Documentation for the Global Human Settlement Layers (GHSL): Population and Built-Up Estimates, and Degree of Urbanization Settlement Model Grid

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Center for International Earth Science Information Network (CIESIN),
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Abstract

This document outlines the basic methodology and data sets used to construct the Global Human Settlement Layer (GHSL) data set, along with use cases, limitations, and use constraints. GHSL contains layers of Built-Up grid (GHS-BUILT), Population grid (GHS-POP), and the Settlement Model grid (GHS-SMOD) conveniently packaged by epochs, 1975, 1990, 2000, and 2014 for GHS-BUILT, and 2015 for GHS-POP and GHS-SMOD. Data from the R2019 release of GHS-POP were already available in the WGS84 geographic projection and are included in the data package unchanged. Data from the Joint Research Centre of the European Commission (JRC-EC) R2018 release of GHS-BUILT and R2019 release of GHS-SMOD were projected from Mollweide Equal Area projection to WGS84 with a Nearest Neighbor transformation using the R2019 GHS-POP as a reference for snapping and extent.

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We appreciate feedback regarding this data set, such as suggestions, discovery of errors, difficulties in using the data, and format preferences. Please contact:

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Contents

I. Introduction

The Built-Up grid (GHS-BUILT), Population Grid (GHS-POP), and the Settlement Model grid (GHS-SMOD) data packages are part of the Global Human Settlement Layer (GHSL) data set. The Joint Research Centre of the European Commission (JRC-EC) and the Directorate-General for Regional and Urban Policy support the GHSL project. GHS-POP is co-authored by NASA SEDAC. The GHSL project produces new global spatial information, evidence-based analytics, and knowledge describing the human presence on the planet. The SEDAC data packages provide users with a convenient way to obtain GHS-BUILT, GHS-POP, and GHS-SMOD for each epoch, 1975, 1990, 2000, and 2014 (BUILT) and 2015 (POP, SMOD), respectively.

II. Data and Methodology

The version of GHS-BUILT included here is derived from Landsat imagery from 1975 to 2014, courtesy of the U.S. Geological Survey. There is a second version of GHS-BUILT derived from Sentinel-1 satellite backscatter images —described in a scientific publication (Corbane et al., 2018a) from 1975 to 2014 which is available directly from JRC (https://ghsl.jrc.ec.europa.eu/datasets.php).

GHS-POP is based on methods developed at JRC-EC and NASA SEDAC, within the framework of the GHSL project. A detailed description of the methods for GHS_POP_MT_GLOBE_R2019A can be found in Freire *et al.,* 2016; 2018.

GHS-SMOD delineates settlement typologies via the logic of population size, population, and built up area density. These values are derived from the 'degree of urbanization' method as described by EUROSTAT. The GHS-SMOD is derived by using the GHS-POP and GHS-BUILT datasets.

Input data

Landsat Data
GHS-BUILT is based on 33,202 Landsat images (Florczyk et al., 2018b) organized and processed with the Symbolic Machine Learning (SML) classifier, a satellite data classification process designed for remote sensing big data analytics (Pesaresi et al., 2016b), into four epochs, 1975, 1990, 2000 and 2014 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).

Census Data
Residential population estimates (number of inhabitants) for target years 1975, 1990, 2000 and 2015 are from NASA SEDAC's Gridded Population of the World, Version 4 Revision 10 (GPWv4.10), and are based on census counts and reporting units. Population estimates for 1975, 1990, 2000, and 2015 were adjusted at the national level to the estimates of the United Nations' World Population Prospects (UN WPP): The 2015 Revision (United Nations, 2015). The medium-variant projections were used for these calculations. For more details, refer to the GPWv4.10 documentation and metadata and to Doxsey-Whitfield et al., 2015.

Settlement Model
The GHS-SMOD layers leverage the integration of Earth Observation-derived information on settlements (GHS-BUILT) and harmonized population statistics (GHS-POP). GHS-SMOD draws on multitemporal (1975, 1990, 2000, 2015) population grids from GHS-POP, which assigns residential population counts and densities from GPWv4.10 to the spatial extents of human settlements (built-up presence). In conjunction with baseline GHSL data, land and water boundaries are extracted from a combination of the Database of Global Administrative Areas (GADM) Map 2.812 and the Global Surface Water Layer Occurrence.

Methods

GHS-BUILT
The GHS-BUILT grids were produced through an image classification methodology based on symbolic machine learning (SML) techniques. (Refer to Pesaresi, M., V. Syrris, and A. Julea. 2016. A New Method for Earth Observation Data Analytics Based on Symbolic Machine Learning. *Remote Sens*. 2016, 8, 399. https://doi.org/10.3390/rs8050399. for an in-depth discussion of the methodology used to create the data set.)

The GHS-BUILT data sets are derived from Landsat imagery collected between 1975 and 2014, at the native resolution from each successive Landsat sensor (e.g. Landsat MSS: 80 m, TM: 30 m, ETM: 15 m and 30 m). For the SEDAC data packages, JRC's R2018 GHS-BUILT were projected from Mollweide Equal Area projection to WGS84 with a Nearest Neighbor transformation using the R2019 GHS-POP as a reference for snapping and extent.

GHS-POP
The GHS-POP grids depict the worldwide distribution of residence-based population, expressed as the number of people per grid cell. Multitemporal population grids for 1975, 1990, 2000 and 2015 were produced by combining best-available population estimates per finest census or administrative unit for 1975, 1990, 2000 and 2015, with best-available assessment of the spatial extents of human settlements as inferred from Landsat satellite data for the same periods. Using a dasymetric mapping approach, UN WPP-adjusted population counts for those epochs were disaggregated to mapped built-up areas from GHSL.

GHS-SMOD
The production of GHS-SMOD urbanization grids are based on methods developed at JRC-EC, within the framework of the GHSL project. Data were produced using information derived from GHS-POP and GHS-BUILT.

GHS-SMOD is produced through the porting of the Degree of Urbanization (DEGURBA) model, as described by EUROSTAT, into the GHSL framework. GHS-SMOD classifies each grid cell based on DEGURBA into the first hierarchical level (L1) classes: a) "Urban Centre", b) "Urban Cluster" and classifies all the other grid cells as c) "Rural Grid Cells" (Table 1). The criteria for the definition of the spatial entities at L1 are:

- "Urban Centre" (also "High Density Cluster" - HDC - Type 3) - An Urban Centre consists of contiguous grid cells (4-connectivity cluster) with a density of at least 1,500 inhabitants per square km of permanent land or with a built-up surface share on permanent land greater than 0.5, and has at least 50,000 inhabitants in the cluster with smoothed boundaries and <15 square km holes filled.
- "Urban Cluster" (also "Moderate Density Cluster" - MDC - Type 2) - An Urban Cluster consists of contiguous grid cells (4-connectivity cluster) with a density of at least 300 inhabitants per square km of permanent land, a built-up surface share on permanent land greater than 0.03 and has at least 5,000 inhabitants in the cluster plus all contiguous (4-connectivity cluster) "Urban Centres".
- "Rural grid cells" (also "Mostly Low Density Cells" - LDC - Type 1) are all the other grid cells that do not belong to an "Urban Cluster". Most of these will have a density below 300 inhabitants per square km. Some Rural grid cells may have a higher density, but they are not part of a cluster with sufficient population to be classified as an "Urban Cluster".

Type 3 and 2, if aggregated, form the "urban domain"; Type 1 forms the "rural domain" and water grid cells (Table 1). This DEGURBA framework is further refined to produce more detailed classification, provided in GHS-SMOD at the finer hierarchical level 2 (L2).

L2 classification follows the same approach based on population density, population size and contiguity with a nested classification into the first hierarchical level. At the second hierarchical level, the GHS-SMOD classifies grid cells by identifying the following spatial entities: a) "Urban Centres" just as HDC at L1; b) "Dense Urban Cluster" and c) "Semi-dense Urban Cluster" as parts of the MDC at L1, classifying all the other grid cells of "Urban Clusters" as "Suburban or peri-urban grid cells"; and identifying d) "Rural Cluster" within the "Rural grid cells". All the other grid cells belonging to the "Rural grid cells" are classified as "Low Density grid cells", "Very Low Density grid cells", or "Water grid cells" (Table 1).

The basic criteria for the definition of the spatial entities at L2 result in eight settlement typologies. GHS-SMOD provides grid cells assigned with a two-digit code (30, 23, 22, 21, 13, 12, 11, 10) into the following classes:

- Class 30: "Urban Centre" (also "Dense, Large Settlement" or "High Density Cluster" - HDC) - An Urban Centre consists of contiguous grid cells (4-connectivity cluster) with a density of at least 1,500 inhabitants per square km of permanent land or with a

built-up surface share on permanent land greater than 0.5, and has at least 50,000 inhabitants in the cluster with smoothed boundaries and <15 square km holes filled;

- Class 23: "Dense Urban Cluster" (also "Dense, Medium Cluster") - A Dense Urban Cluster consists of contiguous grid cells (4-connectivity cluster) with a density of at least 1,500 inhabitants per square km of permanent land or with a built-up surface share on permanent land greater than 0.5, and has at least 5,000 inhabitants in the cluster;
- Class 22: "Semi-dense Urban Cluster" (also "Semi-dense, Medium Cluster") - A Semi-dense Urban Cluster consists of contiguous grid cells (4-connectivity cluster) with a density of at least 300 inhabitants per square km of permanent land, a built-up surface share on permanent land greater than 0.03, has at least 5,000 inhabitants in the cluster and is at least 3-km away from other "Urban Clusters";
- Class 21: "Suburban or peri-urban grid cells" (also Semi-dense grid cells) are all the other cells that belong to the Urban domain but are not part of a "Urban Centre", "Dense Urban Cluster" or a semi-dense "Urban Cluster".
- Class 13: "Rural cluster" (also "Semi-dense, Small Cluster") - A Rural Cluster consists of contiguous cells (4-connectivity cluster) with a density of at least 300 inhabitants per square km of permanent land and has at least 500 and less than 5,000 inhabitants in the cluster.
- Class 12: "Low Density Rural grid cells" (also "Low Density grid cells") are Rural grid cells with a density of at least 50 inhabitants per square km and are not part of a "Rural Cluster".
- Class 11: "Very low density rural grid cells" (also "Very Low Density grid cells") are cells with a density of less than 50 inhabitants per square km and are not water grid cells.
- Class 10: "Water grid cells" are all the cells with more than 0.5 share covered by permanent surface water not populated nor built.

Table 1: Aggregation of L2 classifications, provided by GHS-SMOD layers, to L1 typologies, to Domains.

Domains	**Level 1 (L1) Type**	**Level 2 (L2) Classification**
Urban	3	30
	2	23, 22, 21
Rural	1	13, 12, 11, 10

For the SEDAC data packages, JRC's R2019 GHS-SMOD were projected from Mollweide Equal Area projection to WGS84 with a Nearest Neighbor transformation using the R2019 GHS-POP as a reference for snapping and extent.

III. Data Set Description(s)

The final GHSL multitemporal products are available at a spatial resolution of 9 arc-seconds and 30 arc-seconds in the World Geodetic System 1984 (WGS84) Geographic Coordinate System. GHS-BUILT, GHS-POP, and GHS-SMOD are available in separate layers per individual epoch (1975, 1990, 2000, and 2014/2015). The GHSL data-set product consists of GHS-BUILT, GHS-POP, and GHS-SMOD grids with global coverage that consist of estimates of the degree of built-up presence per grid cell, number of people per grid cell, and settlement classification per grid cell, respectively, for each corresponding epoch, 1975, 1990, 2000, and 2014 (BUILT) and 2015 (POP, SMOD). Data from the JRC-EC R2019 release were projected from Mollweide Equal Area projection to WGS84 with a Nearest Neighbor transformation using the R2019 GHS-POP as a reference for snapping and extent.

Data set web page:
SEDAC URL:
https://sedac.ciesin.columbia.edu/data/set/ghsl-population-built-up-estimates-degree-urban-smod.
Permanent URL: https://doi.org/10.7927/h4154f0w.
Documentation for the JRC-EC GHSL 2019 Data Package Technical Report may be downloaded at: https://ghsl.jrc.ec.europa.eu/documents/GHSL_Data_Package_2019.pdf.

Data set format:
The data are available as global tiles in GeoTIFF format as downloadable zip files. The downloadable files are compressed zip files containing: 1) the selected GeoTIFF tile(s) for the chosen epoch and resolution, 2) Readme.TXT file, and 3) PDF Documentation.

Data set downloads:

- GHSL 1975 - Resolution of 9 arc-seconds (9ss) - WGS84 (EPSG: 4326)
  - ghsl-population-built-up-estimates-degree-urban-smod-ghsl-1975-9ss-v1-geotiff.zip
- GHSL 1975 - Resolution of 30 arc-seconds (30ss) - WGS84 (EPSG: 4326)
  - ghsl-population-built-up-estimates-degree-urban-smod-ghsl-1975-30ss-v1-geotiff.zip
- GHSL 1990 - Resolution of 9 arc-seconds (9ss) - WGS84 (EPSG: 4326)
  - ghsl-population-built-up-estimates-degree-urban-smod-ghsl-1990-9ss-v1-geotiff.zip
- GHSL 1990 - Resolution of 30 arc-seconds (30ss) - WGS84 (EPSG: 4326)
  - ghsl-population-built-up-estimates-degree-urban-smod-ghsl-1990-30ss-v1-geotiff.zip
- GHSL 2000 - Resolution of 9 arc-seconds (9ss) - WGS84 (EPSG: 4326)
  - ghsl-population-built-up-estimates-degree-urban-smod-ghsl-2000-9ss-v1-geotiff.zip

- GHSL 2000 - Resolution of 30 arc-seconds (30ss) - WGS84 (EPSG: 4326)
  - ghsl-population-built-up-estimates-degree-urban-smod-ghsl-2000-30ss-v1-geotiff.zip
- GHSL 2014/2015 - Resolution of 9 arc-seconds (9ss) - WGS84 (EPSG: 4326)
  - ghsl-population-built-up-estimates-degree-urban-smod-ghsl-2014-2015-9ss-v1-geotiff.zip
- GHSL 2014/2015 - Resolution of 30 arc-seconds (30ss) - WGS84 (EPSG: 4326)
  - ghsl-population-built-up-estimates-degree-urban-smod-ghsl-2014-2015-30ss-v1-geotiff.zip

IV. How to Use the Data

The final GHSL multitemporal products are available at a spatial resolution of 9 arc-seconds and 30 arc-seconds in the World Geodetic System 1984 (WGS84) Geographic Coordinate System. GHS-BUILT, GHS-POP, and GHS-SMOD layers are packaged together per corresponding epoch (1975, 1990, 2000, 2014/2015).

GHS-BUILT layers are GeoTIFF raster products that contain grid cells with continuous variables, which represent the proportion of the building footprint area within the total size of the grid cell.

GHS-POP layers are GeoTIFF raster products that contain grid cells with continuous variables, which represent the population distribution by number of people per grid cell.

GHS-SMOD layers are GeoTIFF raster products that contain grid cells with integers, which represent the assigned settlement classification per grid cell.

These data are accessible through open source and proprietary GIS software packages and programming languages, and can be used directly in mapping and geospatial analysis.

V. Potential Use Cases

GHSL products have the potential for multiple applications across a wide range of subjects including but not limited to degree of urbanization, sustainable development, socioeconomics, land use, population growth, global analysis, etc. Some notable publications that apply GHSL in their analyses are:

Corbane, C., P. Politis, M. Pesaresi, T. Kemper, and A. Siragusa. 2018. Estimation of Land Use Efficiency from the Global Human Settlement Layer (GHSL). *In QGIS and*

Applications in Territorial Planning (eds N. Baghdadi, C. Mallet and M. Zribi). https://doi.org/10.1002/9781119457121.ch2.

Hoole, C., S. Hincks, and A. Rae. 2019. The contours of a new urban world? Megacity population growth and density since 1975. *The Town Planning Review*, 90(6), 653-678. https://doi.org/10.3828/tpr.2019.41.

Sapena, M., L. A. Ruiz, and H. Taubenböck. 2020. Analyzing Links between Spatio-Temporal Metrics of Built-Up Areas and Socio-Economic Indicators on a Semi-Global Scale. *ISPRS Int. J. Geo-Inf*. 2020, 9, 436. https://doi.org/10.3390/ijgi9070436.

VI. Limitations

The population grid for 1975 is less reliable at the pixel level due to the combination of uncertainties in hind casting and adjusting population estimates for small census units and limitations in detection and mapping of built-up areas for that epoch.

Due to limitations and uncertainties in source data, scale, and methods, multitemporal analyses for individual grid cells is strongly discouraged. However, regional multitemporal analyses are encouraged.

The projection of GHS-SMOD from Mollweide to WGS84 has the potential to lead to the shifting of grid cells representing settlement types. This should be taken into account and analyzed for any given use case.

VII. Acknowledgments

The Global Human Settlement Layer (GHSL) project is supported through the Joint Research Centre (JRC) of the European Commission (JRC-EC), and the Directorate-General for Regional and Urban Policy.

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VIII. Disclaimer

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IX. Use Constraints

X. Recommended Citation(s)

Data set(s):

Joint Research Centre (JRC), European Commission, and Center for International Earth Science Information Network (CIESIN), Columbia University. 2021. Global Human Settlement Layer: Population and Built-Up Estimates, and Degree of Urbanization Settlement Model Grid. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). https://doi.org/10.7927/h4154f0w. Accessed DAY MONTH YEAR.

Scientific publication:

Florczyk A. J., C. Corbane, D. Ehrlich, S. Freire, T. Kemper, L. Maffenini. M. Melchiorri, M. Pesaresi, P. Politis, M. Schiavina, F. Sabo, and L. Zanchetta. GHSL Data Package 2019, EUR 29788 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-13186-1, JRC 117104. https://doi.org/10.2760/290498. https://publications.jrc.ec.europa.eu/repository/handle/JRC117104.

XI. Source Code

Please contact the GHSL team at ghsl-data@jrc.ec.europa.eu for information about the source code used to develop the data sets.

XII. References

Corbane, C., A. Florczyk, M. Pesaresi, P. Politis, and V. Syrris. 2018. GHS built-up grid, derived from Landsat, multitemporal (1975-1990-2000-2014), R2018A. European Commission, Joint Research Centre (JRC). https://doi.org/10.2905/jrc-ghsl-10007. https://data.europa.eu/89h/jrc-ghsl-10007.

Corbane, C., M. Pesaresi, T. Kemper, P. Politis, A. Florczyk, V. Syrris, M. Melchiorri, Michele, Sabo, and P. Soille. 2019. Automated global delineation of human settlements from 40 years of Landsat satellite data archives. *Big Earth Data* 3, 140–169. https://doi.org/10.1080/20964471.2019.1625528.

Corbane, C., M. Pesaresi. P. Politis, V. Syrris, A. J. Florczyk, P. Soille, L. Maffenini, A. Burger, V. Vasilev, D. Rodriguez, F. Sabo, L. Dijkstra, and T. Kemper. 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, https://doi.org/10.1080/20964471.2017.1397899.

Corbane, C., P. Politis, V. Syrris, and M. Pesaresi. 2018. GHS built-up grid, derived from Sentinel-1 (2016), R2018A. European Commission, Joint Research Centre (JRC). https://doi.org/10.2905/jrc-ghsl-10008. http://data.europa.eu/89h/jrc-ghsl-10008.

Freire S., K. MacManus, M. Pesaresi, E. Doxsey-Whitfield, and J. Mills. 2016. Development of new open and free multi-temporal global population grids at 250 m resolution. Proceedings of the 19th AGILE Conference on Geographic Information Science. Helsinki, Finland, June 14-17, 2016. https://agile-online.org/conference_paper/cds/agile_2016/shortpapers/152_Paper_in_PDF.pdf.

Freire S., M. Schiavina. A. J. Florczyk, K. MacManus, M. Pesaresi, C. Corbane, O. Borkovska, J. Mills, L. Pistolesi, J. Squires, and R. Sliuzas. 2018. Enhanced data and methods for improving open and free global population grids: putting 'leaving no one behind' into practice, *International Journal of Digital Earth*, https://doi.org/10.1080/17538947.2018.1548656.

Pesaresi, M., A. Florczyk, M. Schiavina, M. Melchiorri, and L. Maffenini. 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) [Dataset]. https://doi.org/10.2905/42E8BE89-54FF-464E-BE7B-BF9E64DA5218. http://data.europa.eu/89h/42e8be89-54ff-464e-be7b-bf9e64da5218.

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United Nations' World Population Prospects (UN WPP): The 2015 Revision. https://population.un.org/wpp/Publications/Files/WPP2015_DataBooklet.pdf.

XIII. Documentation Copyright and License

Appendix 1. Data Revision History

No revisions have been made to this data set.

Appendix 2. Contributing Authors & Documentation Revision History

Revision Date	Contributors	Revisions
July 19, 2021	J. F. Martinez, K. MacManus	This document is the 1st instance of documentation.