Package 'flexurba'

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Type Package

Title Construct Flexible Urban Delineations

Version 0.2.3

Description Enables the construction of flexible urban delineations that can be tailored to specific applications or research questions, see Van Migerode et al. (2024) <DOI:10.1177/23998083241262545> and Van Migerode et al. (2025) <DOI:10.5281/zenodo.15173220>. Originally developed to flexibly reconstruct the Degree of Urbanisation classification of cities, towns and rural areas developed by Dijkstra et al. (2021) <DOI:10.1016/j.jue.2020.103312>. Now it also support a broader range of delineation approaches, using multiple datasets – including population, built-up area, and night-time light grids – and different thresholding methods.

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URL https://github.com/cvmigero/flexurba, https://gitlab.kuleuven.be/spatial-networks-lab/research-projects/flexurba, https://flexurba-spatial-networks-lab-research-projects--e74426d1c66ecc.pages.gitlab.kuleuven.be

BugReports https://github.com/cvmigero/flexurba/issues

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Contents

`apply_majority_rule` *Apply the majority rule algorithm*

Description

The functions applies the majority rule to smooth edges of clusters of cells. The function supports two different version of the majority rule algorithm: the version of GHSL Data Package 2022 and GHSL Data Package 2023:

- `version="R2022A"`: If a cell has at least five of the eight surrounding cells belonging to a unique cluster of cells, then the cell is added to that cluster. The process is iteratively repeated until no more cells are added.
- `version="R2023A"`: A cell is added to a cluster if the majority of the surrounding cells belongs to one unique cluster, with majority only computed among populated (`pop > 0`) or land cells (`land > 0.5`). Cells with permanent water (`permanent_water` not `NA`) can never be added to a cluster of cells. The process is iteratively repeated until no more cells are added.

Usage

```
apply_majority_rule(
  x,
  version = "R2022A",
  permanent_water = NULL,
  land = NULL,
  pop = NULL
)
```

Arguments

`x`	SpatRaster. Grid with clusters of cells
`version`	character. Version of the majority rule algorithm. Supported versions are `"R2022A"` and `"R2023A"`.
`permanent_water`	SpatRaster. Grid with permanent water cells (only required when `version="R2023A"`)
`land`	SpatRaster. Grid with proportion of permanent land (only required when `version="R2023A"`)
`pop`	SpatRaster. Grid with population (only required when `version="R2023A"`)

Value

SpatRaster with clusters of cells with smoothed edges

Examples

```
nr <- nc <- 8
r <- terra::rast(nrows = nr, ncols = nc, ext = c(0, nc, 0, nr), vals = c(
  NA, NA, 1, 1, 1, NA, NA, NA,
  NA, NA, NA, 1, 1, NA, NA, NA,
```

```
  NA, NA, 2, NA, NA, NA, NA, NA,
  NA, NA, 2, NA, NA, 2, NA, NA,
  NA, NA, 2, NA, 2, 2, NA, NA,
  2, 2, 2, 2, 2, 2, NA, NA,
  NA, NA, 2, 2, NA, NA, NA, NA,
  NA, NA, NA, 2, NA, NA, NA, NA
))
terra::plot(r)
smoothed <- apply_majority_rule(r)
terra::plot(smoothed)
```

`apply_threshold` *Identify urban areas by applying a threshold on grid cells*

Description

The function identifies urban areas by applying a threshold to individual grid cells. Two key decisions must be made regarding the thresholding approach:

1. **How is the threshold value determined?**
   - The threshold can be *predefined by the user* (`type="predefined"`) or *derived from the data* (`type="data-driven"`).
2. **How and where is the threshold enforced?**
   - The threshold can be enforced *consistently across the study area* (= absolute approach, `regions=NULL`) or *tailored within specific regions* (= relative approach, `regions` not `NULL`).

For more details on these thresholding approaches, including their advantages and limitations, see the `vignette("vig8-apply-thresholds")` The table below outlines the appropriate combination of function arguments for each approach:

	Absolute Approach	**Relative Approach**
Predefined Value	`type="predefined"` with `threshold_value` not `NULL`, and `regions=NULL`	`type="predefined"` wit
Data-Driven Value	`type="data-driven"` with `fun` not `NULL`, and `regions=NULL`	`type="data-driven"` w

Usage

```
apply_threshold(
  grid,
  type = "predefined",
  threshold_value = NULL,
  fun = NULL,
  ...,
  regions = NULL,
  operator = "greater_than",
  smoothing = TRUE
)
```

Arguments

grid	SpatRaster with the data
type	character. Either "predefined" or "data-driven".
threshold_value	numeric or vector. The threshold value used to identify urban areas when type="predefined". If regions is not NULL, a vector of threshold values can be provided, where each value corresponds to a specific region (the respective values are linked to regions in alphabetical order based on their IDs; see examples). In addition, ensure that the threshold values are in the same unit as the grid values.
fun	character or function. This function is used to derive the threshold value from the data when type="data-driven". Either as character: "min", "max", "mean", "median", or "pX" where X denotes a percentile value (e.g., p95 for the 95% percentile value"). It is also possible to provide a custom function for relatively small grids.
...	additional arguments passed to fun
regions	character, SpatRaster or sf object. If not NULL, a different threshold value is applied in the separate regions (i.e. a relative thresholding approach). The argument can either be: • a SpatRaster with a separate value for each region • the path to the region data (as character) • an sf polygon layer In the latter two cases, the function convert_regions_to_grid() will be used to convert the regions to a gridded format.
operator	character. Operator used to enforce the threshold. Either "greater_than", "greater_or_equal", "smaller_than", "smaller_or_equal" or "equals".
smoothing	logical. Whether to smooth the edges of the boundaries. If TRUE, boundaries will be smoothed with the function apply_majority_rule().

Value

named list with the following elements:

- rboundaries: SpatRaster in which cells that are part of an urban area have a value of '1'
- vboundaries: sf object with the urban areas as separate polygons
- threshold: dataframe with per region the threshold value that is applied
- regions: SpatRaster with the gridded version of the regions that is employed

Examples

```
proxies <- load_proxies_belgium()

# option 1: predefined - absolute threshold
predefined_absolute <- apply_threshold(proxies$pop,
  type = "predefined",
  threshold_value = 1500
)
terra::plot(predefined_absolute$rboundaries)
```

```
# option 2: data-driven - absolute threshold
datadriven_absolute <- apply_threshold(proxies$pop,
  type = "data-driven",
  fun = "p90"
)
terra::plot(datadriven_absolute$rboundaries)

# in the examples below we will use 'Bruxelles', 'Vlaanderen' and 'Wallonie' as separate regions
regions <- convert_regions_to_grid(flexurba::units_belgium, proxies$pop, "NAME_1")
terra::plot(regions)

# option 3: predefined - relative threshold
# note that the threshold values are linked to the regions in alphabetical
# order based on their IDs. So, the threshold of 1500 is applied to
# 'Bruxelles', # 1200 to 'Vlaanderen', and 1000 to 'Wallonie'.
predefined_relative <- apply_threshold(proxies$pop,
  type = "predefined",
  threshold_value = c(1500, 1200, 1000),
  regions = regions
)
terra::plot(predefined_relative$rboundaries)

# option 4: data-driven - relative threshold
datadriven_relative <- apply_threshold(proxies$pop,
  type = "data-driven",
  fun = "p95",
  regions = regions
)
terra::plot(datadriven_relative$rboundaries)
```

`convert_regions_to_grid` *Convert regions to a grid*

Description

Convert the value of regions associated with a vector layer to a grid layer.

Usage

```
convert_regions_to_grid(regions, referencegrid, id = NULL)
```

Arguments

`regions`	character / object of class sf. Path to the vector layer with spatial regions, or an object of class sf with spatial regions
`referencegrid`	SpatRaster. Reference grid used to rasterize the values of the regions.
`id`	character. The column that contains the values of the regions. If `NULL` the first column is used.

Value

SpatRaster with the regions

Examples

```
# load data for urban proxies and regions
proxies <- load_proxies_belgium()
regions <- flexurba::units_belgium

# convert Belgian provinces ('GID_2') to a zonal grid
gridded_regions <- convert_regions_to_grid(regions, proxies$pop, "GID_2")
terra::plot(gridded_regions)
```

---

crop_GHSLdata *Crop GHSL data to the provided extent*

Description

The grid cell classification of the Degree of Urbanisation requires three different inputs: a built-up area grid, a population grid, and a land grid. The grids can be downloaded from the GHSL website with download_GHSLdata().

This function reads the downloaded grids from the global_directory and crops them to the provided extent. The newly cropped grids will be saved in the output_directory, together with their respective metadata (in JSON format).

Usage

```
crop_GHSLdata(
  extent,
  output_directory,
  global_directory,
  output_filenames,
  global_filenames,
  buffer = 5
)
```

Arguments

extent	SpatRaster, or any other object that has a SpatExtent
output_directory	character. Path to the directory to save the cropped grids
global_directory	character. Path to the directory where the global grids are saved (created with download_GHSLdata())
output_filenames	vector of length 3 with the filenames used to save the built-up area, population and land grid in output_directory

`global_filenames`
: vector of length 3 with the filenames of the built-up area, population and land grid in `global_directory`

`buffer`
: integer. If larger than 0, a buffer of `buffer` cells will be added around the borders of the extent to allow cities or towns at the edges to be correctly classified.

Value

path to the created files.

`DoU_classify_grid` *Create the DEGURBA grid cell classification*

Description

The function reconstructs the grid cell classification of the Degree of Urbanisation. The arguments of the function allow to adapt the standard specifications in the Degree of Urbanisation in order to construct an alternative version (see section "Custom specifications" below).

For more information about the Degree of Urbanisation methodology, see the methodological manual, GHSL Data Package 2022 and GHSL Data Package 2023.

Usage

```
DoU_classify_grid(
  data,
  level1 = TRUE,
  parameters = NULL,
  values = NULL,
  regions = FALSE,
  filename = NULL
)
```

Arguments

`data`
: path to the directory with the data, or named list with the data as returned by function `DoU_preprocess_grid()`

`level1`
: logical. Whether to classify the grid according to first hierarchical level (`TRUE`) or the second hierarchical level (`FALSE`). For more details, see section "Classification rules" below.

`parameters`
: named list with the parameters to adapt the standard specifications in the Degree of Urbanisation classification. For more details, see section "Custom specifications" below.

`values`
: vector with the values assigned to the different classes in the resulting classification:

  - If `level1=TRUE`: the vector should contain the values for (1) urban centres, (2) urban clusters, (3) rural grid cells and (4) water cells.

- If `level1=FALSE`: the vector should contain the values for (1) urban centres, (2) dense urban clusters, (3) semi-dense urban clusters, (4) suburban or peri-urban cells, (5) rural clusters, (6) low density rural cells, (7) very low density rural cells and (8) water cells.

`regions` logical. Whether to execute the classification in the memory-efficient pre-defined regions. For more details, see section "Regions" below (Note that this requires a large amount of memory).

`filename` character. Output filename (with extension `.tif`). The grid classification together with a metadata file (in JSON format) will be saved if `filename` is not `NULL`.

Value

SpatRaster with the grid cell classification

Classification rules

The Degree of Urbanisation consists of two hierarchical levels. In level 1, the cells of a 1 km² grid are classified in urban centres, urban clusters and rural cells (and water cells). In level 2, urban cluster are further divided in dense urban clusters, semi-dense urban clusters and suburbs or peri-urban cells. Rural cells are further divided in rural clusters, low density rural cells and very low density rural cells.

The detailed classification rules are as follows:

LEVEL 1:

- **Urban centres** are identified as clusters of continuous grid cells (based on rook contiguity) with a minimum density of 1500 inhabitants per km² (or with a minimum built-up area; see section "Built-up area criterium" below), and a minimum total population of 50 000 inhabitants. Gaps smaller than 15 km² in the urban centres are filled and edges are smoothed by a 3x3-majority rule (see section "Edge smoothing" below).
- **Urban clusters** are identified as clusters of continuous grid cells (based on queen contiguity) with a minimum density of 300 inhabitants per km², and a minimum total population of 5000 inhabitants.
- **Water cells** contain no built-up area, no population, and less than 50% permanent land. All other cells not belonging to an urban centre or urban cluster are considered **rural cells**.

LEVEL 2:

- **Urban centres** are identified as clusters of continuous grid cells (based on rook contiguity) with a minimum density of 1500 inhabitants per km² (or with a minimum built-up area; see section "Built-up area criterium" below), and a minimum total population of 50 000 inhabitants. Gaps smaller than 15 km² in the urban centres are filled and edges are smoothed by a 3x3-majority rule (see section "Edge smoothing" below).
- **Dense urban clusters** are identified as clusters of continuous grid cells (based on rook contiguity) with a minimum density of 1500 inhabitants per km² (or with a minimum built-up area; see section "Built-up area criterium" below), and a minimum total population of 5000 inhabitants.

- **Semi-dense urban clusters** are identified as clusters of continuous grid cells (based on rook contiguity) with a minimum density of 900 inhabitants per km², and a minimum total population of 2500 inhabitants, that are not within 2 km away from urban centres and dense urban clusters. Clusters that are within 2 km away are classified as **suburban and peri-urban cells**.
- **Rural clusters** are clusters of continuous grid cells (based on queen contiguity) with a minimum density of 300 inhabitants per km², and a minimum total population of 500 inhabitants.
- **Low density rural cells** are remaining cells with a population density less than 50 inhabitants per km².
- **Water cells** contain no built-up area, no population, and less than 50% permanent land. All cells not belonging to an other class are considered **very low density rural cells**.

For more information about the Degree of Urbanisation methodology, see the methodological manual, GHSL Data Package 2022 and GHSL Data Package 2023.

Custom specifications

The function allows to change the standard specifications of the Degree of Urbanisation in order to construct an alternative version of the grid classification. Custom specifications can be passed in a named list by the argument `parameters`. The supported parameters with their default values are returned by the function `DoU_get_grid_parameters()` and are as follows:

LEVEL 1

- `UC_density_threshold` numeric (default: `1500`).
  Minimum population density per permanent land of a cell required to belong to an urban centre
- `UC_size_threshold` numeric (default: `50000`).
  Minimum total population size required for an urban centre
- `UC_contiguity_rule` integer (default: `4`).
  Which cells are considered adjacent in urban centres: `4` for rooks case (horizontal and vertical neighbours) or `8` for queens case (horizontal, vertical and diagonal neighbours)
- `UC_built_criterium` logical (default: `TRUE`).
  Whether to use the additional built-up area criterium (see section "Built-up area criterium" below). If `TRUE`, not only cells that meet the population density requirement will be considered when delineating urban centres, but also cells with a built-up area per permanent land above the `UC_built_threshold`
- `UC_built_threshold` numeric or character (default: `0.2`).
  Additional built-up area threshold. Can be a value between `0` and `1`, representing the minimum built-up area per permanent land, or `"optimal"` (see section "Built-up area criterium" below). Ignored when `UC_built_criterium` is `FALSE`.
- `built_optimal_data` character / list (default: `NULL`).
  Path to the directory with the data, or named list with the data as returned by function `DoU_preprocess_grid()` used to determine the optimal built threshold (see section "Built-up area criterium" below). Ignored when `UC_built_criterium` is `FALSE` or when `UC_built_threshold` is not `"optimal"`.
- `UC_smooth_pop` logical (default: `FALSE`).
  Whether to smooth the population grid before delineating urban centres. If `TRUE`, the population grid will be smoothed with a moving average of window size `UC_smooth_pop_window`.

- UC_smooth_pop_window integer (default: 5).

  Size of the moving window used to smooth the population grid before delineating urban centres. Ignored when UC_smooth_pop is FALSE.

- UC_gap_fill logical (default: TRUE).

  Whether to perform gap filling. If TRUE, gaps in urban centres smaller than UC_max_gap are filled.

- UC_max_gap integer (default: 15).

  Gaps with an area smaller than this threshold in urban centres will be filled (unit is km²). Ignored when UC_gap_fill is FALSE.

- UC_smooth_edge logical (default: TRUE).

  Whether to perform edge smoothing. If TRUE, edges of urban centres are smoothed with the function UC_smooth_edge_fun.

- UC_smooth_edge_fun character / function (default: "majority_rule_R2023A").

  Function used to smooth the edges of urban centres. Ignored when UC_smooth_edge is FALSE. Possible values are:

  - "majority_rule_R2022A" to use the edge smoothing algorithm in GHSL Data Package 2022 (see section "Edge smoothing" below)
  - "majority_rule_R2023A" to use the edge smoothing algorithm in GHSL Data Package 2023 (see section "Edge smoothing" below)
  - a custom function with a signature similar as apply_majority_rule().

- UCL_density_threshold numeric (default: 300).

  Minimum population density per permanent land of a cell required to belong to an urban cluster

- UCL_size_threshold numeric (default: 5000).

  Minimum total population size required for an urban cluster

- UCL_contiguity_rule integer (default: 8).

  Which cells are considered adjacent in urban clusters: 4 for rooks case (horizontal and vertical neighbours) or 8 for queens case (horizontal, vertical and diagonal neighbours)

- UCL_smooth_pop logical (default: FALSE).

  Whether to smooth the population grid before delineating urban clusters. If TRUE, the population grid will be smoothed with a moving average of window size UCL_smooth_pop_window.

- UCL_smooth_pop_window integer (default: 5).

  Size of the moving window used to smooth the population grid before delineating urban clusters. Ignored when UCL_smooth_pop is FALSE.

- water_land_threshold numeric (default: 0.5).

  Maximum proportion of permanent land allowed in a water cell

- water_pop_threshold numeric (default: 0).

  Maximum population size allowed in a water cell

- water_built_threshold numeric (default: 0).

  Maximum built-up area allowed in a water cell

LEVEL 2

- UC_density_threshold numeric (default: 1500).
  Minimum population density per permanent land of a cell required to belong to an urban centre
- UC_size_threshold numeric (default: 50000).
  Minimum total population size required for an urban centre
- UC_contiguity_rule integer (default: 4).
  Which cells are considered adjacent in urban centres: 4 for rooks case (horizontal and vertical neighbours) or 8 for queens case (horizontal, vertical and diagonal neighbours)
- UC_built_criterium logical (default: TRUE).
  Whether to use the additional built-up area criterium (see section "Built-up area criterium" below). If TRUE, not only cells that meet the population density requirement will be considered when delineating urban centres, but also cells with a built-up area per permanent land above the UC_built_threshold
- UC_built_threshold numeric or character (default: 0.2).
  Additional built-up area threshold. Can be a value between 0 and 1, representing the minimum built-up area per permanent land, or "optimal" (see section "Built-up area criterium" below). Ignored when UC_built_criterium is FALSE.
- built_optimal_data character / list (default: NULL).
  Path to the directory with the data, or named list with the data as returned by function DoU_preprocess_grid() used to determine the optimal built threshold (see section "Built-up area criterium" below). Ignored when UC_built_criterium is FALSE or when UC_built_threshold is not "optimal".
- UC_smooth_pop logical (default: FALSE).
  Whether to smooth the population grid before delineating urban centres. If TRUE, the population grid will be smoothed with a moving average of window size UC_smooth_pop_window.
- UC_smooth_pop_window integer (default: 5).
  Size of the moving window used to smooth the population grid before delineating urban centres. Ignored when UC_smooth_pop is FALSE.
- UC_gap_fill logical (default: TRUE).
  Whether to perform gap filling. If TRUE, gaps in urban centres smaller than UC_max_gap are filled.
- UC_max_gap integer (default: 15).
  Gaps with an area smaller than this threshold in urban centres will be filled (unit is km²). Ignored when UC_gap_fill is FALSE.
- UC_smooth_edge logical (default: TRUE).
  Whether to perform edge smoothing. If TRUE, edges of urban centres are smoothed with the function UC_smooth_edge_fun.
- UC_smooth_edge_fun character / function (default: "majority_rule_R2023A").
  Function used to smooth the edges of urban centres. Ignored when UC_smooth_edge is FALSE. Possible values are:
  - "majority_rule_R2022A" to use the edge smoothing algorithm in GHSL Data Package 2022 (see section "Edge smoothing" below)
  - "majority_rule_R2023A" to use the edge smoothing algorithm in GHSL Data Package 2023 (see section "Edge smoothing" below)

  - a custom function with a signature similar as `apply_majority_rule()`.

- `DUC_density_threshold` numeric (default: `1500`).
  Minimum population density required for a dense urban cluster
- `DUC_size_threshold` numeric (default: `5000`).
  Minimum total population size required for a dense urban cluster
- `DUC_built_criterium` logical (default: `TRUE`).
  Whether to use the additional built-up area criterium (see section "Built-up area criterium" below). If `TRUE`, not only cells that meet the population density requirement will be considered when delineating dense urban clusters, but also cells with a built-up area per permanent land above the `DUC_built_threshold`
- `DUC_built_threshold` numeric or character (default: `0.2`).
  Additional built-up area threshold. Can be a value between `0` and `1`, representing the minimum built-up area per permanent land, or `"optimal"` (see section "Built-up area criterium" below). Ignored when `DUC_built_criterium` is `FALSE`.
- `DUC_contiguity_rule` integer (default: `4`).
  Which cells are considered adjacent in dense urban clusters: `4` for rooks case (horizontal and vertical neighbours) or `8` for queens case (horizontal, vertical and diagonal neighbours)
- `SDUC_density_threshold` numeric (default: `900`).
  Minimum population density per permanent land of a cell required to belong to a semi-dense urban cluster
- `SDUC_size_threshold` numeric (default: `2500`).
  Minimum total population size required for a semi-dense urban cluster
- `SDUC_contiguity_rule` integer (default: `4`).
  Which cells are considered adjacent in semi-dense urban clusters: `4` for rooks case (horizontal and vertical neighbours) or `8` for queens case (horizontal, vertical and diagonal neighbours)
- `SDUC_buffer_size` integer (default: `2`).
  The distance to urban centres and dense urban clusters required for a semi-dense urban cluster
- `SUrb_density_threshold` numeric (default: `300`).
  Minimum population density per permanent land of a cell required to belong to a suburban or peri-urban area
- `SUrb_size_threshold` numeric (default: `5000`).
  Minimum total population size required for a suburban or peri-urban area
- `SUrb_contiguity_rule` integer (default: `8`).
  Which cells are considered adjacent in suburban or peri-urban area: `4` for rooks case (horizontal and vertical neighbours) or `8` for queens case (horizontal, vertical and diagonal neighbours)
- `RC_density_threshold` numeric (default: `300`).
  Minimum population density per permanent land of a cell required to belong to a rural cluster
- `RC_size_threshold` numeric (default: `500`).
  Minimum total population size required for a rural cluster
- `RC_contiguity_rule` integer (default: `8`).
  Which cells are considered adjacent in rural clusters: `4` for rooks case (horizontal and vertical neighbours) or `8` for queens case (horizontal, vertical and diagonal neighbours)

- `LDR_density_threshold` numeric (default: `50`).
  Minimum population density per permanent land of a low density rural grid cell
- `water_land_threshold` numeric (default: `0.5`).
  Maximum proportion of permanent land allowed in a water cell
- `water_pop_threshold` numeric (default: `0`).
  Maximum population size allowed in a water cell
- `water_built_threshold` numeric (default: `0`).
  Maximum built-up area allowed in a water cell

Built-up area criterium

In Data Package 2022, the Degree of Urbanisation includes an optional built-up area criterium to account for the presence of office parks, shopping malls, factories and transport infrastructure. When the setting is enabled, urban centres (and dense urban clusters) are created using both cells with a population density of at least 1500 inhabitants per km² *and* cells that have at least 50% built-up area on permanent land. For more information: see GHSL Data Package 2022, footnote 25. The parameter settings `UC_built_criterium=TRUE` and `UC_built_threshold=0.5` (level 1 & 2) and `DUC_built_criterium=TRUE` and `DUC_built_threshold=0.5` (level 2) reproduce this built-up area criterium in urban centres and dense urban clusters respectively.

In Data Package 2023, the built-up area criterium is slightly adapted and renamed to the "Reduce Fragmentation Option". Instead of using a fixed threshold of built-up area per permanent land of 50%, an "optimal" threshold is employed. The optimal threshold is dynamically identified as the global average built-up area proportion in clusters with a density of at least 1500 inhabitants per permanent land with a minimum population of 5000 people. We determined empirically that this optimal threshold is 20% for the data of 2020. For more information: see GHSL Data Package 2023, footnote 30. The "Reduce Fragmentation Option" can be reproduced with the parameter settings `UC_built_criterium=TRUE` and `UC_built_threshold="optimal"` (level 1 & 2) and `DUC_built_criterium=TRUE` and `DUC_built_threshold="optimal"` (level 2). In addition, the parameter `built_optimal_data` must contain the path to the directory with the (global) data to compute the optimal built-up area threshold.

Edge smoothing

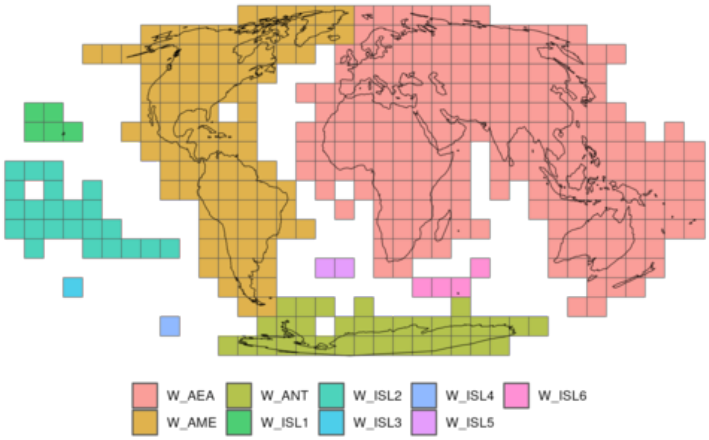
In Data Package 2022, edges of urban centres are smoothed by an iterative majority rule. The majority rule works as follows: if a cell has at least five of the eight surrounding cells belonging to an unique urban centre, then the cell is added to that urban centre. The process is iteratively repeated until no more cells are added. The parameter setting `UC_smooth_edge=TRUE` and `UC_smooth_edge_fun="majority_rule_R2022A"` reproduces this edge smoothing rule.

In Data Package 2023, the majority rule is slightly adapted. A cell is added to an urban centre if the majority of the surrounding cells belongs to an unique urban centre, with majority only computed among populated or land cells (proportion of permanent land > 0.5). In addition, cells with permanent water are never added to urban centres. The process is iteratively repeated until no more cells are added. For more information: see GHSL Data Package 2023, footnote 29. The parameter setting `UC_smooth_edge=TRUE` and `UC_smooth_edge_fun="majority_rule_R2023A"` reproduces this edge smoothing rule.

Regions

Because of the large amount of data at a global scale, the grid classification procedure is quite memory-consuming. To optimise the procedure, we divided the world in 9 pre-defined regions. These regions are the smallest grouping of GHSL tiles while ensuring that no continuous land mass is split into two different regions (for more information, see the figure below and GHSL_tiles_per_region).

If `regions=TRUE`, a global grid classification is created by (1) executing the grid classification procedure separately in the 9 pre-defined regions, and (2) afterwards merging these classifications together. The argument `data` should contain the path to a directory with the data of all pre-defined regions (for example as created by `download_GHSLdata(... extent="regions")`. Note that although the grid classification is optimised, it still takes approx. 145 minutes and requires 116 GB RAM to execute the grid classification with the standard parameters (performed on a Kubernetes server with 32 cores and 256 GB RAM). For a concrete example on how to construct the grid classification on a global scale, see `vignette("vig3-DoU-global-scale")`.



Examples

```
# load the data
data_belgium <- DoU_load_grid_data_belgium()

# classify with standard parameters:
classification1 <- DoU_classify_grid(data = data_belgium)


# classify with custom parameters:
classification2 <- DoU_classify_grid(
  data = data_belgium,
  parameters = list(
    UC_density_threshold = 3000,
    UC_size_threshold = 75000,
    UC_gap_fill = FALSE,
    UC_smooth_edge = FALSE,
    UCL_contiguity_rule = 4
  )
)
```

DoU_classify_grid_rural *Create the DEGURBA grid cell classification of rural cells*

Description

The Degree of Urbanisation identifies rural cells as all cells not belonging to an urban centre or urban cluster.

For more information about the Degree of Urbanisation methodology, see the methodological manual, GHSL Data Package 2022 and GHSL Data Package 2023.

Usage

```
DoU_classify_grid_rural(data, classification, value = 1)
```

Arguments

data	path to the directory with the data, or named list with the data as returned by function DoU_preprocess_grid()
classification	SpatRaster. A grid with the classification of urban centres and urban clusters to which the classification of rural cells will be added. Note that the grid will be adapted in-place.
value	integer. Value assigned to rural cells in the resulting grid

Value

SpatRaster with the grid cell classification of rural cells

Examples

```
data_belgium <- DoU_load_grid_data_belgium()
classification <- DoU_classify_grid_urban_centres(data_belgium)
classification <- DoU_classify_grid_urban_clusters(data_belgium, classification = classification)
classification <- DoU_classify_grid_rural(data_belgium, classification = classification)
DoU_plot_grid(classification)
```

`DoU_classify_grid_urban_centres` *Create the DEGURBA grid cell classification of urban centres*

Description

The Degree of Urbanisation identifies urban centres as clusters of continuous grid cells (based on rook contiguity) with a minimum density of 1500 inhabitants per km² (or with a minimum built-up area; see details), and a minimum total population of 50 000 inhabitants. Gaps smaller than 15 km² in the urban centres are filled and edges are smoothed by a 3x3-majority rule (see details).

For more information about the Degree of Urbanisation methodology, see the methodological manual, GHSL Data Package 2022 and GHSL Data Package 2023.

The arguments of the function allow to adapt the standard specifications in the Degree of Urbanisation in order to construct an alternative version of the grid classification.

Usage

```
DoU_classify_grid_urban_centres(
  data,
  density_threshold = 1500,
  size_threshold = 50000,
  contiguity_rule = 4,
  built_criterium = TRUE,
  built_threshold = 0.2,
  smooth_pop = FALSE,
  smooth_pop_window = 5,
  gap_fill = TRUE,
  max_gap = 15,
  smooth_edge = TRUE,
  smooth_edge_fun = "majority_rule_R2023A",
  value = 3
)
```

Arguments

`data`	path to the directory with the data, or named list with the data as returned by function `DoU_preprocess_grid()`
`density_threshold`	numeric. Minimum population density per permanent land of a cell required to belong to an urban centre
`size_threshold`	numeric. Minimum total population size required for an urban centre
`contiguity_rule`	integer. Which cells are considered adjacent: `4` for rooks case (horizontal and vertical neighbours) or `8` for queens case (horizontal, vertical and diagonal neighbours)

`built_criterium`
: logical. Whether to use the additional built-up area criterium (see details). If `TRUE`, not only cells that meet the population density requirement will be considered when delineating urban centres, but also cells with a built-up area per permanent land above the `built_threshold`

`built_threshold`
: numeric. Additional built-up area threshold. A value between `0` and `1`, representing the minimum built-up area per permanent land. Ignored when `built_criterium` is `FALSE`.

`smooth_pop`
: logical. Whether to smooth the population grid before delineating urban centres. If `TRUE`, the population grid will be smoothed with a moving average of window size `smooth_pop_window`.

`smooth_pop_window`
: integer. Size of the moving window used to smooth the population grid before delineating urban centres. Ignored when `smooth_pop` is `FALSE`.

`gap_fill`
: logical. Whether to perform gap filling. If `TRUE`, gaps in urban centres smaller than `max_gap` are filled.

`max_gap`
: integer. Gaps with an area smaller than this threshold in urban centres will be filled (unit is km²). Ignored when `gap_fill` is `FALSE`.

`smooth_edge`
: logical. Whether to perform edge smoothing. If `TRUE`, edges of urban centres are smoothed with the function `smooth_edge_fun`.

`smooth_edge_fun`
: character / function. Function used to smooth the edges of urban centres. Ignored when `smooth_edge` is `FALSE`. Possible values are:
  - `"majority_rule_R2022A"` to use the edge smoothing algorithm in GHSL Data Package 2022 (see details)
  - `"majority_rule_R2023A"` to use the edge smoothing algorithm in GHSL Data Package 2023 (see details)
  - a custom function with a signature similar as `apply_majority_rule()`.

`value`
: integer. Value assigned to urban centres in the resulting grid

Details

- **Optional built-up area criterium**

In Data Package 2022, the Degree of Urbanisation includes an optional built-up area criterium to account for the presence of office parks, shopping malls, factories and transport infrastructure. When the setting is enabled, urban centres are created using both cells with a population density of at least 1500 inhabitants per km² *and* cells that have at least 50% built-up area on permanent land. For more information: see GHSL Data Package 2022, footnote 25. The parameter setting `built_criterium=TRUE` and `built_threshold=0.5` reproduces this built-up area criterium.

In Data Package 2023, the built-up area criterium is slightly adapted and renamed to the "Reduce Fragmentation Option". Instead of using a fixed threshold of built-up area per permanent land of 50%, an "optimal" threshold is employed. The optimal threshold is dynamically identified as the global average built-up area proportion in clusters with a density of at least 1500 inhabitants per permanent land with a minimum population of 5000 people. For more information: see GHSL Data Package 2023, footnote 30. The optimal built-up threshold can be computed with the function

DoU_get_optimal_builtup(). We determined empirically that this optimal threshold is 20% for the data of 2020.

- **Edge smoothing: majority rule algorithm**

In Data Package 2022, edges of urban centres are smoothed by an iterative majority rule. The majority rule works as follows: if a cell has at least five of the eight surrounding cells belonging to an unique urban centre, then the cell is added to that urban centre. The process is iteratively repeated until no more cells are added. The parameter setting `smooth_edge=TRUE` and `smooth_edge_fun="majority_rule_R2022A"` reproduces this edge smoothing rule.

In Data Package 2023, the majority rule is slightly adapted. A cell is added to an urban centre if the majority of the surrounding cells belongs to an unique urban centre, with majority only computed among populated or land cells (proportion of permanent land > 0.5). In addition, cells with permanent water are never added to urban centres. The process is iteratively repeated until no more cells are added. For more information: see GHSL Data Package 2023, footnote 29. The parameter setting `smooth_edge=TRUE` and `smooth_edge_fun="majority_rule_R2023A"` reproduces this edge smoothing rule.

Value

SpatRaster with the grid cell classification of urban centres

Examples

```
data_belgium <- DoU_load_grid_data_belgium()

# standard parameters of the Degree of Urbanisation:
classification1 <- DoU_classify_grid_urban_centres(data_belgium)
DoU_plot_grid(classification1)

# with custom parameters:
classification2 <- DoU_classify_grid_urban_centres(data_belgium,
  density_threshold = 1000,
  gap_fill = FALSE,
  smooth_edge = FALSE
)
DoU_plot_grid(classification2)
```

DoU_classify_grid_urban_clusters

Create the DEGURBA grid cell classification of urban clusters

---

Description

The Degree of Urbanisation identifies urban clusters as clusters of continuous grid cells (based on queen contiguity) with a minimum density of 300 inhabitants per km², and a minimum total population of 5000 inhabitants.

For more information about the Degree of Urbanisation methodology, see the methodological manual, GHSL Data Package 2022 and GHSL Data Package 2023.

The arguments of the function allow to adapt the standard specifications in the Degree of Urbanisation in order to construct an alternative version of the grid classification.

Usage

```
DoU_classify_grid_urban_clusters(
  data,
  classification,
  density_threshold = 300,
  size_threshold = 5000,
  contiguity_rule = 8,
  smooth_pop = FALSE,
  smooth_pop_window = 5,
  value = 2
)
```

Arguments

`data`	path to the directory with the data, or named list with the data as returned by function `DoU_preprocess_grid()`
`classification`	SpatRaster. A grid with the classification of urban centres to which the classification of urban clusters will be added. Note that the grid will be adapted in-place.
`density_threshold`	numeric. Minimum population density per permanent land of a cell required to belong to an urban cluster
`size_threshold`	numeric. Minimum total population size required for an urban cluster
`contiguity_rule`	integer. Which cells are considered adjacent: `4` for rooks case (horizontal and vertical neighbours) or `8` for queens case (horizontal, vertical and diagonal neighbours)
`smooth_pop`	logical. Whether to smooth the population grid before delineating urban clusters. If `TRUE`, the population grid will be smoothed with a moving average of window size `smooth_pop_window`.
`smooth_pop_window`	integer. Size of the moving window used to smooth the population grid before delineating urban clusters. Ignored when `smooth_pop` is `FALSE`.
`value`	integer. Value assigned to urban clusters in the resulting grid

Value

SpatRaster with the grid cell classification of urban clusters

Examples

```
data_belgium <- DoU_load_grid_data_belgium()
classification <- DoU_classify_grid_urban_centres(data_belgium)
classification <- DoU_classify_grid_urban_clusters(data_belgium, classification = classification)
DoU_plot_grid(classification)
```

`DoU_classify_grid_water` *Create the DEGURBA grid cell classification of water cells*

Description

The Degree of Urbanisation identifies water cells as cells with no built-up area, no population, and less than 50% permanent land.

For more information about the Degree of Urbanisation methodology, see the methodological manual, GHSL Data Package 2022 and GHSL Data Package 2023.

The arguments of the function allow to adapt the standard specifications in the Degree of Urbanisation in order to construct an alternative version of the grid classification.

Usage

```
DoU_classify_grid_water(
  data,
  classification = NULL,
  water_land_threshold = 0.5,
  water_pop_threshold = 0,
  water_built_threshold = 0,
  value = 0,
  allow_overwrite = c(1)
)
```

Arguments

`data`	path to the directory with the data, or named list with the data as returned by function `DoU_preprocess_grid()`
`classification`	SpatRaster. A grid to which the classification of water cells will be added. The grid can already contain the classification or urban centres, urban clusters and rural grid cell, but this is not mandatory. Note that the grid will be adapted in-place.
`water_land_threshold`	numeric. Maximum proportion of permanent land allowed in a water cell
`water_pop_threshold`	numeric. Maximum population size allowed in a water cell
`water_built_threshold`	numeric. Maximum built-up area allowed in a water cell

value	integer. Value assigned to water cells in the resulting grid
allow_overwrite	vector. Values in classification that can be overwritten by water cells. By default, the classification of rural cells (1) can be overwritten, but the classification of urban clusters (2) and urban centres (3) cannot.

Value

SpatRaster with the grid cell classification of water cells

Examples

```
data_belgium <- DoU_load_grid_data_belgium()
classification <- DoU_classify_grid_urban_centres(data_belgium)
classification <- DoU_classify_grid_urban_clusters(data_belgium, classification = classification)
classification <- DoU_classify_grid_rural(data_belgium, classification = classification)
classification <- DoU_classify_grid_water(data_belgium, classification = classification)
DoU_plot_grid(classification)
```

DoU_classify_units *Create the DEGURBA spatial units classification*

Description

The function reconstructs the spatial units classification of the Degree of Urbanisation based on the grid cell classification.

Usage

```
DoU_classify_units(
  data,
  id = "UID",
  level1 = TRUE,
  values = NULL,
  official_workflow = TRUE,
  rules_from_2021 = FALSE,
  filename = NULL
)
```

Arguments

data	named list with the required data, as returned by the function DoU_preprocess_units()
id	character. Unique column in the units data as id for spatial units
level1	logical. Whether to classify the spatial units according to first hierarchical level (TRUE) or the second hierarchical level (FALSE). For more details, see section "Classification rules" below.

`values` vector with the values assigned to the different classes in the resulting units classification:

- If `level1=TRUE`: the vector should contain the values for (1) cities, (2) town and semi-dense areas and (3) rural areas.
- If `level1=FALSE`: the vector should contain the values for (1) cities, (2) dense towns, (3) semi-dense towns, (4) suburb or peri-urban areas, (5) villages, (6) dispersed rural areas and (7) mostly uninhabited areas.

`official_workflow` logical. Whether to employ the official workflow of the GHSL (`TRUE`) or the alternative workflow (`FALSE`). For more details, see section "Workflow" below.

`rules_from_2021` logical. Whether to employ the original classification rules as described in the 2021 version of the DEGURBA manual. The DEUGURBA Level 2 unit classification rules have been modified in July 2024. By default, the function uses the most recent rules as described in the online version of the methodological manual. For more details, see section "Modification of the unit classification rules" below.

`filename` character. Output filename (csv). The resulting classification together with a metadata file (in JSON format) will be saved if `filename` is not `NULL`.

Value

dataframe with for each spatial unit the classification and the share of population per grid class

Classification rules

The Degree of Urbanisation consists of two hierarchical levels. In level 1, the spatial units are classified in cities, towns and semi-dense areas, and rural areas. In level 2, towns and semi-dense areas are further divided in dense towns, semi-dense towns and suburban or peri-urban areas. Rural areas are further divided in villages, dispersed rural areas and mostly uninhabited areas.

The detailed classification rules are as follows:

LEVEL 1:

- **Cities:** units that have at least 50% of their population in urban centres
- **Towns and semi-dense areas:** units that have less than 50% of their population in urban centres and no more than 50% of their population in rural grid cells
- **Rural areas:** units that have more then 50% of their population in rural grid cells

LEVEL 2:

- **Cities:** units that have at least 50% of their population in urban centres
- **Dense towns:** units that have at least 50% of their population in the combination of urban centres and dense urban clusters
- **Semi-dense towns:** units that have less than 50% of their population in the combination of urban centres and dense urban clusters, or have less than 50% of their population in the combination of suburban and peri-urban cells and rural grid cells

- **Suburbs or peri-urban areas:** units that have at least 50% of their population in the combination of suburban and peri-urban cells and rural grid cells
- **Villages**: units that have at least 50% of their population in the combination of urban centres, urban clusters and rural clusters
- **Dispersed rural areas**: units that have less than 50% of their population in the combination of urban centres, urban clusters and rural clusters, or have less than 50% of their population in very low-density rural grid cells
- **Mostly uninhabited areas**: units that have at least 50% of their population in very low-density rural grid cells

Workflow

The classification of small spatial units requires a vector layer with the small spatial units, a raster layer with the grid cell classification, and a raster layer with the population grid. Standard, a population grid of 100 m resolution is used by the Degree of Urbanisation.

The function includes two different workflows to establish the spatial units classification based on these three data sources.

Official workflow according to the GHSL:

For the official workflow, the three layers should be pre-processed by `DoU_preprocess_units()`. In this function, the classification grid and population grid are resampled to a user-defined `resample_resolution` with the nearest neighbour algorithm (the Degree of Urbanisation uses standard a resample resolution of 50 m). In doing this, the values of the population grid are divided by the oversampling ratio (for example: going from a resolution of 100 m to a resolution of 50 m, the values of the grid are divided by 4).

Afterwards, the spatial units classification is constructed with `DoU_classify_units()` as follows. The vector layer with small spatial units is rasterised to match the population and classification grid. Based on the overlap of the three grids, the share of population per flexurba grid class is computed per spatial unit with a zonal statistics procedure. The units are subsequently classified according to the classification rules (see above).

Apart from this, there are two special cases. First, if a unit has no population, it is classified according to the share of *land area* in each of the flexurba grid classes (computed with a zonal statistics procedure). Second, if a unit initially could not be rasterised (can occur if the area of the unit < `resample_resolution`), then it is processed separately as follows. The unit is individually rasterised by all touching cells. The unit is classified according to the share of population in the flexurba grid classes in these touching cells. However, to avoid double counting of population, no population is assigned to the unit in the result.

For more information about the official workflow to construct the units classification, see GHSL Data Package 2023 (Section 2.7.2.3).

Alternative workflow:

Besides the official workflow of the GHSL, the function also includes an alternative workflow to construct the spatial units classification. The alternative workflow does not require rasterising the spatial units layer, but relies on the overlap between the spatial units layer and the grid layers.

The three layers should again be pre-processed by the function `DoU_preprocess_units()`, but this time without `resampling_resolution`. For the classification in `DoU_classify_units()`, the function `exactextractr::exact_extract()` is used to (1) overlay the grids with the spatial units

layer, and (2) summarise the values of the population grid and classification grid per unit. The units are subsequently classified according to the classification rules (see above). As an exception, if a unit has no population, it is classified according to the share of *land area* in each of the flexurba grid classes. The alternative workflow is slightly more efficient as it does not require resampling the population and classification grids and rasterising the spatial units layer.

Modification of the unit classification rules

The unit classification rules of Level 2 of DEGURBA were updated in July 2024. By default, the function `DoU_classify_units()` applies the latest classification rules, as described in the online version of the methodological manual. However, you can also use the original 2021 classification rules if desired, by setting the argument `rules_from_2021` to `TRUE`. In that case, the rules to classify units are as follows:

- **Cities:** units that have at least 50% of their population in urban centres
- **Dense towns:** units that have a larger share of the population in dense urban clusters than in semi-dense urban clusters, and that have a larger share of the population in dense + semi-dense urban clusters than in suburban or peri-urban cells
- **Semi-dense towns:** units that have a larger share of the population in semi-dense urban clusters than in semi-dense urban clusters, and that have a larger share of the population in dense + semi-dense urban clusters than in suburban or peri-urban cells
- **Suburbs or peri-urban areas:** units that have a larger share in suburban or peri-urban cells than in dense + semi-dense urban clusters
- **Villages**: units that have the largest share of their rural grid cell population living in rural clusters
- **Dispersed rural areas**: units that have the largest share of their rural grid cell population living in low density rural grid cells
- **Mostly uninhabited areas**: units that have the largest share of their rural grid cell population living in very low density rural grid cells

Examples

```
# load the grid data
data_belgium <- flexurba::DoU_load_grid_data_belgium()
# load the units and filter for West-Flanders
units_data <- flexurba::units_belgium %>%
  dplyr::filter(GID_2 == "30000")
# classify the grid
classification <- DoU_classify_grid(data = data_belgium)


# official workflow
data1 <- DoU_preprocess_units(
  units = units_data,
  classification = classification,
  pop = data_belgium$pop,
  resample_resolution = 50
)
units_classification1 <- DoU_classify_units(data1)
```

```
# alternative workflow
data2 <- DoU_preprocess_units(
  units = units_data,
  classification = classification,
  pop = data_belgium$pop
)
units_classification2 <- DoU_classify_units(data2, official_workflow = FALSE)

# spatial units classification, dissolved at level 3 (Belgian districts)
data3 <- DoU_preprocess_units(
  units = units_data,
  classification = classification,
  pop = data_belgium$pop,
  dissolve_units_by = "GID_3"
)
units_classification3 <- DoU_classify_units(data3, id = "GID_3")
```

`DoU_get_grid_parameters` *Get the parameters for the DEGURBA grid cell classification*

Description

The argument `parameter` of the function `DoU_classify_grid()` allows to adapt the standard specifications in the Degree of Urbanisation in order to construct an alternative version of the grid classification. This function returns a named list with the standard parameters.

Usage

```
DoU_get_grid_parameters(level1 = TRUE)
```

Arguments

`level1`	logical. Whether to return the standard parameters of level 1 of the Degree of Urbanisation (`TRUE`), or level 2 of the Degree of Urbanisation (`FALSE`).

Value

named list with the standard parameters

Examples

```
# example on how to employ the function to construct
# an alternative version of the grid classification:
# get the standard parameters
parameters <- DoU_get_grid_parameters()
```

```
# adapt the standard parameters
parameters$UCL_density_threshold <- 500
parameters$UCL_size_threshold <- 6000
parameters$UCL_smooth_pop <- TRUE
parameters$UCL_smooth_pop_window <- 7

# load the data
grid_data <- DoU_load_grid_data_belgium()

# use the adapted parameters to construct a grid cell classification
classification <- DoU_classify_grid(
  data = grid_data,
  parameters = parameters
)
```

`DoU_get_optimal_builtup` *Get the optimal built-up area threshold*

Description

In Data Package 2023, the Degree of Urbanisation includes a "Reduce Fragmentation Option" to account for the presence of office parks, shopping malls, factories and transport infrastructure. When the setting is enabled, urban centres are created using both cells with a population density of at least 1500 inhabitants per km² *and* cells that have an "optimal" built-up area on permanent land. This function can be used to determine this "optimal" threshold value.

The optimal threshold is dynamically identified as the global average built-up area proportion in clusters with a density of at least 1500 inhabitants per permanent land with a minimum population of 5000 people. We empirically discovered that the Degree of Urbanisation uses the rounded up (ceiled) optimal threshold to two decimal places.

For more information: see GHSL Data Package 2023, footnote 30. The arguments of the function allow to adapt the standard specifications in order to determine an alternative "optimal" threshold.

Usage

```
DoU_get_optimal_builtup(
  data,
  density_threshold = 1500,
  size_threshold = 5000,
  directions = 4
)
```

Arguments

`data`	path to the directory with the data, or named list with the data as returned by function `DoU_preprocess_grid()`. Ideally, it contains data on a global scale.
`density_threshold`	numeric. Minimum population density per permanent land

size_threshold	numeric. Minimum population size
directions	integer. Which cells are considered adjacent: 4 for rooks case (horizontal and vertical neighbours) or 8 for queens case (horizontal, vertical and diagonal neighbours)

Value

optimal built-up area threshold

Examples

```
data_belgium <- DoU_load_grid_data_belgium()

# determine the optimal built-up threshold with standard specifications
DoU_get_optimal_builtup(data_belgium)

# determine the optimal built-up threshold with custom specification
DoU_get_optimal_builtup(data_belgium,
  density_threshold = 1000,
  size_threshold = 3500,
  directions = 8
)
```

DoU_load_grid_data_belgium

Load the grid data for Belgium to reconstruct DEGURBA classification

---

Description

The function loads the data required to execute the grid classification of the Degree of Urbanisation for Belgium with the function DoU_preprocess_grid().

The data was constructed with the code below:

```
# download the GHSL data on a global scale
download_GHSLdata(output_directory = "inst/extdata/global")

# crop the global grid to Belgium
crop_GHSLdata(extent = terra::ext(192000, 485000, 5821000, 6030000),
              global_directory = "inst/extdata/global",
              output_directory = "inst/extdata/belgium")
```

Usage

```
DoU_load_grid_data_belgium()
```

Value

named list with the data of Belgium required for the grid classification of the Degree of Urbanisation.

Examples

```
DoU_load_grid_data_belgium()
```

DoU_plot_grid *Plot the grid cell classification*

Description

The function can be used to plot the results of the grid cell classification of the Degree of Urbanisation. The implementation relies upon the function `tidyterra::geom_spatraster()`. By default, the standard color scheme of the Global Human Settlement Layer (GHSL) is used (see GHSL Data Package 2023), but this can be altered by the `palette` argument.

Note that the function is computational quite heavy for large spatial extents (regional or global scale). It is advised to use the `extent` argument to plot only a selection of the grid classification.

Usage

```
DoU_plot_grid(
  classification,
  extent = NULL,
  level1 = TRUE,
  palette = NULL,
  labels = NULL,
  title = NULL,
  scalebar = FALSE,
  filename = NULL
)
```

Arguments

`classification`	SpatRaster / character. A SpatRaster with the grid cell classification or the path to the grid cell classification file
`extent`	SpatExtent. If not `NULL`, the grid classification will be cropped to the provided extent before plotting
`level1`	logical. Whether the grid is classified according to level 1 of the Degree of Urbanisation (`TRUE`), or level 2 of the Degree of Urbanisation (`FALSE`).
`palette`	named vector with the color palette used to plot the grid cell classification. If `NULL`, the standard color palette of the GHSL is used (see `GHSL_palette()`).
`labels`	vector with the labels used in the legend. If `NULL`, the standard labels of the GHSL are used (see `GHSL_labels()`).

title	character. Title of the plot.t
scalebar	logical. Whether to add a scale bar to the plot.
filename	character. Path to the location to save the plot

Value

ggplot object

Examples

```
classification <- DoU_classify_grid(DoU_load_grid_data_belgium())

# plot with standard color scheme
DoU_plot_grid(classification)

# use custom palette and labels
DoU_plot_grid(classification,
  palette = c("3" = "#e16c72", "2" = "#fac66c", "1" = "#97c197", "0" = "#acd3df"),
  labels = c("UC", "UCL", "RUR", "WAT")
)
```

DoU_plot_units *Plot the spatial units classification*

Description

The function can be used to plot the results of the spatial units classification of the Degree of Urbanisation. The implementation relies upon the function `ggplot2::geom_sf()`. By default, the standard color scheme of the Global Human Settlement Layer (GHSL) is used (see GHSL Data Package 2023), but this can be altered by the `palette` argument.

Note that the function is computational quite heavy for large spatial extents (regional or global scale). It is advised to use the `extent` argument to plot only a selection of the spatial units classification.

Usage

```
DoU_plot_units(
  units,
  classification = NULL,
  level1 = TRUE,
  extent = NULL,
  column = NULL,
  palette = NULL,
  labels = NULL,
  title = NULL,
  scalebar = FALSE,
  filename = NULL
)
```

Arguments

units	object of class sf. The spatial units to be displayed on the plot
classification	dataframe with the classification of the spatial units, as returned by DoU_classify_units(). If NULL, it is assumed that the classification results are merged in the units object.
level1	logical. Whether the spatial units are classified according to level 1 of the Degree of Urbanisation (TRUE), or level 2 of the Degree of Urbanisation (FALSE).
extent	SpatExtent or an object of class "bbox" (sf). If not NULL, the spatial units will be filtered based on the provided extent before plotting.
column	character. Column name of the spatial units classification. By default, "flexurba_L1" when level1=TRUE and "flexurba_L2" when level1=FALSE.
palette	named vector with the color palette used to plot the spatial units classification. If NULL, the standard color palette of the GHSL is used (see GHSL_palette()).
labels	vector with the labels used in the legend. If NULL, the standard labels of the GHSL are used (see GHSL_labels()).
title	character. Title of the plot.
scalebar	logical. Whether to add a scale bar to the plot.
filename	character. Path to the location to save the plot

Value

ggplot object

Examples

```
# get spatial units classification
data_belgium <- DoU_load_grid_data_belgium()
grid_classification <- DoU_classify_grid(data_belgium)
data1 <- DoU_preprocess_units(
  units = flexurba::units_belgium,
  classification = grid_classification,
  pop = data_belgium$pop
)
units_classification <- DoU_classify_units(data1)

# plot using the standard color palette
DoU_plot_units(data1$units, units_classification)

# plot using custom palette and labels
DoU_plot_units(data1$units, units_classification,
  palette = c("3" = "#e16c72", "2" = "#fac66c", "1" = "#97c197"),
  labels = c("C", "T", "R")
)
```

`DoU_preprocess_grid` *Preprocess the data for the DEGURBA grid cell classification*

Description

The grid cell classification of the Degree of Urbanisation requires three different inputs:

- a built-up area grid
- a population grid
- a land grid

The function rescales the built-up area and land grid if necessary (see details) and computes the population and built-up area per permanent land by dividing the respective grids by the land layer.

Usage

```
DoU_preprocess_grid(
  directory,
  filenames = c("BUILT_S.tif", "POP.tif", "LAND.tif"),
  rescale_land = TRUE,
  rescale_built = TRUE
)
```

Arguments

`directory`	character. Path to the directory where the three input grids are saved (for example generated by the function `download_GHSLdata()`)
`filenames`	vector of length 3 with the filenames of the built-up area, population and land grid
`rescale_land`	logical. Whether to rescale the values of the land grid (see details)
`rescale_built`	logical. Whether to rescale the values of the built-up area grid (see details)

Details

The values of the land grid and built-up area grid should range from `0` to `1`, representing the proportion of permanent land and built-up area respectively. However, the grid values of the GHSL are standard in m². With a cell size of 1 km², the values thus range from `0` to `1 000 000`. The two grids can be rescaled by setting `rescale_land=TRUE` and/or `rescale_built=TRUE` respectively.

Value

named listed with the required data to execute the grid cell classification procedure. The list contains following elements:

- `built`: built-up area grid
- `pop`: population grid

- `land`: land grid
- `pop_per_land`: population per area of permanent land
- `built_per_land`: built-up area per permanent land
- `metadata_BUILT_S`: the metadata of the built-up area grid
- `metadata_POP`: the metadata of the population grid
- `metadata_LAND`: the metadata of the land grid.

`DoU_preprocess_units` *Preprocess the data for the DEGURBA spatial units classification*

Description

The spatial units classification of the Degree of Urbanisation requires three different inputs (all input sources should be in the Mollweide coordinate system):

- a vector layer with the small spatial units
- a raster layer with the grid cell classification of the Degree of Urbanisation
- a raster layer with the population grid

The three input layers are pre-processed as follows. The classification grid and population grid are resampled to the `resample_resolution` with the nearest neighbour algorithm. In doing this, the values of the population grid are divided by the oversampling ratio (for example: going from a resolution of 100 m to a resolution of 50 m, the values of the grid are divided by 4).

In addition, the function makes sure the extents of the three input layers match. If the bounding box of the units layer is smaller than the extent of the grids, then the grids are cropped to the bounding box of the units layer. Alternatively, if the units layer covers a larger area than the grids, then the units that do not intersect with the grids are discarded (and a warning message is printed). This ensures that the classification algorithm runs efficiently and does not generate any incorrect classifications due to missing data.

More information about the pre-processing workflow, see GHSL Data Package 2023 (Section 2.7.2.3).

Usage

```
DoU_preprocess_units(
  units,
  classification,
  pop,
  resample_resolution = NULL,
  dissolve_units_by = NULL
)
```

Arguments

units	character / object of class sf. Path to the vector layer with small spatial units, or an object of class sf with the small spatial units
classification	character / SpatRaster. Path to the grid cell classification of the Degree of Urbanisation, or SpatRaster with the grid cell classification
pop	character / SpatRaster. Path to the population grid, or SpatRaster with the population grid
resample_resolution	numeric. Resolution to which the grids are resampled during pre-processing. If NULL, the grids are resampled to the smallest resolution among the population and classification grid.
dissolve_units_by	character. If not NULL, the units are dissolved by this column's value, can for example be used to dissolve spatial units to a certain administrative level (see examples).

Value

named list with the required data to execute the spatial units classification procedure, and their metadata. The list contains the following elements:

- classification: the (resampled and cropped) grid cell classification layer
- pop: the (resampled and cropped) population grid
- units: the (dissolved and filtered) spatial units (object of class sf)
- metadata: named list with the metadata of the input files. It contains the elements units, classification and pop (with paths to the respective data sources), resample_resolution and dissolve_units_by if not NULL. (Note that when the input sources are passed by object , the metadata might be empty).

Examples

```
# load the grid data
grid_data <- flexurba::DoU_load_grid_data_belgium()
# load the units and filter for West-Flanders
units_data <- flexurba::units_belgium %>%
  dplyr::filter(GID_2 == "30000")
# classify the grid
classification <- DoU_classify_grid(data = grid_data)

# preprocess the data for units classification
data1 <- DoU_preprocess_units(
  units = units_data,
  classification = classification,
  pop = grid_data$pop,
  resample_resolution = 50
)

# preprocess the data for units classification at level 3 (Belgian districts)
```

```
data2 <- DoU_preprocess_units(
  units = units_data,
  classification = classification,
  pop = grid_data$pop,
  resample_resolution = 50,
  dissolve_units_by = "GID_3"
)
```

`download_GHSLdata` *Download data products from the GHSL website*

Description

The function will download data products with certain specifications from the Global Human Settlement Layer (GHSL) website. The following data products are supported:

- **BUILT_S**: the built-up area grid
- **POP**: the population grid
- **LAND**: the land grid (with the proportion of permanent land)

These are also the three data products that are required for the grid cell classification of the Degree of Urbanisation. For more information about the data products and their available specifications, see GHSL Download page. The downloaded data will be saved in the `output_directory` together with a JSON metadata-file. This function downloads large volumes of data, make sure the timeout parameter is sufficiently high (for example: `options(timeout=500)`).

Note that the land grid is only available for epoch 2018 and release R2022A on the GHSL website. The land grid will consequently always be downloaded with these specifications, regardless of the epoch and release specified in the arguments (a warning message is printed).

Usage

```
download_GHSLdata(
  output_directory,
  filenames,
  products = c("BUILT_S", "POP", "LAND"),
  epoch = 2020,
  release = "R2023A",
  crs = 54009,
  resolution = 1000,
  version = c("V1", "0"),
  extent = "global"
)
```

Arguments

`output_directory`
: character. Path to the output directory

`filenames`
: character. Filenames for the output files

`products`
: vector with the types of the data products: `"BUILT_S"`, `"POP"` and/or `"LAND"` for the built-up area grid, the population grid and the land grid respectively

`epoch`
: integer. Epoch

`release`
: character. Release code (only release `"R2022A"` and `"R2023A"` are supported)

`crs`
: integer. EPSG code of the coordinate system: for example, `54009` for Mollweide.

`resolution`
: integer. Resolution (in meters for Mollweide projection).

`version`
: vector with the version code and number

`extent`
: character or vector representing the spatial extent. There are three possibilities:

  - `extent = "global"`: The data is downloaded on a global scale.
  - `extent` is a vector of GHSL tile ids: The data is downloaded for each tile separately and afterwards merged together. For more information about the GHSL tiles and their extent see `GHSL_tiles` or GHSL Download page.
  - `extent = "regions"`: The data will be downloaded in 9 pre-defined regions. The pre-defined regions are the smallest grouping of GHSL tiles possible while ensuring that no continuous land mass is split over two regions. The regions are constructed to execute the Degree of Urbanisation classification algorithms in a memory-efficient manner. For each of the regions, the data products will be downloaded and saved in a sub-directory of `output_directory` (e.g., for region `W_AME`, the directory `output_directory/W_AME` is created). For more information, see the documentation of `GHSL_tiles_per_region`.

Value

path to the created files.

Examples

```
# Download the population grid for epoch 2000 for specific tiles
download_GHSLdata(
  output_directory = tempdir(),
  filename = "POP_2000.tif",
  products = "POP",
  extent = c("R3_C19", "R4_C19"),
  epoch = 2000,
)
```

`fill_gaps` *Fill gaps in clusters of cells*

Description

The function fills gaps with an area smaller than `max_gap`. A gap is considered a patch of `NA` cells that lies within a cluster of cells with the same value. The implementation of the function relies on the function `nngeo::st_remove_holes()`.

Usage

```
fill_gaps(x, max_gap = 15)
```

Arguments

`x`	SpatRaster
`max_gap`	numeric. Gaps with an area smaller than `max_gap` are filled (see details for more information about the unit of this value).

Details

`max_gap` has the same unit as the resolution of `x`. For example, with a SpatRaster in Mollweide (`EPSG:54009`) and a resolution of 1 km², `max_gap` is interpreted in km².

Value

SpatRaster

Examples

```
nr <- nc <- 8
r <- terra::rast(nrows = nr, ncols = nc, ext = c(0, nc, 0, nr), crs = "epsg:25831")
terra::values(r) <- c(
  NA, NA, NA, NA, 1, 1, 1, NA,
  NA, 2, 2, 2, NA, NA, 1, NA,
  NA, 2, NA, 2, 2, NA, 1, 1,
  NA, 2, NA, NA, 2, 2, NA, NA,
  NA, 2, 2, 2, 2, NA, NA, NA,
  NA, NA, NA, NA, NA, NA, NA, NA,
  NA, NA, NA, NA, NA, NA, NA, NA,
  NA, NA, NA, NA, NA, NA, NA, NA
)
terra::plot(r)
gaps_filled <- fill_gaps(r)
terra::plot(gaps_filled)
```

`get_adjacent` *Identify adjacent cells*

Description

The function identifies all cells that are adjacent to non-NA cells in `x`. The implementation of the function relies on the function `terra::adjacent()`.

Usage

```
get_adjacent(
  x,
  cells = "all",
  adjacent_value = 1,
  include = TRUE,
  directions = 8
)
```

Arguments

`x`	SpatRaster
`cells`	character / integer. Either `"all"` or a specific cell value. If `cells="all"`, adjacent cells are identified for all non-NA cells in `x`. Otherwise, adjacent cells are only identified for cells in `x` with the specific cell value.
`adjacent_value`	integer. Value assigned to adjacent cells in the resulting grid
`include`	logical. Whether to include the focal cells in the resulting grid
`directions`	integer. Which cells are considered adjacent: `4` for rooks case (horizontal and vertical neighbours) or `8` for queens case (horizontal, vertical and diagonal neighbours)

Value

SpatRaster with adjacent cells

Examples

```
set.seed(10)
nr <- nc <- 10
r <- terra::rast(
  ncols = nc, nrows = nr,
  ext = c(0, nc, 0, nr),
  vals = sample(c(NA, 1, 2), nr * nc, replace = TRUE, prob = c(0.8, 0.1, 0.1))
)
terra::plot(r)
adj1 <- get_adjacent(r)
terra::plot(adj1)
adj2 <- get_adjacent(r, cells = 1, include = FALSE)
terra::plot(adj2)
```

`get_clusters` *Identify clusters of cells that meet the criteria*

Description

Identify clusters of cells that meet the minimum density criterium/citeria, the minimum size criterium and the contiguity criterium.

The function can be executed with one density criterium, or with two density criteria:

- **With one density criterium:** Cells are selected if their value is above or equal to the density threshold (`xden >= minden`). Selected cells are afterwards grouped together based on the contiguity rule. Groups of cells are valid clusters if they also meet the total size criterium (sum of `xsiz` per group above or equal to`minsiz`).
- **With two density criteria:** Cells are selected if their value is above or equal to one of two density thresholds (`xden >= minden`, or `xden2 >= minden2`). Selected cells are afterwards grouped together based on the contiguity rule. Groups of cells are valid clusters if they also meet the total size criterium (sum of `xsiz` per group above or equal to`minsiz`).

Usage

```
get_clusters(
  xden,
  minden,
  xden2 = NULL,
  minden2 = NULL,
  xsiz = NULL,
  minsiz,
  directions
)
```

Arguments

`xden`	SpatRaster. Grid for density criterium 1
`minden`	numeric. Minimum density threshold 1
`xden2`	SpatRaster. Grid for density criterium 2
`minden2`	numeric. Minimum density threshold 2
`xsiz`	SpatRaster. Grid for the size criterium. If `NULL`, then `xden` is employed for the size criterium.
`minsiz`	numeric. Minimum size threshold
`directions`	integer. Which cells are considered adjacent: `4` for rooks case (horizontal and vertical neighbours) or `8` for queens case (horizontal, vertical and diagonal neighbours)

Value

SpatRaster with cluster of cells. The value of the cells represent the id of the clusters.

Examples

```
# load data
grid_data_belgium <- flexurba::DoU_load_grid_data_belgium()

# get clusters of cells (4-cell connectivity) with at least 1500 inhabitants
# per km² of permanent land and a minimum total population of 50 000
# inhabitants:
terra::plot(get_clusters(
  xden = grid_data_belgium$pop_per_land,
  minden = 1500,
  xsiz = grid_data_belgium$pop,
  minsiz = 50000,
  directions = 4
))

# get clusters of cells (4-cell connectivity) with at least 1500 inhabitants
# per km² of permanent land or at least 20% built-up area per permanent
# land, and a minimum total population of 50 000 inhabitants:
terra::plot(get_clusters(
  xden = grid_data_belgium$pop_per_land,
  minden = 1500,
  xden2 = grid_data_belgium$built_per_land,
  minden2 = 0.2,
  xsiz = grid_data_belgium$pop,
  minsiz = 50000,
  directions = 4
))

# get clusters of cells (8-cell connectivity) with at least 300 inhabitants
# per km² of permanent land, and a minimum total population of 5000
# inhabitants:
terra::plot(get_clusters(
  xden = grid_data_belgium$pop_per_land,
  minden = 300,
  xsiz = grid_data_belgium$pop,
  minsiz = 5000,
  directions = 8
))
```

---

get_patches *Detect patches of cells*

Description

The function detects patches of cells based on rook contiguity (horizontal and vertical neighbours) or queen contiguity (horizontal, vertical and diagonal neighbours).

Patches of cells are groups of cells that are surrounded by NA of NaN values. The function identifies patches by converting the SpatRaster into polygons with the functions `geos::as_geos_geometry()` and `geos::geos_unnest()`. During this conversion polygons are automatically created as cells

with rook contiguity. Touching polygons are afterwards dissolved to create patches with queen contiguity.

The function is similar as `terra::patches()`, but is faster for large SpatRasters (see details).

Usage

```
get_patches(x, directions, cells = "all")
```

Arguments

`x`	SpatRaster
`directions`	integer. Which cells are considered adjacent: `4` for rooks case (horizontal and vertical neighbours) or `8` for queens case (horizontal, vertical and diagonal neighbours)
`cells`	character / vector. Either `"all"` or a vector with specific cell values. If `cells="all"`, patches are identified based on all non-`NA` cells in `x`. Otherwise, patches are only identified for cells in `x` with the specific cell values.

Details

The function is similar as `terra::patches()`, but is faster for large SpatRasters.

Rook contiguity

Size SpatRaster	`terra::patches(directions=4)`	`flexurba::get_patches(directions=4)`
4000 x 4000 (106 642 not-`NA` cells)	75.157 s	5.351 s
4000 x 4000 (423 888 not-`NA` cells)	324.846 s	8.336 s

Queen contiguity

Size SpatRaster	`terra::patches(directions=8)`	`flexurba::get_patches(directions=8)`
4000 x 4000 (106 642 not-`NA` cells)	37.322 s	7.737 s
4000 x 4000 (423 888 not-`NA` cells)	183.428 s	24.094 s

Value

SpatRaster with patches of cells. The value of the cells represent the id of the patches.

Examples

```
r <- terra::rast(nrows = 8, ncols = 8, vals = c(
  2, 2, NA, NA, NA, NA, NA, NA,
  NA, NA, NA, NA, NA, NA, NA, NA,
  NA, NA, 1, NA, NA, NA, NA, NA,
  NA, NA, NA, 1, NA, NA, NA, NA,
  NA, NA, NA, NA, 1, 1, 1, 1,
  NA, NA, NA, NA, NA, 1, 1, 1,
  2, NA, NA, NA, NA, NA, NA, NA,
```

```
  NA, 2, NA, NA, NA, NA, NA, NA
))
terra::plot(r)
patches_rook1 <- get_patches(r, directions = 4)
terra::plot(patches_rook1)
patches_rook2 <- get_patches(r, directions = 4, cells = 1)
terra::plot(patches_rook2)
patches_queen1 <- get_patches(r, directions = 8)
terra::plot(patches_queen1)
patches_queen2 <- get_patches(r, directions = 8, cells = 1)
terra::plot(patches_queen2)
```

`GHSL_tiles` *A dataframe with existing GHSL tiles*

Description

The Global Human Settlement Layer (GHSL) divides the world into different rectangular areas called "tiles". These tiles can be used to download the GHSL products from the website (see GHSL Download page).

The dataset `GHSL_tiles` contains the geometry and metadata of all valid tiles.

Usage

```
GHSL_tiles
```

Format

`GHSL_tiles`**:**

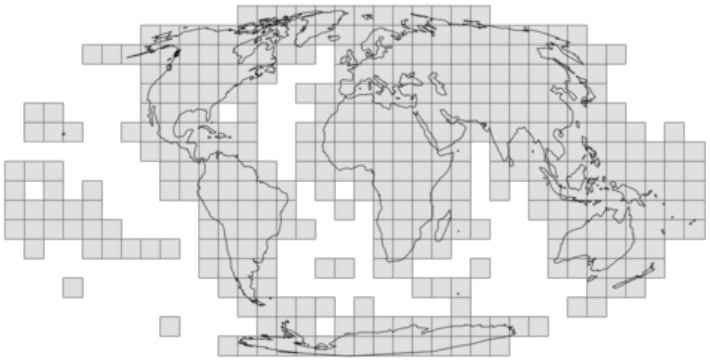
A dataframe with 375 rows and 6 columns

tile_id id of the tile

left, top, right, bottom The coordinates of the bounding box of the tile (in Mollweide, EPSG: 54009)

geometry `sfc_POLYGON` geometry of the tile

Details



Spatial distribution of the GHSL tiles:

Source

https://ghsl.jrc.ec.europa.eu/download/GHSL_data_54009_shapefile.zip

---

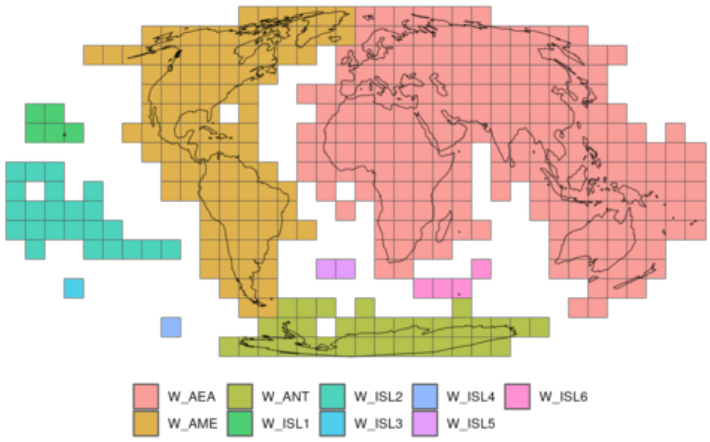
`GHSL_tiles_per_region` *Division of GHSL tiles in 9 regions*

Description

The Global Human Settlement Layer (GHSL) divides the world into different rectangular tiles. To execute the Degree of Urbanisation in a memory-efficient manner, we grouped these tiles into 9 different regions. These regions are the smallest possible grouping of GHSL tiles, ensuring that no continuous land mass is split across two regions. By splitting the world into different parts, the RAM required to execute the Degree of Urbanisation is optimised. For a concrete example on how to use the regions to construct the grid classification on a global scale, see `vignette("vig3-DoU-global-scale")`.

The 9 regions cover approximately the following areas:

- **W_AEA:** Asia - Europe - Africa - Oceania (eastern hemisphere)
- **W_AME:** North and South America (+ Greenland and Iceland)
- **W_ISL1:** Hawaii
- **W_ISL2:** Oceanic Islands (western hemisphere)
- **W_ISL3:** Chatham Islands
- **W_ISL4:** Scott Island
- **W_ISL5:** Saint-Helena, Ascension and Tristan da Cunha
- **W_ISL6:** French Southern and Antarctic Lands
- **W_ANT:** Antarctica



For more information about the GHSL tiles and their extent see GHSL Download page.

Usage

```
GHSL_tiles_per_region
```

Format

`GHSL_tiles_per_region`:

A named list of length 9:

- the names represent the 9 different regions (`W_AEA`, `W_AME`, `W_ISL1`, `W_ISL2`, `W_ISL3`, `W_ISL4`, `W_ISL5`, `W_ISL6`, `W_ANT`)
- the elements are vectors with the GHSL tile ids that make up the regions

Source

https://ghsl.jrc.ec.europa.eu/download/GHSL_data_54009_shapefile.zip

---

load_proxies_belgium *Load the data for three urban proxies for Belgium*

Description

The function loads example population, built-up area and night-time light data for Belgium. It is based on the global datasets provided in the accompanying `flexurbaData` package.

```
# POPULATION DATA
terra::rast(system.file("proxies/processed-ghs-pop.tif", package = "flexurbaData")) %>%
   terra::crop(terra::ext(187000, 490000, 5816000, 6035000)) %>%
   terra::writeRaster('inst/extdata/belgium/processed-ghs-pop-belgium.tif')
```

```
# BUILT-UP AREA DATA
terra::rast(system.file("proxies/processed-ghs-built-s.tif", package = "flexurbaData")) %>%
   terra::crop(terra::ext(187000, 490000, 5816000, 6035000)) %>%
   terra::writeRaster('inst/extdata/belgium/processed-ghs-built-s-belgium.tif')

# LIGHT DATA
terra::rast(system.file("proxies/processed-viirs-light.tif", package = "flexurbaData")) %>%
   terra::crop(terra::ext(187000, 490000, 5816000, 6035000)) %>%
   terra::writeRaster('inst/extdata/belgium/processed-viirs-light-belgium.tif')
```

The data are processed versions of the population and built-up grid from the Global Human Settlement Layer and the night-time light grid from the Earth Observation Group. See the `flexurbaData` package for more information of how these raw data produced were processed.

Usage

```
load_proxies_belgium()
```

Value

named list with gridded population, built-up area and night-time light data for Belgium.

Examples

```
load_proxies_belgium()
```

---

units_belgium *Spatial units of Belgium*

Description

An object of class `sf` with the small spatial units of Belgium (based on data from the Algemene Directie Statistiek - Statistics Belgium). The data is aggregated to municipal level and converted to the Mollweide projection with the following code:

```
# read the data
statsec <- st_read('sh_statbel_statistical_sectors_31370_20240101.geojson')

# aggregate units to munipal level and rename variables
units_belgium <- statsec %>%
  group_by(cd_munty_refnis) %>%
  summarise(UID = first(as.integer(cd_munty_refnis)),
            GID_0 = first(cd_country),
            NAME_0 = 'Belgium',
            GID_1 = first(cd_rgn_refnis),
            NAME_1 = first(tx_rgn_descr_nl),
            GID_2 = first(cd_prov_refnis),
```

```
            NAME_2 = first(tx_prov_descr_nl),
            GID_3 = first(cd_dstr_refnis),
            NAME_3 = first(tx_adm_dstr_descr_nl),
            GID_4 = first(cd_munty_refnis),
            NAME_4 = first(tx_munty_descr_nl)
  )

# simplify geometries and convert to Mollweide
units_belgium <- units_belgium %>% select(-cd_munty_refnis) %>%
  rmapshaper::ms_simplify() %>%
  st_transform('ESRI:54009') %>%
  rename(geom = geometry)
```

Usage

```
units_belgium
```

Format

`units_belgium`:
A object of class `sf` with spatial units for Belgium

Source

https://statbel.fgov.be/nl/open-data/statistische-sectoren-2024

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