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

Heatwaves effects on human health is a growing concern worldwide, particularly for vulnerable populations such as the elderly, infants, and pregnant women. However, there is no universally accepted definition of a heatwave, with various studies employing different temperature thresholds, durations, and metrics to characterize these events [1]. For this analysis, 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. This definition is based on the approach used by the World Meteorological Organization (WMO) in the "Heatwaves and Health: Guidance on Warning-System Development" [2]. This dual-threshold definition captures both the direct heat stress caused by high daytime temperatures and the physiological strain associated with insufficient nighttime cooling [3], [4] 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-Land reanalysis dataset [5], gridded at a 0.1° × 0.1° 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 [6].

We classified daily heatwave severity into three tiers—**Low-Intensity**, **Severe**, and **Extreme**—based on the methodology of the Australian Bureau of Meteorology [6].

Vulnerable Groups

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

- **Elderly ($\geq$ 65 years):** Age-related decrements in thermoregulation (e.g., reduced sweating) occur significantly by age 65 [7]. Additionally, the risk of underlying chronic conditions such as cardiovascular, renal, and respiratory diseases—secondary aggravators of heat stress—increases with advanced age [8].
- **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 [9].
- **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 [10].

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** [11], derived from the ISIMIP Histsoc dataset. This data was resampled to a $0.1° \times 0.1°$ 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** [12] available at a $1 \text{ km} \times 1 \text{ km}$ resolution based on the "top-down unconstrained approach." Aggregated age/sex groups were downscaled to match the ERA5-Land grid by summing values within each cell.
- **2015–2025:** We utilized the **updated WorldPop dataset** [13], 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 (≥ 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.

We are also proposing to include Dr Mitchell Black as a co-author for this indicator.

Data

- Climate Data: ECMWF ERA5-Land reanalysis dataset.
- Demographic Data (1980–2000): Hybrid gridded demographic dataset from the Lancet Countdown 2023 (0.25° resolution) [11].

- Demographic Data (2000–2015): WorldPop Age and Sex Structure Unconstrained Global Mosaic [12].
- Demographic Data (2015–2025): WorldPop Age and Sex Structure Unconstrained Global Mosaic [13].

Caveats & Limitations

Climate Data
The ERA5-Land reanalysis dataset provides high-resolution temperature data suitable for heatwave analysis. However, reanalysis datasets may have biases compared to in-situ observations. These biases can affect the accuracy of heatwave detection and characterization. Additionally, the spatial resolution of ERA5-Land ($0.1° \times 0.1°$) may not capture microclimatic variations in urban areas, where heatwaves can be more intense due to the urban heat island effect.

Heatwave Definition
The chosen heatwave definition (3 consecutive days with both minimum and maximum temperatures above the 95th percentile) may not capture all relevant heatwave events, and does not account for humidity or other environmental factors that influence heat stress.

Demographic Data
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.

Additional Analyses and Figures
Figure 1 illustrates the change in the number of heatwave days in 2025 compared to the baseline period, highlighting intense events across all continents, particularly in regions such as Africa, Asia.

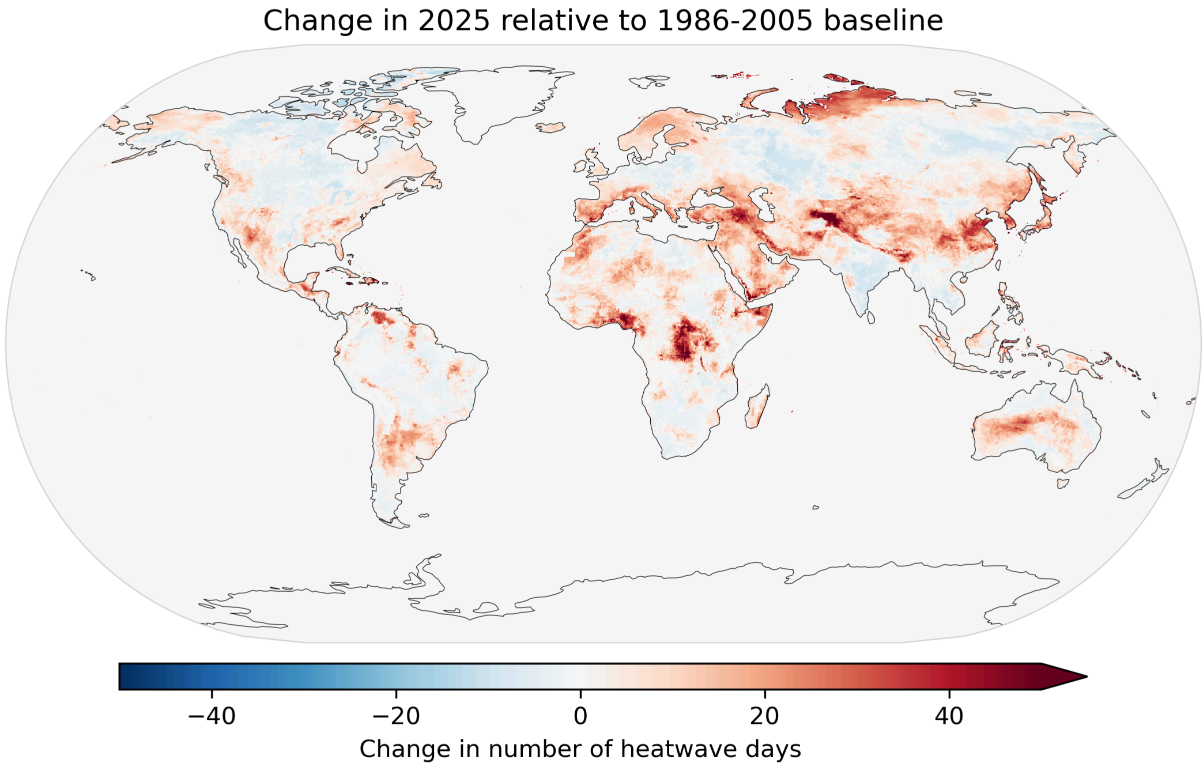

Figure 1: Map showing the change in heatwave days in 2025 compared to the 1986–2005 baseline.

While the total number of heatwave days decreased from last year, older adults (65+ y) were exposed to record 10 billion person-days of heatwaves (the second highest year on record), while infants under one year experienced 2.9 billion person-days, as illustrated in Figure 2.

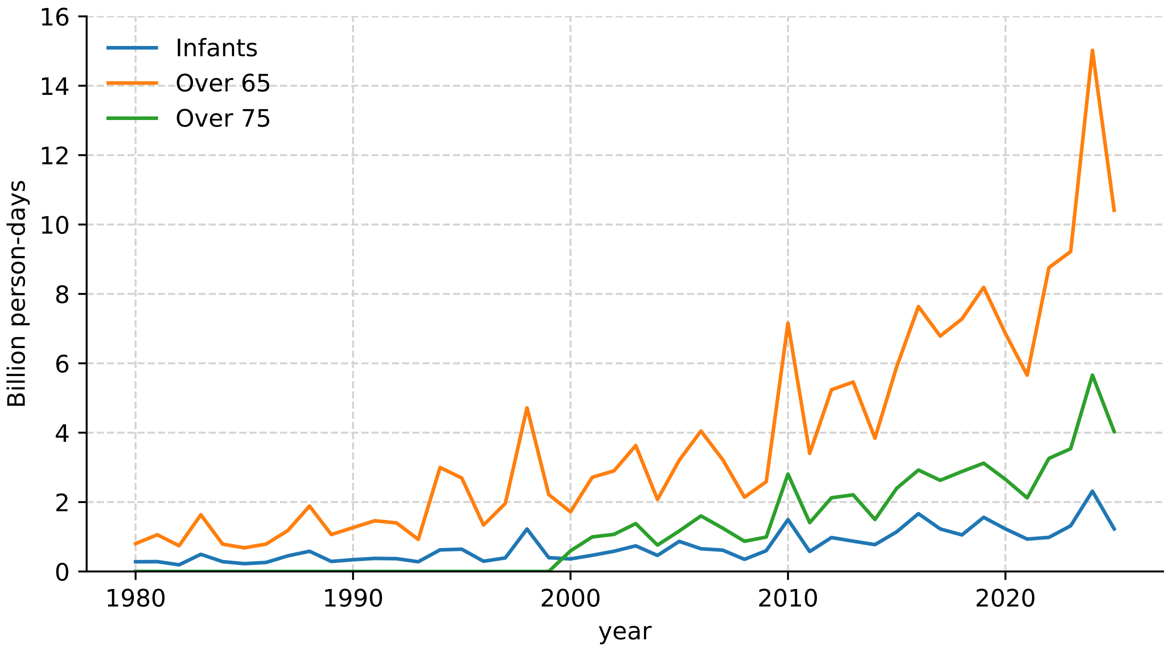

Figure 2: Total number of heatwaves days experienced per year by older adults (over 65) and infants.

When normalized by population size, individuals over 65 years experienced on average 12.4 heatwave days per person in 2025, while infants experienced 9.5 heatwave days per person, as shown in Figure 3.

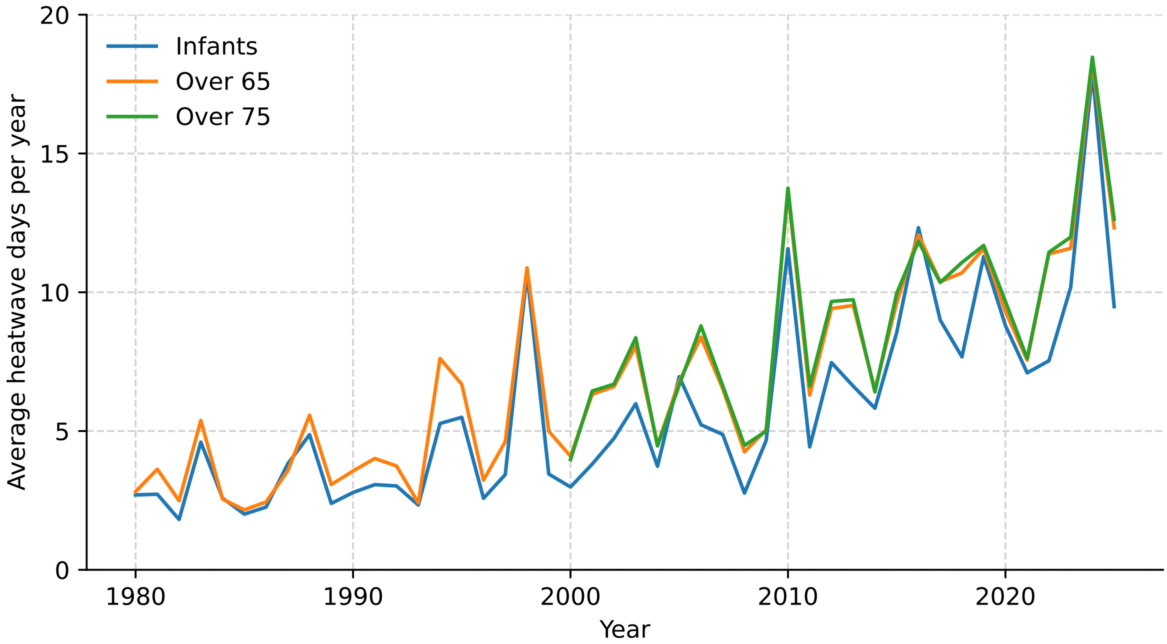

Figure 3: Average number of heatwave days experienced per person per year by older adults (over 65) and infants.

Heatwave Severity and Duration

Heatwaves are also becoming longer, with the number of average days per heatwave event increasing over time, as shown in Figure 4.

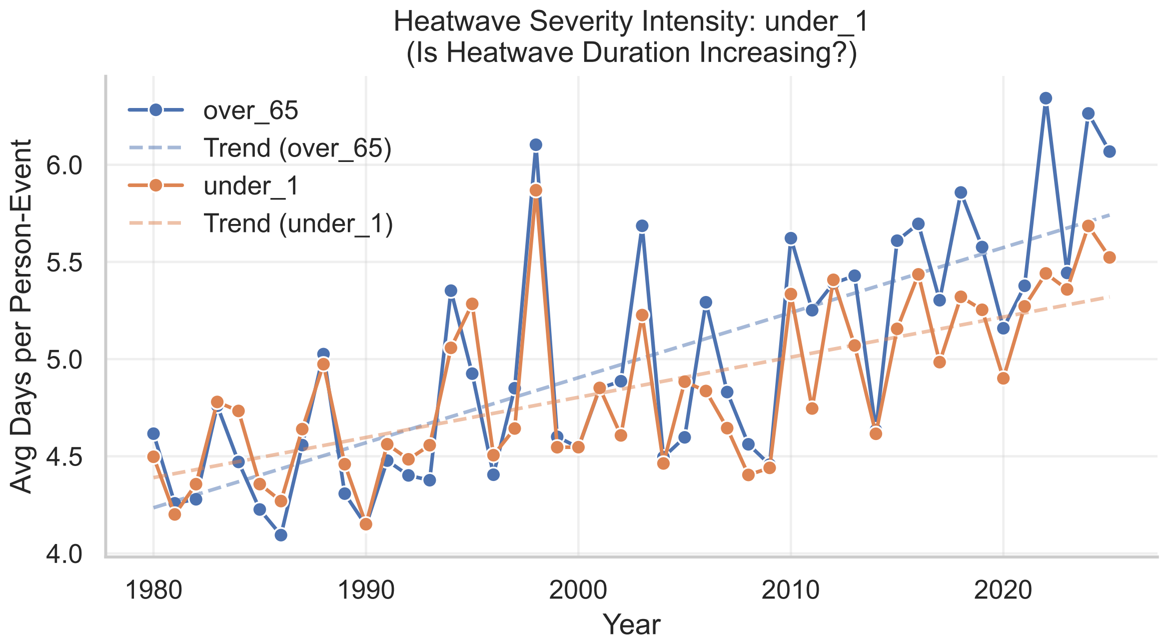

Figure 4:

It should be noted that the exposure of vulnerable populations to heatwaves calculated using the EHF metric is higher than that calculated using simpler temperature-threshold definitions. This is because the EHF captures not only extreme temperature events but also moderate heatwaves that can have significant health impacts, especially on vulnerable groups. Figure 5 illustrates the increasing contribution of severe and extreme heatwaves to total heatwave exposure over time. It also shows that if low-intensity heatwaves are included, the total exposure of vulnerable populations (over 65) to heatwaves would be even higher than what reported in Figure 2. A total of 30 billion person-days of heatwaves (all severities) were experienced by individuals over 65 in 2025 alone. This is the second highest on record after 2024 (39 billion person-days).

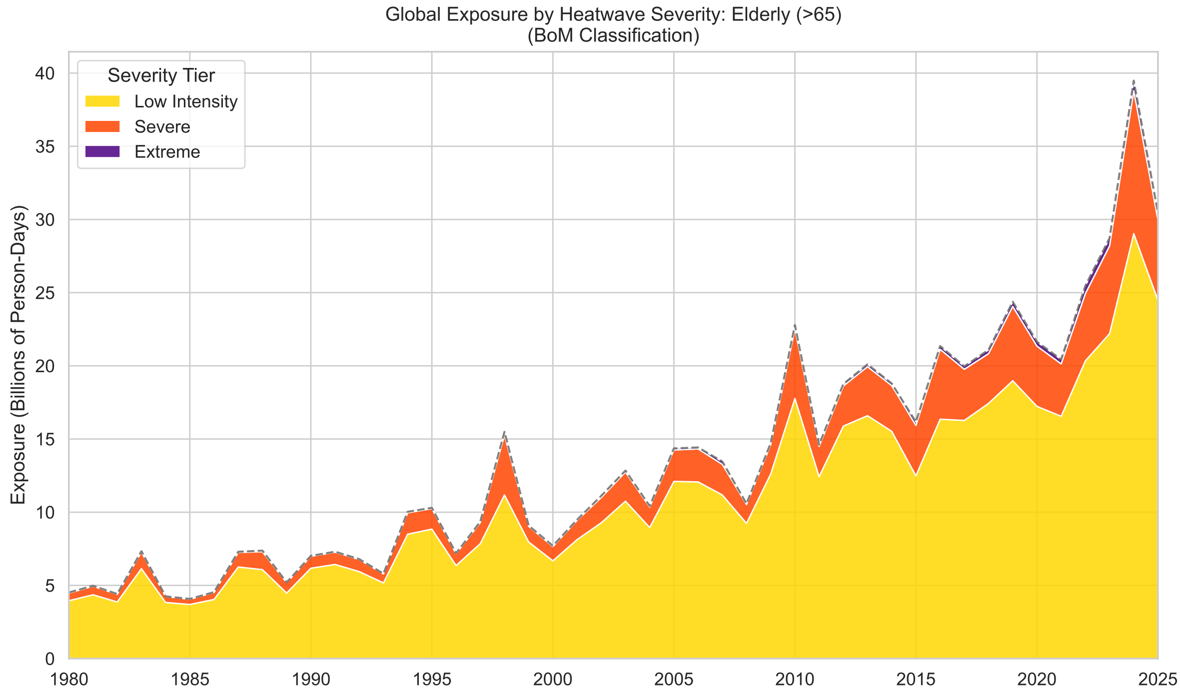

Figure 5: Stacked area chart showing the contribution of low-intensity, severe, and extreme heatwaves to total heatwave exposure for individuals over 65 years from 1980 to 2025.

The trend in exposure to severe and extreme heatwaves is shown in Figure 6. Extreme heatwaves are becoming increasingly common, and the more than 5 billion person-days of exposure to severe heawtwaves in 2025 is the third highest on record after 2024 (9.5 billion) and 2023 (6 billion).

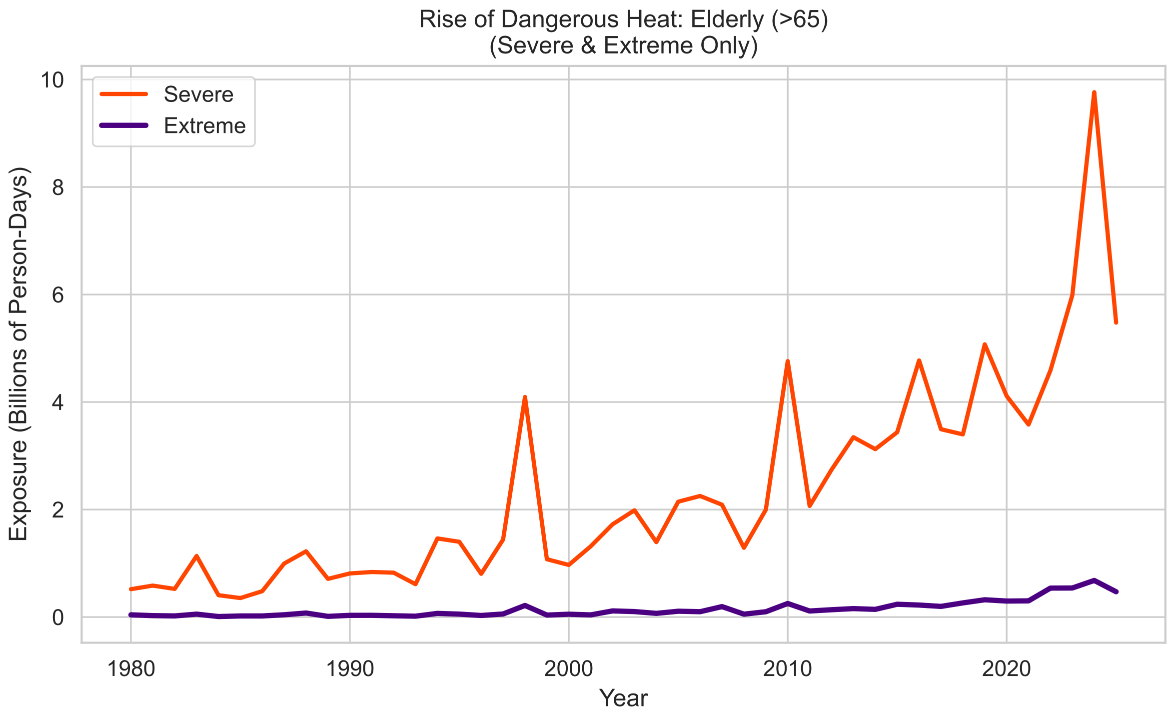

Figure 6:

The spatial distribution of the increase in heatwave exposure for vulnerable populations is illustrated in Figure 7. This figure compares the change in heatwave days to the absolute population of vulnerable people across different latitudinal zones. It highlights that regions with significant populations, particularly latitudes between +10 and +60, are also experiencing substantial increases in heatwave exposure.

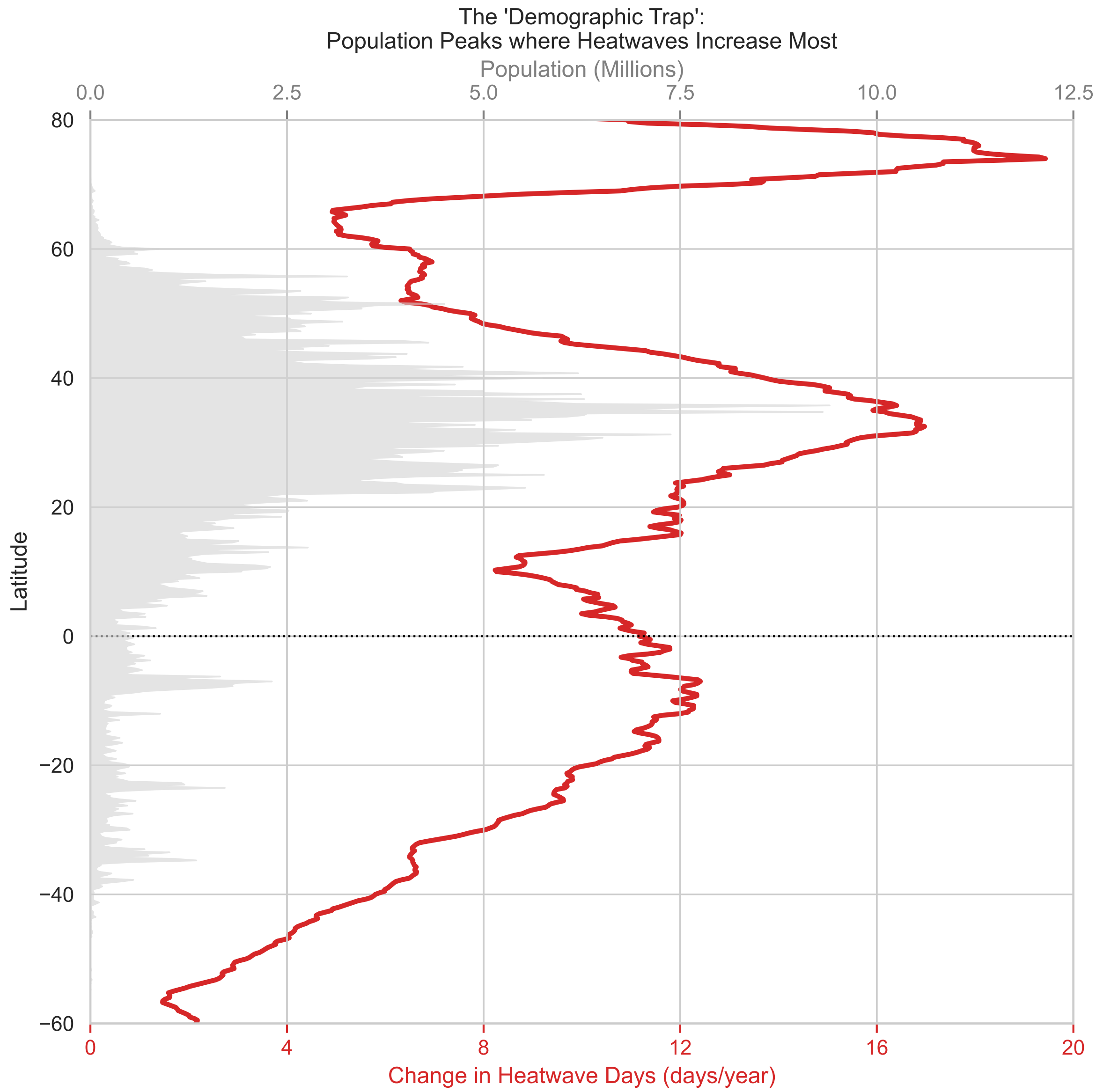

Figure 7: Population-weighted latitudinal distribution of the change in heatwave days for vulnerable populations from 1986–2005 to 2025.

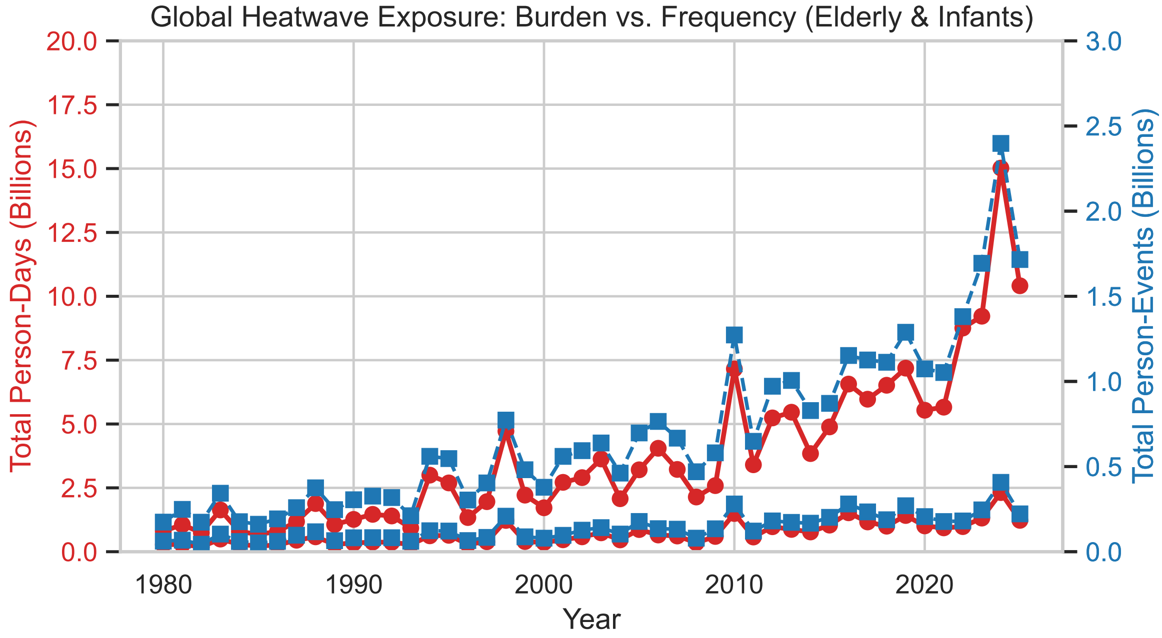
Global Heatwave Exposure: Burden vs. Frequency (Elderly & Infants)
Total Person-Days (Billions)
Total Person-Events (Billions)
Year
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
1980
1990
2000
2010
2020

Figure 8:

Heatwave Exposure by Regions and Countries

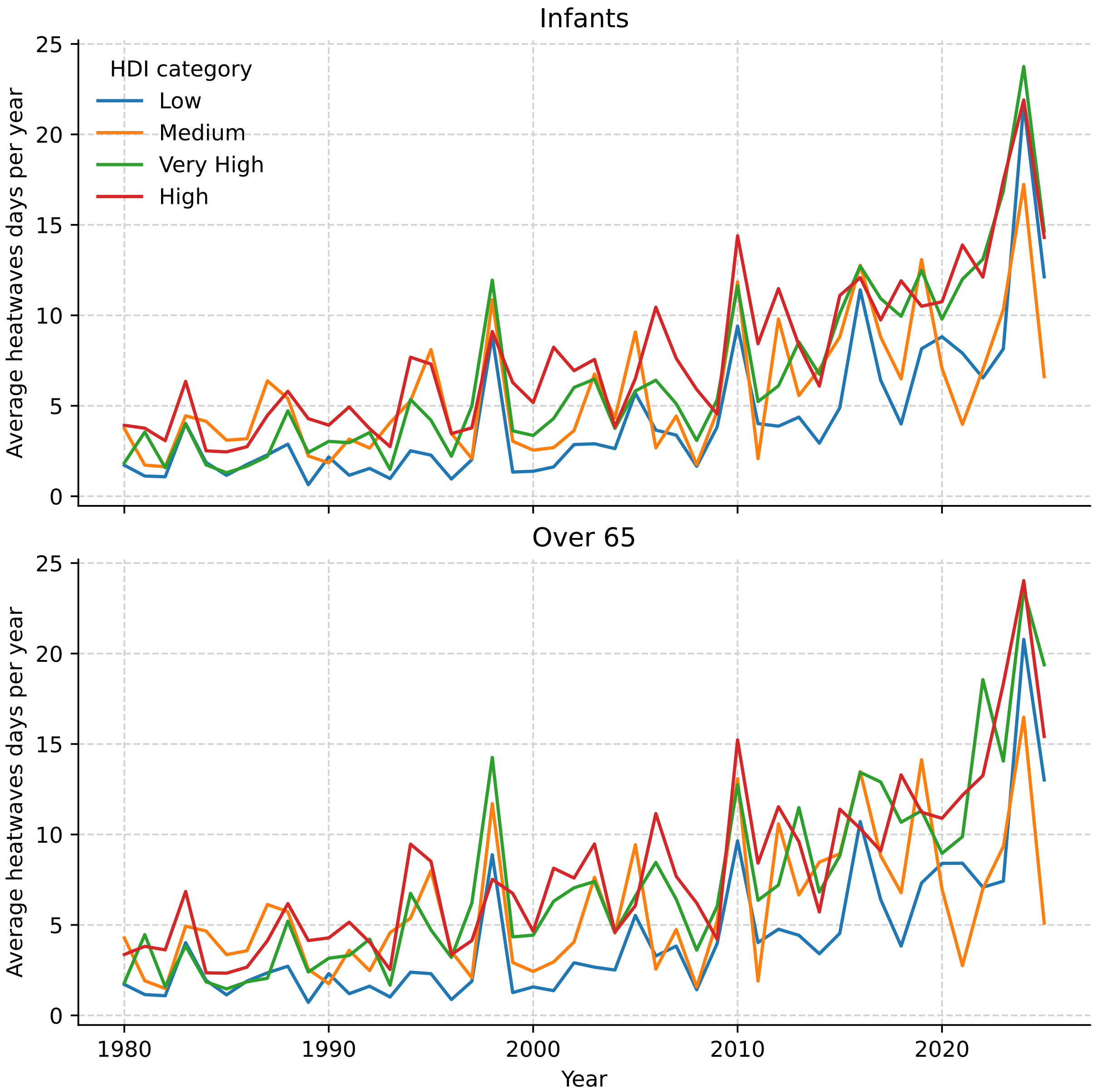

Figure 9:

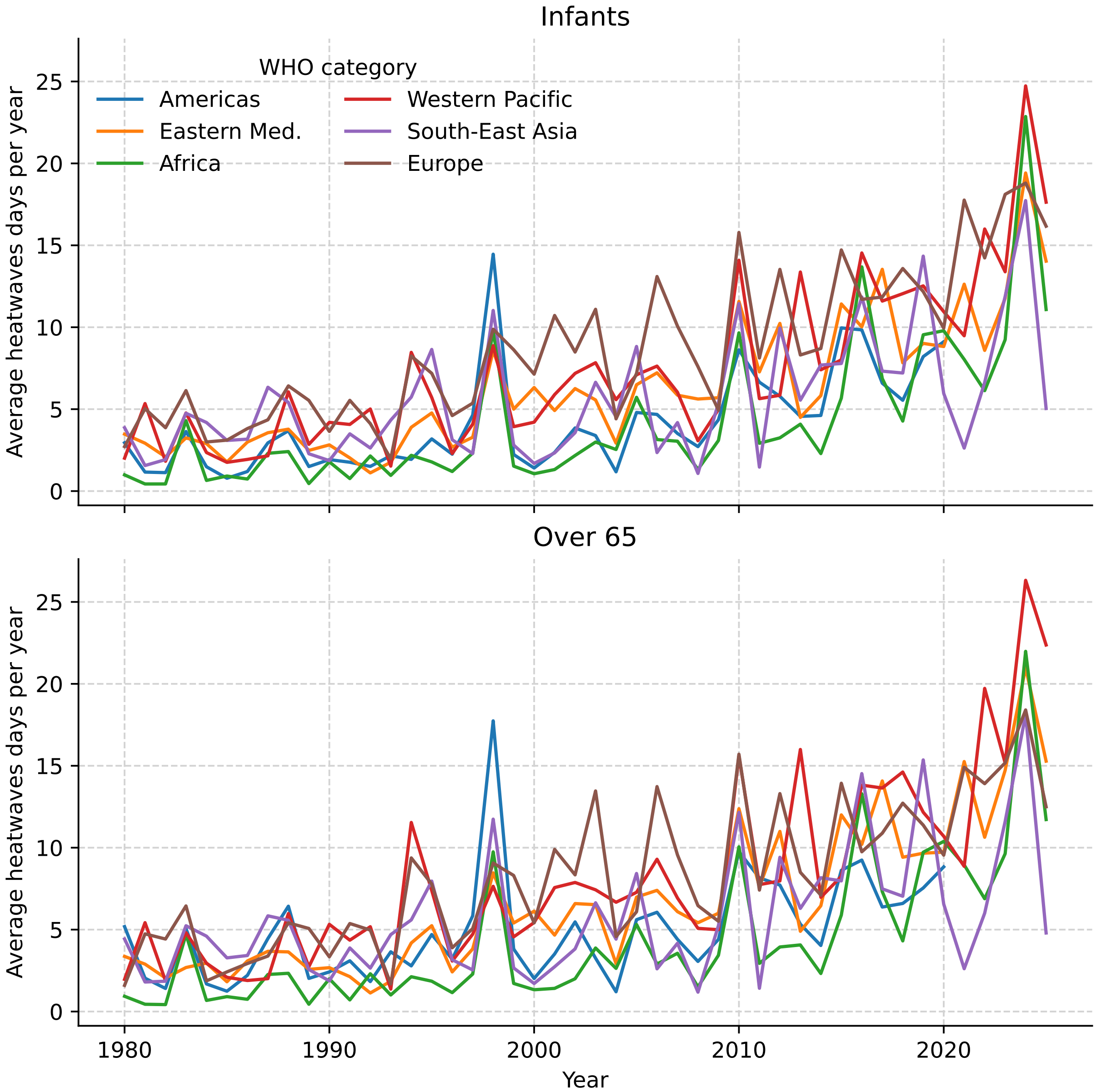
Infants
WHO category
Americas
Eastern Med.
Africa
Western Pacific
South-East Asia
Europe
Average heatwaves days per year
25
20
15
10
5
0
Over 65
Average heatwaves days per year
25
20
15
10
5
0
1980
1990
2000
2010
2020
Year

Figure 10:

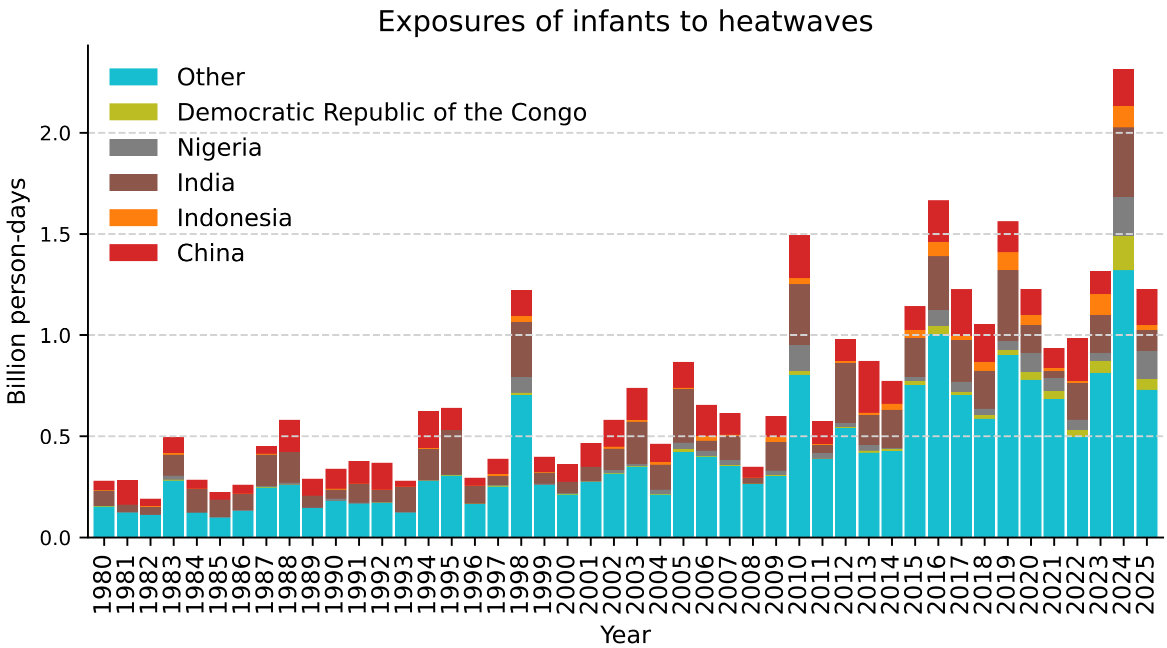

Figure 11:

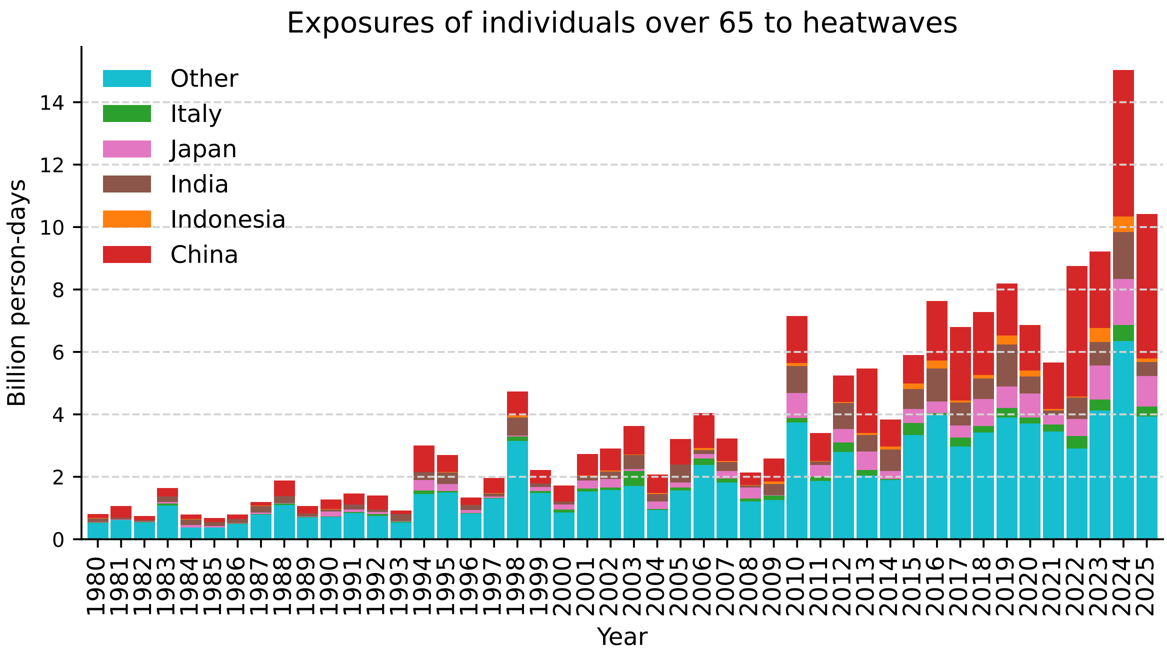

Figure 12:

Drivers of Change in Heatwave Exposure

Two factors are driving the increase in heatwave exposure for vulnerable populations: climate change and population growth. Figure 13 shows the global trend in total population of vulnerable groups from 1980 to 2025, highlighting the significant growth in the elderly population over this period. The number of individuals over 65 has more than doubled from approximately 290 million in 1980 to over 800 million in 2025, while the infant population has only seen a slight increase from around 100 million to 130 million.

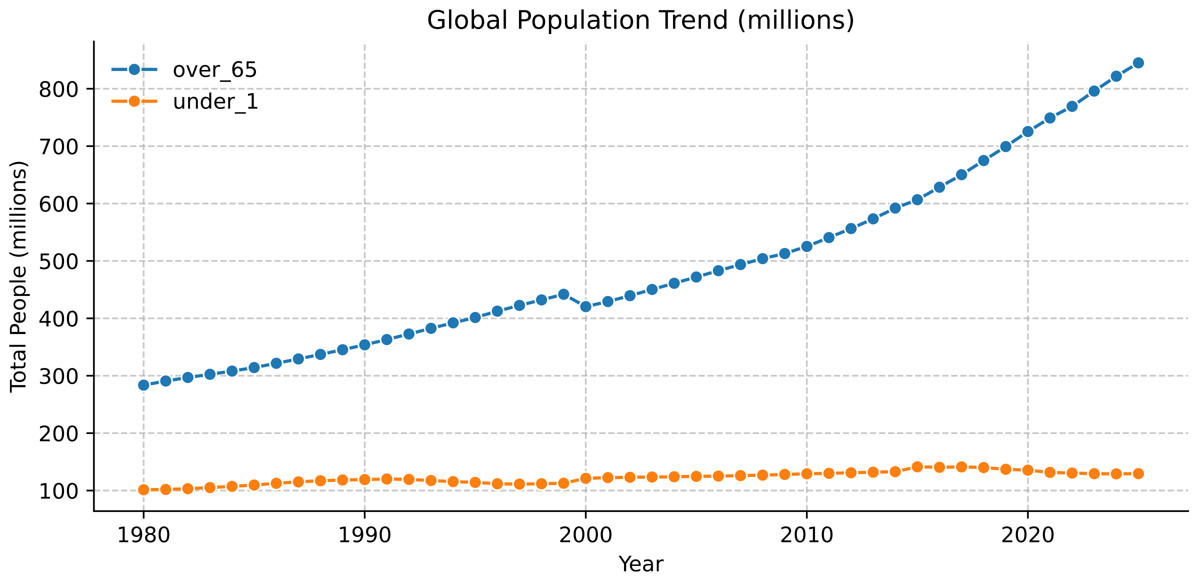

Figure 13:

Figure 14 compares the periods 1986–2005 and 2006–2024 to estimate how many heatwave days vulnerable populations would have experienced if climate change had not occurred, considering only demographic shifts. Climate change is the primary driver of increased heatwave exposure for infants, accounting for all of the observed increase. For the elderly population, both climate change and population growth contribute significantly, with populaton growth being the dominant factor in recent years.

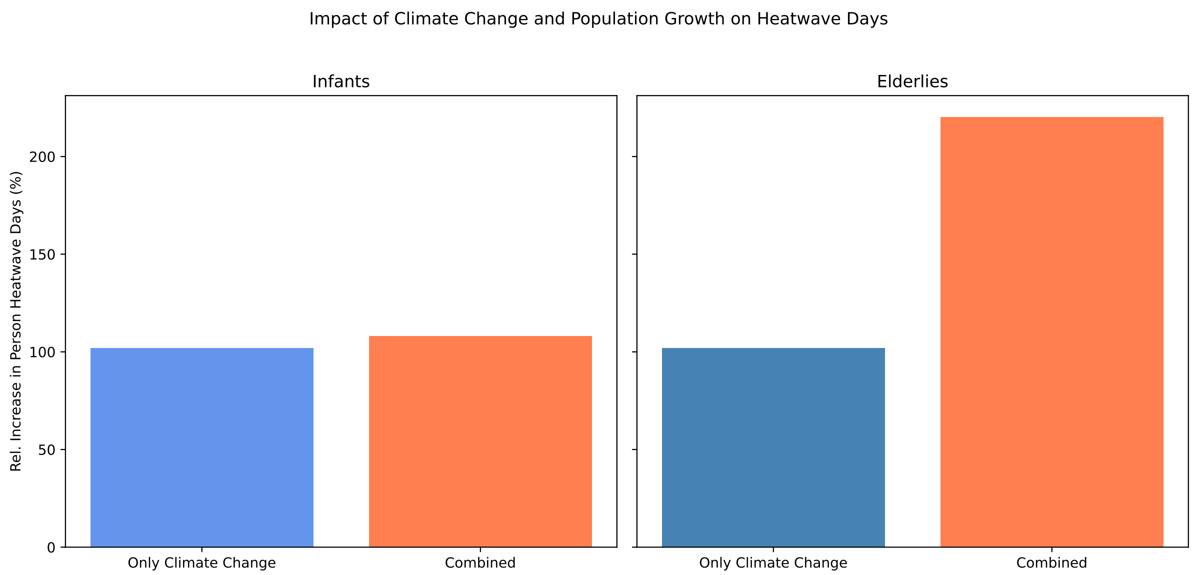

Figure 14:

Baseline Comparisons

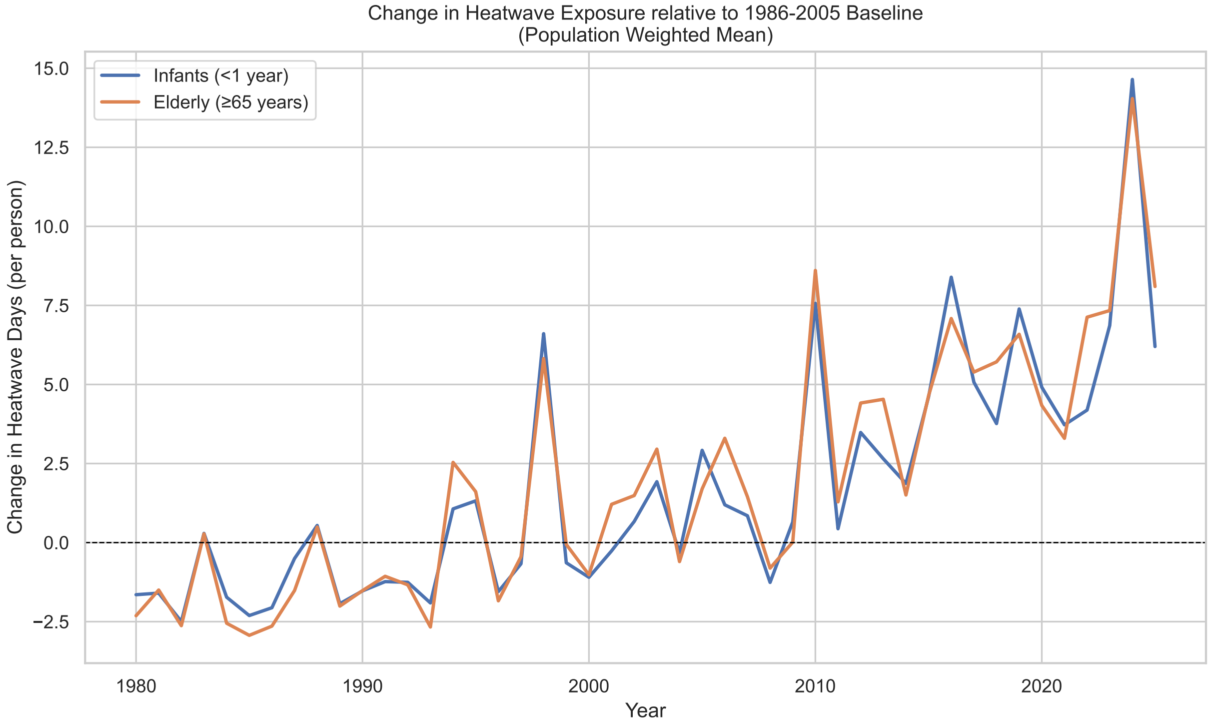

Figure 15:

When analyzed by country, as shown in Figure 3 and Figure 4, China and India are the countries with the highest number of affected individuals in both age categories, primarily due to their large populations. In 2024, a significant number of people over 65 were also impacted in Japan, the United States of America, and Italy, while heatwave exposure among infants was particularly high in Indonesia, Nigeria, and the Democratic Republic of the Congo.

Figure 4. Total heatwave person-days experienced by infants under one year old, presented by year and by the most affected countries.

Figure 5. Total heatwave person-days experienced by individuals over 65, presented by year and by the most affected countries. Before 2024, countries classified as 'Low' HDI, on average, exhibited lower heatwave exposure for both age groups, as shown in Figure 6. However, these countries experienced the fastest growth in 2024 rising from 7.5 to 21.0 days—a 181% increase.

Figure 6. Average number of heatwave days experienced aggregated by HDI level. Figure 7 presents data aggregated by WHO regions. The Wester Pacific region was the most affected for the infants (under 1) and the over-65 population.

Figure 7. Average number of heatwave days experienced aggregated by WHO region. Additional analysis While climate change drives the increase in heatwave days, population growth also contributes to the rising number of heatwave person-days. This section compares the periods 1986–2005 and 2006–2024 to estimate how many heatwave days vulnerable populations would have experienced if climate change had not occurred, considering only demographic shifts. For each geographic coordinate, the average annual heatwave days affecting both elderly and infant populations were calculated for 2006–2024. The same calculation was repeated while holding heatwave incidence constant to the 1986–2005 levels, isolating the impact of climate change. Comparing these scenarios reveals how many heatwave days vulnerable populations would have been exposed to purely due to demographic changes. Under a constant heatwave incidence at baseline levels, vulnerable populations would have experienced an average of 5.4 heatwave days per

person per year in 2006–2024—50% fewer than observed. Infants faced an average increase of 4.6 heatwave days per year, while individuals over 65, a rapidly growing group, experienced an additional 5.3 heatwave days annually. For infants a slight decrease in per-person heatwave exposure (from 4.8 to 4.6) would have been observed if heatwave incidence remained at 1986–2005 levels, reflecting shifts in the geographic distribution of vulnerable populations. No change would have been observed for adults ages 65 years or over.

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