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SORA 2.5 – Ground Risk

Population density mapping

Version	Person	Date
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Contents

1. Introduction

The following report provides insights into the population density map of Switzerland, produced as a part of the SORA 2.5 update. It covers the project's context, data sources, the 100x100 m layer mapping methodology, and a discussion of the results.

1.1 Background of the project

The Specific Operations Risk Assessment (SORA), published by JARUS in 2017 "is a methodology for the classification of the risk posed by a drone flight in the specific category of operations and for the identification of mitigations and of the safety objectives" (*Specific Operations Risk Assessment (SORA) | EASA, 2024*). The "specific" category includes flights beyond visual line of sight (BVLOS), exceeding 120m in altitude, or weighing more than 25kg. The SORA framework separates the risk assessment into two components: air risk and ground risk mitigation. This report focuses on ground risk, specifically Step #2, which involves calculating the intrinsic Ground Risk Class (iGRC)—a key factor directly linked to population density**.** Mapping the population helps evaluate the ground risk level based on the UA's trajectory and characteristics. It provides users with geospatial information reflecting real population density in the operational volume and buffer zones.

The SORA 2.5 update introduces new population density classes, making the previous population density map obsolete (see Figure 1).

Intrinsic UAS Ground Risk Class						
Max UA characteristics dimension		1 m / ~ 3 ft	3 m / ~ 10 ft	8 m / ~ 25 ft	20 m / ~ 65 ft	40 m / ~ 130 ft
Max cruise speed		25 m/s	35 m/s	75 m/s	150 m/s	200 m/s
Maximum iGRC population density (ppl/km2)	Controlled ground area	1	2	3	4	5
	< 25	3	4	5	6	7
	< 250	4	5	6	7	8
	< 2'500	5	6	7	8	9
	< 25'000	6	7	8	9	10
	< 250'000	7	8	9	10	11
	> 250'000	7	9	Not part of SORA		

Intrinsic UAS Ground Risk Class						
Max UA characteristics dimension		1 m / ~ 3 ft	3 m / ~ 10 ft	8 m / ~ 25 ft	20 m / ~ 65 ft	40 m / ~ 130 ft
Max cruise speed		25 m/s	35 m/s	75 m/s	150 m/s	200 m/s
Maximum iGRC population density (ppl/km2)	Controlled ground area	1	1	2	3	3
	< 5	2	3	4	5	6
	< 50	3	4	5	6	7
	< 500	4	5	6	7	8
	< 5'000	5	6	7	8	9
	< 50'000	6	7	8	9	10
	> 50'000	7	8	Not part of SORA		

Figure 1: Old VS New SORA 2.5 iGRC classification (JARUS Guidelines on Specific Operations Risk Assessment (SORA), 2024)

This updated product consists of two maps:

- A 100x100 m resolution map **(new).**
- A 200x200m as suggested by JARUS being an aggregated version of the first one.

A 100x100 m layer was added not only because is the finest and most optimal resolution allowed by the available data sources, but also allows for an easy higher levels aggregation as it is a common denominator for all the suggested grid sizes (see *Table 1*). Additionally, the map is in vector format, enabling each cell to store the population density in km^2 along with additional relevant information.

The population density targets both the resident and mobile population (i.e., workers) in order to provide the most accurate picture of the ground risk. However, since the data is static, the map offers a yearly estimation rather than real-time population figures. Future updates should be easy to implement as long as the new datasets format is not altered. Finally, for consistency, the color palette previously used in the SORA ground risk map will be maintained and adapted to the new GRC classes.

Table 1: Optimal grid size (source: JARUS Guidelines on Specific Operations Risk Assessment (SORA), 2024))

Max. Height (AGL)		**Suggested Optimal Grid Size (meter x meter)**
Feet	**Meters**	
500	152	>200 x 200
1,000	305	>400 x 400
2,500	762	>1,000 x 1,000
5,000	1,524	> 2,000 x 2,000
10,000	3,048	>4,000 x 4,000
20,000	6,096	>5,000 x 5,000
60,000	18,288	>10,000 x 10,000

1.2 Guiding principles

The map was developed following three main principles:

- **User-friendliness**: compiling available data in instinctively interpretable, easy to process and visually esthetic map.
- **Data reliability**: priority is given to the most up-to date, accurate and complete datasets.
- **Worst case scenario approach:** since the primary purpose of this map is the estimation of the ground risk posed by UA operations, it was considered more reasonable to be on the safest side, potentially overestimating population density. As a result, this population density map might not be well suited for purposes beyond iGRC calculations.

2. Data

The population density map is based on five primary datasets summarized in the *Table 2*. Additionally, three auxiliary datasets were used for filtering purposes.

2.1 Primary datasets

Table 2: Summary table of population datasets

Dataset	Publisher	Structure	Format	Projection
STATPOP, (2024)	FSO	100x100 m	csv	EPSG:2056
STATENT, (2023)				
GHS-POP 2020-2025 *Schiavina M., Freire S., Carioli A.,MacManus K. (2023)*	Joint Research Centre (JRC)	100x100 m	TIFF (raster)	Mollweide, EPSG: 4326
Bevölkerungsdichte (2023)	Statistikportal Liechtenstein	100x100 m	shp	EPSG: 2025
Arbeitsplatzdichte (2023)				

STATPOP stores essential demographic data and is based on municipal and national registers. The attribute of interest BTOT represents the total permanent population.

STATENT contains data on the Swiss economy and is used to extract the B08VZAT attribute which indicates the full time equivalent amount of employments. It includes jobs with an annual salary of at least 2,300 CHF. Since employment data accounts for daily commuters, STATENT helps estimate the mobile population.

Both STATPOP and STATENT are published annually and are geocoded using the Federal Register of Buildings and Dwellings (RegBD) and the Business and Enterprise Register (RegBE). STATPOP represents the static population, while STATENT reflects the mobile population.

GHS-POP is part of the Global Human Settlement Layer (GHSL). The utilized data is an estimate of the 2020-2025 population. Compared to the last two datasets its extent is global. It is based on census data from CIESIN which has been disaggregated on built-up areas derived from satellite imagery.

Bevölkerungsdichte & Arbeitsplatzdichte are the Liechtenstein equivalents of STATPOP and STATENT respectively. The only difference is that the population density is published as an interval not an exact number. Thus, the highest bound was always chosen as the population density in each cell.

2.2 Ancillary datasets

The Topographic Landscape Model TLM accessible through the Federal GIS NP BV database contains various type of geographical data covering Switzerland and Liechtenstein. The ones used in this project are:

- *tlm_gebaeude_footprint:* containing the footprints of the buildings
- *tlm_bodenbedeckung*: showing the land cover used for extracting rivers
- *tlm_eisenbahn:* containing railroads

3. Methodology

The process was run on FME Workbench 2023.2.1. The corresponding simplified flowchart is displayed in Figure 2.

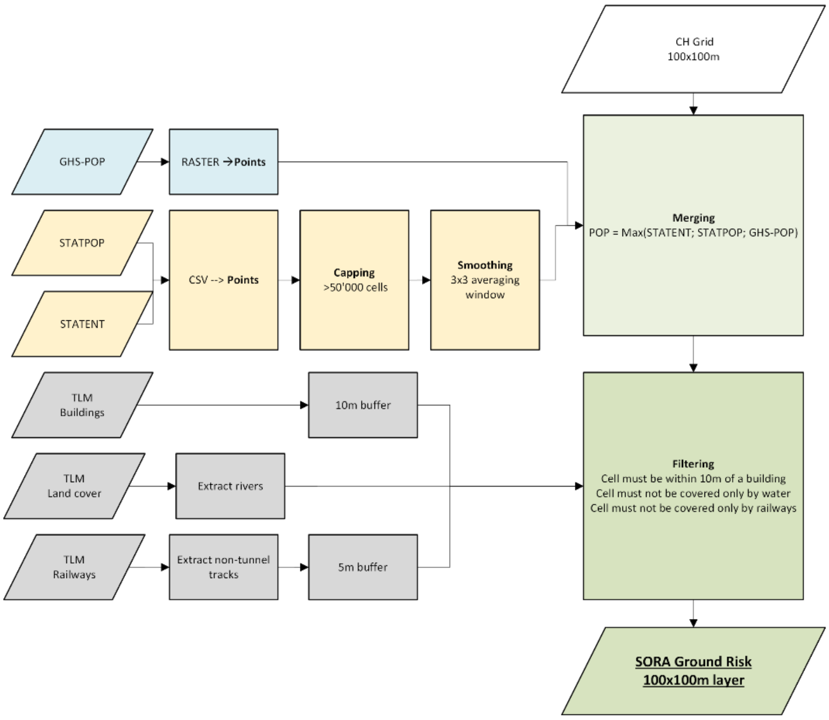

Figure 2: Flowchart of the SORA population map production

The initial step involved transforming the STATENT, STATPOP and GHS-POP point-grids into cell-grids to align them with the gird used by the Federal Statistical Office (FSO) for demographic data. The 100x100 m grid was clipped using a 5km buffered geometry of Switzerland and Liechtenstein.

The processing consists of three main parts: smoothing the FSO datasets with a **moving 3×3 averaging window** (see Figure 3) and **capping the density value at 50'000 ppl/km²**, merging the datasets, and filtering out abnormal cells while reducing the rural sprawl induced by smoothing (see Figure 7).

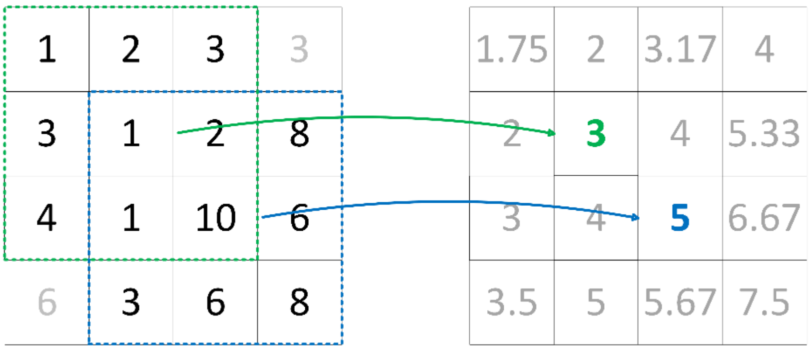

Figure 3: Smoothing 3x3 averaging window illustration

To adhere to the worst-case scenario approach, during the merging **each time data sources overlapped in the same cell, the maximum value was selected**.

The filtering criteria were designed to identify cells with population data that should be excluded due to a lack of “built-up evidence” indicating the presence of significant population. More specifically, **a cell was considered invalid if it did not intersect any building (within a 10 m buffer) or if it completely overlapped with a river or railway.**

The exact same process was performed in parallel with the data from Liechtenstein.

Finally, the 100x100 m grid got aggregated into a 200x200 m grid by taking the mean population density of the four smaller cells within each bigger cell.

4. Results

4.1 Map

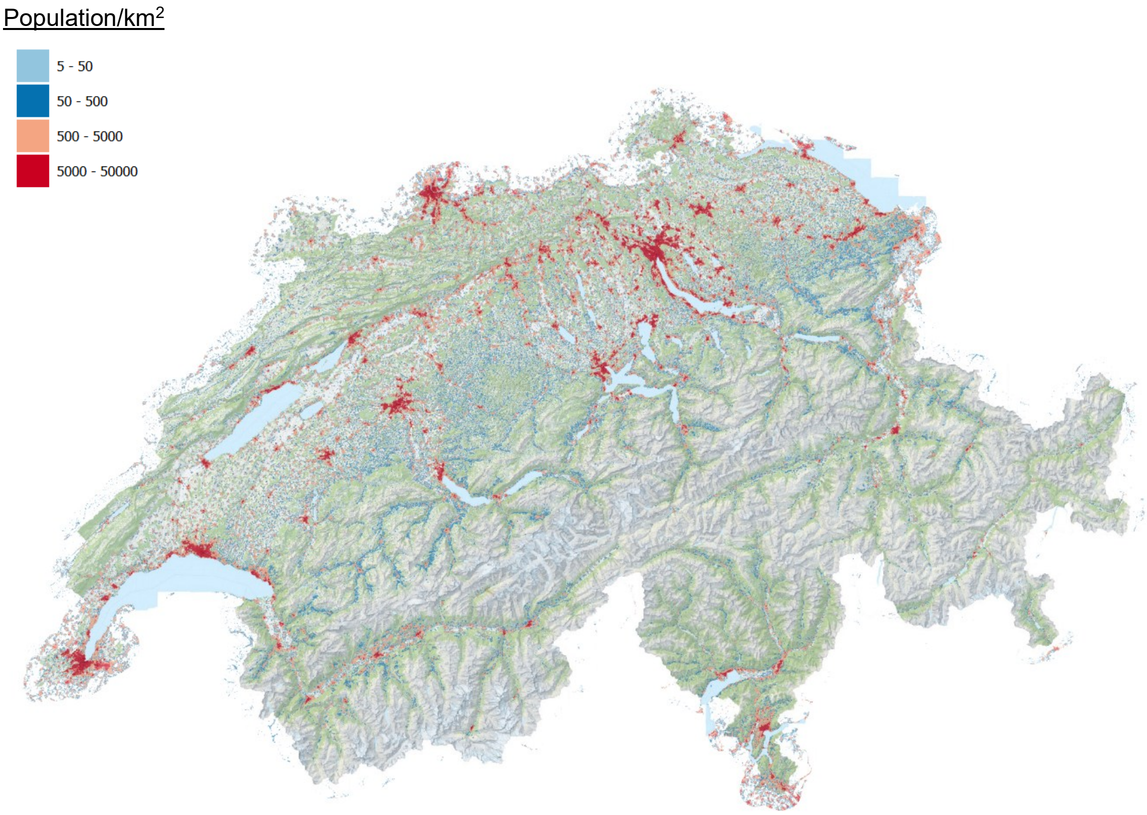

Figure 4: SORA2.5 density map of Switzerland

4.2 Attribute table

Table 3: Attribute table snippet – Attributes in gray can be found exclusively in the 100x100 m layer

id	density_pop_km2
17285	10
17286	300

4.3 General overview

The final product is made of 795'632 cells containing non-null population values. In theory, summing the population values across all cells should approximate the total Swiss and Liechtenstein population (~9 million people). However, the actual computed total is 13'608'936 people, so more than the expected value. This can be interpreted as the effect of the inclusion of both the residents and the employees. Since most individuals don't work and live in the same location, they are effectively counted twice; once at their residence (from STATPOP) and once at their workplace (from STATENT). There is also the 5km buffer around both countries that is partly responsible for this overcount.

4.4 Population data source

Concerning data sources, STATENT (9,4% of the data) and STATPOP (41,9%) dominate urban areas, whereas GHS-POP (48,7%) appears primarily in remote areas, as shown in Figure 5. Nearly half of the

GHS-POP data did not overlap with any FSO cell, partly because it was the only dataset available in the buffer zone.

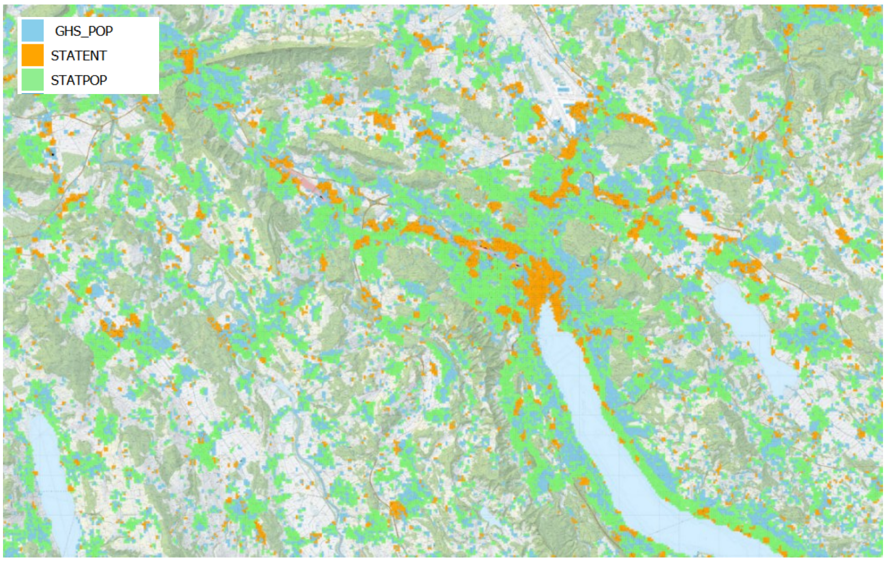

Figure 5: Spatial distribution of data sources around Zürich

Another good illustration is the campus of EPFL (see illustration in Figure 6). Without the GHS-POP the whole opaque blue part wouldn't have any data because of how STATENT population was aggregated in specific places of the campus displayed in orange. Thus, it acts like a security buffer.

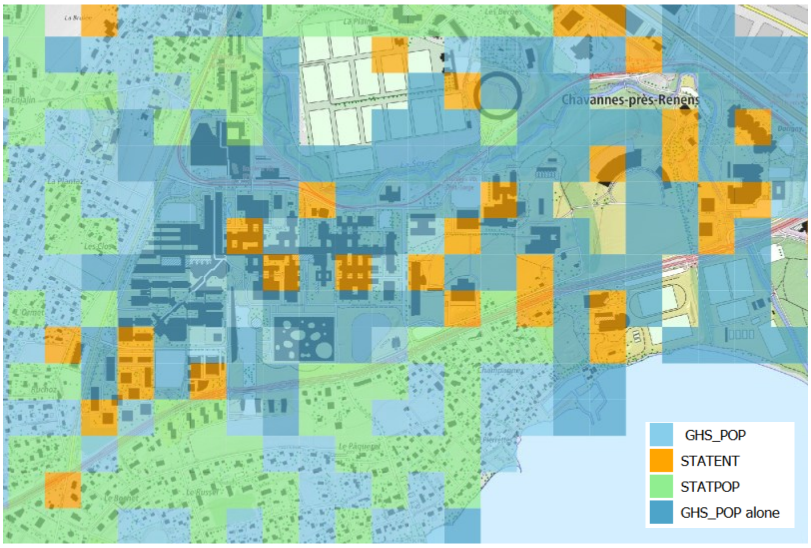

Figure 6: Spatial distribution of data sources at the EPFL campus

To understand the disparity in distribution between the Swiss and EU data, an overview of their production methods is necessary. The key difference lies in the disaggregation technique. For GHS-POP, population estimates from census data were disaggregated at the polygon level, corresponding to administrative boundaries such as districts and municipalities. In contrast, data from RegBD and RegBE are grouped by address. This means that if a building or work area covers a large geographic area, all employees are assigned to the single cell corresponding to the building's registered address.

4.5 Filtering

A total of 431’259 non-null cells were filtered out; they can be visualized on Figure 7. Most of them are smoothing residues in rural areas and outliers of the GHSL dataset. Most of the removed cells represent smoothing artifacts in rural areas and outliers within the GHSL dataset. Many of these cells were located in mountainous regions, where bare rock was mistakenly classified as built-up area by land cover classification algorithms. This misclassification likely caused census-based population estimates to be incorrectly assigned to these areas in the GHS-POP dataset.

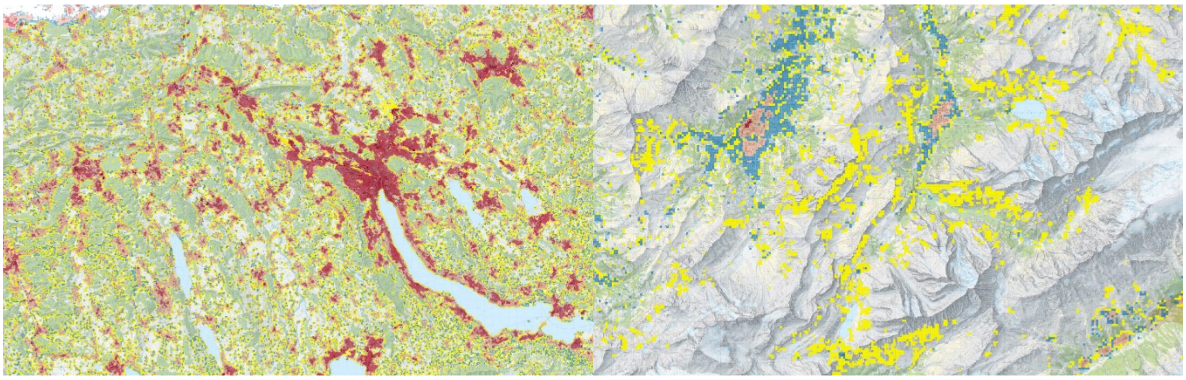

Figure 7: Filtered out cells (in yellow) around urban (ZH) and in mountainous regions (Oeshinen’s lake re-gion)

4.6 Differences from the previous map

Below is a list of all the elements of the methodology that have been updated in this version of the map (see Figure 8):

- **Correction of a calculation error:** A mistake in the population density aggregation in the previous version caused each cell to underestimate the actual density by a factor of four. This significantly impacted the classification, making many areas appear less dense than they should be.
- **Revised merging logic**: As covered previously, there are three different data sources potentially overlapping over the same cell. The question is how we choose which one should be valid there. In the previous map, the following order of priority was set: GHS-POP > STATPOP > STATENT. This meant that GHS-POP was always prioritized when available, while STATENT was only used as a last resort. However, given the known inaccuracies of GHS-POP, this hierarchy has been replaced by a worst-case scenario approach, where the highest population value from any data source is used for each cell.
- **Filtering:** Additional datasets were used to identify and remove GHS-POP data in remote areas where population presence is unlikely.
- **Capping:** Although it was rare, some cells (mostly STATENT) fell in the >50’000 ppl/km^2 category which was considered unreasonable knowing this is comparable to a Hong Kong population density or an assembly of people. Therefore, a threshold of 50’000 ppl/km^2 has been applied.
- **Updated density classes:** Due to the SORA 2.5 update, class thresholds have changed. As a result, some cells have been reclassified, leading to a visual adjustment of colors on the map.
- **Updated source datasets:** The previous version used FSO population data from 2020, whereas this update incorporates new datasets from 2023 and 2024, improving accuracy.
- **New separate datasets for Liechtenstein:** In the last version Liechtenstein was relying solely on GHSL data. Here, employment, residency from national registers and land use data were also included.

- **Introduction of the 100x100 m layer:** Previously, the methodology directly merged the three datasets into a 200x200m grid before selecting the dominant value per cell. In this version, data is first processed at 100x100 m resolution, then aggregated to 200x200 m using the mean. This change improves precision by allowing each larger cell to incorporate information from multiple sources instead of losing details during aggregation.

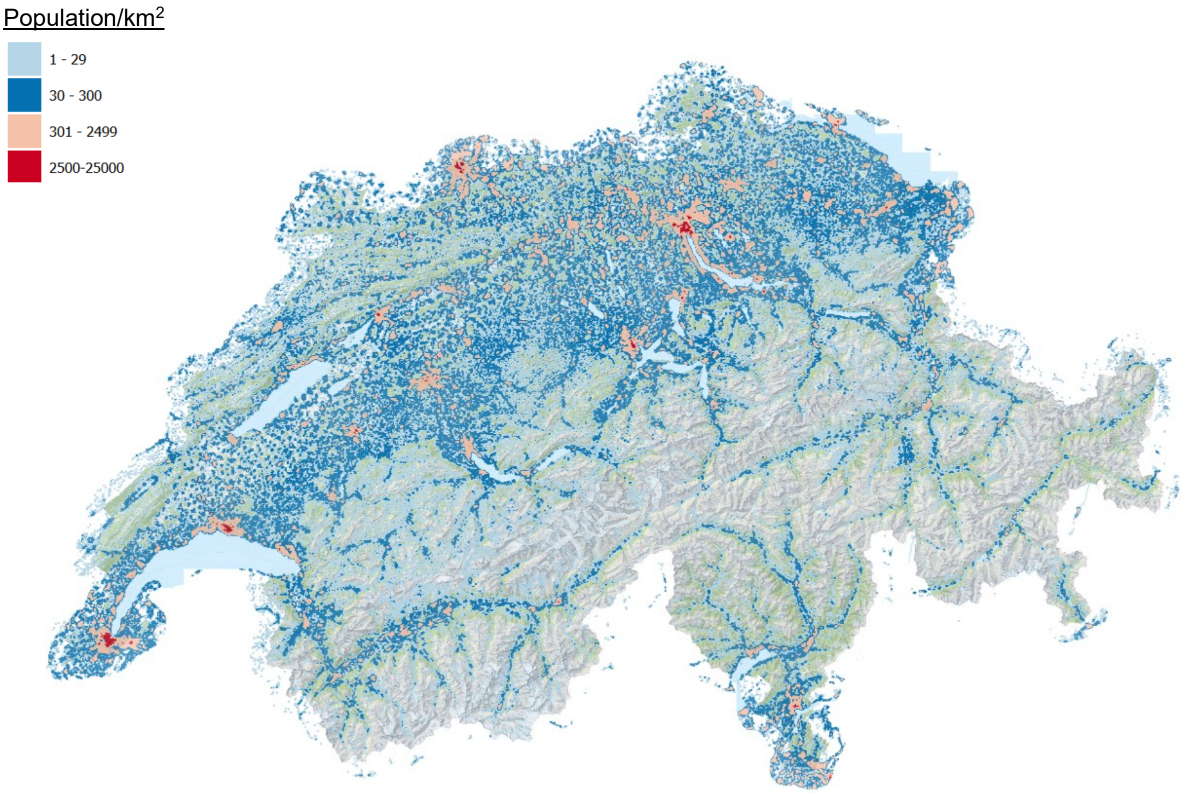

Figure 8: Previous population density map of Switzerland for SORA 2.0

5. Limitations

When using this product, it is important to keep in mind its limitations:

- **Static population data**: The recorded population includes only residents and employees, meaning social gatherings (e.g., events, tourism) are not accounted for. Additionally, seasonal and daily population changes are not captured by this map, although the STATPOP and STATENT attributes provide some indication of day and night population differences to a certain extent.
- **Data validity period**: The dataset is not fully up to date, with FSO data from 2023/2024 and GHS-POP estimates ranging from 2020-2025.
- **Spatial accuracy**: Since FSO census data was aggregated prior to publication, the exact localization of population may not be precise. Additionally, the GHS-POP data was originally slightly shifted towards North-East and uses satellite imagery which is not 100% reliable to detect built-up areas. More generally, the map's precision cannot be higher than the precision of the underlying data.
- **Smoothing causing a blur of the sharp local variations.**
- **Unfiltered buffer zone**: The datasets used for filtering were confined within CH and LI borders therefore the buffer zone around is made up only of unfiltered GHS-POP cells.
- **Assumption of even distribution within the cell**.
- **The modifiable areal unit problem (MAUP):** "*MAUP refers to the situations that when the boundary of zones used in a spatial analysis change, the statistical inference and interpretation derived from the zones are also different*" (Xu et al., 2016). This effect is inherent to this type of projects. In this case the "arbitrary" parameter influencing the population statistics is the size and position of the grid.
- **Comparing different disaggregation methods:** As explained in point 4.4, comparing FSO with GHSL data is not ideal as they have different aggregation/disaggregation techniques.

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