Assessment of PM Exposure at intra-urban scale in preparation of MAIA mission (APEMAIA) Project

WP2104 – PM2.5 and PM10 population exposure

DEL010 – Description of the third system module (WP2) for the analysis of population exposure to PM2.5 and PM10 at high resolution (SW007 and SW008)

Contract n. 2023-39-HH.0

CUP n. F83D23000210005

ASI CONTRACT N°	2023-39-HH.0		
PROJECT NAME	Assessment of PM Exposure at intra-urban scale in preparation of MAIA mission (APEMAIA)	**CONTRACTOR**	National Research Council – Institute of Atmospheric Pollution Research
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PROJECT BEGIN DATE	26/09/2023	**PROJECT END DATE**	25/09/2025

EXECUTIVE SUMMARY			
This document is the **D010** preliminary deliverable of the **A**ssessment of **P**M **E**xposure at an intra-urban scale in preparation for the **MAIA** mission (APEMAIA) project. It is released at the conclusion of activities scheduled for Work Package WP2104 – PM2.5 and PM10 population exposure. The release adheres to the planned schedule: (T0+7M). The document represents a preliminary version of the **D010 Deliverable** to be submitted in its final version at Third Release of Advancements (**RA3**) of the project.			
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STAR CODE		No OF VOLUMES:	

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1. AIM OF THE DOCUMENT

This document represents the first version of deliverable D010 - Description of the third system module (WP2) for the analysis of population exposure to PM2.5 and PM10 at high resolution (SW007 and SW008). It is being submitted as the preliminary document release of WP2104 as within the **A**ssessment of **P**M **E**xposure at an intra-urban scale in preparation for the **MAIA** mission (APEMAIA) Project.

The APEMAIA project's activities are carried out by a consortium led by the Institute of Atmospheric Pollution Research of the National Research Council of Italy (CNR-IIA), acting as the prime contractor, and supported by the Apulian Regional Agency for Environmental Protection (ARPA Puglia) and the Physics Department of the University of Bari (DIF-UNIBA).

List of goals:

- Production of monthly, seasonal and annual PM2.5 exposure maps with high spatial resolution (≤ 500m)
- Production of monthly, seasonal and annual PM10 exposure maps with high spatial resolution (≤ 500m)
- Production of 'warning area' maps based on time series analysis of exposure data, both trend and spikes

In this preliminary release, the primary focus is on generating an updated grid population density map for each study area. This is a crucial step in calculating exposure levels and identifying warning areas, as population distribution plays a significant role in determining human exposure to pollutants like PM2.5 and PM10.

The end of the preliminary activities leading to this release is scheduled for T0+7M (seven months from the project start date).

The final release of this deliverable (D010) is expected at T0+22M (22 months from the project start date).

This deliverable plays a foundational role in achieving the larger objectives of the APEMAIA project by ensuring that accurate, up-to-date population density maps are integrated into the analysis of air pollution exposure across the selected urban areas.

1.1 Applicable and reference documents

This document incorporates provisions from other dated or undated documents. These references are cited at appropriate places in the text and are listed hereafter. For undated references, the latest edition of the publication referred applies.

In case of conflict between two or more applicable documents, the higher document will prevail.

1.2 Applicable documents

[AD 1] ASI Contract No. 2023-39-HH.0

[AD 2] DEL_004 – Technical Report "User Requirement Document (preliminary version)"

[AD 3] DEL_008 – Description of the first system module (WP2) for the extraction of high-resolution AOD maps (SW004); description of the Data-driven and Knowledge-Driven procedures for the extraction of LCLU maps in urban areas (SW005) (preliminary version)

1.3 Reference documents

[RD 1] WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide.

[RD 2] Aquilino, M., Adamo, M., Blonda, P., Barbanente, A., Tarantino, C., 2021. Improvement of a Dasymetric Method for Implementing Sustainable Development Goal 11 Indicators at an Intra-Urban Scale. Remote Sens. 13, 2835. https://doi.org/10.3390/rs13142835.

1.4 Acronyms and abbreviations

Table 1-1 provides the acronym list.

Table 1-1: Acronyms and abbreviations

Acronym	Description
AOD	Aerosol Optical Depth
AI	Artificial Intelligence
APEMAIA	Assessment of PM Exposure at intra-urban scale in preparation of MAIA mission
ARPA Puglia	Apulian Regional Agency for Environmental Protection

2. Essential variable for air pollution population exposure analysis

To achieve the goals of WP2104 - HR PM2.5 and PM 10 population exposure, the first step involves obtaining a realistic population density map of the study areas.

The spatial distribution of population is specifically considered as an essential variable requested for quantifying SDG 11 indicators. The SDG 11.6.2 on the annual mean levels of particulate matter PM 10 and PM 2.5 (population weighted) can be specifically computed by a spatial overlay of grid population density map with air pollution information maps [RD 1].

2.1 The CNR-IIA vector-based dasymetric method

Demographic data are usually represented by a choropleth map where the statistical data are aggregated with census area. This type of representation is reported to have several limitations with respect to spatial analysis and population distribution (Mennis 2003). To overcome this issue CNR-IIA developed an automatic workflow that implements a reproducible dasymetric mapping method [RD 2]. Dasymetric mapping refers to a technique used to distribute population data more accurately across a geographic area: typically, by identifying natural spots of concentration and rarefaction based on supplementary data (like land use or satellite imagery).

The rationale behind this weighting procedure is to account for the fact that, due to multifloor buildings, population density values are generally higher in urban areas than in rural contexts.

The criteria proposed to define the weights of population re-distribution are described as follows:

- In residential areas, population allocation is proportional to Building Footprint Areas/Volumes.
- In non-residential areas, population allocation in a specific cell depends also on building use and relative correction factors.

To facilitate the exploitability and interoperability between models and the reproducibility of the results, the dasymetric mapping model developed by CNR-IIA has been published using the Virtual Earth Laboratory (VLab) framework, in two versions (a basic and an advanced one for expert users). The code was written in Python 3.7 programming language by mainly using pyQGIS libraries for Python 3.7. ***Errore. L'origine riferimento non è stata trovata.*** shows the main differences between the basic and advanced versions and the links to the respective GitHub repositories.

Table 2-1. Differences in setting options between basic and advanced workflow implementations.

Setting options	Dasy2 (Basic implementation) https://github.com/MarA-iia/DasymetricV2.2	Dasy3 (For advanced users) https://github.com/AM-IIA/Dasymetric3.git
Building use layer	Urban Atlas as input, Building use classes not configurable	Generic Land Use map, Building use classes configurable
Building heights	Required	Optional
Weight's correction factors	Fixed	Configurable

The option "Volumes" has been introduced in 2.0 version of the dasymetric method, and it is applicable when Building Heights data are available. The introduction of building height information can discriminate between residential areas of greater or lesser density.

An experimental plugin for QGIS was also developed as an additional open-source tool for sharing the dasymetric method with QGIS community users, which include urban planners, statisticians, technical employees of local and regional authorities. Dasy QGIS Pugin is available at official repository of QGIS as an experimental plugin: https://plugins.qgis.org/plugins/dasy/#plugin-details.

The first step of the dasymetric method consists of a double intersection of the input vector information layers: polygons of census areas; polygons of different building uses and the final output grid. The elements resulting from such double intersections are shown in Figure 2-1. The colours represent the different building uses. The red strokes identify the polygons of the census areas, while the blue strokes delimit the output grid cells.



Figure 2-1 Double intersection of input vector layers [RD 2].

The following formula reflects the dasymetric computation method implemented in the QGIS environment:

$$P_{grid} = \sum_{j=1}^{m} P_{j,census} \frac{\sum_{i=1}^{n} BF_{sub_elemGRID_i} * Hmean_{sub_elemGRID_i} * Corr_{factor}}{\sum_{l=1}^{k} BF_{sub_elemCENSUS_l} * Hmean_{sub_elemCENSUS_l} * Corr_{factor}} \quad (1)$$

where,

- $BF_{sub_{elemCENSUS_l}}$ is the built-up footprint area in a generic sub-element l of a census zone having different building use;
- k is the number of census zone sub-elements with different building use, derived from the intersection of vector layers census zones and building use;
- $BF_{sub_elemGRID_i}$ is the built-up footprint area in a generic sub-element i of a census zone, with different building use, included in the output cell considered;
- n is the number of census zones sub-elements, with different building uses, within a grid cell, derived from the double intersection;
- $P_{j,census}$ is the population of a generic census zone;
- m is the number of census zones in a cell;
- P_{grid} is the final population allocated to a cell of a regular grid;
- $Hmean_{sub_elemGRID_i}$ is a mean value of building heights of sub-elements in a cell. The constant value 1.0 was set for the dasymetric method (version 1.0);

- $Hmean_{sub_elemCENSUS_l}$ is a mean value of building heights in census zones. The constant value 1.0 was set for the dasymetric method (version 1.0);
- $Corr_{factor}$ are correction factors based on building uses, as documented in [RD 2].

The block diagram of the version 2.0 software implementation in the QGIS environment (compatible with Python 3.7.) is shown in Figure 2-2.

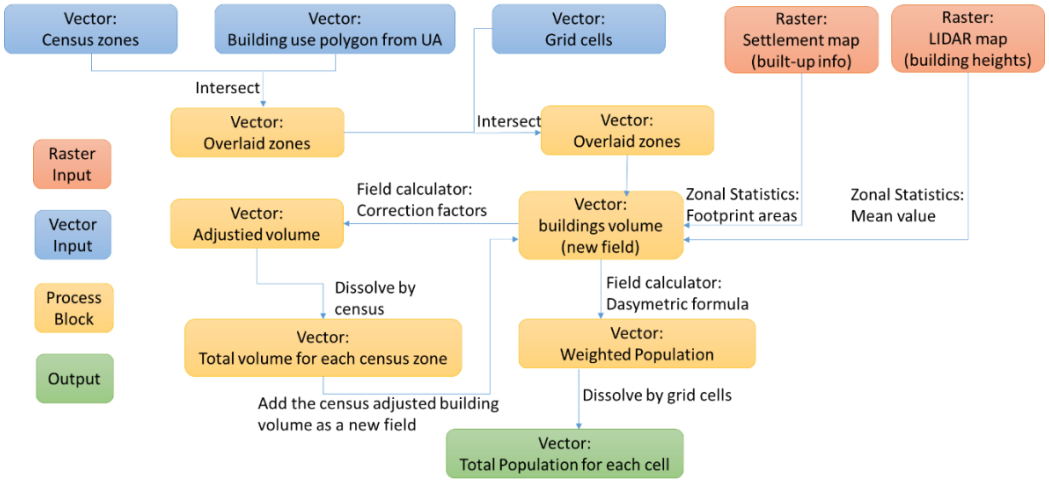


Figure 2-2- Dasymetric 2.0 version [RD 2].

2.2 Step-by-Step process to generate density population map in the study areas

For APEMAIA project we have chosen to use a QGIS implementation plugin, specifically the Dasy plugin, for generating grid-based population density maps for each area of study.

Here's a summary of Step-by-Step process that need to be carried out for APEMAIA project:

A. Access the Plugin: The plugin, known as Dasy, is available in the QGIS Plugin Repository and can be found at this link: https://plugins.qgis.org/plugins/dasy/#plugin-details
B. Install the Plugin: Open QGIS (a popular open-source geographic information system). Navigate to the Plugins tab and search for "Dasy" in the repository. Install the Dasy plugin to integrate it into your QGIS environment
C. Gather relevant geospatial data for the area of study such as:
    - Population data, usually in the form of census data, with counts at a coarse resolution (e.g., city level, district level).
    - Administrative boundaries of the study areas.

- Land use/land cover data or other auxiliary data that help refine the population distribution.
- Digital elevation model/building heights of the study areas (optional input).

The official source of population census data in Italy is ISTAT (Italian national institute of STATistics).

ISTAT provides the results of the **permanent census of population and housing** for the following sub-municipal territorial levels:

- **Census sections** for all Italian municipalities.
- **Sub-municipal administrative areas**, where such partitions exist.

The last update dataset (after the oldest, in 2011) refers to the census population as of **December 31, 2021**. Databases provide also new layers on the administrative boundaries: **2021 Territorial Base**. These bases reflect updates to municipal demography and territorial changes that occurred since the 2011 census.

The first digits of the census section codes correspond to the municipalities as they existed on **December 31, 2021**. While the data structure has been made consistent with past censuses, direct comparability is not guaranteed due to changes in territorial boundaries and population allocation methods. The census provides information on population variables, including sex, age, citizenship, education, employment, and households. Additionally, the number of occupied dwellings is included. Such categorization is very important in the light to carry on an exposure analysis tailored to the most vulnerable group of the urban population.

An update of land cover map is in progress as reported in [AD 3]. Building use information have been extracted from Copernicus Urban Atlas dataset.

The source of average building heights is DTM and DSM will be obtained for the study areas. For Bari site they have been generated from a PLEIADES stereo image acquired in July 2021. However, for all the study areas, a DTM and DSM for 2008 can be obtained from LiDAR data provided by the Ministry of the Environment's Extraordinary Remote Sensing Plan. It is planned to request LiDAR data for the Taranto and Rome study areas.

The choice of evaluating heights as an average value in the LiDAR data (dated 2008) is a criterion that is useful to overcome the issue of missing information for buildings constructed after 2008. Such an approximation is justified by the existence of municipal regulations that prevent the construction of new buildings with height values differing from those prevailing in the urban context.

For Bari site the acquisition of new 2021 population updated dataset is completed. In addition, for this site, a dataset for population dates back to 1 January 2020 is available (obtained through direct interaction with the Municipality of Bari, Figure 2-3).

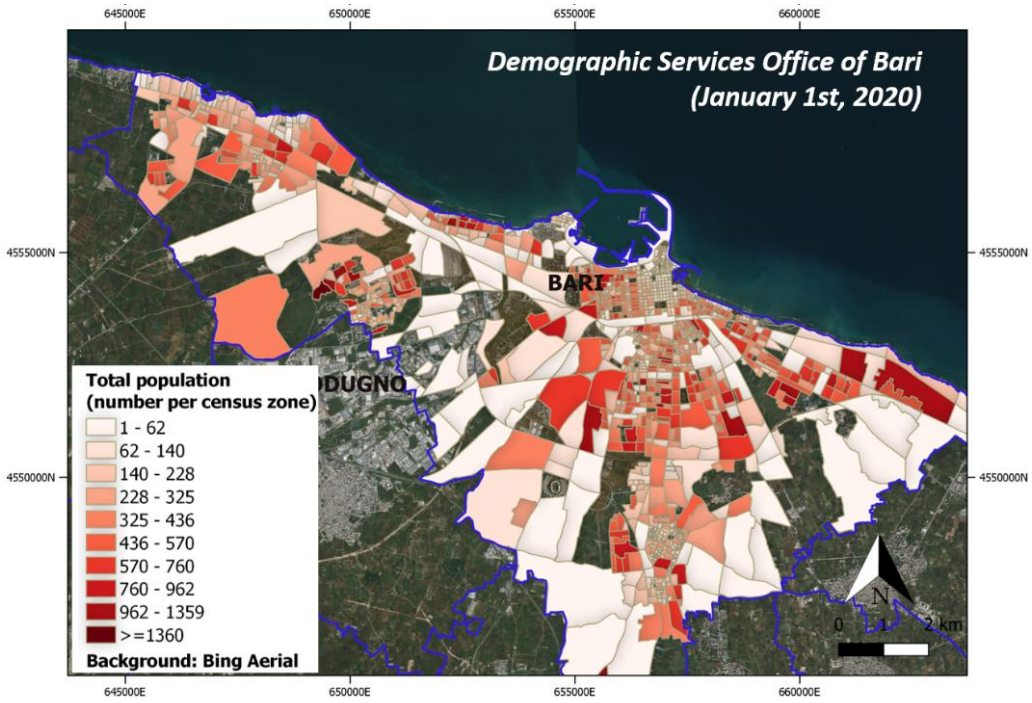


Figure 2-3: Population data provided by Municipality of Bari relevant for 2020.

The method has applied to new data (DSM, DTM and population) for Bari with the aim to obtain updated Total population density maps for 2020 (Figure 2-4) and 2021.

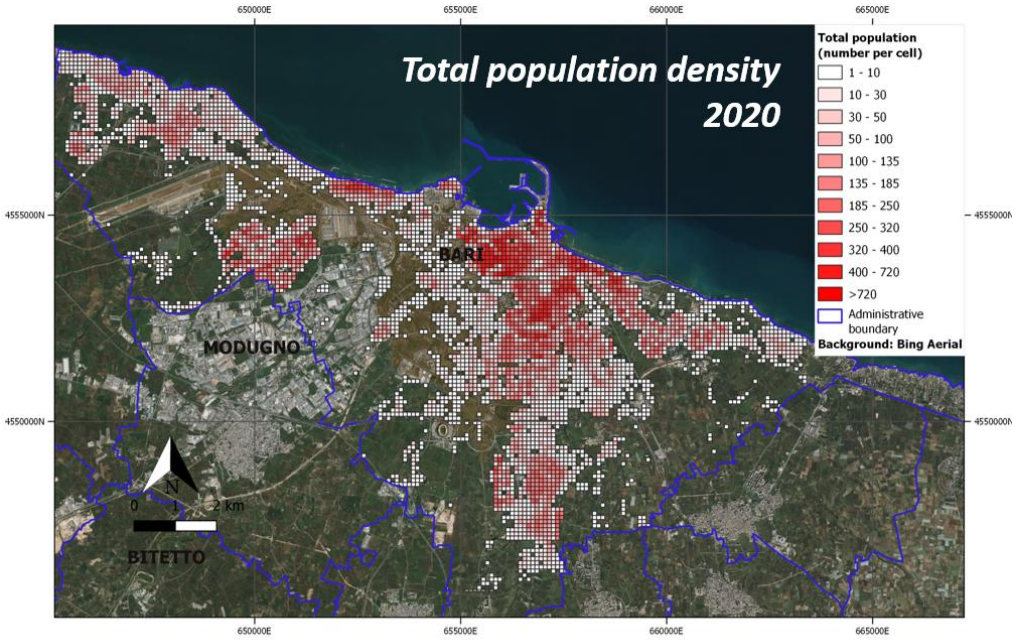


Figure 2-4: Total Population density map for Bari (100x 100 m) generated with 2020 population census data.

The acquisition for updated population data from the municipalities of Bari, Taranto and Rome is planned and will be completed within the end of WP2104.