# Section 1: Health Hazards, Exposure, and Impact

## 1.1.1.2 Exposure of vulnerable populations to heatwaves

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**Methods**

**Heatwave Occurrence and Duration**

We defined a heatwave as a period of three or more consecutive days in which both the daily minimum and maximum temperatures exceeded the 95th percentile of the local climatology [1]. This dual-threshold definition captures both the direct heat stress caused by high daytime temperatures and the physiological strain associated with insufficient nighttime cooling [2], [3] Two climatological baselines were used:

- 1986-2005 reference period.
- 2007-2016 to align with the Paris Agreement.

To determine these events, we utilized daily 2-meter temperature data from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5 reanalysis dataset [4], gridded at a 0.25° × 0.25° global resolution. For each grid cell and each year from 1980 to 2025, we calculated two primary metrics:

- Heatwave Duration: The total number of days per year spent during a heatwave.
- Heatwave Frequency: The total number of discrete heatwave events per year.

**Heatwave Severity (Excess Heat Factor)**

To assess the changing intensity of heatwaves, we calculated the Excess Heat Factor (EHF), a metric that accounts for both the long-term climatological anomaly and short-term acclimatization [5].

We classified daily heatwave severity into three tiers—**Low-Intensity**, **Severe**, and **Extreme**—based on the methodology of the Australian Bureau of Meteorology [5].

**Vulnerable Groups**

We focused on three demographic groups particularly susceptible to heat-related health impacts:

- **Elderly (≥ 65 years):** Age-related decrements in thermoregulation (e.g., reduced sweating) occur significantly by age 65 [6]. Additionally, the risk of underlying chronic conditions such as cardiovascular, renal, and respiratory diseases—secondary aggravators of heat stress—increases with advanced age [7].
- **Infants (< 1 year):** Infants are highly vulnerable due to a high surface area-to-mass ratio (up to 4-fold greater than adults) and a limited behavioral ability to avoid heat [8].
- **Pregnant Women:** Pregnancy places significant physiological strain on the cardiovascular and thermoregulatory systems. Extreme heat exposure during pregnancy has been linked to adverse outcomes including preterm birth, low birth weight, and stillbirth [9].

**Population Data Integration**

To construct a continuous annual time series of global population distribution from 1980 to 2025, we combined three distinct datasets:

- **1980–1999:** We utilized the **Lancet Countdown 2023 dataset** [10], derived from the ISIMIP Histsoc dataset. This data was resampled to a 0.25° × 0.25° resolution using 2D linear interpolation incorporating population densities and NASA GPWv4 land area data.

- **2000–2014:** We used global gridded demographic data from the **WorldPop project** [11] available at a 1 km × 1 km resolution based on the "top-down unconstrained approach." Aggregated age/sex groups were downscaled to match the ERA5 grid by summing values within each cell.
- **2015–2025:** We utilized the **updated WorldPop dataset** [12], providing high-resolution annual estimates that account for recent migration and urbanization trends.

For infants counts were derived by aggregating the age bands 0–1 from the respective datasets. For the elderly ($\geq$ 65 years), we summed the age bands 65–70, 70–75, 75–80, and 80+.

### Heatwave Exposure Calculation
Exposure to heatwaves for each vulnerable group was calculated by combining heatwave occurrence data with gridded demographic datasets.

For each grid cell, the annual heatwave exposure (in person-days) was computed as:

$$\text{Exposure} = \text{Heatwave Days} \times \text{Population}$$

Where:
- **Heatwave Days:** The total number of heatwave days in that grid cell for the year.
- **Population:** The number of individuals in the vulnerable group residing in that grid cell.

The total annual exposure for each vulnerable group was obtained by summing the exposure across all grid cells globally.

### Code and resources to reproduce the results
The results were generated using Python, a copy of the code is available in this public repository https://github.com/FedericoTartarini/paper-lancet-countdown-global. Users who want to reproduce the results will first need to download the datasets listed below. Then they can use the code to reproduce the results, please refer to the README file in the public repository which contains detailed instructions on how to run the Python code.

### Updates Introduced for 2026
In this 2026 update, we have introduced:
- the assessment of heatwave severity using the Excess Heat Factor (EHF) metric, allowing us to differentiate between low-intensity, severe, and extreme heatwaves.
- the inclusion of pregnant women as a vulnerable group, recognizing their heightened susceptibility to heat-related health impacts.
- improved demographic data integration by utilizing the latest WorldPop datasets.
- removed the people aged 75+ since this group is already included in the 65+ age group.
- given that the population data now extends to 2025, we did not need to project population estimates beyond 2020 as done in previous years.
- we have included the analysis of heatwave exposure trends under the 2007–2016 baseline, to align with the Paris Agreement.

### Data
- Climate Data: ECMWF ERA5 reanalysis dataset.
- Demographic Data (1980–2000): Hybrid gridded demographic dataset from the Lancet Countdown 2023 (0.25° resolution) [10].
- Demographic Data (2000–2015): WorldPop Age and Sex Structure Unconstrained Global Mosaic [11].
- Demographic Data (2015–2025): WorldPop Age and Sex Structure Unconstrained Global Mosaic [12].

**Caveats & Limitations**

To ensure consistency over time, data from multiple sources were integrated to capture both spatial and temporal demographic trends. However, validation of this integrated dataset is limited. In regions with sparse demographic data or shifting political boundaries, inconsistencies may arise in the spatial distribution of populations. For example, the division of Sudan is reflected in the dataset as missing or incomplete information for infant populations, illustrating the challenges of maintaining demographic continuity in dynamically changing regions. WorldPop's "top-down unconstrained" approach was used for population mapping. This method estimates population distribution without restricting allocation to residential areas, unlike the "constrained" approach, which relies on satellite imagery to identify inhabited locations. While this method ensures continuous coverage across all land areas, it may overestimate populations in low-density regions and underestimate them in high-density areas.

**Future form of the indicator**

Results will be updated each year using the latest available climate and population data. The definition of conditions that constitute a "heatwave" may be altered to align with emerging standardization from organizations such as the World Meteorological Society. The estimation of heat stress risk may also be expanded beyond heatwave days to include thermophysiological indices that account for dry-bulb air temperature, humidity, solar radiation, and wind speed, providing a more comprehensive assessment of heat-related health risks.

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