the menu that appears. The Layer property window will appear.
- Go the Style tab and click on the botton "Style" on the bottom right to change the style proposed in this example in order to facilitate the interpretation of the values. The visualisation style **LUE_style.qml** proposed is located in the folder provided for this application (*Location: data/LUE_style.qml)*



- In this colour palette, the values are reclassified in the interval [-1, +0.5], in order to highlight the contrast. A possible interpretation is the following:
  - Negative values (red to orange): loss of population and constant built-up surface.

- Positive values (green to blue) : increment of population faster than built-up increment (due to the increment of the density or because of the expansion of the urban area).
- Values around zero (yellow): stable zones with a linear increment of built-up surfaces and population.

In the example of the city of Pretoria, Figure 1 shows the results of the calculation of the LUE indicator for two intervals: $Id_{1990\text{-}2000}$ and $Id_{2000\text{-}2014}$.

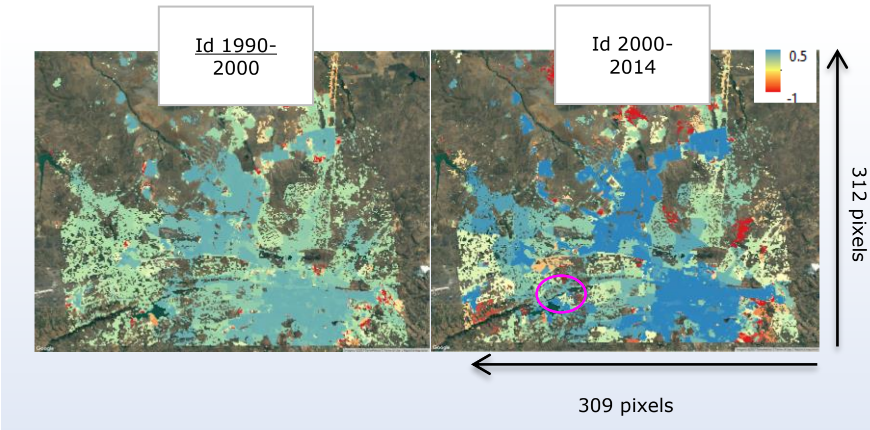


Figure 2 Results of the calculation of the LUE indicator for two intervals: $Id_{1990\text{-}2000}$ *and* $Id_{2000\text{-}2014}$ *(cells of 250 m x 250 m)*

The main statistics on the results of both the LUE and the SDG 11.3.1 ($LCRPGR$) indicator are summarised in a csv file automatically created in the same folder of the geotiff output file (see example below).

	A	B	C	D	E	F	G
1	Years_Interval	LUE_sum	LUE_mean	LUE_min	LUE_max	LUE_std	SDG_11.3
2	15	565.986	0.0672592	-3.16611	0.666152	0.125792	0.20685
3							

1.2.4.1 One possible interpretation

Comparing the results of the land use efficiency of the two different periods, there is an increase in the values of the LUE indicator in the core of the city during the period 2000-2014 concomitant with a decrease of the LUE in the peripheral areas. Especially in the north and east of the city, there is a decline of the LUE values corresponding to the orange and red areas in the right figure. This can be due to the migration of population from the peripheries towards the centre.

On the other hand, there is a general increase in the values of the LUE indicator between the period 1990-2000 and 2000-2014, particularly in the area represented in Figure 3 by an ellipse. A deeper analysis of this area shows that it corresponds to a typical area of the urban landscape of the city of Pretoria where social housing was built by the government in the last ten years to respond to the housing crisis. However, this solution did not solve the housing problem for the poor population. In fact, now this landscape is characterised /by over-occupancy of existing formal dwellings and by the construction of backyard shacks, an example of which is given for the area represented by the ellipse.

Figure 3 Example of backyard shacks that are formal government-built housing, but where over-occupation corresponds to an average of 15 people live in a 4-room dwelling (Gervais-Lambony 2013). This explains the increase in the value of the LUE indicator in these areas.

1.2.4.2 Limits of the method

The method for calculating the land use efficiency indicator from GHSL data can be easily applied to any set of data on built-up areas and population (i.e. more detailed local data or data at the municipality level, or regionally). It can be adapted to the monitoring purposes of the LUE indicator. It also provides a source of comparative information in time and space (e.g. between cities) that is essential for assessing the impact of local urban planning policies.

Its main limitation lays in the impossibility to grasp the vertical development of constructions due to two factors: 1) at the moment, the input data represents 2D information of built surface and population; 2) the proposed indicator does not take into account information on the volume of cities, because of the difficulties in obtaining this information at a global scale.

Among the developments envisaged within the framework of GHSL, there is the provision of information on the volume of built-up areas on a global scale. This will be used for a more precise modelling of population data and to improve the estimation of the LUE indicator.

3)Conclusion

The Sustainable Development Goal 11 calls for "making cities and human settlements inclusive, safe, resilient and sustainable". In particular the target 11.3 aims, by 2030, at enhancing inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries. One of the way that the international community identified to measure the progress towards this target is to measure the land-use efficiency, through a specific calculation that relates the land consumption rate with the population growth rate.

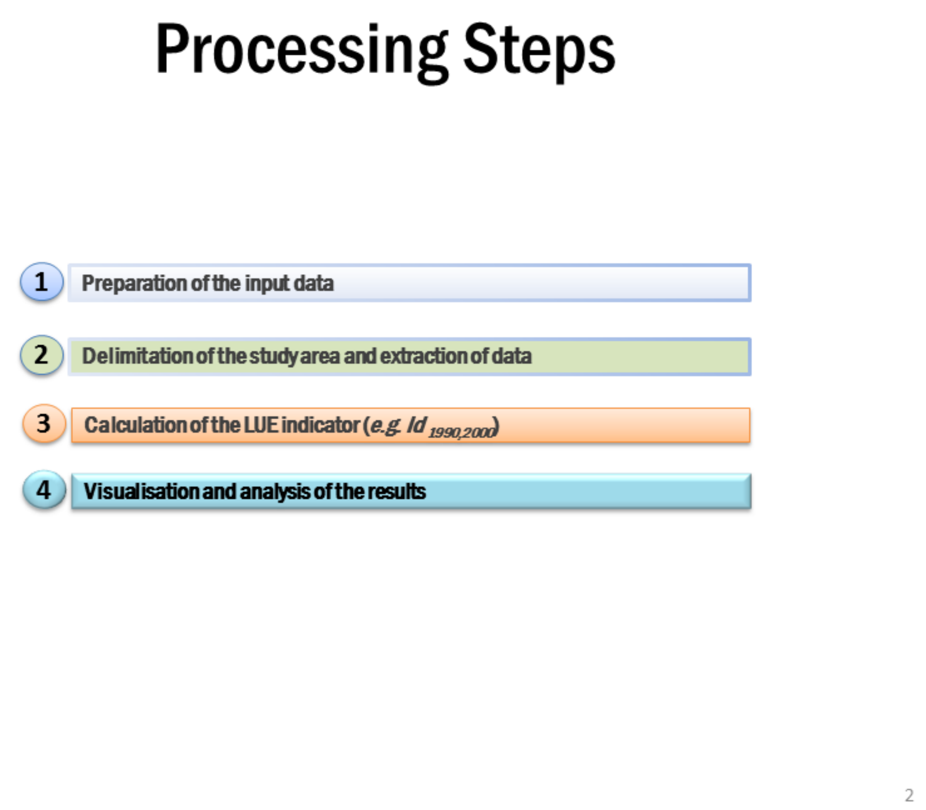
Despite that the monitoring system that was put in place by the UN system relies on data collected at country level, it is indeed relevant to measure how cities performs. An easy tool to do it in a comparable and consistent way is to use the GHSL dataset on built-up area and population and the associated tools developed by the JRC.

4) References

CORBANE Christina, Politis Panagiotis, Siragusa Alice (2017); *Estimation de l'efficience de l'usage des sols à partir d'indicateurs dérivés de la couche mondiale des établissements humains (GHSL).* In ISTE (2017), *Mise en oeuvre pratique des applications de la télédétection sous QGIS*. In publication

Pesaresi Martino, Melchiorri Michele, Siragusa Alice, Kemper Thomas (2016); Atlas *of the Human Planet 2016. Mapping Human Presence on Earth with the Global Human Settlement Layer*; EUR 28116 EN; doi:10.2788/582834

ANNEX 1: a step-by-step estimation of LUE from the GHSL data



1 Preparation of the input data

3

1 Preparation of the input data

4

1 Preparation of the input data

GHS BUILT-UP

Built-up data (GHS- BU) at 250 m resolution for the dates 1990 – 2000 – 2014

Directory of http://cidportal.jrc.ec.europa.eu/ftp/jrc-opendata/GHSL/GHS_BUILT_LDSMT_GLOBE_R2015B/

(/jrc-opendata/GHSL/GHS_BUILT_LDSMT_GLOBE_R2015B)

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Anonymous user logged in

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drwxr-xr-x    8 47303      36233              4096 Nov 30 16:56 ..
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drwxr-xr-x    3 35276      65534              4096 Oct 28 17:00 GHS_BUILT_LDS1975_GLOBE_R2016A_54009_1k
drwxr-xr-x    3 35276      65534              4096 Oct 28 17:00 GHS_BUILT_LDS1975_GLOBE_R2016A_54009_250
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drwxr-xr-x    3 35276      65534              4096 Oct 28 17:00 GHS_BUILT_LDS1990_GLOBE_R2016A_54009_250
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Apache/2.4.10 (Debian) Server at cidportal.jrc.ec.europa.eu Port 80

5

1 Preparation of the input data

GHS POP

Data on Population (GHS- POP) at 250 m resolution for the dates 1990 – 2000 – 2014

Directory of http://cidportal.jrc.ec.europa.eu/ftp/jrc-opendata/GHSL/GHS_POP_GPW4_GLOBE_R2015A/

(/jrc-opendata/GHSL/GHS_POP_GPW4_GLOBE_R2015A)

```
Anonymous user logged in

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drwxr-xr-x    8 47303      36233              4096 Nov 30 16:56 ..
drwxr-xr-x    3 35276      65534              4096 Oct 28 17:00 GHS_POP_GPW41975_GLOBE_R2015A_54009_1k
drwxr-xr-x    3 35276      65534              4096 Oct 28 16:45 GHS_POP_GPW41975_GLOBE_R2015A_54009_250
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drwxr-xr-x    3 35276      65534              4096 Oct 28 17:00 GHS_POP_GPW42000_GLOBE_R2015A_54009_1k
drwxr-xr-x    3 35276      65534              4096 Oct 28 17:00 GHS_POP_GPW42000_GLOBE_R2015A_54009_250
drwxr-xr-x    3 35276      65534              4096 Oct 28 17:00 GHS_POP_GPW42015_GLOBE_R2015A_54009_1k
drwxr-xr-x    3 35276      65534              4096 Oct 28 17:00 GHS_POP_GPW42015_GLOBE_R2015A_54009_250
-rwx------    1 47303      36233               314 Jul 16  2015 copyright.txt
```

Apache/2.4.10 (Debian) Server at cidportal.jrc.ec.europa.eu Port 80

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1 Preparation of the input data

Unzip files in the same directory, preserving the structure and name of the original files

- GHS_BUILT_LDS1990_GLOBE_R2016A_54009_250_v1_0
- GHS_BUILT_LDS2000_GLOBE_R2016A_54009_250_v1_0
- GHS_BUILT_LDS2014_GLOBE_R2016A_54009_250_v1_0
- GHS_POP_GPW41990_GLOBE_R2015A_54009_250_v1_0
- GHS_POP_GPW42000_GLOBE_R2015A_54009_250_v1_0
- GHS_POP_GPW42015_GLOBE_R2015A_54009_250_v1_0

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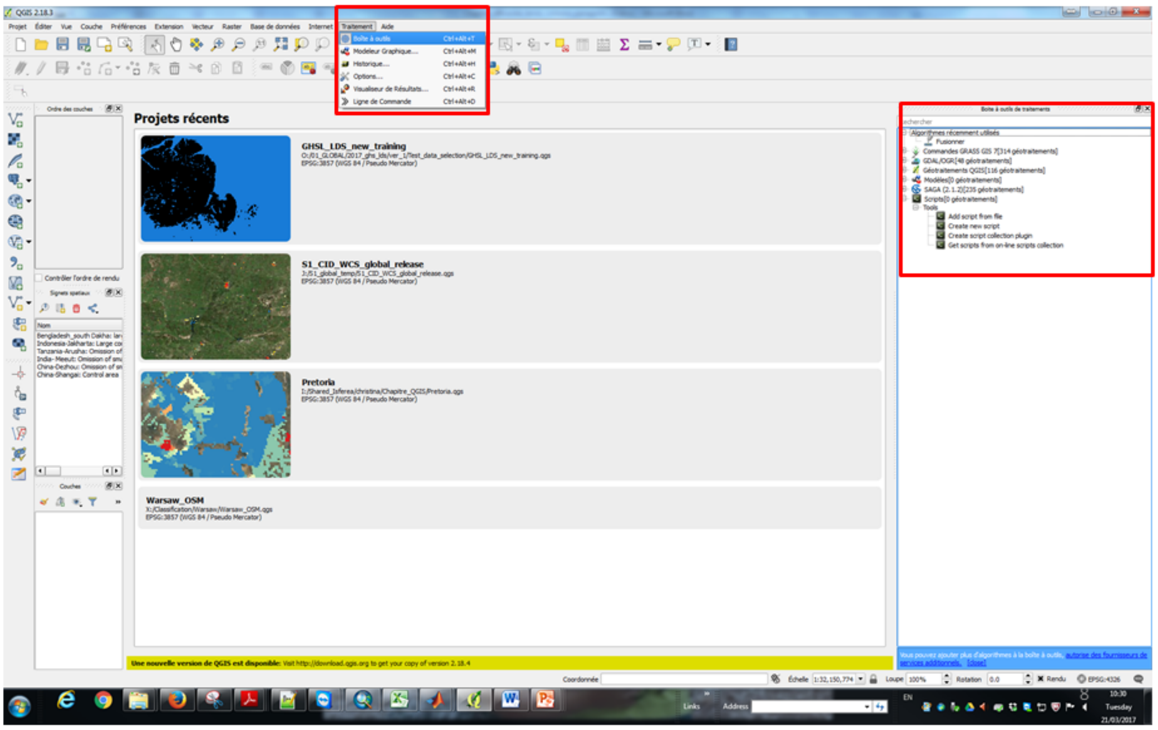
1 Preparation of the input data

1.1 Installation of the calculation tool for the LUE indicator in QGIS

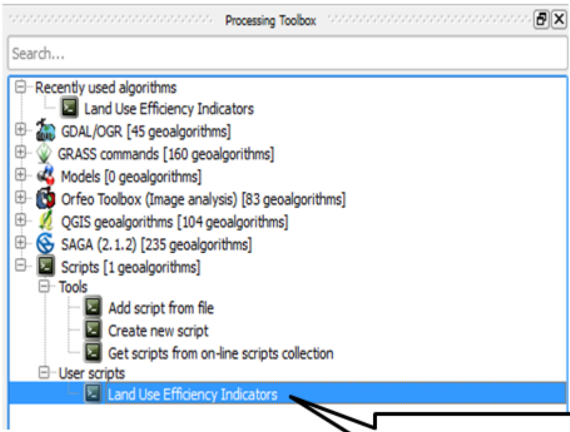


1 Preparation of the input data

1.2 Installation of the calculation tool for the LUE indicator in QGIS

Load LUE.py into scripts -> Tools -> Add script from file

Location: User_files \ LUE.py



The LUE tool appears in the list of user scripts

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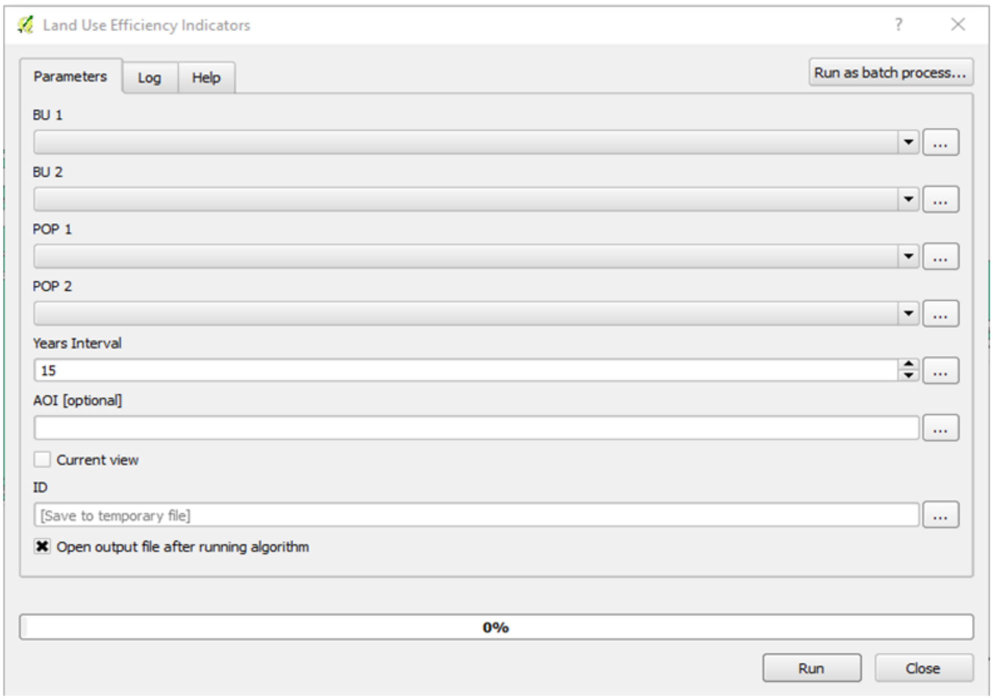
2 Delimitation of the study area and extraction of data

2.1 Launch the LUE tool by double clicking on it



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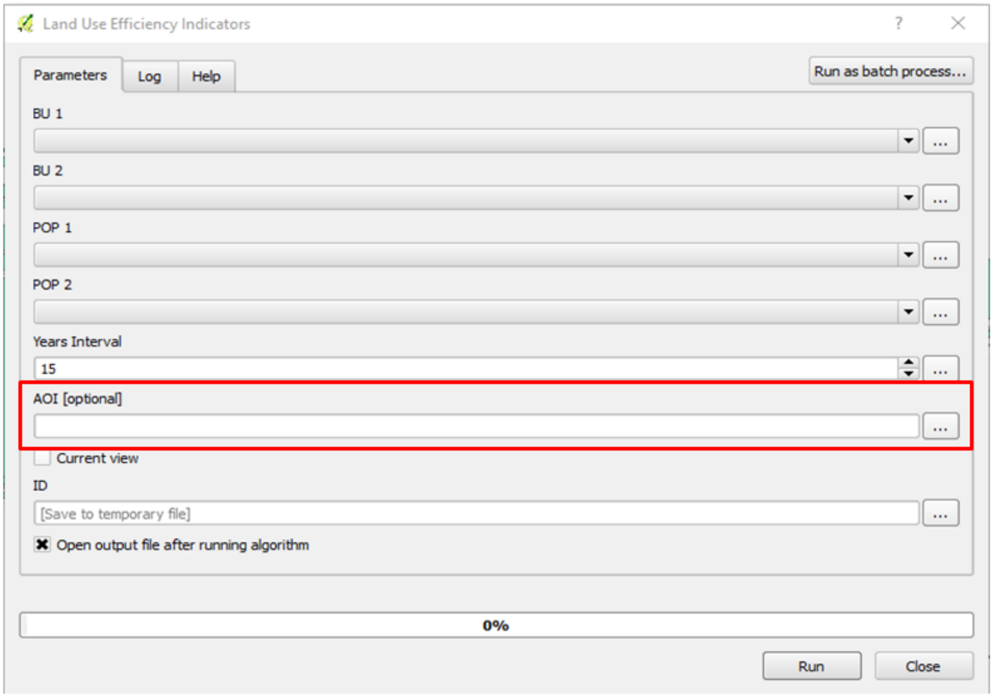
2 **Delimitation of the study area and extraction of data**

2.2 Define the Area of Interest



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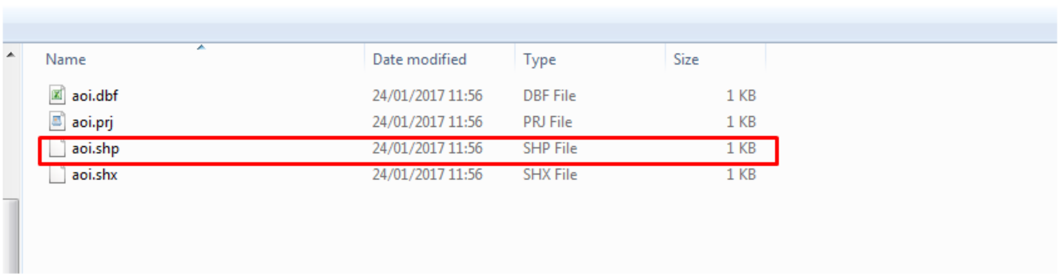
2 **Delimitation of the study area and extraction of data**

2.3 Load the file in .shp format

(Location: Fichiers_utilisateurs/aoi/aoi.shp)



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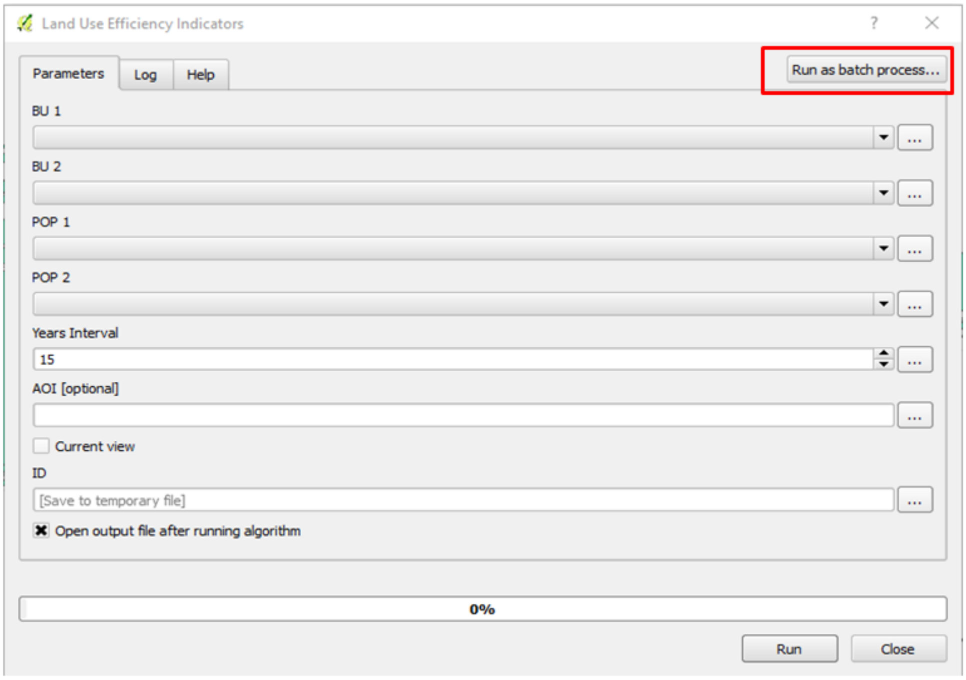
2 Delimitation of the study area and extraction of data

2.4 Define the path to the data and settings

Click on "run as batch process"



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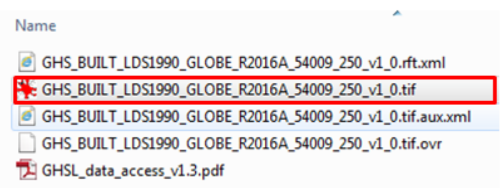
3 Calculation of the LUE indicator (*e.g. ld* $_{1990,2000}$)

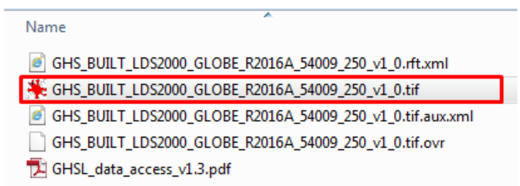
3.1 Define the path to two input data: GHS-BU and GHS-POP for the two different dates

Upload the file ***.tif*** *from the proper folder (location after the decompression)*

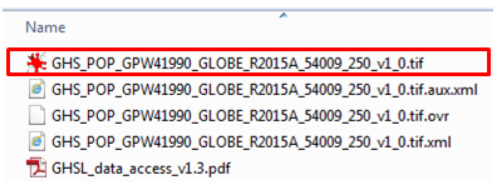
BU1



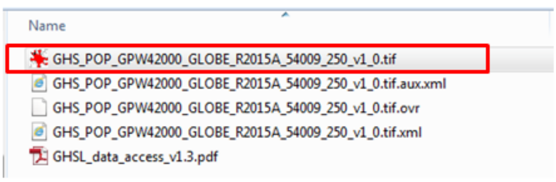
BU2



POP1



POP2



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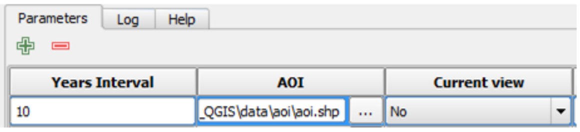
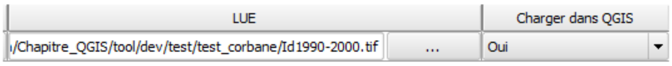
3 Calculation of the LUE indicator (*e.g. Id* $_{1990,2000}$)

3. 2 Define the parameters: number of years (n=10 in the example) and the Area of Interest



3.3 Define the location of the output: Id1990-2000.tif

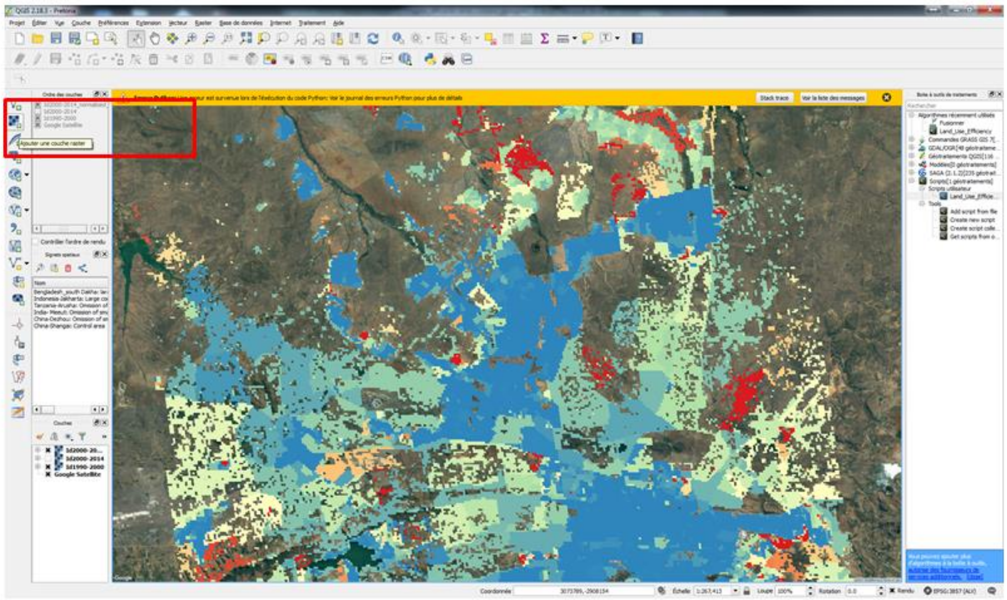


3.4 Repeat the steps 3.1, 3.2 and 3.3 for the dates 2000 and 2014 Making sure to change the number of years parameter and set n = 15

3.5 Click on RUN

4 Visualisation and analysis of the results

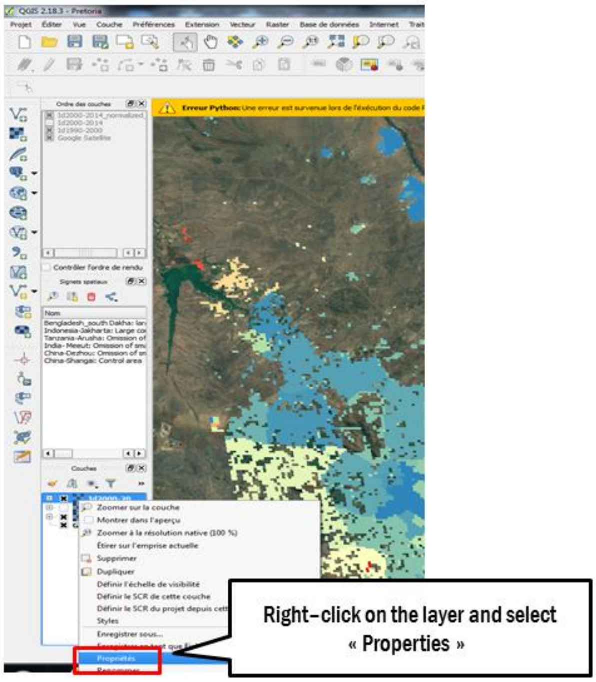
4.1 Upload the results in the Qgis project



4 Visualisation and analysis of the results

4.2 Load the visualization style file (.qml) provided with the data

(location: Fichiers_utilisateurs/LUE_style.qml)



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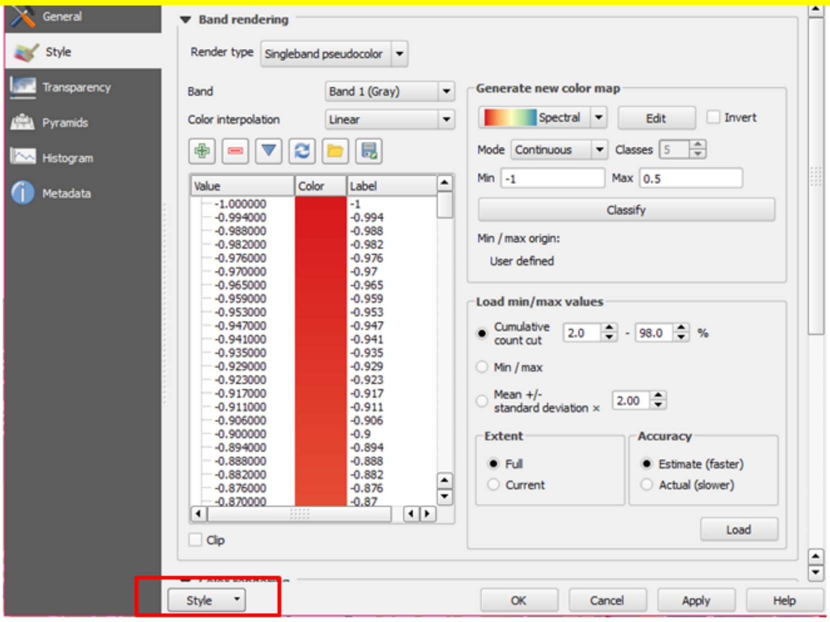
4 Visualisation and analysis of the results

4.2 Load the display style provided with the data

(Location: Fichiers_utilisateurs/LUE_style.qml)



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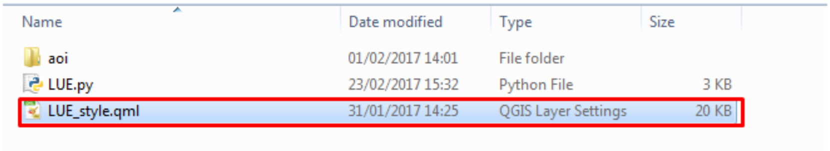
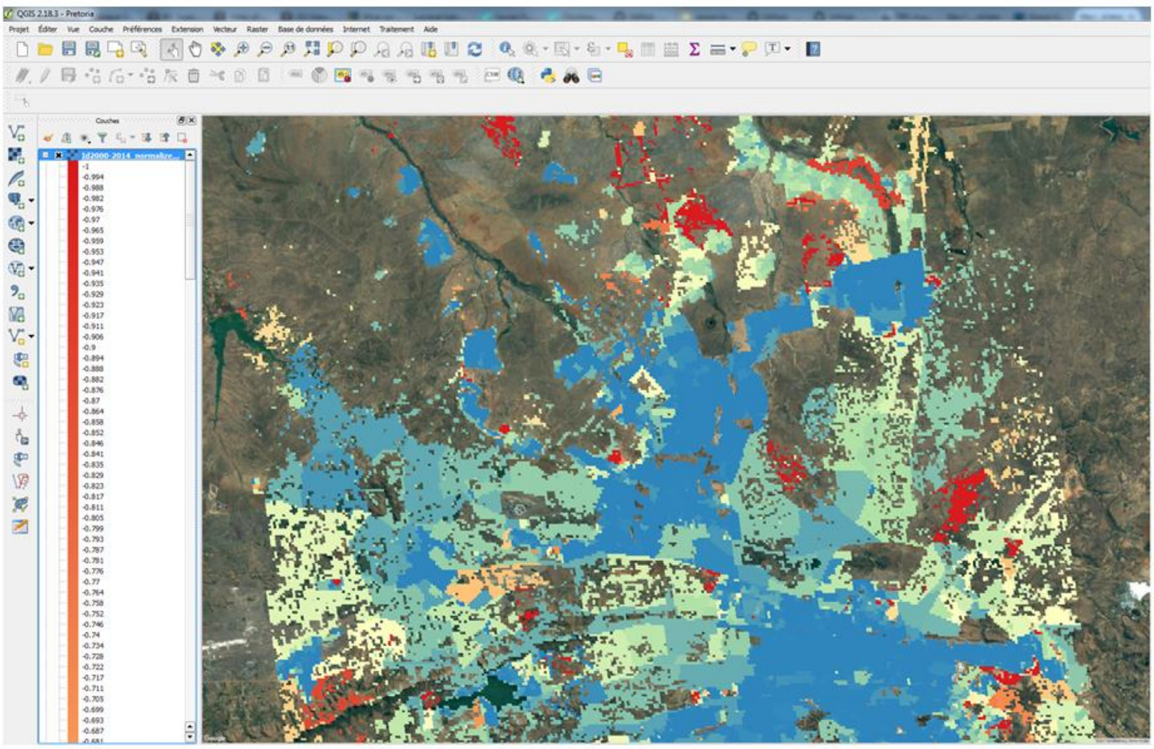
4 Visualisation and analysis of the results

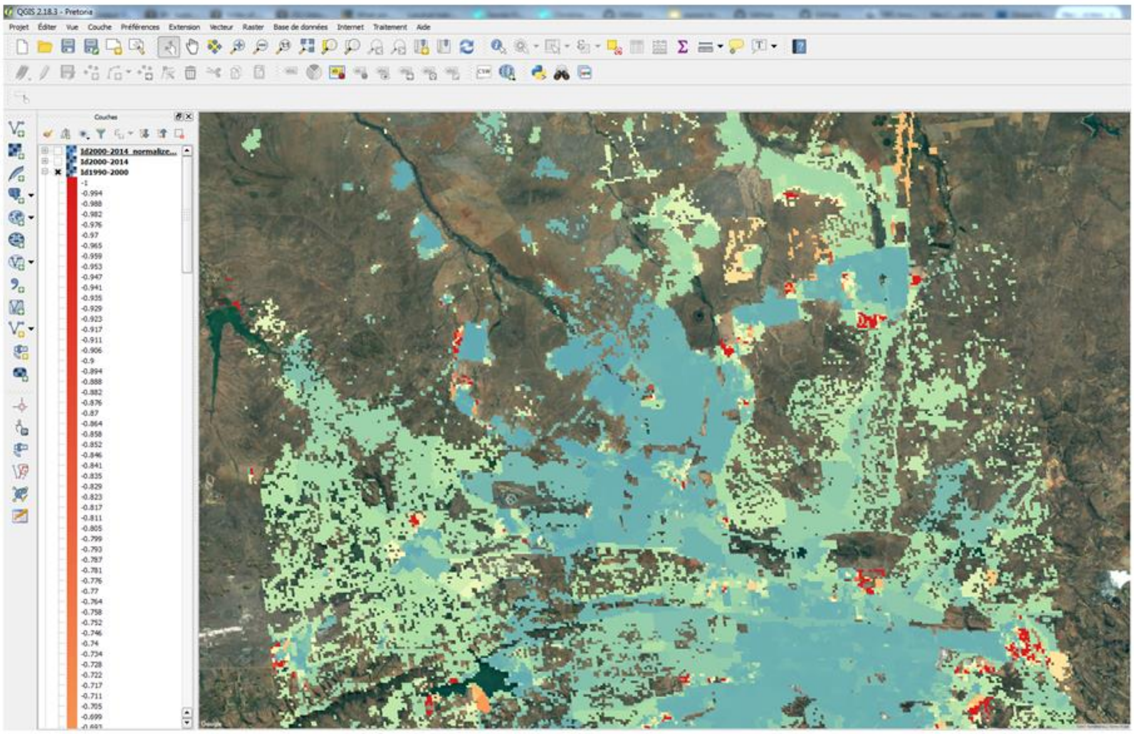
4.2 Load the display style provided with the data
(Location: Fichiers_utilisateurs/LUE_style.qml)



4 Visualisation and analysis of the results



4 Visualisation and analysis of the results



List of figures

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