Methodology: City-Level Single-Age Life Table Generation

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1. Objective

To generate single-age life tables (ages 0–100) for Romanian cities under two distinct scenarios:

1. **No-CC (Baseline)**: Mortality rates based on demographic projections only.
2. **CC (Climate Change)**: Mortality rates adjusted for projected heat/cold-related excess deaths.

2. Input Data Sources

Source	Description	Granularity
Wittgenstein Centre	Demographic projections (Population, Age-Specific Survival Rates).	Country Level, 5-year intervals.
Urban Audit	Historical city-level population and mortality data.	City Level, Broad Age Groups.
Impact Assessment	Projected Attributable Numbers (AN) for heat/cold mortality.	City Level, aggregated by period/SSP.

3. Statistical Process

3.1. Downscaling (Country → City)

Since demographic projections differ between national averages and specific urban centers, we apply a scaling factor derived from historical data.

$$Pop_{city}(t) = Pop_{country}(t) \times \left(\frac{Pop_{city}(t_{hist})}{Pop_{country}(t_{hist})} \right)$$

For mortality, a similar scaling factor is applied to deaths to ensure the life table reflects the specific healthy/unhealthy nature of the city relative to the national average.

3.2. Single-Age Expansion (Interpolation)

Input data is provided in 5-year age groups $(0-4, 5-9, \ldots)$. To generate a Life Table, we expand this to single years of age $(0, 1, 2, \ldots)$.

- **Method**: Uniform Distribution (Step Function).
- **Assumption**: For an age group spanning n years (e.g., 5 years), the population and deaths are distributed equally across each single year i within that group.

$$Pop_i = \frac{Pop_{group}}{n}, \quad Deaths_i = \frac{Deaths_{group}}{n}$$

3.3. Scenario Integration

Scenario A: No Climate Change (Baseline) The baseline mortality rate (m_x) is derived purely from the downscaled demographic projections.

$$m_x^{no\_cc} = \frac{Deaths_x}{Pop_x}$$

Scenario B: With Climate Change (CC) We add the specific **Climate Attributable Number** (AN_{clim}) to the baseline deaths.

- **Assumption for Youth**: For ages $0 - 19$, we assume **zero** additional climate mortality ($AN_{clim} = 0$).
- **Adults (20+)**: AN_{clim} is distributed across relevant ages.

The adjusted mortality rate is:

$$m_x^{cc} = \frac{Deaths_x + AN_{clim,x}}{Pop_x} = m_x^{no\_cc} + \text{ExcessRate}_x$$

(Note: While Rates (m_x) are additive, Life Expectancy (e_x) is not subtractive due to non-linearities in survival).

4. Life Table Construction (Actuarial Method)

We assume a cohort size (radix) of $l_0 = 100,000$. In the formulas below, n represents the width of the age interval (e.g., $n = 1$ for single year, $n = 5$ for 5-year groups).

Metric	Symbol	Formula / Method	Description	Units
Exposure	${}_nK_x$	Observed / Input	Person-years of exposure to risk (denominator for rates).	Person-Years
Deaths	${}_nD_x$	Observed / Input	Count of observed deaths in the population.	Persons
Mortality Rate	${}_nm_x$	${}_nm_x = \frac{{}_nD_x}{{}_nK_x}$	Central death rate observed in the population.	Deaths per person-year
Person-Years Factor	${}_na_x$	Typically $n/2$	Average years lived in interval by those who die.	Years
Probability of Death	${}_nq_x$	${}_nq_x = \frac{n \cdot {}_nm_x}{1+(n-{}_na_x)\cdot {}_nm_x}$	Probability of dying between age x and $x + n$.	Probability (0 to 1)
Probability of Survival	${}_np_x$	${}_np_x = 1 -_n q_x$	Probability of surviving from x to $x + n$.	Probability (0 to 1)
Survivors	l_x	$l_{x+n} = l_x \times_n p_x$	Number of people surviving to exact age x.	Persons
Life Table Deaths	${}_nd_x$	${}_nd_x = l_x - l_{x+n}$	Number of deaths in the hypothetical cohort.	Persons
Person-Years	${}_nL_x$	${}_nL_x = n \cdot l_{x+n} +_n a_x \cdot_n d_x$	Total years lived by the cohort between x and $x + n$.	Person-Years

Metric	Symbol	Formula / Method	Description	Units
Total Future Years	T_x	$T_x = \sum_{i=x}^{\omega} {}_nL_i$	Total years lived by survivors from age x until extinction.	Person-Years
Life Expectancy	e_x	$e_x = \frac{T_x}{l_x}$	Average years remaining for a person of age x.	Years

4.1. Key Observation on T_x

Users may notice that T_x differs between scenarios at young ages $(0 - 19)$ even if m_x is identical.

- **Zero Impact Assumption (0-19)**: All mortality variables (m_x, q_x, l_x, d_x) are identical between scenarios for ages 0-19. We assume no climate effect for this cohort due to data limitations.
- **Baseline Year (2010)**: For the baseline year 2010, there is no difference between the CC and No-CC scenarios across any age group.
- **Reason for T_x Divergence**: T_x is a cumulative sum of **future** person-years ($T_0 = L_0 + L_1 + \cdots + L_{100}$).
- **Effect**: Climate change affects adults (20+), changing $L_{20}, L_{21}, \ldots$. This change propagates backward to T_0, altering Life Expectancy at Birth (e_0) even if infant mortality rates remain unchanged.

4.2. Key Observation on d_x vs Attributable Numbers

A common intuition is that the number of deaths in the climate scenario (d_x^{cc}) should equal the baseline deaths ($d_x^{no\_cc}$) plus the attributable deaths (AN).

$$d_x^{cc} \neq d_x^{no\_cc} + AN_{clim}$$
$$d_x^{cc} \neq d_x^{no\_cc} + (AN_{full} - AN_{demo})$$

This inequality holds true for two fundamental reasons:

1. **Cohort Dynamics (The "Harvesting" Effect)**:
   - In a life table, death is a one-time event effectively removing an individual from the "at risk" population (l_x).
   - Climate change modifies mortality risks. If mortality increases at earlier ages (e.g., due to heat), the cohort size (l_x^{cc}) shrinks faster than the baseline ($l_x^{no\_cc}$). Conversely, reduced cold stress could decrease mortality.
   - By the time the cohort reaches older ages (e.g., 85), there are significantly fewer survivors in the high-impact scenario. Even if the *risk* of death (q_x) is higher, applying it to a much smaller population (l_x) can result in **fewer** absolute deaths (d_x) compared to the baseline.
   - *Simply put: People who die early from heat cannot die later from old age. You cannot merely "add" deaths; you shift the distribution of death to younger ages.*
2. **Scale Mismatch**:
   - AN **(Attributable Number)** is calculated on the **Real Population**, which varies in size (e.g., 2 million people).
   - d_x **(Life Table Deaths)** is calculated on a **Hypothetical Cohort** (Radix = 100,000).
   - These are two different universes. To compare them, one would first need to scale AN down to the life table radix, but even then, point #1 (Survivor bias) prevents simple addition.

Correct Relationship: The relationship is additive only at the level of the **Rate** (m_x), not the Count (d_x).

$$m_x^{cc} \approx m_x^{no\_cc} + \frac{AN_{clim}}{Pop_{real}}$$

5. Metadata columns

The final output includes Attributable Numbers broken down by specific drivers for validation:

- `an_clim`: Deaths strictly due to changing climate (Delta Temperature).
- `an_demo`: Deaths due to demographic changes (Aging population).
- `an_full`: Total attributable burden vs reference period.

6. Outputs and Visualization

The analysis pipeline produces tabular summaries and graphical visualizations to audit the impact of climate change on urban longevity.

6.1. Full Life Table Dataset (`results_csv/romania_city_lifetables_full.csv`)

This is the primary output file containing single-age life tables (ages 0-100) for every combination of city, scenario, period, and adaptation level.

Key Columns: * `mx_no_cc` / `mx_cc`: Mortality rates (Baseline vs. Climate Change). * `lx_no_cc` / `lx_cc`: Number of survivors at age x. * `ex_no_cc` / `ex_cc`: Life expectancy at age x. * `an_clim`, `an_demo`, `an_full`: Attributable deaths for that specific single age (distributed from broad age groups).

6.2. Life Expectancy Summary (`results_csv/city_life_expectancy_summary.csv`)

A unified table tracking the evolution of life expectancy (e_0) every 5 years for each city and scenario.

Column	Description
`e0_baseline`	Life expectancy in the No-CC scenario (based on shared socioeconomic pathways).
`e0_climate`	Life expectancy after adjusting for climate-attributable mortality.
`loss_years`	The gap between baseline and climate scenarios ($e_0^{no\_cc} - e_0^{cc}$).
`pct_change`	Relative impact ($\frac{Diff}{Baseline}$).

6.3. Visualizations (`plots/`)

A. Life Expectancy Loss Over Time

- **Metric**: Months of life lost ($Loss_{years} \times 12$).
- **Interpretation**: Traces the growing burden of climate change from 2010 to 2100.
- **Note on Variability**: "Jumps" or fluctuations in the trend line often reflect internal climate variability and the bias-correction blocks used in the ISIMIP3 climate models (warming years vs. calendar years).

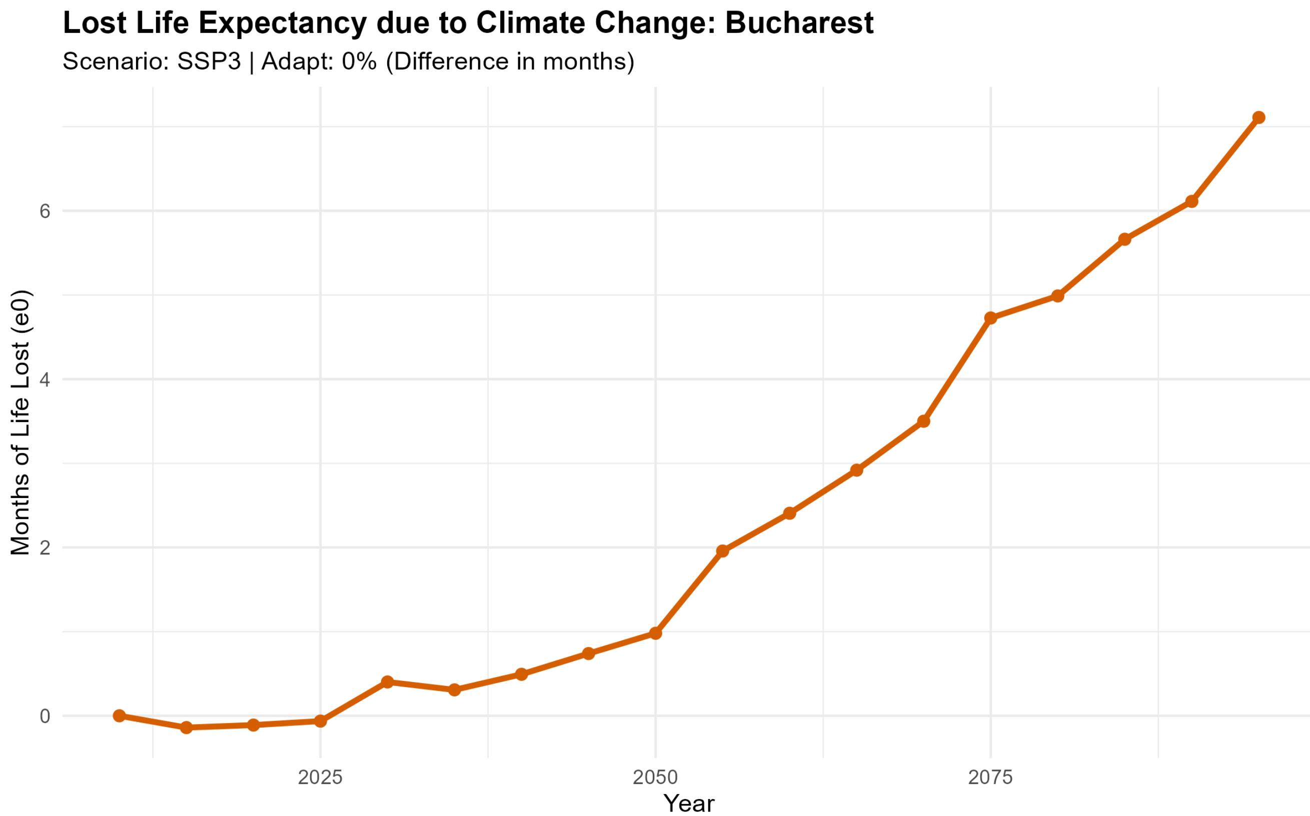

Figure 1: Life Expectancy Loss Over Time

B. Survival Curve Shift (l_x)

- **Metric**: Number of survivors out of 100,000 at each age.
- **Interpretation**: Visually demonstrates the "Harvesting Effect." The CC curve typically dips below the No-CC curve in adulthood/old age, indicating premature mortality.

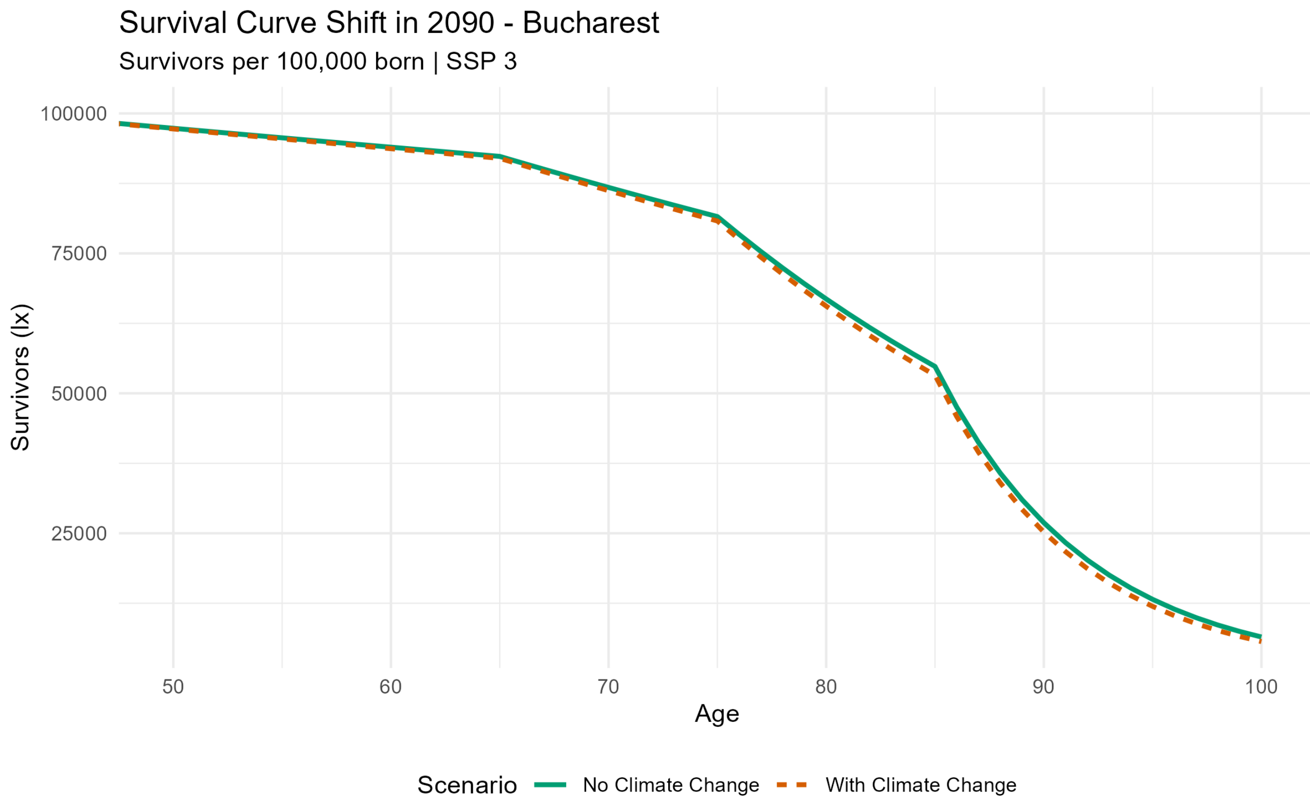

Figure 2: Survival Curve Shift

C. Relative Risk Ratio

- **Metric**: Ratio of Mortality Rates ($m_x^{cc}/m_x^{no\_cc}$).
- **Interpretation**: Shows the age-specific intensity of the climate impact. A ratio > 1.0 indicates increased risk. Spikes often occur in elderly populations where absolute mortality is highest.

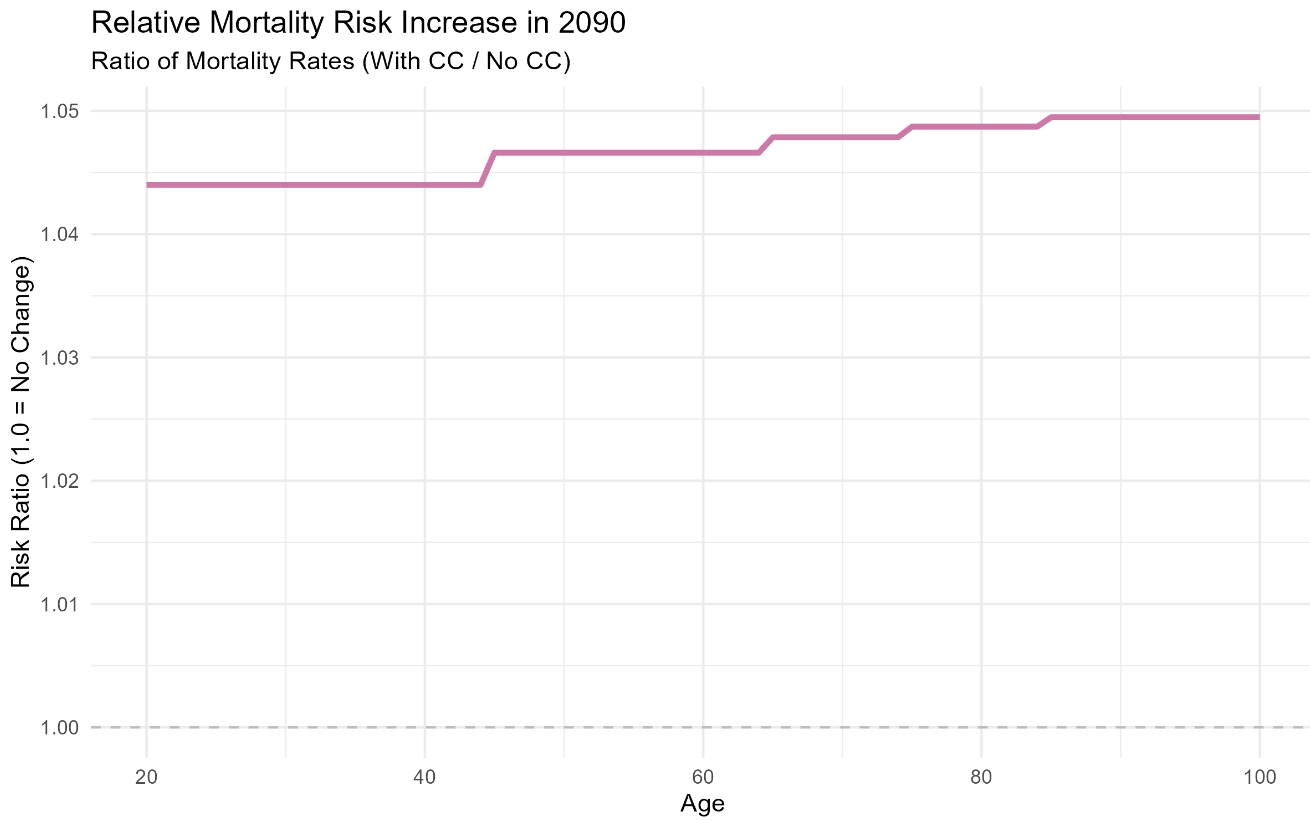

Figure 3: Relative Risk Ratio