Technical Appendix: Methods

Overview

We analyzed deaths among King County residents from 2015 through 2024 using death certificate data from the Washington State Department of Health Center for Health Statistics. We calculated age-adjusted death rates and life expectancy for individual years, then compared these measures across time and demographic subpopulations to identify changes and disparities.

Data Sources

Death Data

Final death certificate data for King County residents from 2015-2024 were obtained from the Washington State Department of Health Center for Health Statistics. Deaths were allocated based on residency (i.e., King County residents who died outside King County were included; non-residents who died in King County were excluded).

Population Data

Population estimates were obtained from the Washington State Office of Financial Management.

Cause of Death Definitions

We identified causes of death using International Classification of Diseases, Tenth Revision (ICD-10) underlying cause of death codes. The underlying cause of death is defined as "the disease or injury which initiated the train of events leading directly to death."

We utilized several cause-of-death frameworks:

1. **CDC 113 Selected Causes of Death** (ages 1+): Standard cause categories including cancer, heart disease, Alzheimer's disease, cerebrovascular disease, diabetes mellitus, and others.

2. **CDC ICD-10 Injury Matrix** (ages 1+): Intent-mechanism combinations for injury-related deaths, including unintentional injuries, firearms, motor vehicle traffic, homicides, suicides, and drownings.

3. **Opioid-Involved Deaths (ages 1+):** Deaths where the underlying cause is poisoning (X40-X44, X60-X64, X85, Y10-Y14): AND at least one contributing cause indicates opioid involvement: Opium (T40.0); Heroin (T40.1); Natural and semi-synthetic

opioids (T40.2); Methadone (T40.3); Synthetic opioids other than methadone (T40.4); Other and unspecified opioids (T40.6) (Ahmad, 2025).

Demographics

General Considerations

A physician, coroner, or medical examiner certifies the cause of death on a death certificate, while a funeral director, in consultation with the legal next of kin, records demographic information. If the legal next of kin is unavailable or cannot be located, the funeral director may categorize the decedent based on their own observations. Consequently, there is no guarantee that a person's preferred gender, or racial or ethnic identity, will be accurately reflected in the death records. As a result, the gender designation (female or male) on a death certificate typically corresponds to the sex assigned at birth.

Race and Ethnicity

In this analysis, Hispanic is treated as a mutually exclusive racial category, i.e., individuals are classified as either Hispanic or another race. Multi-racial individuals were excluded from race/ethnicity-specific analyses due to misclassification issues on death certificates, but are included in overall countywide, regional, and sex-specific analyses. This analytical approach should not be interpreted as a position on the conceptual relationship between race and ethnicity.

Racial and ethnic classifications may be differentially misclassified on death certificates compared to population estimates based on self-reported identity. This differential misclassification may introduce bias, particularly for smaller populations such as American Indian/Alaska Native (AIAN) and Native Hawaiian/Pacific Islander (NHPI) residents.

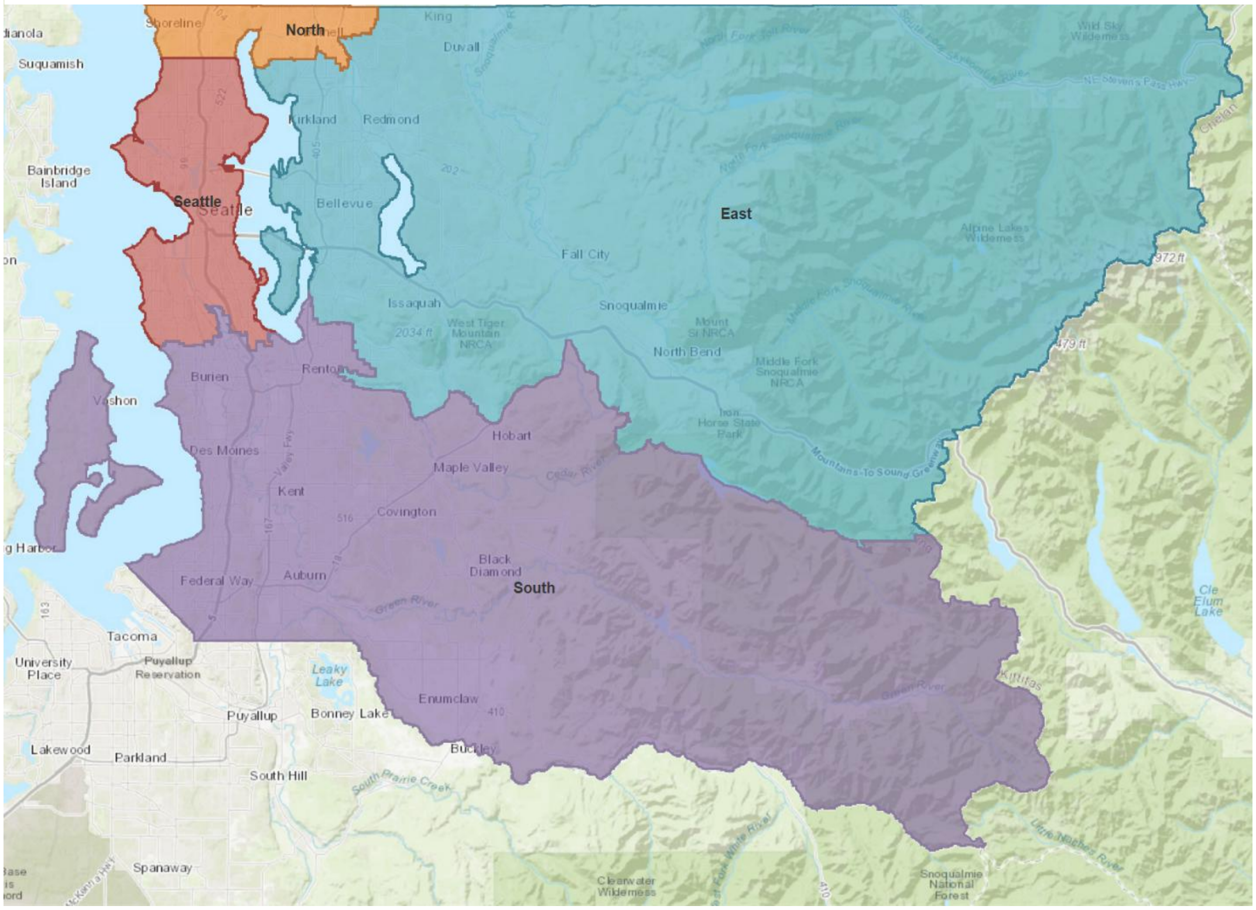
Geographic Regions

King County was divided into four regions for regional analyses:

- **Seattle**: Seattle city limits
- **East King County**: Bear Creek, Bellevue, Carnation, Duvall, Issaquah, Kirkland, Medina, Mercer Island, Newcastle, North Bend, Redmond, Sammamish, Skykomish, and Snoqualmie
- **North King County**: Bothell, Cottage Lake, Kenmore, Lake Forest Park, Shoreline, and Woodinville

- **South King County**: Algona, Auburn, Black Diamond, Burien, Covington, Des Moines, Enumclaw, Fairwood, Federal Way, Hobart, Kent, Lakeland, Maple Valley, Milton, Normandy Park, Pacific, Renton, Tukwila, SeaTac, Skyway, White Center, and Vashon Island

Figure 1. *King County Regions*



Analytic Framework

Data Requirements

For cause-specific analyses, we suppressed estimates when the total number of deaths in King County was fewer than 10 for a given cause and time period. This threshold balances the need for stable estimates with privacy considerations.

Age-Adjusted Death Rates

Age Adjustment

All death rates were age-adjusted to the 2000 U.S. standard population using 11 age groups (0-1, 1-5, 5-10, 10-15, 15-18, 18-20, 20-25, 25-35, 35-45, 45-55, 55-65, 65-75, 75-85, 85+). Age adjustment standardizes the age distribution across populations and time periods, enabling more accurate comparisons. This technique is particularly important when comparing populations with different age structures or when the age distribution of a population changes over time.

Analysis was restricted to individuals aged one year and older due to infants having distinct mortality epidemiology that does not align with standard cause-of-death classifications

Rate Calculation

Age-adjusted death rates per 100,000 population were calculated using the direct method. Exact 95% confidence intervals were computed using the Fay-Feuer method based on the gamma distribution.

Formula for age-adjusted rate:

$ADR = \Sigma(w_i \times r_i) \times 100{,}000$

where w_i is the weight for age group i in the standard population, and r_i is the crude rate for age group i in the population of interest.

Life Expectancy

Life Table Construction

Life expectancy at birth was calculated using standard abridged life table methods following Chiang (1979). We used the following age intervals: 0-1, 1-5, 5-10, 10-15, 15-18, 18-20, 20-25, 25-35, 35-45, 45-55, 55-65, 65-75, 75-85, 85+.

Variance Estimation

Standard errors for life expectancy were calculated using the Silcocks approximation for the oldest age group, as the standard Chiang method becomes unstable for open-ended age intervals.

Comparison Methodology

Changes in life expectancy and disparities in life expectancy were calculated by comparing estimates from different time periods or demographic groups using the Monte Carlo approach described above.

Leading Causes of Death

The leading causes of death categories are aggregations of the standard CDC 113 Selected Causes of Death. Table 1 displays how we combined these causes to identify the top 10 leading causes of death. Note that the leading causes of death are ranked based on the death count, not age adjusted rates.

Table 1. *Crosswalk between the Leading Causes of Death and CDC 113 Selected Causes of Death*

Leading Cause of Death	CDC 113 Select Causes of Death
Cancer	Malignant neoplasms of lip, oral cavity and pharynx
Cancer	Malignant neoplasm of esophagus
Cancer	Malignant neoplasm of stomach
Cancer	Malignant neoplasms of colon, rectum and anus
Cancer	Malignant neoplasms of liver and intrahepatic bile ducts
Cancer	Malignant neoplasm of pancreas
Cancer	Malignant neoplasm of larynx
Cancer	Malignant neoplasms of trachea, bronchus and lung
Cancer	Malignant melanoma of skin
Cancer	Malignant neoplasm of breast
Cancer	Malignant neoplasm of cervix uteri
Cancer	Malignant neoplasms of corpus uteri and uterus, part unspecified
Cancer	Malignant neoplasm of ovary
Cancer	Malignant neoplasm of prostate
Cancer	Malignant neoplasms of kidney and renal pelvis
Cancer	Malignant neoplasm of bladder
Cancer	Malignant neoplasms of meninges, brain and other parts of central nervous system
Cancer	Hodgkin's disease
Cancer	Non-Hodgkin's lymphoma
Cancer	Leukemia
Cancer	Multiple myeloma and immunoproliferative neoplasms
Cancer	Other and unspecified malignant neoplasms of lymphoid, hematopoietic and related tissue
Cancer	All other and unspecified malignant neoplasms
Heart disease	Acute rheumatic fever and chronic rheumatic heart diseases
Heart disease	Hypertensive heart disease
Heart disease	Hypertensive heart and renal disease
Heart disease	Acute myocardial infarction
Heart disease	Other acute ischemic heart diseases
Heart disease	Atherosclerotic cardiovascular disease, so described
Heart disease	All other forms of chronic ischemic heart disease
Heart disease	Acute and subacute endocarditis

Leading Cause of Death	CDC 113 Select Causes of Death
Heart disease	Diseases of pericardium and acute myocarditis
Heart disease	Heart failure
Heart disease	All other forms of heart disease
Unintentional injuries	Motor vehicle crash
Unintentional injuries	Unintentional injury: Other land transport
Unintentional injuries	Unintentional injury: Water, air and space, and other transport
Unintentional injuries	Falls
Unintentional injuries	Accidental discharge of firearms
Unintentional injuries	Accidental drowning and submersion
Unintentional injuries	Accidental exposure to smoke, fire and flames
Unintentional injuries	Accidental poisoning and exposure to noxious substances
Unintentional injuries	Other and unspecified nontransport accidents and their sequelae
Alzheimer's disease	Alzheimer's disease
Stroke	Cerebrovascular diseases
Chronic lower resp. disease	Bronchitis, chronic and unspecified
Chronic lower resp. disease	Emphysema
Chronic lower resp. disease	Asthma
Chronic lower resp. disease	Other chronic lower respiratory diseases
Diabetes mellitus	Diabetes mellitus
Suicide	Intentional self-harm (suicide) by discharge of firearms
Suicide	Intentional self-harm (suicide) by other and unspecified means and their sequelae
Primary hypertension	Essential (primary) hypertension and hypertensive renal disease
Chronic liver disease	Alcoholic liver disease
Chronic liver disease	Other chronic liver disease and cirrhosis
Influenza and pneumonia	Influenza
Influenza and pneumonia	Pneumonia
Parkinson's disease	Parkinson's disease

Rate Ratios and Differences

Time Comparisons

We calculated year-over-year rate ratios and differences (e.g., 2024 vs. 2023, 2023 vs. 2022) for all causes and demographic subgroups. These comparisons characterize short-term changes.

Disparity Analyses

For each year and cause, we calculated disparity ratios and differences comparing each demographic group to a reference group:

- **Sex:** Female (reference) vs. Male
- **Race/ethnicity:** Asian (reference) vs. AIAN, Black, Hispanic, NHPI, White

- **Region:** East King County (reference) vs. North King County, Seattle, South King County

Reference groups were selected based on generally having the most favorable health outcomes (i.e., longest life expectancy, lowest mortality rates).

Proportionate Mortality

Proportionate mortality represents the percentage of all deaths attributable to a specific cause. For example, if the unintentional injury death rate was 50/100,000 and the all-cause death rate was 500/100,000, then the proportionate mortality would be 10%. This measure helps illustrate the relative contribution of different causes to overall mortality and can highlight the burden of specific causes within particular populations or age groups. Proportionate mortality is calculated as: (cause-specific deaths / all-cause deaths) × 100.

Statistical Methods

Uncertainty Propagation

The following approach was used to quantify uncertainty in all comparisons throughout this analysis, including rate ratios/differences, life expectancy comparisons, and trend analyses. We quantified uncertainty in rate comparisons (ratios and differences) and life expectancy comparisons using Monte Carlo simulation via the propagate_uncertainty() function in the R RADS package. This approach:

1. Generates 10,000 random draws from the sampling distribution of each estimate
2. Computes the ratio or difference for each pair of draws
3. Calculates summary statistics (mean, 95% confidence interval) from the resulting distribution

For disparity analyses involving AIAN and NHPI populations, we increased to 55,000 draws to ensure adequate precision given the higher variability in these smaller populations.

Monte Carlo simulations included convergence diagnostics to ensure stable estimates. Simulations were monitored for convergence by comparing estimates from the first 50 draws to estimates from all draws, with a convergence tolerance of 0.01.

Hypothesis Testing

Statistical significance for all comparisons was assessed using two-tailed tests with $\alpha = 0.05$. P-values were calculated using the proportion of simulated contrast values on the opposite side of the null hypothesis value (0 for differences, 1 for ratios).

We did not adjust for multiple comparisons. Given the exploratory nature of this analysis and the large number of comparisons conducted, some statistically significant findings may be due to chance. Readers should consider the magnitude and consistency of findings across related analyses, not solely statistical significance.

Trend Analysis

Overview

We employed segmented regression (joinpoint regression) to identify statistically significant changes in trends over the 2015-2024 period using the segmented package in R (Muggeo 2008). This analysis was applied to disparity ratios and differences to characterize how disparities changed over time.

Methodology

For each metric-demographic-outcome combination (e.g., ratio of male-to-female life expectancy, or difference between South and East King County in all-cause mortality), we:

1. **Fit a linear model** to the entire 2015-2024 period, weighted by the inverse square of the standard error. If the slope was not significantly different from zero ($p \geq 0.05$), we refit as an intercept-only model (horizontal line).
2. **Test a one-breakpoint model**, requiring:
    - At least 3 years of data per segment
    - Statistically significant improvement over the linear model (using either Davies test for breakpoint significance or Akaike Information Criterion)
3. **Test a two-breakpoint model** (when ≥7 years of data available), requiring:
    - At least 3 years of data per segment
    - Statistically significant improvement over both the linear and one-breakpoint models
4. **Select the best-fitting model** based on:
    - Statistical significance of breakpoints (Davies test when available)
    - Model fit (AIC)
    - Segment validity (each segment must have ≥3 years)

Trend Interpretation

For each segment, we classified trends as:

- **Increasing**: Positive slope
- **Decreasing**: Negative slope
- **Stable**: Slope not significantly different from zero

Breakpoints represent years when the direction or magnitude of the trend changed.

Limitations

Segmented regression assumes:

- Piecewise linear relationships
- Correct specification of the number of breakpoints
- Independent observations

With only 10 years of data, we are limited to detecting at most two breakpoints. Short time series may have limited power to detect true changes or may identify spurious breakpoints due to random variation.

Software and Reproducibility

All analyses were conducted using R version 4.5.1. Key packages included:

- **rads** (v1.5.1): Custom package for Public Health - Seattle & King County data access and standardized calculations
- **data.table** (v1.17.8): High-performance data manipulation
- **segmented** (v2.1.4): Segmented regression/joinpoint analysis

Random number generation used seed 98104 for reproducibility of Monte Carlo simulations.

Limitations

1. **Underlying cause of death**: With the exception of opioid-involved deaths, which use both underlying and contributing causes, we report only the underlying cause of death. This prioritizes the initiating condition over intermediate or contributing causes. This approach may underestimate the full impact of certain conditions (e.g., diabetes, hypertension) that contribute to death but are not recorded as the underlying cause.
2. **Small population groups**: Estimates for AIAN and NHPI populations were sometimes suppressed and have wide confidence intervals due to small numbers.

This reflects true uncertainty but does not negate the importance of monitoring health equity for these populations.

3. **Demographic misclassification**: Race and ethnicity are subject to misclassification on death certificates. This introduces bias that varies across racial/ethnic groups and may affect both rates and disparity estimates.
4. **Geographic assignment**: Deaths are assigned to King County regions based on residence, not where the death occurred.
5. **Multiple comparisons**: We conducted numerous statistical tests without adjustment for multiple comparisons. Some statistically significant findings may be due to chance, particularly for rare causes or small subgroups.
6. **Data exclusions**: Children under age one were excluded from most analyses due to distinct cause-of-death coding. Multi-racial was excluded due to substantial misclassification on death certificates.

References

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Silcocks PB, Jenner DA, Reza R. Life expectancy as a summary of mortality in a population: statistical considerations and suitability for use by health authorities. Journal of Epidemiology and Community Health. 2001;55(1):38-43.

Data Availability

Death data are available from the Washington State Department of Health Center for Health Statistics. Population data are available from the Washington State Office of Financial Management. Both datasets are accessible to researchers through established data sharing agreements. Aggregate results are available through Public Health - Seattle & King County.

Contact Information

For questions about methodology or data access: Public Health - Seattle & King County Assessment, Policy Development and Evaluation Unit: Data.Request [@] kingcounty.gov.