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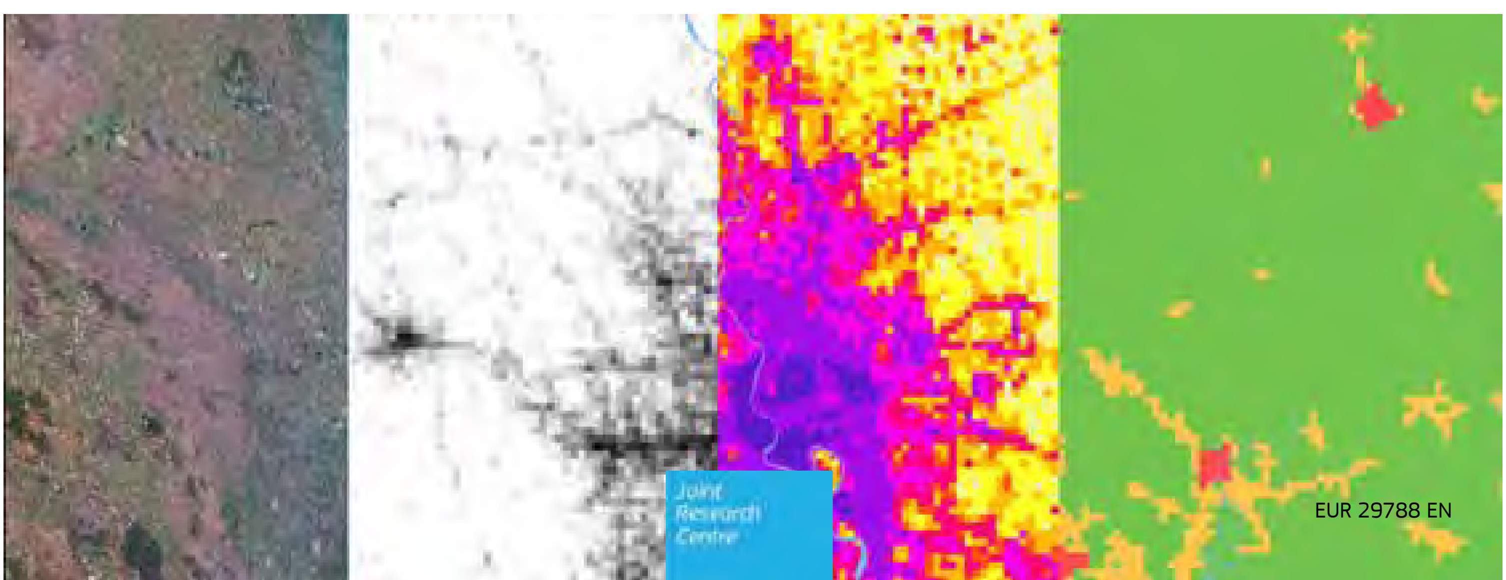
2019



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Abstract

The Global Human Settlement Layer (GHSL) produces new global spatial information, evidence-based analytics and knowledge describing the human presence on the planet Earth. The GHSL operates in a fully open and free data and methods access policy, building the knowledge supporting the definition, the public discussion and the implementation of European policies and the international frameworks such as the 2030 Development Agenda and the related thematic agreements. The GHSL supports the GEO Human Planet Initiative (HPI) that is committed to developing a new generation of measurements and information products providing new scientific evidence and a comprehensive understanding of the human presence on the planet and that can support global policy processes with agreed, actionable and goal-driven metrics. The Human Planet Initiative relies on a core set of partners committed in coordinating the production of the global settlement spatial baseline data. One of the core partners is the European Commission, Directorate General Joint Research Centre, Global Human Settlement Layer project. The Global Human Settlement Layer project produces global spatial information, evidence-based analytics, and knowledge describing the human presence on the planet.

This document describes the public release of the GHSL Data Package 2019 (GHS P2019). The release provides improved built-up area and population products as well as a new settlement model and functional urban areas

Prior to cite this report, please access the updated version available at:
http://ghsl.jrc.ec.europa.eu/documents/GHSL_Data_Package_2019.pdf

1 Introduction

1.1 Overview

The Global Human Settlement Layer (GHSL) project produces global spatial information, evidence-based analytics, and knowledge describing the human presence in the planet. The GHSL relies on the design and implementation of new spatial data mining technologies that allow automatic processing, data analytics and knowledge extraction from large amounts of heterogeneous data including global, fine-scale satellite image data streams, census data, and crowd sourced or volunteered geographic information sources.

This document accompanies the public release of the GHSL Data Package 2019 (GHS P2019) and describes the contents.

— Each product is named according to the following convention:

GHS_<name>_<temporalCoverage>_<spatialExtent>_<releaseId>

For example, a product name "GHS_BUILT_LDSMT_GLOBE_R2018A" indicates the GHSL Built-up area layer (GHS-BUILT) with multi-temporal coverage and a global spatial extent release R2019A.

— Each dataset is named according to the following convention:

GHS_<name>_<epochCode>_<extent>_<releaseId>_<EPSG>_<resolution>_<version>.<ext>

A dataset unique identifier like "GHS_POP_E2000_GLOBE_R2019A_54009_250_V1_0.tif" indicates the GHSL Population layer (GHS-POP) of the epoch 2000 with global extent, release R2019A in World Mollweide projection at 250 m resolution v1.0 in GeoTiff format.

The GHSL Data Package 2019 contains the following products:

— GHS Built-up area grid (GHS-BUILT), derived from Sentinel-1 (2016), R2018A [GHS_BUILT_S1NODSM_GLOBE_R2018A]. This product was distributed as part of the Community pre-Release of the GHSL Data Package 2018 (GHS CR2018) (Florczyk *et al*. 2018);

— GHS Built-up area grid (GHS-BUILT), derived from Landsat, multi-temporal (1975-1990-2000-2014), R2018A [GHS_BUILT_LDSMT_GLOBE_R2018A];

— GHS population grid (GHS-POP), derived from GPW4.1, multi-temporal (1975-1990-2000-2015), R2019A [GHS_POP_MT_GLOBE_R2019A]. This product was distributed as part of the Community pre-Release of the GHSL Data Package 2018 (GHS CR2018) (Florczyk *et al*. 2018); however, an updated version of the datasets is available (v2.0);

— GHS Settlement Model grid (GHS-SMOD), derived from GHS-POP and GHS-BUILT, multi-temporal (1975-1990-2000-2015), R2019A [GHS_SMOD_POPMT_GLOBE_R2019A].

1.2 Rationale

Open data and free access are core of principles GHSL (Melchiorri et al., 2019). They are in-line with the Directive on the re-use of public sector information (Directive 2003/98/EC[1]). The free and open access policy facilitates the information sharing and collective knowledge building, thus contributing to a democratisation of the information production.

The GHSL Data Package 2019 contains the new GHSL data produced at the European Commission Directorate General Joint Research Centre in the Directorate for Space, Security and Migration in the Disaster Risk Management Unit (E.1) in the period 2017 – 2019.

1.3 History and Versioning

In 2016 the first GHSL Data Package was released (GHS P2016). It consisted in several multi-temporal and multi-resolution products, including built-up area grids (GHS-BUILT), population grids (GHS-POP), settlement model (GHS-SMOD) and selected quality grids (data mask and confidence grids for GHS-BUILT).

The GHS-BUILT product is the result of a large scale experiment conducted in 2014/1025 aimed at extracting information on built-up areas from Landsat (Pesaresi et al., 2016a), producing the first multi-temporal explicit description of the evolution of built-up presence in the past 40 years. The main product is the

[1] http://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:32003L0098

GHS_BUILT_LDSMT_GLOBE_R2015B[2] (Pesaresi et al., 2015), and two quality grids accompany it: (1) a built-up confidence layer (GHS_BUILTt_LDSMTCNFD_GLOBE_R2015B[3]) and (2) data mask layer (GHS_BUILTt_LDSMTDM_GLOBE_R2015B[4]).

The population grids (GHS_POP_GPW41MT_GLOBE_R2016A[5]) were produced in collaboration with Columbia University, Center for International Earth Science Information Network (CIESIN) in 2015, and the GHS-SMOD grids (GHS_SMOD_POP_GLOBE_R2016A[6]) present an implementation of the REGIO degree of urbanization model using as input the population grid cells.

The products from the GHS R2016 are available at GHSL collection in JRC Open Data Repository[7].

In 2017, a revised image processing workflow was implemented in the JRC Earth Observation Data and Processing Platform (JEODPP), and applied the Landsat multi-temporal imagery collection. As a result, an updated version of the multi-temporal built-up area and population grids has been produced, GHS_BUILT_LDSMT_GLOBE_R2018A and GHS_POP_GPW41MT_GLOBE_R2018A respectively. These early version of the products were distributed only for testing purposes as "preliminary" within the Community pre-Release of the GHSL Data Package 2018 (GHS CR2018) (Florczyk et al., 2018a), together with the GHS_BUILT_S1NODSM_GLOBE_R2018A.

Current data release contains the most updated products and datasets, therefore all previous releases and versions shall be treated as obsolete data.

1.4 Main Characteristics

In order to facilitate the data analytics, as it was done in the GHS P2016, the release includes a set of multi-resolution products produced by aggregation of the main products. Additionally, the density grids are produced in an equal-area projection in grids of 250 m and 1 km spatial resolution. For example, the multi-temporal population grids were produced in grids of 250 m spatial resolution, later aggregated to 1 km^2.

The main differences between the products in GHS P2016 and the current products (GHS P2019) are:

— Improved workflow for built-up area extraction from satellite image, for example, refined learning datasets (e.g., GHS_BUILT_S1NODSM_GLOBE_R2018A_V1_0), production at 30 m spatial resolution;

— Improved approach for production of population grids;

— Technical specification of the grids (i.e., the grid origin);

— Encoding of NoData values (e.g., projection domain, NoData within the data domain).

— Production of population grids in WGS 1984 coordinate system through a thorough volume-preserving warping procedure.

— Improved formulation of the settlement model GHS-SMOD with two hierarchical levels.

The subsections of the Section 2 introduce briefly each product (including more details on differences with the corresponding past version). Dedicated reports are under preparation.

1.5 Terms of Use

The data in this data package are provided free-of-charge © European Union, 2019. Reuse is authorised, provided the source is acknowledged. The reuse policy of the European Commission is implemented by a Decision of 12 December 2011 (2011/833/EU). For any inquiry related to the use of these data please contact the GHSL data producer team at the electronic mail address:

JRC-GHSL-DATA@ec.europa.eu

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[2] http://data.europa.eu/89h/jrc-ghsl-GHS_built_ldsmt_globe_r2015b
[3] http://data.europa.eu/89h/jrc-ghsl-GHS_built_ldsmtcnfd_globe_r2015b
[4] http://data.europa.eu/89h/jrc-ghsl-GHS_built_ldsmtdm_globe_r2015b
[5] http://data.europa.eu/89h/jrc-ghsl-GHS_pop_gpw4_globe_r2015a
[6] http://data.europa.eu/89h/jrc-ghsl-GHS_smod_pop_globe_r2016a
[7] http://data.jrc.ec.europa.eu/collection/ghsl

Disclaimer: The JRC data are provided "as is" and "as available" in conformity with the JRC Data Policy[8] and the Commission Decision on reuse of Commission documents (2011/833/EU). Although the JRC guarantees its best effort in assuring quality when publishing these data, it provides them without any warranty of any kind, either express or implied, including, but not limited to, any implied warranty against infringement of third parties' property rights, or merchantability, integration, satisfactory quality and fitness for a particular purpose. The JRC has no obligation to provide technical support or remedies for the data. The JRC does not represent or warrant that the data will be error free or uninterrupted, or that all non-conformities can or will be corrected, or that any data are accurate or complete, or that they are of a satisfactory technical or scientific quality. The JRC or as the case may be the European Commission shall not be held liable for any direct or indirect, incidental, consequential or other damages, including but not limited to the loss of data, loss of profits, or any other financial loss arising from the use of the JRC data, or inability to use them, even if the JRC is notified of the possibility of such damages.

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[1] JRC Data Policy https://doi.org/10.2788/607378

2 Products

2.1 GHS built-up area grid, derived from Sentinel-1 (2016), R2018A [GHS_BUILT_S1NODSM_GLOBE_R2018A]

The Sentinel-1 product is a layer grid that contains a built-up area classification derived from Sentinel-1 backscatter images. This product increases the spatial coverage of the product produced in 2016, referred to as GHS_BUILT_S12016NODSM_GLOBE_R2016A. The same product has been distributed within the Community pre-Release of the GHSL Data Package 2018 (GHS CR2018).

The information extraction of Sentinel-1A data at global scale is described in a scientific publication (Corbane et al., 2018). The main workflow builds on a new artificial intelligence approach for the satellite data classification process named "Symbolic Machine Learning" (SML) (Pesaresi et al., 2016a). The SML classifier automatically generates inferential rules linking the image data to available high-abstraction semantic layers used as training sets.

The SML workflow was adapted to exploit the key features of the Sentinel-1 Ground Range Detected (GRD) data which are: i) the spatial resolution of 20m with a pixel spacing of 10m and ii) the availability of dual polarisation acquisitions (VV and VH) widely used for monitoring urban areas since different polarizations have different sensitivities and different backscattering coefficients for the same target.

The learning data at the global level consisted of the union of the built-up obtained from the GHSL-Landsat for 2014 and the Global Land Cover map at 30 m resolution (GLC30). The latter has been also derived from Landsat imagery through operational visual analysis techniques (Chen *et al.*, 2015).

The massive processing of more than 7,000 Sentinel-1 scenes (Figure 1) was enabled by JEODPP platform developed in the framework of the JRC Big Data Pilot Project. The platform is set-up to answer the emerging needs of the JRC Knowledge Production units following the new challenges posed by Earth Observation entering the big data era.

Figure 1 Mosaic of the S1 scenes processed within the SML for extracting built-up areas

2.1.1 Input Data

The input imagery collection consists of Sentinel-1A (S1A) and Sentinel-1B (S1B) images:

- 5,026 S1A images from December 2015 to October 2016;
- 1,695 S1A and 329 S1B images from November 2016 to December 2017.

2.1.2 Technical Details

Author: *Christina Corbane*, *Panagiotis Politis*, *Vasileios Syrris*, *Martino Pesaresi*; Joint Research Centre (JRC) European Commission

Product name: GHS_BUILT_S1NODSM_GLOBE_R2018A

Spatial extent: Global

Temporal extent: 2016

Coordinate System: Spherical Mercator (EPSG:3857)

Resolution available: 20 m

*Encoding**: Built-up area classification map (integer) [0,1];

Data organisation (*): VRT file (with TIFF tiles); pyramids; SHP file of the tile schema. **ArcGIS users of the 30 m product: *ESRI.vrt. file**

The grid is provided as a VRT file (with GeoTIFF tiles), and with pyramids. Table 1 below outlines the technical characteristics of the datasets pre-Released in this data package.

Table 1. Technical details of the datasets in GHS_BUILT_S1NODSM_GLOBE_R2018A

GHS_BUILT_S1NODSM_GLOBE_R2018A			
ID	**Description**	**Resolution (projection)**	**Size**
GHS_BUILT_S1NODSM _GLOBE_R2018A _3857_20_V1_0.vrt	Classification map depicting built-up presence. 0 = no built-up or no data 1 = built-up are **ArcGIS users: *ESRI.vrt.file**	20 m (Pseudo Mercator)	8.6 GB

2.1.3 How to cite

Dataset:

Corbane, Christina; Politis, Panagiotis; Syrris, Vasileios; Pesaresi, Martino (2018): GHS built-up grid, derived from Sentinel-1 (2016), R2018A. European Commission, Joint Research Centre (JRC) doi:10.2905/jrc-ghsl-10008 PID: http://data.europa.eu/89h/jrc-ghsl-10008

Concept & Methodology:

Corbane, Christina; Pesaresi, Martino; Politis, Panagiotis; Syrris, Vasileios; Florczyk, Aneta J.; Soille, Pierre; Maffenini, Luca; Burger, Armin; Vasilev, Veselin; Rodriguez, Dario; Sabo, Filip; Dijkstra, Lewis; Kemper, Thomas (2017): Big earth data analytics on Sentinel-1 and Landsat imagery in support to global human settlements mapping, Big Earth Data, 1:1-2, 118-144, DOI: 10.1080/20964471.2017.1397899

2.2 GHS built-up area grid (GHS-BUILT), derived from Landsat, multi-temporal (1975-1990-2000-2014), R2018A [GHS_BUILT_LDSMT_GLOBE_R2018A]

The Landsat product contains a set of multi-temporal and multi-resolution grids. The main product is the multi-temporal classification layer on built-up presence derived from the Global Land Survey (GLS) Landsat[9] image collections (GLS1975, GLS1990, GLS2000, and ad-hoc Landsat 8 collection 2013/2014). This data release contains version 2.0 of the product which is an updated version of the one distributed within the Community pre-Release of the GHSL Data Package 2018 (GHS CR2018).

2.2.1 Improvements comparing to the previous version

The satellite-derived information extraction tasks included in the GHSL production workflow used to produce the products GHS_BUILT_LDSMT_GLOBE_R2015B and GHS_BUILT_LDSMT_GLOBE_R2018A, builds on the Symbolic Machine learning (SML) method that was designed for remote sensing big data analytics (Pesaresi et al., 2016b). For the purpose of the GHS_BUILT_LDSMT_GLOBE_R2018A, a revised image processing workflow was implemented in the JRC Earth Observation Data and Processing Platform (JEODPP).

Comparing to the previous publicly released version (R2015B), these datasets include a number of improvements, as shown through visual comparison in Figure 2. Such improvement are:

- Improved spatial coverage (additional Landsat 8 scenes)
- Improved spatial resolution (30 m)
- Improved methods (e.g., improved learning data set), which resulted in:
    - Reduction in omission error (i.e. more built-up areas were detected)
    - Reduction in commission error (i.e. less detection of false built-up areas)

Corbane et al., (2019) explains in detail the rationale, the workflow deployed to generate the layer, mainly the usage of the GHSL Sentinel-1 data set (GHS_BUILT_S1NODSM_GLOBE_R2018A) as a learning dataset, and the multi-temporal validation of the layer.

2.2.2 Input Data

The new product GHS_BUILT_LDSMT_GLOBE_R2018A (version 2.0) is based on 33,202 images (Florczyk et al., 2018b) organized in four Landsat data collections centred at 1975, 1990, 2000 and 2014 that were processed with the SML classifier as follows:

- 7,597 scenes acquired by the Multispectral Scanner (collection 1975);
- 7,375 scenes acquired by the Landsat 4-5 Thematic Mapper (TM) (collection 1990);
- 8,788 scenes acquired by the Landsat 7 Enhanced Thematic Mapper Plus (ETM+) (collection 2000) and;
- 9,442 scenes acquired by Landsat 8 (collection 2014).

2.2.3 Technical Details

Author: *Christina Corbane*, *Aneta J. Florczyk*, *Martino Pesaresi*, *Panagiotis Politis*, *Vasileius Syrris*; Joint Research Centre (JRC) European Commission

Product name: GHS_BUILT_LDSMT_GLOBE_R2018A

Spatial extent: Global

Temporal extent: 1975-1990-2000-2014

*Coordinate Systems**: Spherical Mercator (EPSG:3857), World Mollweide (EPSG:54009)

*Resolutions available**: 30 m, 250 m, 1 km

[9] http://glcf.umd.edu/data/gls/

*Encoding**: Multi-temporal built-up area classification map (integer): [1,6], NoData: 0; Built-up density grid (float32): [0-100], NoData [-200]

Data organisation (*): VRT file (with GeoTIFF tiles) or GeoTIFF files; as single global layers, with pyramids and SHP file of tile schema, or tiled; **ArcGIS users of the 30 m product: *ESRI.vrt.file**.

Table 2 outlines the technical characteristics of the datasets released in this data package.

(*) product dependent, see Table 2. Disclaimer: the re-projection of the World Mollweide version of the GHS_BUILT_LDSMT_GLOBE_R2018A to coordinate systems requires specific technical knowledge. No responsibility is taken for workflows developed independently by users.

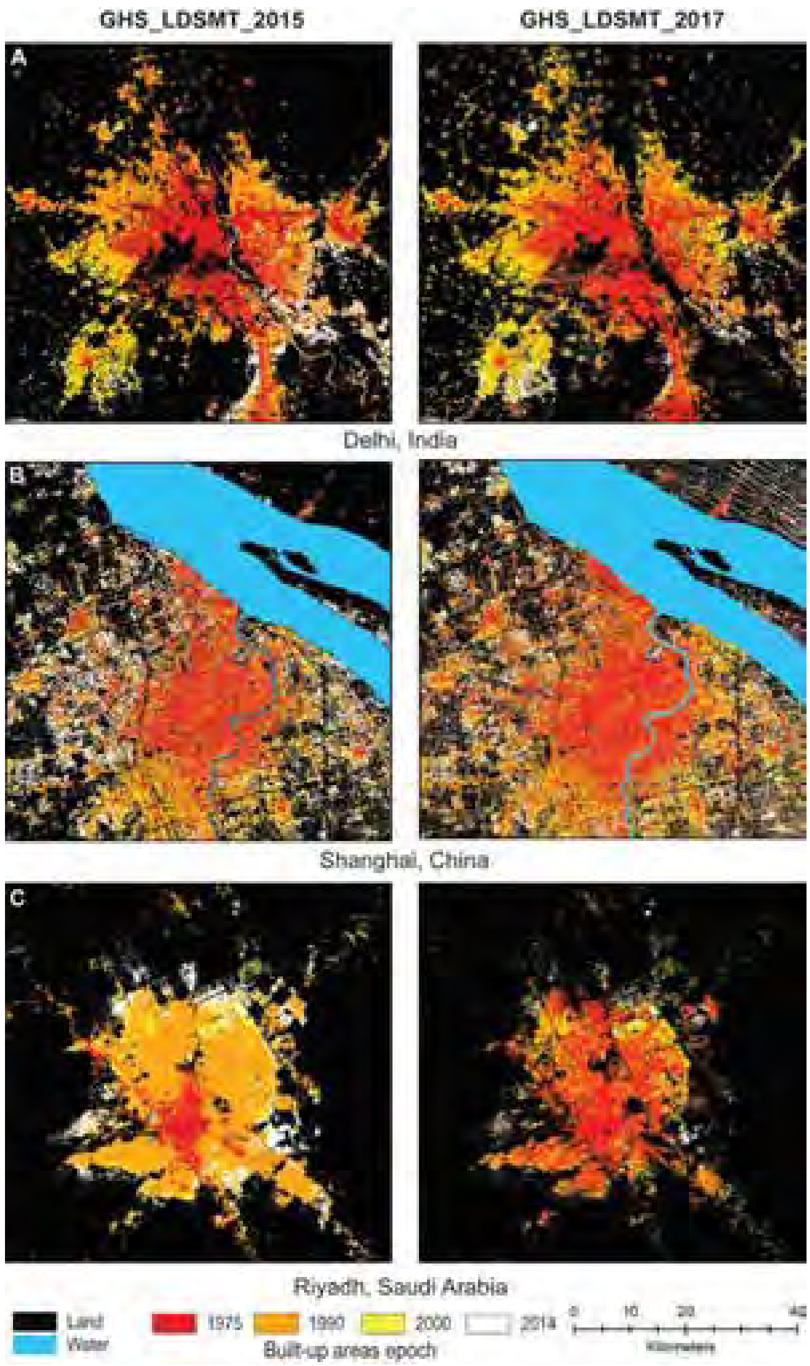

Figure 2 Comparison between GHS_BUILT_LDSMT_GLOBE_R2015B (left panel – GHS_LDSMT_2015) and GHS_BUILT_LDSMT_GLOBE_R2018A, version 2.0 (right panel – GHS_LDSMT_2017). In (Corbane et al., 2019)

Table 2. Technical details of the datasets in GHS_BUILT_ LDSMT_GLOBE_R2018A

GHS_BUILT_LDSMT_GLOBE_R2018A			
ID	**Description**	**Resolution (projection)**	**Size**
GHS_BUILT_LDSMT _GLOBE_R2018A _3857_30_V2_0	Multi-temporal classification of built-up presence. 0 = no data 1 = water surface 2 = land no built-up in any epoch 3 = built-up from 2000 to 2014 epochs 4 = built-up from 1990 to 2000 epochs 5 = built-up from 1975 to 1990 epochs 6 = built-up up to 1975 epoch **ArcGIS users: *ESRI.vrt.file**	30 m (Pseudo Mercator)	4.3 GB
GHS_BUILT_LDS2014 _GLOBE_R2018A _54009_250_V2_0	Built-up area density for epoch 2014, aggregated from 30 m. Values are expressed as decimals (Float) from 0 to 100 NoData [-200]: -200 – out of projection domain or NoData	250 m (World Mollweide)	398 MB
GHS_BUILT_LDS2000 _GLOBE_R2018A _54009_250_V2_0	Built-up area density for epoch 2000, aggregated from 30 m. Values are expressed as decimals (Float) from 0 to 100 NoData [-200]: -200 – out of projection domain or NoData	250 m (World Mollweide)	353 MB
GHS_BUILT_LDS1990 _GLOBE_R2018A _54009_250_V2_0	Built-up area density for epoch 1990, aggregated from 30 m. Values are expressed as decimals (Float) from 0 to 100 NoData [-200]: -200 – out of projection domain or NoData	250 m (World Mollweide)	316 MB
GHS_BUILT_LDS1975 _GLOBE_R2018A _54009_250_V2_0	Built-up area density for epoch 1975, aggregated from 30 m. Values are expressed as decimals (Float) from 0 to 100 NoData [-200]: -200 – out of projection domain or NoData	250 m (World Mollweide)	274 MB
GHS_BUILT_LDS2014 _GLOBE_R2018A _54009_1K_V2_0	Built-up area density for epoch 2014, aggregated from 30 m. Values are expressed as decimals (Float) from 0 to 100 NoData [-200]: -200 – out of projection domain or NoData	1 km (World Mollweide)	86 MB
GHS_BUILT_LDS2000 _GLOBE_R2018A _54009_1K_V2_0	Built-up area density for epoch 2000, aggregated from 30 m. Values are expressed as decimals (Float) from 0 to 100 NoData [-200]: -200 – out of projection domain or NoData	1 km (World Mollweide)	76 MB
GHS_BUILT_LDS1990 _GLOBE_R2018A _54009_1K_V2_0	Built-up area density for epoch 1990. Aggregated from 30 m. Values are expressed as decimals (Float) from 0 to 100 NoData [-200]: -200 – out of projection domain or NoData	1 km (World Mollweide)	68 MB
GHS_BUILT_LDS1975 _GLOBE_R2018A _54009_1K_V2_0	Built-up area density for epoch 1975. Aggregated from 30 m. Values are expressed as decimals (Float) from 0 to 100 NoData [-200]: -200 – out of projection domain or NoData	1 km (World Mollweide)	58 MB

2.2.4 How to cite

Dataset:

Corbane, Christina; Florczyk, Aneta; Pesaresi, Martino; Politis, Panagiotis; Syrris, Vasileios (2018): GHS built-up grid, derived from Landsat, multitemporal (1975-1990-2000-2014), R2018A. European Commission, Joint Research Centre (JRC) doi:10.2905/jrc-ghsl-10007 PID: http://data.europa.eu/89h/jrc-ghsl-10007

Concept & Methodology:

Corbane, Christina., Pesaresi, Martino., Kemper, Thomas., Politis, Panagiotis., Florczyk, Aneta J., Syrris, Vasileios, Melchiorri, Michele, Sabo, Filip, and Soille, Pierre (2019). Automated global delineation of human settlements from 40 years of Landsat satellite data archives. Big Earth Data 3, 140–169. DOI:10.1080/20964471.2019.1625528

2.3 GHS population grid (GHS-POP), derived from GPW4.10, multi-temporal (1975-1990-2000-2015), R2019A [GHS_POP_MT_GLOBE_R2019A]

This spatial raster product depicts the distribution and density of population (Figure 3), expressed as the number of people per cell. Residential population estimates for target years 1975, 1990, 2000 and 2015 provided by CIESIN Gridded Population of the World, version 4.10 (GPWv4.10) at polygon level, were disaggregated from census or administrative units to grid cells, informed by the distribution and density of built-up as mapped in the Global Human Settlement Layer (GHSL) global layer per corresponding epoch. The disaggregation methodology is described in a conference scientific paper (Freire et al., 2016)). This an updated version of the product (GHS_POP_GPW41MT_GLOBE_R2018A) distributed within the Community pre-Release of the GHSL Data Package 2018 (GHS CR2018).

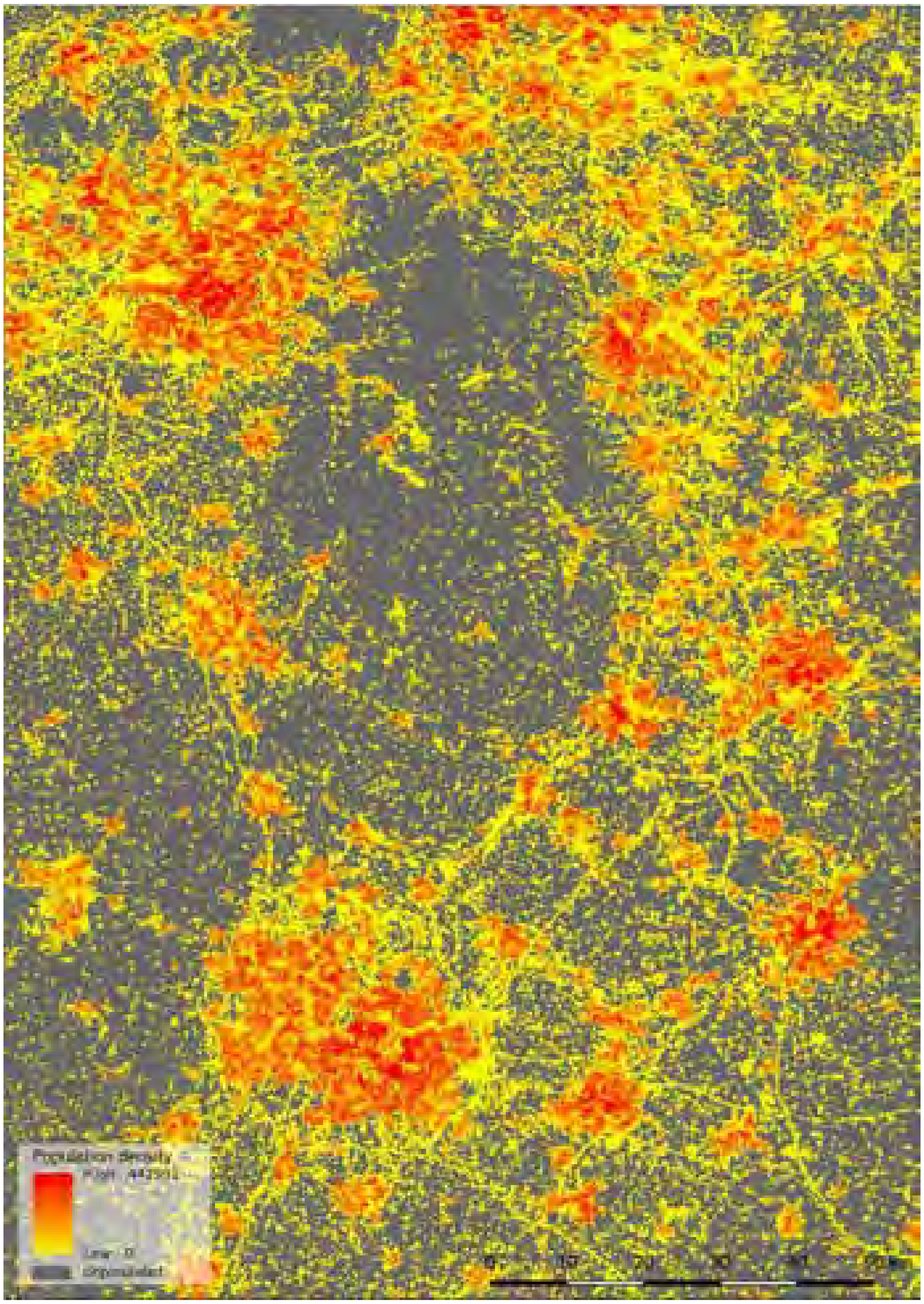

Figure 3 GHS Population grid (GHS-POP) GHS_POP_E2015_GLOB_R2019A_54009_250_V1_0 displayed in West Midlands (United Kingdom).

2.3.1 Improvements comparing to the previous version

The new version of the GHSL population distribution grids aimed at incorporating improvements originating from input datasets, namely population estimates and built-up presence. While the disaggregation relied essentially on the same clear and simple approach, there were significant differences to the input data that had a positive effect on the final quality and accuracy of population grids. Here, we describe the main differences between the currently released products (GHS_POP_MT_GLOBE_R2019A) and the previous one (GHS_POP_GPW41_GLOBE_R2015A), for more information on these improvements, see the related scientific publication (Freire et al., 2018).

For the new GHS-POP (GHS_POP_MT_GLOBE_R2019A), the new Landsat based GHS-BUILT (GHS_BUILT_LDSMT_GLOBE_R2018A, version 2.0) was used as target for disaggregation of population estimates. Cells declared as "NoData" in built-up layers were treated as zero for population disaggregation.

The base source of population estimates (both counts and geometries) for the four epochs mapped was the Gridded Population of the World, version 4.10 (GPWv4.10), from CIESIN/SEDAC. Respect to the previous release of GHSL Data Package 2016 (GHS P2016), this release used GPW source data that incorporated boundary or population updates for 67 countries.

Due to the previous GHSL population grids being produced in last quarter of 2015, before the final GPWv4 data set was fully assembled, more changes were included in population sources in the current release than those incorporated in the GPW data between GPWv4 and the current GPWv4.10. For detailed information on what has changed in GPWv4.10, refer to:

https://sedac.ciesin.columbia.edu/data/collection/gpw-v4/whatsnewrev10

GHS-POP product is produced in Mollweide at 250 m, and then aggregated at 1 km. These two datasets are then warped to WGS 1984 coordinate system, at 9 arcsec and 30 arcsec resolution respectively, by applying a thorough volume-preserving procedure (i.e. oversampling at 10-times higher resolution; transformation of raster to points, using cell centroids; vector warping to WGS 1984; and rasterization in the final grid by adding point values per pixel).

2.3.1.1 Harmonisation of Coastlines

Seashore and waterfront can be especially intense and dynamic zones, contributing to making census or administrative geometries outdated and inaccurate. Inconsistencies between census data and GHSL along coastlines (including inland water bodies) were detected and reconciled accordingly. The high-resolution GHSL layer on built-up areas for 2014 (from R2015B) was used to detect significant human presence (i.e. built-up areas presence) beyond censuses' coastlines and these lines were reconciled accordingly. This harmonization was carried out in the following countries:

Albania	Finland	Romania
Austria	France	Russia
Azerbaijan	Guinea-Bissau	Singapore
Bulgaria	Iceland	Sweden
Bahrain	Japan	Tunisia
Switzerland	Republic of Korea	Ukraine
Germany	Malaysia	USA
Denmark	Netherlands	Venezuela
United Arab Emirates	Norway	Viet Nam

2.3.1.2 Revision of Unpopulated Areas

Units deemed as "uninhabited" in the census data were critically assessed for presence of residential population, based on ancillary data and high-resolution imagery. Inconsistencies between census data and contradicting evidence were detected and reconciled accordingly. An automated method was devised to split and merge these polygons, based on geographical proximity, with those ones adjacent and containing population. This procedure was implemented while minimizing changes to source geometry, preserving the regional distribution of population, and the overall counts. This procedure was carried out in the following countries:

Afghanistan
Armenia
Democratic Republic of the Congo
Colombia
Cyprus
Egypt
Georgia
Guyana
Iraq
Lebanon
Mali
Malawi
Nepal
Rwanda
Thailand
Ukraine

2.3.2 Input Data

The new product GHS_BUILT_LDSMT_GLOBE_R2018A (version 2.0) was used as target for disaggregation of population estimates. The base source of population estimates for the four epochs was the Gridded Population of the World, version 4.10 (GPWv4.10), from CIESIN/SEDAC, with some modifications as described above.

2.3.3 Technical Details

Author: Sergio Freire, Marcello Schiavina, Joint Research Centre (JRC) European Commission; *Kytt MacManus* Columbia University, Center for International Earth Science Information Network - CIESIN.

Product name: GHS_POP_MT_GLOBE_R2019A

Spatial extent: Global

Temporal extent: 1975-1990-2000-2015

Coordinate Systems: World Mollweide (EPSG: 54009) and WGS 1984 (EPSG: 4326)

Resolutions available: 250 m, 1 km, 9 arcsec, 30 arcsec

Encoding: Population data float32 [0, ∞); NoData: -200

Data organisation: The grids are provided as GeoTIFF file as single global layer with pyramids or tiled.

Table 3 outlines the technical characteristics of the datasets released in this data package.

Table 3. Technical details of the datasets in GHS_POP_MT_GLOBE_R2019A

GHS_POP_MT_GLOBE_R2019A			
ID	**Description**	**Resolution (Projection/Coordinate system)**	**Size**
GHS_POP_E2015_ GLOBE_R2019A _54009_250_V1_0	Population density for epoch 2015 Values are expressed as decimals (Float) from 0 to 442591 NoData [-200]	250 m (World Mollweide)	515 MB
GHS_POP_E2000_ GLOBE_R2019A _54009_250_V1_0	Population density for epoch 2000 Values are expressed as decimals (Float) from 0 to 303161 NoData [-200]	250 m (World Mollweide)	476 MB
GHS_POP_E1990_ GLOBE_R2019A _54009_250_V1_0	Population density for epoch 1990 Values are expressed as decimals (Float) from 0 to 237913 NoData [-200]	250 m (World Mollweide)	451 MB
GHS_POP_E1975 _GLOBE_R2019A _54009_250_V1_0	Population density for epoch 1975 Values are expressed as decimals (Float) from 0 to 899329 NoData [-200]	250 m (World Mollweide)	427 MB
GHS_POP_E2015 _GLOBE_R2019A _54009_1K_V1_0	Population density for epoch 2015 Values are expressed as decimals (Float) from 0 to 442591 NoData [-200]	1 km (World Mollweide)	124 MB
GHS_POP_E2000 _GLOBE_R2019A _54009_1K_V1_0	Population density for epoch 2000 Values are expressed as decimals (Float) from 0 to 341997 NoData [-200]	1 km (World Mollweide)	121 MB

GHS_POP_E1990 _GLOBE_R2019A _54009_1K_V1_0	Population density for epoch 1990 Values are expressed as decimals (Float) from 0 to 1013921 NoData [-200]	1 km (World Mollweide)	120 MB
GHS_POP_E1975 _GLOBE_R2019A _54009_1K_V1_0	Population density for epoch 1975 Values are expressed as decimals (Float) from 0 to 3017848 NoData [-200]	1 km (World Mollweide)	122 MB
GHS_POP_E2015 _GLOBE_R2019A _4326_9SS_V1_0	Population count for epoch 2015 Values are expressed as decimals (Float) from 0 to 302832 NoData [-200]	9 arcsec (WGS84)	1.52 GB
GHS_POP_E2000 _GLOBE_R2019A _4326_9SS_V1_0	Population count for epoch 2000 Values are expressed as decimals (Float) from 0 to 209939 NoData [-200]	9 arcsec (WGS84)	1.50 GB
GHS_POP_E1990 _GLOBE_R2019A _4326_9SS_V1_0	Population count for epoch 1990 Values are expressed as decimals (Float) from 0 to 164755 NoData [-200]	9 arcsec (WGS84)	1.53 GB
GHS_POP_E1975 _GLOBE_R2019A _4326_9SS_V1_0	Population count for epoch 1975 Values are expressed as decimals (Float) from 0 to 611544 NoData [-200]	9 arcsec (WGS84)	1.58 GB
GHS_POP_E2015 _GLOBE_R2019A _4326_30SS_V1_0	Population count for epoch 2015 Values are expressed as decimals (Float) from 0 to 459435 NoData [-200]	30 arcsec (WGS84)	240 MB
GHS_POP_E2000 _GLOBE_R2019A _4326_30SS_V1_0	Population count for epoch 2000 Values are expressed as decimals (Float) from 0 to 303161 NoData [-200]	30 arcsec (WGS84)	237 MB
GHS_POP_E1990 _GLOBE_R2019A _4326_30SS_V1_0	Population count for epoch 1990 Values are expressed as decimals (Float) from 0 to 650409 NoData [-200]	30 arcsec (WGS84)	241 MB
GHS_POP_E1975 _GLOBE_R2019A _4326_30SS_V1_0	Population count for epoch 1975 Values are expressed as decimals (Float) from 0 to 2109200 NoData [-200]	30 arcsec (WGS84)	247 MB

2.3.4 How to cite

Dataset:

Schiavina, Marcello; Freire, Sergio; MacManus, Kytt (2019): GHS population grid multitemporal (1975, 1990, 2000, 2015) R2019A. European Commission, Joint Research Centre (JRC) DOI: ***under release, updated on:*** *http://ghsl.jrc.ec.europa.eu/documents/GHSL_Data_Package_2019.pdf*

Concept & Methodology:

Freire, Sergio; MacManus, Kytt; Pesaresi, Martino; Doxsey-Whitfield, Erin; Mills, Jane (2016): Development of new open and free multi-temporal global population grids at 250 m resolution. Geospatial Data in a Changing World; Association of Geographic Information Laboratories in Europe (AGILE). AGILE 2016.

2.4 GHS Settlement Model grid (GHS-SMOD), derived from GHS-POP and GHS-BUILT, multi-temporal (1975-1990-2000-2015), R2019A [GHS_SMOD_POPMT_GLOBE_R2019A]

The GHS Settlement Model grid (GHS-SMOD) GHS_SMOD_POPMT_GLOBE_R2019A delineates and classify settlement typologies (Figure 4) via a logic of population size, population and built-up area densities as a refinement of the 'degree of urbanization' method as described by EUROSTAT[10]. The GHS-SMOD is derived by using the GHS-POP (GHS_POP_MT_GLOBE_R2019A, version 1.0) and GHS-BUILT (GHS_BUILT_LDSMT_GLOBE_R2018A, version 2.0) released within this GHSL Data Package 2019 (GHS P2019).

2.4.1 Improvements comparing to the previous version

The GHS Settlement Model grid is an improvement of the GHS Settlement Grid (R2016A) introducing a more detailed classification of settlements in two levels, also called 'refined degree of urbanization'. The Settlement Model is provided at the detailed level (Second Level - L2). First level, as a porting of the Degree of Urbanization adopted by EUROSTAT can be obtained aggregating L2 as shown in the first level (L1) description (see Table 7).

The L2 classifies seven settlement typologies plus permanent water surfaces as showed in Table 4. Settlement typologies are identified at L2 with a two digit code (30 – 23 – 22 – 21 – 13 – 12 – 11 – 10), linking to grid level and municipal level description terms (both the municipal and grid level terms are accompanied by a technical term). Classes 30 – 23 – 22 – 21 if aggregated form the "urban domain", 13 – 12 – 11 – 10 form the "rural domain". Table 5 shows the L2 grid cells population (expressed as people per square kilometre: people/km^2) and built-up area (expressed as square kilometres: km^2) expected characteristics in terms of min-max population and built-up density bounds. Table 6 presents the logic to define settlement typologies:

- **Typology 30**, is defined as: all cells with a local population density of at least 1,500 people/km^2 *or* with a local built-up area share of at least 0.50, *and* clustered in a 4-connectivity object of at least 50,000 people *or* all cells resulting from 3x3 median filtering *or* by gap filling < 15 km^2 (median filtering and gap filling applied to cluster of cells that met the previous logics);
- **Typology 23**, is defined as: all cells with a local population density of at least 1,500 people/km^2 *or* with a local built-up area share of at least 0.50, *and* clustered in a 4-connectivity object of at least 5,000 people *and are not* typology 30;
- **Typology 22**, is defined as: all cells with a local population density of at least 300 people/km^2 *and* with a local built-up area share of at least 0.03, *or* all cells with a local population density of at least 1,500 people/km^2 *or* built-up area share of at least 0.5, clustered in a 4-connectivity object of at least 5,000 people, farther than 3 km from a typology 23 *or* typology 22, *and are not* typology 30 *or* typology 23;
- **Typology 21**, is defined as: all cells with a local population density of at least 300 people/km^2 *and* with a local built-up area share of at least 0.03, *or* all cells with a local population density of at least 1,500 people/km^2 *or* built-up area share of at least 0.5, clustered in a 4-connectivity object of at least 5,000 people, within than 3 km from a typology 23 *or* typology 22, *and are not* typology 30 *or* typology 23;
- **Typology 13**, is defined as: all cells with a local population density of at least 300 people/km^2 *or* with a local built-up area share of at least 0.50, *and* clustered in a 4-connectivity object of at least 500 people *and are not* typology 30 *or* typology 2X;
- **Typology 12**, is defined as: all cells with a local population density of at least 50 people/km^2 *and are not* typology 30 *or* typology 2X *or* typology 13;
- **Typology 11**, is defined as: all cells that are on land *and are not* typology 30 *or* typology 2X *or* typology 13 *or* typology 12;
- **Typology 10**, is defined as: all cells that are not on land.

[10] https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Degree_of_urbanisation

Table 4 Settlement Model L2 legend

SECOND LEVEL (L2)			
Code	**RGB**	**Grid level term** ***Technical term***	**Municipal level term** ***Technical term***
30	255, 0, 0	URBAN CENTRE *LARGE CLUSTER*	CITY *LARGE SETTLEMENT*
23	115, 38, 0	DENSE URBAN CLUSTER *DENSE MEDIUM-SIZED CLUSTER*	DENSE TOWN *DENSE MEDIUM SETTLEMENT*
22	168, 112, 0	SEMI-DENSE URBAN CLUSTER *SEMI-DENSE MEDIUM-SIZED CLUSTER*	SEMI-DENSE TOWN *SEMI-DENSE MEDIUM SETTLEMENT*
21	255, 255, 0	SUBURBAN GRID CELL *SEMI-DENSE GRID CELL NEAR A MEDIUM OR LARGE CLUSTER*	SUBURBS *SEMI-DENSE AREA NEAR A MEDIUM OR LARGE SETTLEMENT*
13	55, 86, 35	RURAL CLUSTER *SMALL CLUSTER*	VILLAGE *SMALL SETTLEMENT*
12	171, 205, 102	LOW DENSITY RURAL GRID CELL *LOW DENSITY RURAL GRID CELL*	RURAL DISPERSED AREA *LOW DENSITY DISPERSED AREA*
11	205, 245, 122	VERY LOW DENSITY GRID CELL *VERY LOW DENSITY GRID CELL*	MOSTLY UNINHABITED *VERY LOW DENSITY AREA*
10	122, 182, 245	WATER	WATER

Table 5 Settlement Model L2 grid cells population and built-up area characteristics

L2 GRID CELLS CHARACTERISTICS (min-max bounds)				
Code	**Population**		**Built-up areas**	
	Minimum density expected (people/km²)	**Maximum density expected (people/km²)**	**Minimum on land share (km²)**	**Maximum on land share (km²)**
30	0	∞	0	1
23	0	50,000	0	1
22	0	5,000	0	1
21	0	5,000	0	1
13	0	5,000	0	1
12	50	500	0	1
11	0	50	0	1
10	0	0	0	0

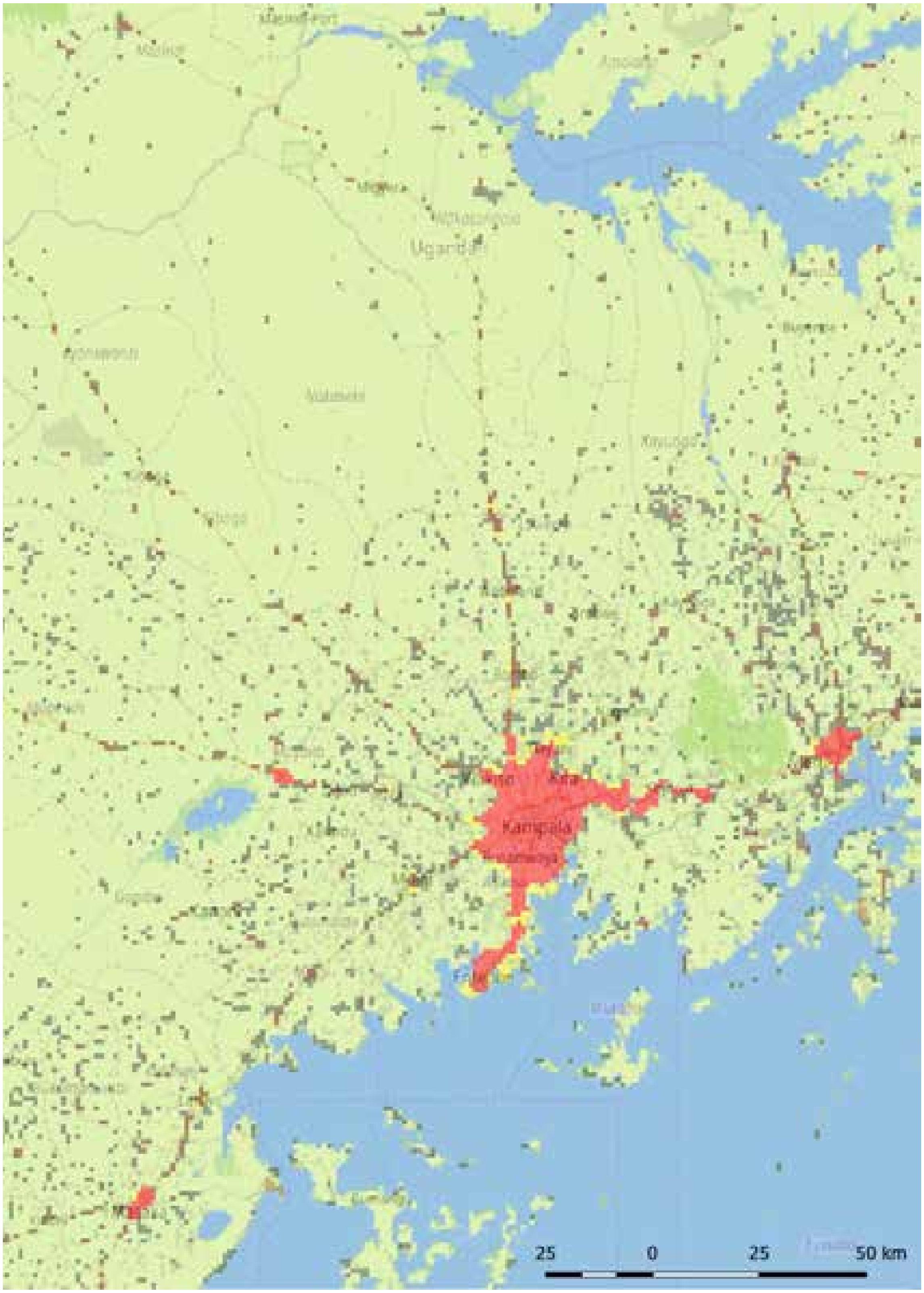

Figure 4 GHS Settlement Model grid (GHS-SMOD) GHS_SMOD_POP2015_GLOBE_R2019A_54009_1K_V1_0 displayed in the area of Kampala (Uganda) –Legend in Table 4. The boundaries and the names shown on this map do not imply official endorsement or acceptance by the European Union © OpenStreetMap

Table 6 Settlement Model L2 synthetic explanation of logical definition and grid cell sets

L2 LOGIC								
		Grid cell sets used in the logical definition (shares defined on land surface)						
Code	**Logical Definition at 1 km² grid cell**	**P_{dens}: Local Population Density lower bound ">" (people/km²)**	**$P2_{dens}$: Local Population Density lower bound ">" (people/km²)**	**P_{min}: Cluster Population lower bound ">" (people)**	**B_{dens}: Local share of Built-up Area lower bound ">" (km²)**	**$B2_{dens}$: Local share of Built-up Area lower bound ">" (km²)**	**T_{con}: Topological constrains**
30	$(P_{dens} \vee B_{dens}) \wedge P_{min} \wedge T_{con} \vee$ [median_filter(3-by-3)] $\vee$ [gap_fill(<15km2)]	1,500	none	50,000	0.50	none	4-connectivity objects
23	$(P_{dens} \vee B_{dens}) \wedge P_{min} \wedge T_{con} \wedge \neg 30$	1,500	none	5,000	0.50	none	4-connectivity objects
22	$((P_{dens} \wedge B_{dens}) \vee (P2_{dens} \vee B2_{dens})) \wedge P_{min} \wedge T_{con} \wedge \neg (30 \vee 23)$	300	1,500	5,000	0.03	0.50	4-connectivity objects; farther than 3km from 23 or 30
21	$((P_{dens} \wedge B_{dens}) \vee (P2_{dens} \vee B2_{dens})) \wedge P_{min} \wedge T_{con} \wedge \neg (30 \vee 23)$	300	1,500	5,000	0.03	0.50	4-connectivity objects; (within 3km from 23 or 30)
13	$(P_{dens} \vee B_{dens}) \wedge P_{min} \wedge T_{con} \wedge \neg (30 \vee 2X)$	300	none	500	0.50	none	4-connectivity objects
12	$P_{dens} \wedge \neg (30 \vee 2X \vee 13)$	50	none	none	none	none	none
11	$T_{con} \wedge \neg (30 \vee 2X \vee 13 \vee 12)$	none	none	none	none	none	On Land (Land>=50% $\vee$ BU[11]>0% $\vee$ Pop>0)
10	T_{con}	none	none	none	none	none	Not on Land

[11] Retaining only contiguous BU at least partially on land.

The first level (L1) is obtained by aggregation of L2 according to the first digit of the code, as shown in Table 7 and it represents a porting of the EUROSTAT "degree of urbanization".

Table 7 Aggregation of L2 class typologies to L1 class typologies (EUROSTAT Degurba model)

30	→	3
23 – 22 – 21	→	2
13 – 12 – 11 – 10	→	1

L1 classifies three settlement typologies as displayed in Table 8. Settlement typologies are identified at L1 with a single digit code (3 – 2 – 1), and grid level and municipal level terms (both the municipal and grid level are accompanied by a technical term), HDC for type 3, MDC for type 2, and LDC for type 1). Classes 3 - 2 if aggregated form the "urban domain", 1 forms the "rural domain". Table 9 shows the L1 grid cells population and built-up area characteristics in terms of min-max population and built-up density bounds. Table 10 presents the logic to define settlement typologies:

— **Typology 3**, is defined as: all cells with a local population density of at least 1,500 people/km^2 *or* with a local built-up area share of at least 0.50, *and* clustered in a 4-connectivity object of at least 50,000 people *or* all cells resulting from 3x3 median filtering *or* by gap filling < 15 km^2 (median filtering and gap filling applied to cluster of cells that met the previous logics);

— **Typology 2**, is defined as: all cells with a local population density of at least 300 people/km^2 *and* with a local built-up area share of at least 0.03, *or* all cells with a local population density of at least 1,500 people/km^2 *or* built-up area share of at least 0.50, clustered in a 4-connectivity object of at least 5,000 people *and are not* typology 3;

— **Typology 1**, all cells that *are not* typology 3 and typology 2.

Table 8 Settlement Model L1 legend

FIRST LEVEL (L1)			
Code	**RGB**	**Grid level term** ***Technical term***	**Municipal level term** ***Technical term***
3	255, 0, 0	URBAN CENTRE *HIGH DENSITY CLUSTER (**HDC**)*	CITY *DENSELY POPULATED AREA*
2	*255, 170, 0*	URBAN CLUSTER *MODERATE DENSITY CLUSTER (**MDC**)*	TOWNS & SUBURBS *INTERMEDIATE DENSITY AREA*
1	115, 178, 115	RURAL GRID CELLS *LOW DENSITY GRID CELL (**LDC**)*	RURAL AREA *THINLY POPULATED AREA*

Table 9 Settlement Model L1 grid cells population and built-up area characteristics

L1 GRID CELLS CHARACTERISTICS (min-max bounds)				
Code	**Population**		**Built-up Area**	
	Minimum density expected (people/km^2)	**Maximum density expected (people/km^2)**	**Minimum on land share (km^2)**	**Maximum on land share (km^2)**
3	0	∞	0	1
2	0	50,000	0	1
1	0	5,000	0	1

Table 10 Settlement Model L1 synthetic explanation of logical definition and grid cell sets

L1 LOGIC							
Code	**Logical Definition at 1 km² grid cell**	**Grid cell sets used in the logical definition (shares defined on land surface)**					
		P_{dens}: **Local Population Density lower bound ">" (people/km²)**	**$P2_{dens}$:** **Local Population Density lower bound ">" (people/km²)**	**P_{min}:** **Cluster Population lower bound ">" (people)**	**B_{dens}:** **Local share of Built-up Area lower bound ">" (km²)**	**$B2_{dens}$:** **Local share of Built-up Area lower bound ">" (km²)**	**T_{con}:** **Topological constrains**
3	$((P_{dens} \lor B_{dens}) \land P_{min} \land T_{con}) \lor$ [median_filter(3-by-3)] $\lor$ [gap_fill(<15km²)]	1,500	none	50,000	0.50	none	4-connectivity objects
2	$((P_{dens} \land B_{dens}) \lor (P2_{dens} \lor B2_{dens})) \land P_{min} \land T_{con} \land \neg 3$	300	1,500	5,000	0.03	0.50	4-connectivity objects
1	$\neg (3 \lor 2)$	none	none	none	none	none	none

2.4.2 Input Data

The input data are the multi-temporal GHS-BUILT and GHS-POP grids of the GHSL Data Package 2019 (GHS P2019). Land is extracted as a combination of the Global ADMinstrative Map 2.8[12] and the Global Surface Water Layer Occurrence[13].

2.4.3 Technical Details

Author: *Martino Pesaresi*, *Aneta Florczyk*, *Marcello Schiavina*, *Luca Maffenini*, *Michele Melchiorri*, Joint Research Centre (JRC) European Commission.

Product name: GHS_SMOD_POP_GLOBE_R2019A

Spatial extent: Global

Temporal extent: 1975-1990-2000-2015

Coordinate System: World Mollweide (EPSG: 54009)

Resolution available: 1 km

Encoding: integer16 [30 – 23 – 22 – 21 – 13 – 12 – 11 – 10], No Data: -200

Data organisation: TIF with CLR colormap (L2_colcod.tif.clr) file as single global layer or tiled.

Table 11 outlines the technical characteristics of the datasets released in this data package.

Table 11. Technical details of the datasets in GHS_SMOD_POPMT_GLOBE_R2019A

GHS_SMOD_POPMT_GLOBE_R2019A			
ID	**Description**	**Resolution (Projection)**	**Size**
GHS_SMOD_POP2015 _GLOBE_R2019A _54009_1K_V1_0	Settlement typology codes for epoch 2015 NoData [-200]	1 km (World Mollweide)	12 MB
GHS_SMOD_POP2000 _GLOBE_R2019A _54009_1K_V1_0	Settlement typology codes for epoch 2000 NoData [-200]	1 km (World Mollweide)	11.5 MB
GHS_SMOD_POP1990 _GLOBE_R2019A _54009_1K_V1_0	Settlement typology codes for epoch 1990 NoData [-200]	1 km (World Mollweide)	11 MB
GHS_SMOD_POP1975 _GLOBE_R2019A _54009_1K_V1_0	Settlement typology codes for epoch 1975 NoData [-200]	1 km (World Mollweide)	10.5 MB

2.4.4 How to cite

Dataset:

Pesaresi, Martino; Florczyk, Aneta; Schiavina, Marcello; Melchiorri, Michele; Maffenini, Luca (2019): GHS settlement grid, updated and refined REGIO model 2014 in application to GHS-BUILT R2018A and GHS-POP R2019A, multitemporal (1975-1990-2000-2015), R2019A. European Commission, Joint Research Centre (JRC) DOI: ***under release, updated on:*** *http://ghsl.jrc.ec.europa.eu/documents/GHSL_Data_Package_2019.pdf*

Concept & Methodology:

Florczyk, Aneta J.; Corbane, Christina; Ehrlich, Daniele; Freire, Sergio; Kemper, Thomas; Maffenini, Luca; Melchiorri, Michele; Pesaresi, Martina; Politis, Panagiotis; Schiavina, Marcello; Sabo, Filip; Zanchetta, Luigi (2019): GHSL Data Package 2019, EUR 29788 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-08725-0, doi:10.2760/062975, JRC 117104

[12] https://gadm.org/data.html
[13] https://global-surface-water.appspot.com/download

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