Documentation for the Low Elevation Coastal Zone (LECZ) Global Delta Urban-Rural Population and Land Area Estimates, Version 1

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Abstract

The Low Elevation Coastal Zone (LECZ) Global Delta Urban-Rural Population and Land Area Estimates, Version 1 data set provides country-level estimates of urban, quasi-urban, rural, and total population (count), land area (square kilometers), and built-up areas in river delta- and non-delta contexts for 246 statistical areas (countries and other UN-recognized territories) for the years 1990, 2000, 2014 and 2015. The population estimates are disaggregated such that compounding risk factors including elevation, settlement patterns, and delta zones can be cross-examined. The Intergovernmental Panel on Climate Change (IPCC) recently concluded that without significant adaptation and mitigation action, risk to coastal communities will increase at least one order of magnitude by 2100, placing people, property, and environmental resources at greater risk. Greater-risk zones were then generated: 1) the global extent of two low-elevation zones contiguous to the coast, one bounded by an upper elevation of 10m (LECZ10), and one by an upper elevation of 5m (LECZ05); 2) the extent of the world's major deltas; 3) the distribution of people and built-up area around the world; 4) the extent of urban centres around the world. The data are layered spatially, along with political and land/water boundaries, allowing the densities and quantities of population and built-up area, as well as levels of urbanization (defined as the share of population living in "urban centres") to be estimated for any country or region, both inside and outside the LECZs and deltas, and at two points in time (1990 and 2015). In using such estimates of populations living in 5m and 10m LECZs and outside of LECZs, policymakers can make informed decisions based on perceived exposure and vulnerability to potential damages from sea level rise.

Data set citation: Center for International Earth Science Information Network (CIESIN), Columbia University, and CUNY Institute for Demographic Research (CIDR), City University of New York. 2024. Low Elevation Coastal Zone (LECZ) Global Delta Urban-Rural Population and Land Area Estimates, Version 1. Palisades, New York: NASA Socioeconomic Data and Applications Center (SEDAC). https://doi.org/10.7927/4hgr-db70. Accessed DAY MONTH YEAR.

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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 Low Elevation Coastal Zone (LECZ) Global Delta Urban-Rural Population and Land Area Estimates dataset provides country-level estimates of urban, quasi-urban, rural, and total population (count), land area (square kilometers), and built-up areas in river delta- and non-delta contexts for 246 statistical areas (countries and other UN recognized territories) for the years 1990, 2000, 2014* and 2015. This data set was prepared for an article entitled “Is rapid urbanization of low elevation deltas undermining adaptation to climate change: a global review" (McGranahan et al., 2023).

Understanding patterns of human settlements along the coasts, and particularly in deltas where climate hazards will intersect with other biogeophysical challenges, is important for assessing and mitigating risk. Population estimates are disaggregated such that compounding risk factors such as elevation, settlement patterns, and delta zones can be cross-examined. Estimates of populations living in 5m and 10m LECZs (as well as outside of LECZs) can be used to inform planning and policy-making decisions based on perceived exposure and vulnerability (risk tolerance) to potential damages from sea level rise and storm surge.

Though major deltas only account for about 0.5% of the world's land area, in recent years land use patterns in these deltas have intensified at a much greater rate than the rest of the world. Several very serious hazards, most notably flooding, are prevalent in low elevation coastal areas and especially deltas. People and economic capital are also more concentrated in these areas, and this concentration may be growing.

Coastal and estuarine flooding is already an important category of disaster, and the latest report by Working Group II of the Intergovernmental Panel on Climate Change (IPCC) concludes that, "Risks to coastal cities and settlements are projected to increase by at least one order of magnitude by 2100 without significant adaptation and mitigation action (high confidence)" (IPCC, 2022, page 63). Global climate change and environmentally harmful development are increasing the severity and extent of environmental hazards, placing people, property and environmental resources in these areas at still greater risk.

These data define greater-risk zones using: 1) the global extent of two low-elevation zones contiguous to the coast, one bounded by an upper elevation of 10 metres (LECZ10), and another by an upper elevation of 5 metres (LECZ05); 2) the extent of the world's major deltas; 3) the distribution of people and built-up area around the world; 4) the extent of urban centres around the world (with statistics based on other generally smaller and less densely settled urban areas, such as towns and suburban or peri-urban land forms). The different data sets are layered spatially, along with political and land/water boundaries, allowing the densities and quantities of population and built-up area, as well as levels of urbanization (defined as the share of population living in "urban centres") to be estimated for any country or region, both inside and outside the LECZs and deltas, and at two points in time (1990 and 2015).

II. Data and Methodology

The Low Elevation Coastal Zone (LECZ) Global Delta Urban-Rural Population and Land Area Estimates, Version 1 is taken from MacManus et al., 2021:

- MacManus, K., D. Balk, H. Engin, G. McGranahan, and R. Inman. 2021. Estimating population and urban areas at risk of coastal hazards, 1990–2015: how data choices matter. Earth Syst. Sci. Data, 13, 5747–5801. https://doi.org/10.5194/essd-13-5747-2021.

Elevation assessments are based on the Multi-Error-Removed Improved-Terrain Digital Elevation Model (MERIT-DEM) and are available in raster format at 9 arc-second resolution in 3 classes (0-5 metres LECZ05, 5-10 metres LECZ10, and outside LECZ) for the year 2000 (MERIT is 3 arc-second in original form). For urban extents, MacManus et al., 2021 uses the classification "Urban" (U), "Quasi-Urban" (Q), and "Rural" (R) for comparison across four different data sources, some of which are continuous variables with no previously stated categorizations. These correspond to "Urban Centres", "Urban Clusters" and "Rural" in the associated paper.

Global delta area extents are taken from Tessler et al., 2015:

- Tessler Z. D., C. J. Vörösmarty, M. Grossberg, I. Gladkova, H. Aizenman, J. P. Syvitski, and E. Foufoula-Georgiou. 2015. ENVIRONMENTAL SCIENCE. Profiling risk and sustainability in coastal deltas of the world. 349(6248):638-43. https://pubmed.ncbi.nlm.nih.gov/26250684/.
- Tessler Z. D., C. J. Vörösmarty, M. Grossberg, I. Gladkova, H. Aizenman, J. P. Syvitski, and E. Foufoula-Georgiou. 2015. Profiling risk and sustainability in coastal deltas of the world. *Science* **349**(6248), 638-643. https://doi.org/10.1126/science.aab3574.

Forty-eight major delta areas were defined in vector format in the WGS84 equirectangular Geographic Coordinate System. Population summaries designated as "inside delta" are extracted from these extents. These data only include major deltas, which account for about one-fifth of the LECZ10. A significant share of the urban population in the LECZ10 that is not in these major deltas is likely to be at other river mouths, often on smaller deltas. Delta areas were cross-tabulated with national boundaries to produce statistics by country for deltas.

Population estimates for 246 countries and territories are taken from the Global Human Settlement Layer (GHSL) R2019 collection, Gridded Population of the World, Version 4, Revision 11 (GPWv4.11) UN WPP for years 1990, 2000, and 2015, WorldPop, and ORNL LandScan for years 2000 and 2015.

Built-up areas are taken from Global Human Settlement built-up grid R2018A (GHS-BUILT, Corbane et al., 2018):

- 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.

and are Raster, 9 arc-second resolution, representing percentage of detected built-up, for the years 1990, 2000, and 2014.

*GHS-Built is produced for the year 2014, but population estimates reference the year 2015.

Input data

The Low Elevation Coastal Zone (LECZ) Global Delta Urban-Rural Population and Land Area Estimates, Version 1 data set updates and improves population and land area estimates for the 0-5m and 5-10m elevation zones contiguous to the coast for countries and territories globally. To produce this data set, researchers evaluated and compared input data from five elevation data sources, four population count data sources, and four data sources of urban-rural disaggregation. The thirteen data sources assessed are described in Table 1.

Table 1: Input Data

Theme	Data Set	Abbreviation	Input Spatial Resolution	Paper Reference
Elevation	Shuttle Radar Topography Mission Elevation Low Elevation Coastal Zones	SRTM	3 arc-second	(ISciences, 2003)
	Multi-Error-Removed Improved-Terrain Digital Elevation Model	MERIT-DEM	3 arc-second	(Yamazaki et al., 2017)
	TerraSAR-X add-on for Digital Elevation Measurement	TanDEM-X	3 arc-second	(Wessel et al., 2018)
	CoastalDEM90	CoastalDEM	3 arc-second	(Kulp and Strauss, 2018)
	ALOS World 3D - 30m Digital Surface Model	AW3D30	1 arc-second	(Tadono et al., 2014)
Urban Concept	Global Human Settlement - Settlement “Degree of Urbanization” Model Grid R2019a v2	GHS-SMOD	30 arc-second	(Florczyk et al., 2019)
	Global Human Settlement - Built-up Grid R2019	GHS-BUILT	9 arc-second	(Pesaresi et al., 2019), (Florczyk et al., 2019)
	Global Rural-Urban Mapping Project, Version 1 (GRUMPv1): Urban Extents Grid	GRUMPv1	30 arc-second	(Balk et al., 2005), (CIESIN et al., 2011)

	VIIRS Plus DMSP Change in Lights (VIIRS+DMSP dLIGHT)	dLIGHT	15 arc-second	(Small et al., 2020)
Population	Global Human Settlement - Population Grid R2019	GHS-POP	9 arc-second	(Freire et al., 2016), (Florczyk et al., 2019)
	Gridded Population of the World, Version 4, Population Count Adjusted to Match 2015 Revision of UN WPP Country Totals, Revision 11	GPWv4.11 UN WPP	30 arc-second	(CIESIN et al., 2018d), (Doxsey-Whitfield et al., 2015)
	LandScan 2015 High Resolution Population Data Set	LandScan	30 arc-second	(Bright and Coleman, 2001; Bright et al., 2016)
	WorldPop Global High Resolution Population Denominators	WorldPop	3 arc-second	(Lloyd et al., 2019)

In addition to the twelve primary sources, several ancillary data inputs were also utilized to produce LECZ Global Delta Version 1:

- Gridded Population of the World, Version 4 (GPWv4): National Identifier Grid, Revision 11 (CIESIN, 2018a) (NID) is used to construct the extent of countries and territories, as well as summary statistics for those units. The horizontal resolution of this data set is 30 arc-seconds or approximately 1 km at the equator.

- Gridded Population of the World, Version 4 (GPWv4): Land and Water Area, Revision 11 (CIESIN, 2018b) forms the basis of land area estimates, as the land area grid accounts for the reduction in the underlying area of regular rectangular grid cells as they approach the poles. This allows for the accurate area measurements without requiring the use of an Equal Area projection. The resolution of this data set is 30 arc-seconds or approximately 1 km at the equator.

- Gridded Population of the World, Version 4 (GPWv4): Data Quality Indicators, Revision 11 (CIESIN, 2018c) Mean Administrative Unit Area raster, which represents the nominal resolution of the input vector geographies which were then matched to census population estimates prior to gridding. Smaller values indicate areas with high resolution input geographies, which therefore are less impacted by modelling. This raster better enables an understanding of the precision and

accuracy of pixel level population estimates. The resolution of this data set is 30 arc-seconds or approximately 1 km at the equator.

- Global Human Settlement - Built-up Grid R2019 (GHS-BUILT) provides an information layer on the intensity or percentage of the built environment as derived from Landsat image collections. This data set could be used to independently evaluate how much land in the LECZ is built-up. The native resolution of GHS-Built is 250 meters and is in the Mollweide coordinate system.

Methods

Elevation

Four digital elevation models were used to construct 0-5m and 5-10m low elevation coastal zones: Multi-Error-Removed Improved-Terrain Digital Elevation Model (MERIT-DEM); Shuttle Radar Topography Mission Elevation Low Elevation Coastal Zones (SRTM); TerraSAR-X add-on for Digital Elevation Measurement (TanDEM-X); and CoastalDEM90 (CoastalDEM)[1].

Multiple steps were taken in order to ensure cross-comparison between the five elevation data sets. Each of the source data sets were projected to WGS84 horizontal coordinate systems with EGM96 geoid height. Out of the 5 DEMs evaluated, 3 of them (SRTM, MERIT-DEM, and CoastalDEM) were referenced to the EGM96 Vertical Coordinate System (EPSG:5773) natively. TanDEM-X elevations were natively referenced to the WGS84 (G1150) ellipsoid (EPSG:4979) and were therefore converted to EGM96 geoid heights using the GDAL Warp tool, in order to conform with the vertical reference of the other 3 elevation sources.

All elevation data were preprocessed into a common framework and subset by country boundaries as defined by the GPWv4.11 National Identifier Grid (NID). Elevation tiles were loaded into an Esri File Geodatabase mosaic data set, which included corresponding vector layers (footprints) of the input raster extents and identifying metadata. A python script was used to clip the raster footprints by country boundaries from the NID. This created country level layers with attributes (i.e. file names and locations) from intersecting footprints for each of the elevation sources, which were then used to isolate a subset list of elevation tiles belonging to a given country. All elevation data were then aggregated with the MEAN method of the Esri ArcGIS Aggregate tool to a 9 arc-second horizontal resolution.

From here, steps were taken to construct the 0-5m low elevation coastal zone, 5-10m low

[1] In order to obtain complete spatial coverage, CoastalDEM country files with partial spatial coverage were mosaicked with JAXA ALOS 30m global DEM (AW3D30) grids. The 1 arc-second AW3D30 data was aggregated to 3 arc-seconds in order to conform with CoastalDEM. The aggregation was accomplished by taking the mean elevation value. Countries with combined CoastalDEM and AW3D30 data were the Aland Islands, Canada, Finland, the Faroe Islands, Great Britain, Greenland, Iceland, Norway, Russia, Svalbard and Jan Mayan, Sweden, and the United States.

elevation coastal zone, and non-coastal areas of any elevation:

1) The GPWv4.11 NID was buffered by 1 km on a per country basis in order to prevent the loss of population due to coastline mismatches, or the loss of the low elevation coastal zone when the elevation data source uses a coastline that is seaward of the NID.

2) The nine arc-second country elevation mosaics for each elevation source were reclassified into integers representing the following zones: 0 to 5m, 5 to 10m and greater than 10m.

3) These reclassified images were then segmented with the Esri ArcGIS Region Group tool with eight neighbors using the WITHIN parameter. The resultant region grouped images where groups of pixels with like values were combined such that each connected group (or region) receives its own unique identifier, along with a count of the number of pixels within the group.

4) In order to isolate coastally contiguous regions, the region grouped images were converted into polygons and selected by the location where each polygon intersects the border of a country as determined from the 1 km buffered GPWv4.11 NID. This effectively isolated all regions connected to administrative boundary coastlines.

5) Quality Assurance manual checking for spurious lowland regions contiguous with inland values.

6) The isolated, quality-assured regions were then used as extraction masks on the reclassified DEMs while non-connected inland values were coded as above 10m (the corresponding value in our resulting spatial data is coded as 31).

The resulting rasters contained coastally contiguous pixels coded into 0-5m and 5-10m LECZs, and a third category representing non-coastal areas of any elevation area (outside of LECZs). The Low Elevation Coastal Zone Global Delta raster derived from the global MERIT-DEM data product is distributed with LECZ Version 3.

Population

Population distribution data were sourced from Global Human Settlement - Population Grid R2019 (GHS-POP), Gridded Population of the World, Version 4, Revision 11 (GPWv4.11 UN WPP), LandScan 2015 High Resolution Population Data Set (Landscan), and WorldPop Global High Resolution Population Denominators (WorldPop). The original resolutions for the data sets were as follows: WorldPop (3 arc-seconds); GHS-POP (9 arc-seconds); GPWv4.11 UN WPP (30 arc-seconds); and LandScan (30 arc-seconds). If required, these data sets were processed from their native resolutions to comparable 9 arc-seconds (nominally 300m) resolution data sets. Accordingly, WorldPop was aggregated from 3 arc-seconds to 9 arc-seconds using the Esri ArcGIS Aggregate

tool. GPWv4.11 UN WPP and LandScan were uniformly disaggregated by a factor of 100 and quality-assured to have the same total population before and after the sampling. Once processed in a standardized 9 arc-second resolution, population data sets were subset by country.

Urban-Rural Concept

The four data sets used in this estimation of urban and rural populations were the Global Rural-Urban Mapping Project, Version 1 (GRUMPv1): Urban Extents Grid, VIIRS Plus DMSP Change in Lights (VIIRS+DMSP dLIGHT), Global Human Settlement - Built-Up Grid R2019 (GHS-BUILT), and the Global Human Settlement - Settlement "Degree of Urbanization" model Grid R2019a v2 (GHS-SMOD). These data sets were preprocessed in order to conform to a comparable 9 arc-second horizontal resolution. dLIGHT is natively 15-arc seconds, while GHS-SMOD and GRUMPv1 are natively 30 arc-seconds. These data sets were uniformly up-sampled to a 9 arc-second resolution, using a Nearest Neighbor approach since the underlying data is categorical. Additionally, GHS-BUILT was projected into the WGS84 coordinate system with a Nearest Neighbor cell assignment. Afterwards, the data sets were subset by country using the GPWv4.11 NID.

In working with heterogeneous urban proxy data sets, it was necessary to establish an urban-rural classification scheme to facilitate inter-comparison. For this reason, our urban-rural population estimates rely on three simplified thematic categories; Urban, Quasi-Urban, and Rural. The GHS-SMOD data set already contains classification and aggregation schemas that align with Urban, Quasi-Urban, and Rural categorical designations, the so called Level 1 schema. GHS-BUILT was reclassified into Urban (> 50% built-up), Quasi-Urban (> 3% and ≤ 50% built-up), and Rural (≤ 3% built-up) using the Esri ArcGIS Reclassify tool. dLIGHT was visually cross-referenced with GHS-SMOD and GHS-BUILT in order to determine the following thresholds; Urban (> 100 dn), Quasi-Urban (> 3 and < 100 dn), and Rural (< 3 dn) using the Esri ArcGIS Reclassify tool, where digital numbers (dn), 0 to 255, represent the relative luminosity of pixels across the time periods represented in the data set (1992, 2002, 2013). GRUMPv1 Urban Extents Grid was constructed as a dichotomous urban-rural grid and cannot be applied to classifications outside of this binary.

Processing auxiliary data sets

GPWv4.11 Land Area grid had a native horizontal resolution of 30 arc-seconds. It was uniformly up-sampled to 9 arc-seconds resolution by a factor of 100 and quality assured to have the same total land area per pixel both before and after the sampling. After up-sampling, the land area data was subset by country

The GPWv4.11 Mean Administrative Unit Area grid also had a native horizontal resolution of 30 arc-seconds, but because the values in this grid represent the average size of input population units, there was no need to up-sample. These data were simply resampled at 9 arc-second resolution. After resampling, the data was subset by country.

GHS-BUILT was used here not only to discriminate between Urban, Quasi-Urban, and

Rural as a categorical data set, but also to summarize built-up intensities as a measure in its own right. It was projected from the Mollweide coordinate system into WGS84 coordinates using Nearest Neighbor at 9 arc-seconds. After reprojection, the data was subset by country.

III. Data Set Description(s)

The Excel-based data sets include the full LECZ Delta v1 population and land area estimates database in a macro-enabled workbook, as well as a worksheet of summary tables. The Excel workbook for LECZ Delta v1 contains a database of the resulting population estimates from each permutation of the 12 data sources, as well as land area estimates, estimates of the average built-up percentages, and data quality information about the average size of input census geographies. This data is available for the years 1990, 2000, and 2015. Pivot tables are used to summarize the database, and summaries are available at the county, continent, and UN region level. These pivot tables facilitate data exploration by allowing a user to expose the underlying data behind each cell. By double-clicking on a cell, the pivot table creates a new spreadsheet that contains all of the data that generated the value of that cell.

Pivot tables allow a user to filter data based on chosen criteria, excluding information outside of the specified criteria. Multiple filters can be used at once, to further refine the data. The filters for LECZ Delta v1 are:

- Continent filter
- UN Region Filter
- Country Filter
- Elevation Source Filter
- Urban Concept Filter
- LECZ Description filter
- Settlement Description Filter
- Year Filter

Furthermore, tabular data are provided to users in summary tables. These tables summarize data sources, as well as global-level results in overall aggregate terms and as a percent change over time (1990-2015). A list of tables is included in the front sheet of the summary table Excel workbook.

Data set web page:
SEDAC URL: https://sedac.ciesin.columbia.edu/data/set/lecz-delta-urban-rural-population-land-area-estimates-v1
Permanent URL: https://doi.org/10.7927/4hgr-db70

Data set format:
The data are available in tabular format in a Microsoft Excel workbook. The downloadable is a compressed zip file containing: 1) XLSX files, 2) Readme.TXT file, and 3) PDF Documentation.

Data set downloads:
- lecz-delta-urban-rural-population-land-area-estimates-v1-xlsx.zip

IV. How to Use the Data

This data set is global in extent. The Excel data set can be used in statistical and Geographic Information System (GIS) software. Excel data can be subset by country or by any of the fields listed in the Codebook.

V. Potential Use Cases

The Low Elevation Coastal Zone (LECZ) Global Delta Urban-Rural Population and Land Area Estimates, Version 1 data set assesses current and past risks related to areas in river delta- and non-delta contexts and increased natural disasters. With this information, adaptation and mitigation strategies can be tailored to the geographic locations that exhibit risk factors. Some potential applications include:

- Evaluating population and development trajectories in “high risk” delta zones. This information can be evaluated in comparison to non-coastal areas, in order to assess high-risk development practices in the context of broader development trends.

- Assessing current sovereign, regional, and continental sea level rise exposure based on population counts and urban-proxy measures.

- Identifying where increasing development in the built environment is intersecting with increased vulnerability to sea level rise and/or natural disasters.

VI. Limitations

The elevation data is produced and distributed in the World Geodetic System 1984 (WGS84) Geographic Coordinate System. The GHSL data product, however, is produced and distributed in the Mollweide Equal Area Projected Coordinate System (not including GHS-POP, which is also released in a WGS84 version). In order to conduct analyses on these data sources, it is necessary to harmonize their coordinate systems, but the

projection of raster data is not without complications.

When a raster data set is projected from one coordinate system to another, the registration and total number of pixels represented are altered. In other words, the number of pixels may change along with the location of those pixels relative to ground truth. The projection of the elevation data source (WGS84) was maintained to avoid introducing uncertainties about the location of the LECZs. Therefore, it was needed to project GHS-BUILT and GHS-SMOD to conform with that elevation source. The thematic layers (GHS-BUILT, GHS-SMOD) were not simple to validate owing to the fact that there is no available alternative source for these data to compare with. Any error introduced by projecting these data from Mollweide to WGS84 using a Nearest Neighbor approach is quite minimal, however, it should be noted that because of the fact that the LECZs represent small swaths of land area, they are also more sensitive to any apparent shifts of pixel locations. Although the projection issue does produce some uncertainty, it would not have been possible to use these data sources together without taking this approach.

Uncertainty associated with coastlines, and how they align with other data sets, is a known problem because there is no authoritative, global data set on coastlines, and because coastlines are dynamic. This is especially an issue for island nations where such mismatches are aggravated, and where low-lying coastal land may be found in high proportions.

VII. Acknowledgments

These data were produced with funding from SEDAC and the World Resources Institute's Center for Urban Transitions. The production team was led by Kytt MacManus (CIESIN) and Deborah Balk (CIDR), with critical contributions from Hasim Engin (CIDR), Rya Inman (CIESIN), and Gordon McGranahan from the Institute of Development Studies (IDS). Mairead Milan, Alexandra Hays, Sarah Colenbrander, Catlyne Haddaoui, and Leah Lazar provided additional support and comments.

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VIII. Disclaimer

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IX. Use Constraints

X. Recommended Citation(s)

Data set(s):

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Scientific publication:

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XI. Source Code

Many of the techniques utilized to generate estimates of populations by elevation, population source, and along the urban continuum leverage well-known workflows and geo-processing tools. More information on source code can be accessed from the Low Elevation Coastal Zone (LECZ) Urban-Rural Population and Land Area Estimates, Version 3 at https://doi.org/10.7927/d1x1-d702.

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Appendix 1. Data Revision History

No revisions have been made to this data set.

Appendix 2. Contributing Authors & Documentation Revision History

Revision Date	ORCID	Contributors	Revisions
June 12, 2024	0000-0002-6416-1837	Christina Deodatis, Kytt MacManus	This document is the 1st instance of documentation.