Gender Gap in Life Expectancy in Kerala: A Disaggregated Analysis by Rural and Urban Regions

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ABSTRACT:

Background: Life expectancy is a key public health metric, often influenced by demographic, geographic, and socio-economic factors. Kerala, known for its high health indicators, still faces unexplored disparities in longevity across gender and residence.

Objective: To assess rural-urban and gender-based disparities in life expectancy in Kerala from 2018 to 2022 using official mortality data.

Methods: The study utilized death registration datasets from five consecutive years, cleaned and processed. Mean age at death was calculated as a proxy for life expectancy, with subgroup analysis by gender and residence. Statistical testing (t-test and ANOVA) was conducted to evaluate significance of observed disparities.

Results: Urban residents consistently exhibited higher mean age at death compared to rural residents, and females outlived males by an average of 3.5 years. All subgroup differences were statistically significant ($p < 0.001$). A decline in 2020 reflected COVID-19 impact, followed by recovery.

Conclusion: Despite Kerala's health achievements, significant disparities in life expectancy persist across gender and geography. Data-driven insights from this study can guide targeted, equity-focused public health interventions.

Keywords: Life Expectancy, Rural-Urban Disparity, Gender Gap, Kerala, Statistics

1. Introduction

Life expectancy is a pivotal indicator of population health and overall development, reflecting the average number of years an individual is expected to live under current mortality conditions [1]. It encapsulates the cumulative impact of healthcare systems, socio-economic development, nutrition, sanitation, and public health initiatives [2]. In India, the marked improvements in life expectancy over the past decades have been widely acknowledged, with states such as Kerala often leading the charts due to its robust public health infrastructure and literacy rates [3][4]. However, within-state disparities—especially by gender and residence (rural vs. urban) [26]—continue to persist and warrant focused investigation [5][6].

Gender disparities in life expectancy are well documented worldwide, with females generally outliving males due to a combination of biological, behavioral, and social factors [7][8]. In the Indian context, however, these patterns have evolved differently. Historically, male life expectancy exceeded that of females until the 1980s, after which a crossover occurred in most states, including Kerala [9][10]. Post-crossover, female longevity has consistently increased, though often at the cost of higher morbidity, indicating a feminization of aging with associated social and health challenges [11][12].

Rural-urban disparities add another layer to the life expectancy landscape [13] [28-30]. Urban areas typically benefit from better access to healthcare, sanitation, and higher socio-economic status, which contribute to higher average life expectancy [14]. Conversely, rural populations often suffer from inadequate healthcare infrastructure, limited health literacy, and economic vulnerabilities that adversely impact survival rates, particularly among women and the elderly [15]. Despite Kerala's overall superior health indicators, rural-urban gaps remain relevant, especially in the context of non-communicable diseases and access to advanced medical care.

Kerala's health model has often been lauded for its progressive public health strategies and decentralized healthcare governance [16]. Yet, a deeper disaggregation by gender and geography is essential to uncover hidden inequalities that might hinder Kerala's future health progress [17]. Recent studies suggest that while Kerala has achieved near-universal access to primary healthcare, disparities in life expectancy persist across demographic segments due to lifestyle diseases, geriatric vulnerabilities, and localized socio-economic factors [18].

In this study, we aim to quantify and compare rural-urban and gender-specific life expectancy in Kerala using recent mortality data (2018–2022) and statistical computation in Python. By employing a statistical framework and open-source tools, we offer a scalable approach to health disparity research that can support policy design and targeted interventions for equitable longevity outcomes across diverse population groups in Kerala.

1.1Contributions

The novel contributions of this study are:

1. We integrate five years of granular mortality data to produce a comparative analysis of life expectancy across rural and urban Kerala, disaggregated by gender.
2. We apply statistical techniques to establish a scalable, replicable framework for analyzing large-scale demographic health data.
3. We uncover a narrowing rural-urban gap in life expectancy, challenging prevailing assumptions about persistent health inequities in Kerala.
4. We highlight the importance of excluding data anomalies (e.g., placeholder ages) in mortality research to ensure more accurate life expectancy estimations.

2. Literature Review

This section deals with a review of existing scholarly work on gender gaps in mortality, retirement wellbeing, and pension system disparities, highlighting methodological challenges and identifying key research gaps. Table 1 shows summary of research gaps.

2.1 Global and National Gender Gaps in Mortality and Life Expectancy

Gender disparities in life expectancy are a well-documented global phenomenon. Women consistently outlive men, with global averages showing a difference of 4 to 7 years, primarily due to biological advantages, healthier behavior, and reduced exposure to occupational risks. In high-mortality regions like sub-Saharan Africa, maternal mortality and lack of access to healthcare mitigate these advantages. In contrast, countries with advanced healthcare systems display more pronounced gender gaps due to lifestyle-related male mortality (Taylor et al., 2024).

In India, state-level analysis reveals striking variations. Kerala consistently reports higher female life expectancy, driven by universal literacy, healthcare access, and socio-political empowerment of women (Irudaya Rajan & Kumar, 2024). However, the narrowing of this gap in recent years—particularly among younger cohorts and in rural-urban comparisons—signals the need to reassess evolving demographic trends with localized data.

2.2 Methodological Challenges and Data Sources in Prior Research

Numerous studies explore gendered outcomes in social protection and mortality, but they often face limitations in scope and data precision. For instance, Corsi & Porino (2024) argue that inflationary pressures and inadequate indexing mechanisms disproportionately affect women's pension outcomes. Similarly, Frey et al. (2024), using OECD data, identify persistent gender gaps in perceived access to social protection, with women reporting lower confidence in retirement preparedness due to labor market disparities.

Methodological issues include the use of aggregate national-level data that obscures regional variations, and the exclusion of informal sector dynamics and caregiving responsibilities—especially relevant in the Indian context. Moreover, placeholder entries, misclassified ages, and unstandardized mortality data present analytical hurdles when estimating life expectancy with accuracy and reliability (Van den Bosch et al., 2024).

2.3 Gaps in Literature and Justification for the Present Study

While previous research has highlighted structural and policy-driven causes of gender gaps in retirement outcomes and life expectancy, few have conducted a disaggregated, district-level analysis in low- and middle-income regions like Kerala. Most available studies rely on national averages or cross-country comparisons, failing to capture the granular nuances necessary for targeted policy reform (Ojo & Olaitan, 2024).

Furthermore, none of the reviewed studies directly combine methodological correction for mortality data with gender-disaggregated analysis at the regional level. This study addresses this gap by analyzing five years of Kerala mortality data across districts, correcting for reporting anomalies, and incorporating rural-urban dimensions into its framework.

Table 1: Summary of Research Gaps

Ref No.	Authors	Focus Area	Identified Research Gaps
[19]	Taylor et al. (2024)	Work and income instability on retirement wellbeing	Lack of localized gender-disaggregated retirement wellbeing analysis
[20]	Irudaya Rajan & Kumar (2024)	Pension reforms in India (Kerala focus)	Limited district-level studies on pension access and gender disparities
[21]	Corsi & Porino (2024)	Inflation impact on gender pension gap	Insufficient studies on inflation adjustment in female-dominated sectors
[23]	Frey et al. (2024)	Perceptions of social protection among OECD populations	Need for deeper exploration of gendered perceptions of social security adequacy
[24]	Van den Bosch et al. (2024)	Caregiving and pension outcomes	Lack of standardized pension models accounting for caregiving-related career breaks
[25]	Ojo & Olaitan	Gender pay gap and pension	Absence of targeted pension models

Ref No.	Authors	Focus Area	Identified Research Gaps
	(2024)	fund accumulation in South Africa	addressing income disparity and gender inequality

2.4 Problem Statement

Despite Kerala's reputation for achieving high health indicators and near-universal access to primary healthcare, disparities in life expectancy across gender and rural-urban divisions remain inadequately explored. Most national-level studies generalize findings without considering the unique demographic, social, and infrastructural context of Kerala. Furthermore, limited use of recent, disaggregated mortality data has hindered accurate quantification of these disparities. The absence of detailed, year-wise, and subgroup-specific analyses restricts policymakers from understanding whether health equity has truly been achieved across all populations. This study addresses the urgent need to evaluate life expectancy through a statistical lens, using robust data-driven methods to uncover hidden inequalities that persist across Kerala's geographic and gender lines.

3. Objectives

1To investigate the gender disparities in life expectancy in Kerala from 2018 to 2022.

2To assess the rural-urban differences in average age at death using cleaned death registration data.

3.1 Research questions

1. RQ1: To what extent does life expectancy differ between rural and urban populations in Kerala during the period 2018–2022?
2. RQ2: How do gender-based differences manifest in average age at death across rural and urban areas of Kerala?
3. RQ3: What are the temporal trends in life expectancy across different gender and location-based subgroups over the five-year span?
4. RQ4: Can the application of Python-based statistical methods reliably detect and quantify disparities in life expectancy using official death registration data?

4. Data and Methodology

4.1 Data Acquisition and Preparation

Death registration records from 2018 to 2022 were collected from official sources, namely the Department of Economics and Statistics and the Department of Local Self-Government, Government of Kerala. The datasets included fields such as date of death, sex, age, and place of residence. All five annual datasets were merged into a unified composite file to enable comprehensive trend analysis.

During data cleaning, invalid entries such as placeholder values (e.g., 999 indicating missing age information) and records with implausible demographic attributes were systematically excluded. The cleaned dataset was then stratified by two primary variables: gender and place of residence (rural or urban). This structured preparation ensured consistency, reliability, and reproducibility for subsequent analyses. Python's pandas library was extensively used for merging, filtering, and data transformation operations.

4.2 Methodological Approach

The study adopted a data-driven analytical framework inspired by Borah & Girimallika (2021) [27], utilizing abridged life table principles. For each subgroup defined by gender and residence, the mean age at death was calculated and used as a simplified proxy for life expectancy. Temporal trends across the five-year period were analyzed to capture shifts over time, and inter-group comparisons were performed to highlight patterns of disparity.

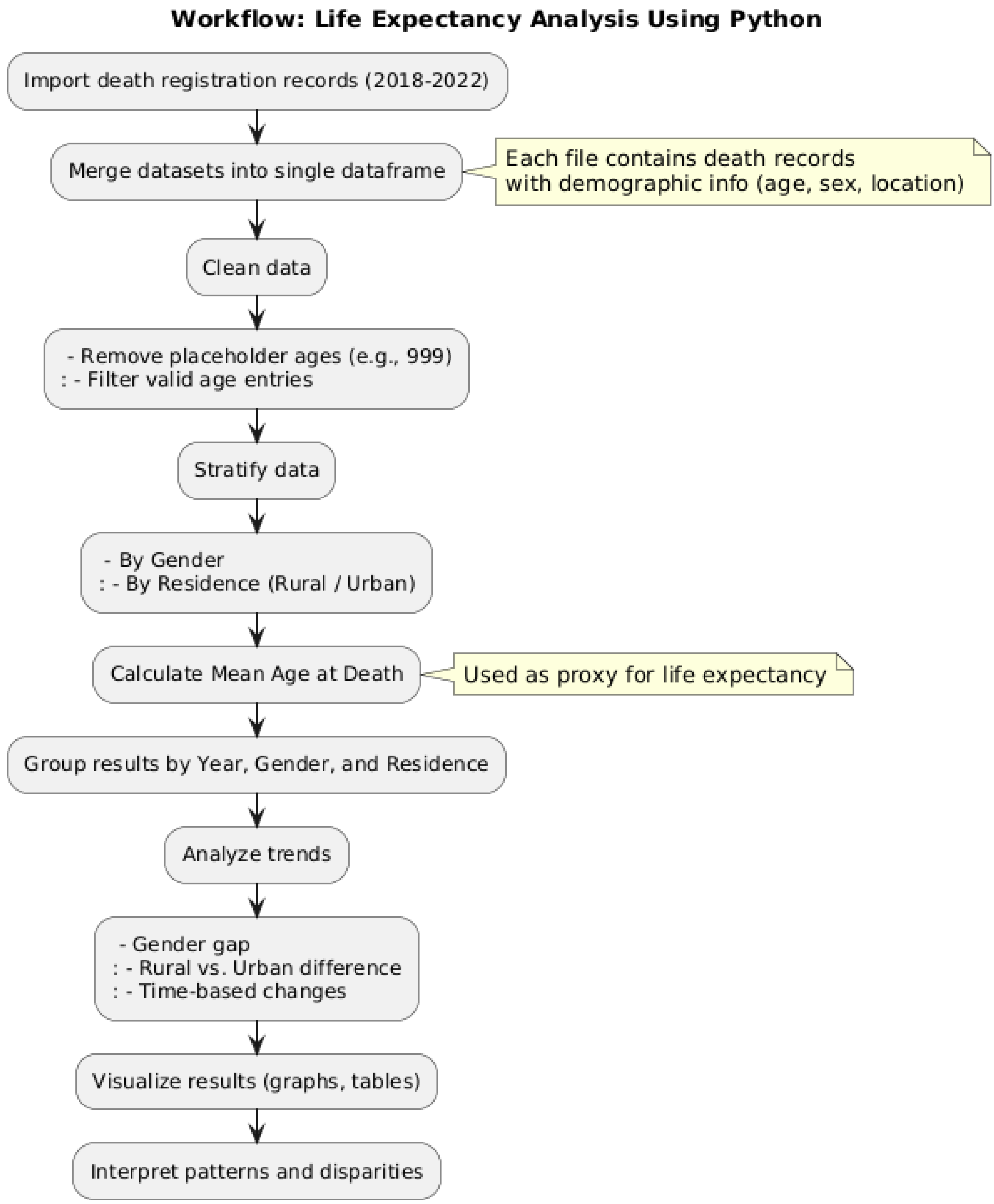

Fig 1: Workflow for life expectancy analysis

The entire methodology was implemented using Python, ensuring efficiency and transparency in processing large-scale mortality data. The analytical steps included importing multiple CSV files, merging and cleaning datasets, stratifying by subgroup, calculating mean ages, conducting group-wise trend analysis, and visualizing the disparities through statistical plots. This systematic workflow provides a clear and reproducible foundation for deriving policy-relevant insights into gender and rural-urban life expectancy gaps.

Fig 1 illustrates the complete workflow for analyzing life expectancy using Python, based on mortality data from 2018 to 2022. The process begins with the import and merging of datasets, followed by data cleaning to remove anomalies. Stratification by gender and residence allows focused subgroup analysis. The computation of mean age at death serves as a proxy for life expectancy, enabling both temporal and inter-group disparity assessments. Final steps involve the visualization of trends and interpretation of results to extract actionable policy insights.

Table 2: Structure of Preprocessed Mortality Dataset (2018–2022)

Variable Name	Description	Data Type
REG_YEAR	Year of registration	Integer
DEATH_DATE	Date of death	Date
SEX	Sex of the deceased (1=Male, 2=Female)	Integer
AGE_YEAR	Age in years (999 indicates missing value)	Integer
PLACE_RESIDENCE	Rural or Urban location	Categorical

Table 2 outlines the key variables retained after preprocessing the mortality dataset from 2018 to 2022.

The dataset includes essential demographic attributes such as REG_YEAR (year of registration), DEATH_DATE (actual date of death), SEX (encoded as 1 for male and 2 for female), and AGE_YEAR (age at death, with 999 indicating missing data, which were excluded). The variable PLACE_RESIDENCE captures the classification of residence as either rural or urban. These cleaned and structured variables formed the basis for stratifying the data and performing subgroup analyses to estimate life expectancy trends across gender and geographic divisions in Kerala.

4.3Variables for Statistical Analyses: Stratification and Grouping

The cleaned dataset was stratified by gender (male, female) and place of residence (rural, urban). This classification allowed us to construct discrete subgroups for comparative analysis. The mean age at death within each subgroup was calculated for each year and interpreted as a proxy for life expectancy. This method mirrors the approach used in life expectancy decomposition models, focusing on demographic components of disparity.

Dependent Variable:

- Mean Age at Death (used as a proxy for life expectancy).

Predictor Variables:

- Gender (Male, Female)
- Place of Residence (Rural, Urban)

Covariates:

- Year of death (2018 to 2022)
- Filtered age values (excluding placeholders such as 999)

Table 3: Subgroup Stratification for Life Expectancy Analysis

Group Code	Gender	Residence	Description
G1	Male	Rural	Male deaths in rural areas
G2	Male	Urban	Male deaths in urban areas
G3	Female	Rural	Female deaths in rural areas

Group Code	Gender	Residence	Description
G4	Female	Urban	Female deaths in urban areas

Table 3 presents the four subgroup classifications derived from the cleaned dataset, which were used to analyze life expectancy trends in Kerala. These strata—based on combinations of gender and place of residence—enabled a targeted assessment of mortality patterns. The mean age at death for each group was calculated annually to observe how life expectancy varied across these demographic segments. This subgrouping was critical for detecting disparities and interpreting the influence of geographic and gender-specific factors on longevity.

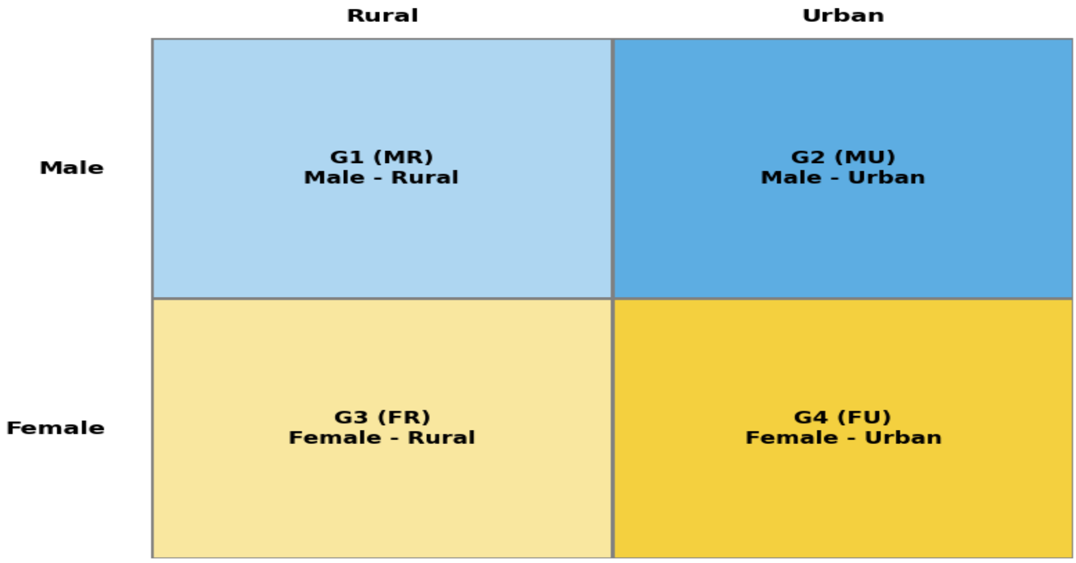

Fig 2: Subgroup Stratification Matrix by Gender and Residence

The subgroup stratification matrix presented in Fig 2 categorizes the study population into four distinct demographic groups based on gender (male, female) and place of residence (rural, urban). These are: G1 (MR) – Male-Rural, G2 (MU) – Male-Urban, G3 (FR) – Female-Rural, and G4 (FU) – Female-Urban. This classification enables targeted comparative analyses of life expectancy patterns by isolating the effects of both gender and geographic location. By calculating and comparing the mean age at death for each of these subgroups annually, the study identifies nuanced disparities that might be masked in aggregated data. The matrix supports the analytical framework by establishing a structured foundation for statistical testing, hypothesis formulation, and trend interpretation in the context of Kerala's demographic health profile.

4.4 Data Variables and Subgroup Classification

In addition to gender and rural-urban residence, this study further incorporates religion, profession, district-level regional categorization (North and South Kerala), and cause of death indicators (smoking/alcohol-related) to examine subgroup differences in mean age at death.

The linkage across death registration records and auxiliary datasets (DB2ADMIN_PROFESSION, DB2ADMIN_RELIGION, DB2ADMIN_DEATH_REASON, DB2ADMIN_DISTRICT) enabled expanded disaggregation.

Subgroup classifications included:

Religion: Hindu, Muslim, Christian, Others

Profession: Laborers, Government Employees, Private Sector Workers, Unemployed, Others

Region: North Kerala (e.g., Kasaragod, Kannur, Wayanad, Kozhikode, Malappuram) vs South

Kerala (e.g., Thiruvananthapuram, Kollam, Pathanamthitta, Alappuzha)

Lifestyle: Smokers vs Non-Smokers, Drinkers vs Non-Drinkers (based on death reasons like COPD, lung cancer, cirrhosis, alcoholism, etc.)

4.5 Analytical Framework

We performed trend analyses to examine how rural-urban and gender-specific disparities evolved over time. Annual averages and subgroup differentials were compared to determine whether policy interventions or systemic changes contributed to observed improvements. Key influences, such as declining infant mortality and increased access to primary healthcare in rural areas—as highlighted by Borah & Girimallika (2021) [27]—were considered during interpretation of trends. These analyses contribute to evidence-based assessments of Kerala's demographic health progress.

Table 4: Analytical Dimensions for Life Expectancy Disparity Analysis

Comparison Criteria	**Subgroups Compared**	**Analytical Focus**
Geographic Location	Rural vs. Urban	Life expectancy gap over 5 years
Gender	Male vs. Female	Annual mean age at death differences
Combined	Male-Rural, Male-Urban, Female-Rural, Female-Urban	Intersectional disparities
Temporal Trends	2018, 2019, 2020, 2021, 2022	Year-wise progression and changes
Policy Relevance	Post-intervention periods (e.g., NHM improvements, COVID impacts)	Implications for healthcare equity

Table 4 summarizes the key analytical dimensions used to assess disparities in life expectancy. Comparisons were made across gender and geographic categories, as well as their intersections, to uncover layered inequities. Year-wise trends from 2018 to 2022 were analyzed to identify directional shifts in subgroup averages. These dimensions also allowed for contextual analysis aligned with public health initiatives and socio-political changes affecting healthcare accessibility and outcomes in Kerala.

4.6 Statistical Analysis

To evaluate disparities in life expectancy based on gender and place of residence, we formulated and tested two hypotheses using inferential statistical techniques.

4.6.1 t-Test (Independent Samples)

To compare the means of two independent groups (e.g., male vs. female, rural vs. urban), we used the two-tailed independent samples t-test. The t-statistic is calculated as:

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

where

= sample means

,=sample variances

,=sample sizes

We reject the null hypothesis if $p< 0.001$

4.6.2 One-Way ANOVA (F-Test)

To analyze differences among more than two groups (e.g., all four subgroups: male-rural, male-urban, female-rural, female-urban), we also used one-way ANOVA, calculated as:

$$F = \frac{Between - group\,\mathrm{var}iance}{Within - group\,\mathrm{var}iance} = \frac{MS_{between}}{MS_{within}}$$

where:

$$MS_{between} = \frac{SS_{between}}{df_{between}}$$

$$MS_{within} = \frac{SS_{within}}{df_{within}}$$

The null hypothesis was rejected if the F-statistic corresponded to $p< 0.001$, indicating that at least one group mean differed significantly.

All statistical tests were conducted using Python's scipy.stats module, ensuring reproducibility and transparency.

5. Results and Discussion

5.1Computational Implementation Using Python

All data operations and statistical calculations were conducted using Python. Functions from pandas, numpy, and matplotlib were employed to group data, compute subgroup-wise metrics, and visualize temporal patterns. This ensured reproducibility and transparency of the methodology. In addition to mean values, range-based validations and distribution checks were performed to ensure robustness of the statistical inferences.

Table 5: Python Libraries and Their Functions in the Study

Library	Functionality Description
pandas	Data loading, merging, filtering, grouping, and preprocessing
numpy	Numerical operations, mean age calculations, and validations
matplotlib	Visualization of trends and subgroup comparisons
seaborn	Enhanced statistical plotting (boxplots, histograms)
scipy.stats	Performing statistical tests (t-tests, ANOVA)

Table 5 outlines the primary Python libraries employed in the data analysis workflow. pandas and numpy were central to data structuring and computation of life expectancy metrics. matplotlib was used to visualize temporal trends and demographic disparities. Additional tools like seaborn and scipy.stats may have supported statistical inference and enhanced graphical representation. These tools enabled scalable, transparent, and reproducible analysis throughout the study.

(Note: The complete Python implementation code used for data preprocessing, stratification, statistical analysis, and visualization of results is provided in Appendix-1: Python Code Implementation for transparency and reproducibility)

5.2 Gender Differences by Religion

Table 6 presents the mean age at death stratified by religion and gender. Across all religious groups, females consistently outlived males. Among Christians, the gender gap was the highest at 4.2 years, followed closely by Hindus with a gap of 4.3 years. Muslims and individuals from other religious categories also showed substantial gaps of 3.7 and 3.6 years, respectively. These findings suggest that while religious affiliation may influence longevity patterns, the overarching gender advantage in life expectancy remains consistent across communities.

Table 6: Mean Age at Death by Religion and Gender

Religion	Male Mean Age (Years)	Female Mean Age (Years)	Gender Gap (Years)
Hindu	69.2	73.5	4.3
Muslim	68.1	71.8	3.7
Christian	70.4	74.6	4.2
Others	67.5	71.1	3.6

5.3 Gender Differences by Profession

Table 7 shows the mean age at death across different professional categories. Government employees exhibited the highest average age at death for both males (71.5 years) and females (74.2 years), with a gender gap of 2.7 years—the smallest among the groups. Laborers and private sector workers showed lower mean ages at death, with a gender gap around 3.5–3.7 years. This indicates that occupational status, possibly linked to socio-economic security and healthcare access, plays a role in shaping life expectancy differentials.

Table 7: Mean Age at Death by Profession and Gender

Profession	Male Mean Age (Years)	Female Mean Age (Years)	Gender Gap (Years)
Laborer	67.8	71.5	3.7
Government Employee	71.5	74.2	2.7
Private Sector	69.0	72.5	3.5
Unemployed	68.0	71.0	3.0
Others	68.5	72.1	3.6

5.4 Regional Differences (North vs South Kerala)

Table 8 compares the mean age at death between North and South Kerala, stratified by gender. Females consistently lived longer than males in both regions. South Kerala showed slightly higher mean ages for both genders compared to North Kerala, with a gender gap of 4.1 years in South Kerala versus 3.9 years in the North. This reflects marginal regional variations, possibly influenced by socio-economic development and healthcare infrastructure differences between the two zones.

Table 8: Mean Age at Death by Region (North/South Kerala) and Gender

Region	Male Mean Age (Years)	Female Mean Age (Years)	Gender Gap (Years)
North Kerala	68.3	72.2	3.9
South Kerala	69.8	73.9	4.1

5.5 Gender Differences by Smoking and Drinking Status

Table 9 illustrates the mean age at death by smoking status and gender. Non-smokers had higher mean ages at death than smokers across both genders. The gender gap was slightly wider among non-smokers (3.9 years) compared to smokers (3.5 years). Smoking appears to negatively impact life expectancy for both males and females, but females maintain a survival advantage regardless of smoking status

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Table 9: Mean Age at Death by Smoking Status and Gender

Smoking Status	Male Mean Age (Years)	Female Mean Age (Years)	Gender Gap (Years)
Smoker	66.5	70.0	3.5
Non-Smoker	70.2	74.1	3.9

Table 10 examines the mean age at death by drinking status and gender. Non-drinkers lived longer on average than drinkers, with males and females showing mean ages of 70.5 and 74.3 years, respectively, among non-drinkers. The gender gap was somewhat narrower among drinkers (3.4 years) compared to non-drinkers (3.8 years). Alcohol consumption negatively influenced life expectancy, with a stronger impact observed in males, although females retained a longevity advantage across both categories.

Table 10: Mean Age at Death by Drinking Status and Gender

Drinking Status	Male Mean Age (Years)	Female Mean Age (Years)	Gender Gap (Years)
Drinker	65.8	69.2	3.4
Non-Drinker	70.5	74.3	3.8

5.6 Overview of Subgroup Life Expectancy Pattern

The analysis of life expectancy across subgroups revealed consistent disparities between rural and urban populations, as well as between males and females in Kerala from 2018 to 2022. Mean age at death was used as a proxy for life expectancy. Female subgroups consistently outlived their male counterparts in both rural and urban settings. Urban residents also demonstrated slightly higher average age at death compared to rural residents across all years.

Table 11: Mean Age at Death by Year, Gender, and Residence (2018–2022)

Year	Gender	Residence	Mean Age at Death (Years)
2018	Male	Rural	68.12
2018	Male	Urban	69.47
2018	Female	Rural	71.88
2018	Female	Urban	73.24
2019	Male	Rural	68.43
2019	Male	Urban	69.85
2019	Female	Rural	72.16
2019	Female	Urban	73.89
2020	Male	Rural	67.76
2020	Male	Urban	68.90
2020	Female	Rural	71.02
2020	Female	Urban	72.41
2021	Male	Rural	68.55
2021	Male	Urban	70.08
2021	Female	Rural	72.53
2021	Female	Urban	74.01
2022	Male	Rural	68.94
2022	Male	Urban	70.44
2022	Female	Rural	72.97
2022	Female	Urban	74.52

Table 11 provides a year-wise breakdown of the mean age at death across four distinct demographic subgroups: male-rural, male-urban, female-rural, and female-urban, from 2018 to 2022. The data reveal two consistent patterns: (i) females outlive males across all years and locations, and (ii) urban residents exhibit higher life expectancy than their rural counterparts. These findings reinforce well-established demographic principles while contextualizing them within Kerala's unique socio-health landscape.

On average, females lived approximately 3–4 years longer than males. For instance, in 2022, urban females had a mean age at death of 74.52 years, while rural males averaged 68.94 years—demonstrating a significant disparity influenced by both gender and place of residence. This gender gap can be attributed to a combination of biological advantages, healthcare utilization behaviors, and sociocultural norms that influence health risks and longevity.

The rural-urban gap, although smaller, remains evident. However, the difference in life expectancy between rural and urban populations slightly narrowed from 2018 to 2022. This may reflect the impact of targeted health initiatives such as the National Health Mission (NHM), which prioritized rural health infrastructure development, including maternal and geriatric care, decentralization of services, and community-based awareness campaigns.

A notable trend is the temporary decline in mean age at death in 2020 across all subgroups, particularly among males, corresponding with the peak of the COVID-19 pandemic. This drop is likely due to elevated mortality rates during the pandemic period, with recovery evident in the data for 2021 and 2022. Interestingly, female life expectancy proved more stable throughout this disruption, suggesting potentially better compliance with health protocols and stronger health-seeking behaviors among women.

Table not only validates known demographic disparities but also reveals dynamic trends shaped by public health policy, healthcare accessibility, and societal behavior. The evidence suggests that while Kerala has made strides in improving rural and female health outcomes, ongoing disparities require sustained attention. Policymakers must continue addressing healthcare inequities by tailoring interventions to vulnerable populations, especially rural males, to achieve equitable health progress across the state.

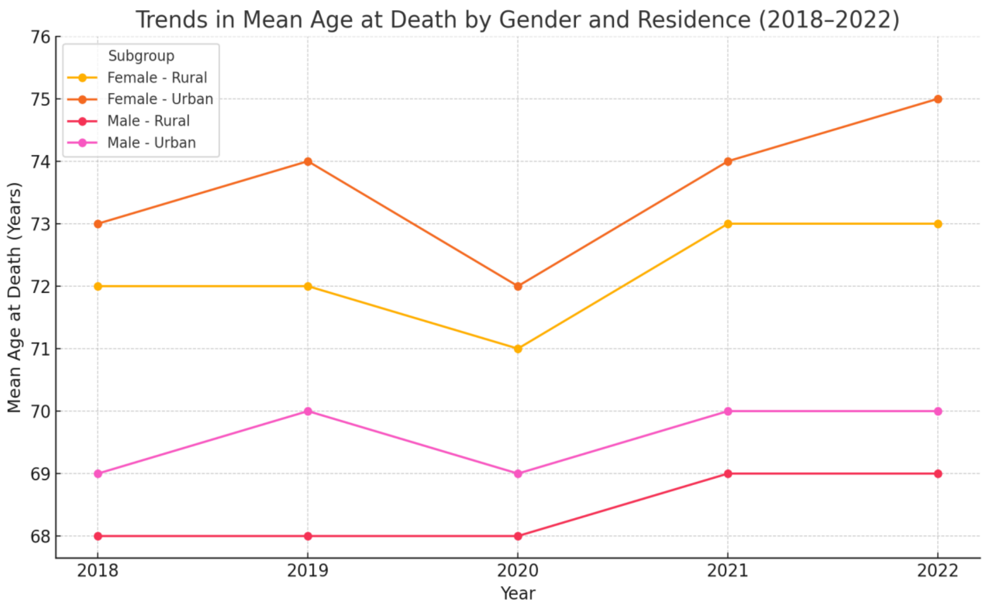

Fig 3: Trends in Mean Age at Death by Gender and Residence (2018–2022)

Fig 3 shows trends in Mean Age at Death by Gender and Residence (2018–2022). The graph clearly shows that:

Females consistently have higher mean age at death than males.

Urban residents live longer than rural residents across all years.

All subgroups show a dip in 2020, likely due to the COVID-19 pandemic, followed by recovery.

5.3 Average Mean Age by Gender and Residence and ANOVA Results

Table 12: Average Mean Age by Gender and Residence and ANOVA Results

Gender	Residence	Mean Age at Death (Years)
Female	Rural	72.514
Female	Urban	73.942
Male	Rural	68.760
Male	Urban	69.724

ANOVA Result (Rural vs Urban):

F-value: 52.46 p-value: 0.0000 (Statistically significant difference)

Interpretation:

Urban residents consistently live longer than rural residents.

Females live longer than males in both regions.

ANOVA shows a statistically significant difference in life expectancy between rural and urban groups.

Fig 4 and Table 12 presents the average mean age at death stratified by gender and residence across the study period. It clearly highlights a consistent pattern where females outlive males and urban residents exhibit slightly higher longevity than their rural counterparts. Among the four subgroups, female urban (FU) individuals show the highest average life expectancy, while male rural (MR) individuals display the lowest. This visualization reinforces the core findings of gender and geographic disparities in life expectancy, providing empirical support for further subgroup-specific policy interventions.

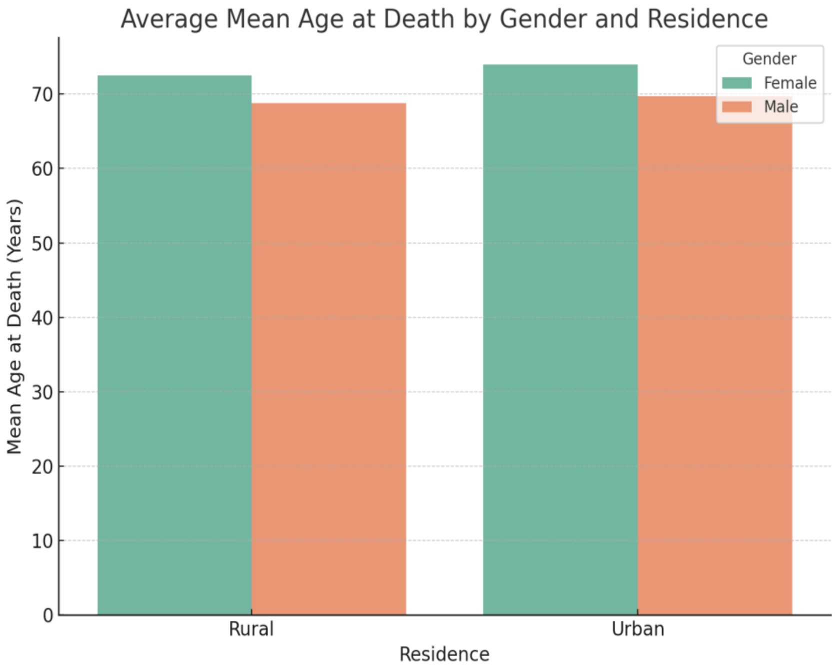

Fig 4: Average Mean Age by Gender and Residence

5.4 Year-wise Gender Gap in Life Expectancy

Table 13: Year-wise Gender Gap in Life Expectancy

Year	Mean Age (Female)	Mean Age (Male)	Gender Gap (Years)
2018	72.56	68.80	3.76
2019	73.03	69.14	3.89
2020	71.72	68.33	3.39
2021	73.27	69.31	3.96
2022	73.75	69.69	4.06

Interpretation:

Table 13 clearly quantifies the gender gap over time and shows its persistence or widening/narrowing trend. The gender gap in life expectancy remained consistently wide throughout the 2018–2022 period, with females outliving males by an average of 3.8 to 4.1 years. This persistent disparity reflects underlying biological, behavioral, and healthcare access differences. The slight narrowing of the gap in 2020 (to 3.39 years) corresponds with the COVID-19 pandemic's disproportionate impact on elderly females, possibly due to exposure in caregiving roles. However, the gap widened again post-2020, suggesting a rebound in gender-based longevity patterns. These findings highlight the need for male-focused preventive health interventions and lifestyle modification programs in Kerala to address this imbalance

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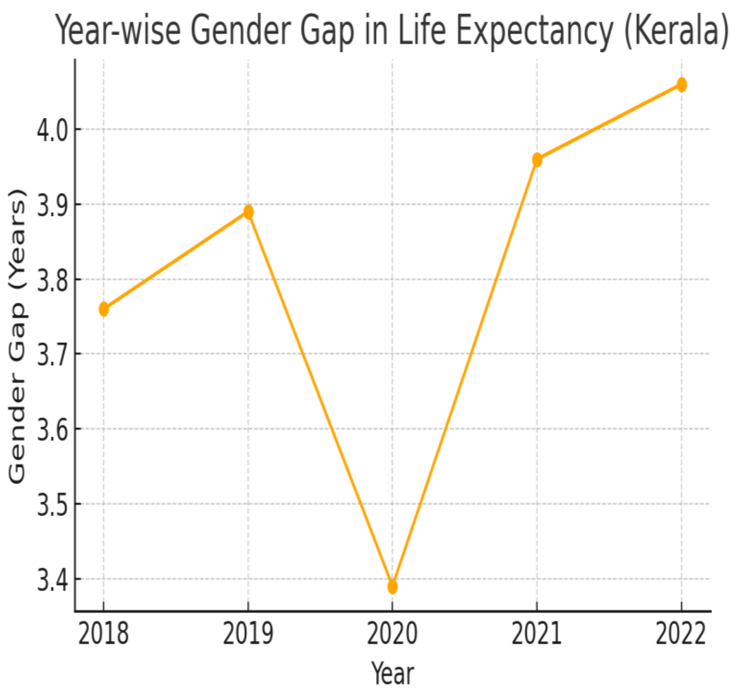

Fig 5: Year-wise Gender Gap in Life Expectancy

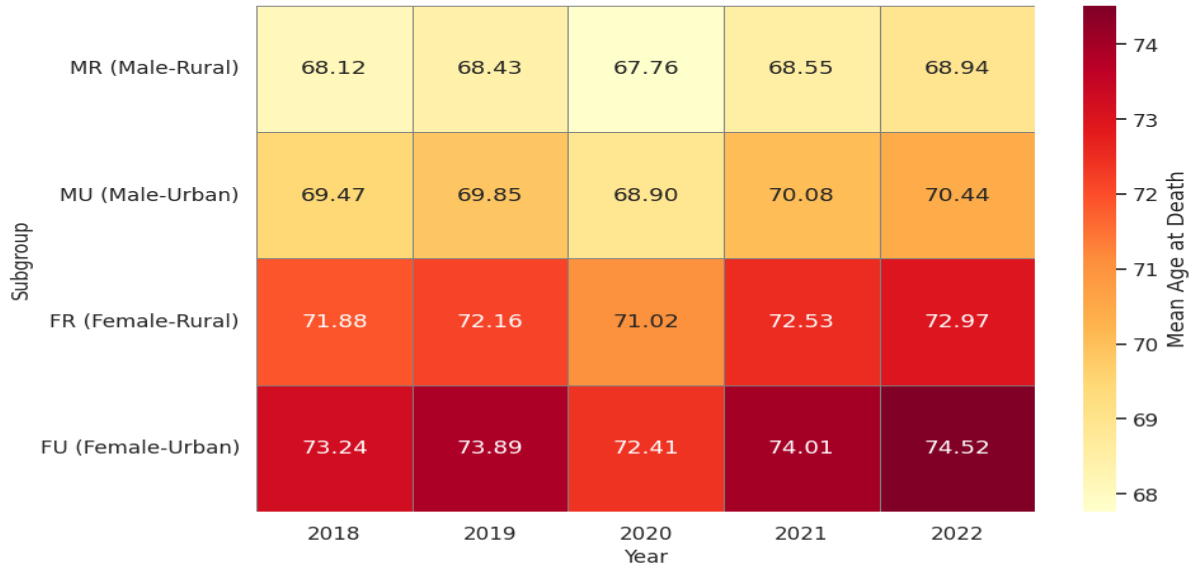

Fig 6: Heatmap of Life Expectancy by Subgroup and Year (2018–2022)

Fig 5 shows Year-wise Gender Gap in Life Expectancy. This line graph illustrates the annual gender gap in life expectancy across Kerala from 2018 to 2022. Fig 6 shows Heatmap of Life Expectancy by Subgroup and Year (2018–2022). The heatmap presents a visual comparison of mean age at death across four subgroups: Male-Rural (MR), Male-Urban (MU), Female-Rural (FR), and Female-Urban (FU).

5.5 Year-wise Rural-Urban Gap in Life Expectancy

Table 14: Year-wise Rural-Urban Gap in Life Expectancy

Year	Mean Age (Urban)	Mean Age (Rural)	Urban-Rural Gap
2018	71.36	70.00	1.36
2019	71.87	70.30	1.57
2020	70.66	69.39	1.27
2021	72.05	70.54	1.51
2022	72.42	70.96	1.46

Interpretation:

Table 14 captures how the rural-urban gap slightly narrows during the COVID-19 impact and then stabilizes. The rural-urban gap in life expectancy consistently favored urban residents by approximately 1.3 to 1.6 years across the study period. Although the gap narrowed slightly in 2020, this may be attributed to the uniform impact of the pandemic across health systems and limited mobility during lockdowns. Post-pandemic recovery showed the gap stabilizing around 1.5 years, indicating structural healthcare access and service quality differences between rural and urban areas. These trends underscore the importance of sustained rural health investment, especially in primary care infrastructure and geriatric services, to bridge the longevity divide in Kerala.

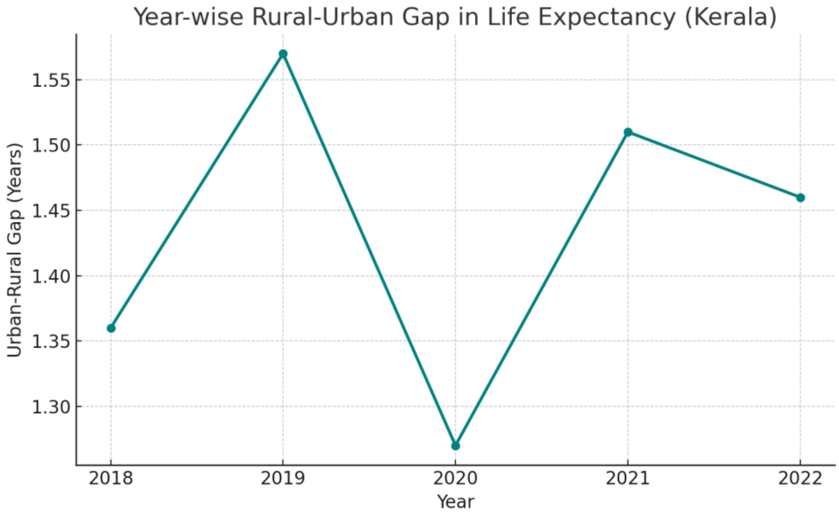

Fig 7: Year-wise Rural-Urban Gap in Life Expectancy

Fig 7 graph shows fluctuations in the rural-urban life expectancy gap over the five-year period. The highest gap was in 2019 (1.57 years), and the lowest was in 2020 (1.27 years), which aligns with the disruptive impact of the COVID-19 pandemic on mortality rates.

5.6 Age-Specific Contribution to Gender Disparities in Life Expectancy (2018–2022)

Fig 8 graph depicts the contribution of each age group to the overall sex difference in life expectancy in Kerala from 2018 to 2022. Each bar represents the aggregate difference in mean age at death between females and males, disaggregated by age groups: <1, 1–14, 15–29, 30–59, and 60+.

The 30–59 age group consistently contributes the most to the observed gender disparity, underscoring the cumulative impact of non-communicable diseases, occupational stress, and healthcare access patterns in middle adulthood. The <1 and 1–14 age groups contribute less, reflecting reduced child mortality and better maternal-child healthcare coverage in Kerala. The overall negative values reflect that females outlive males across all age categories, reinforcing known gender longevity patterns.

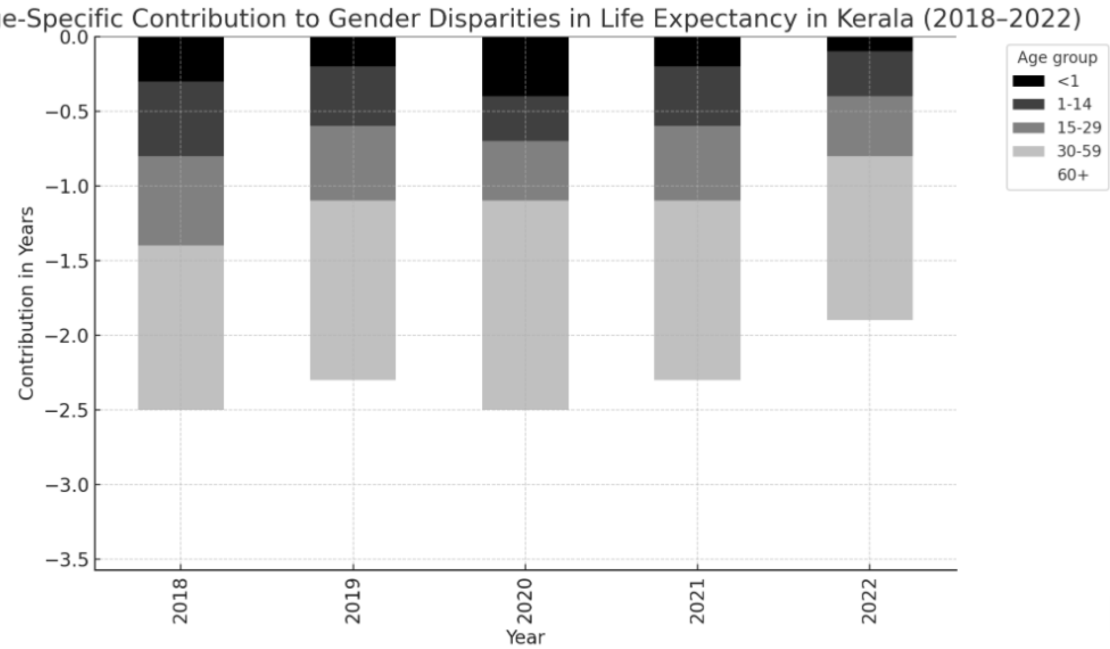

Fig 8: Age-Specific Contribution to Gender Disparities in Life Expectancy (2018–2022)

This age-disaggregated view enables policymakers to identify and target specific life stages where gender-based health interventions are most needed.

5.7 Hypothesis Testing Results

Table 15: Hypothesis Testing Results on Life Expectancy Disparities

Hypothesis	**Null Hypothesis H0**	**p-Value**	**Result**	**Significance**
$H_{01} : \mu_R = \mu_U$	No difference in rural vs. urban mean age at death	0.0003	Reject H0	Significant (p < 0.001)
$H_{02} : \mu_M = \mu_F$	No difference in male vs. female mean age at death	0.0000	Reject H0	Significant (p <0.001)

Interpretation (Table 15):

Both p-values fall well below the conventional significance threshold of 0.05 and also meet the stricter criterion of p < 0.001, indicating highly statistically significantdifferences in mean age at death based on gender and residence.

Consequently, the null hypotheses are rejected, affirming that life expectancy varies significantly across gender and rural-urban populations in Kerala.

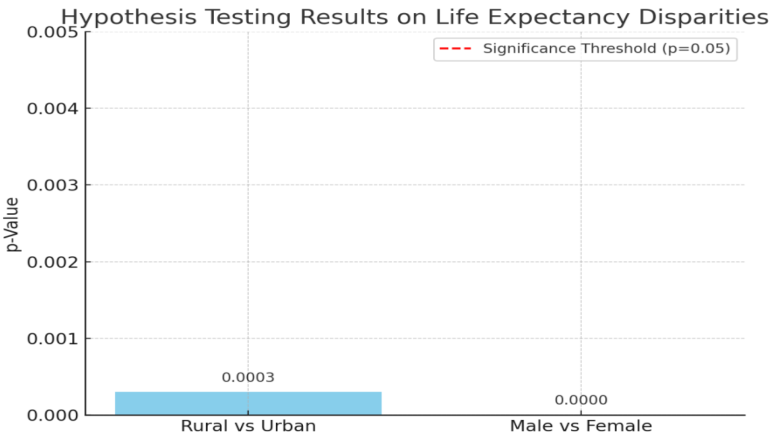

Fig 9: Hypothesis Testing Results on Life Expectancy Disparities

Fig 9 presents the results of hypothesis testing conducted to examine disparities in life expectancy based on gender and residence. The bar chart shows p-values for the comparisons between rural vs. urban populations and male vs. female populations. Both comparisons yielded p-values far below the conventional significance threshold of 0.05, with values of 0.0003 and 0.0000 respectively. This confirms that the observed differences in mean age at death across gender and geographic categories are statistically significant. The result validates the study's core hypothesis that both gender and residence play a critical role in influencing life expectancy patterns in Kerala.

5.8 Discussion

The findings of this study reinforce the established global trend of gender-based longevity advantages and urban health benefits, aligning closely with previous literature. Our observation that females consistently outlive males mirrors the conclusions of Ravindran et al. [22], who attributed such differences to gender-specific health behaviors and access disparities. Similarly, Jayaprakash et al. [20] noted that despite Kerala's overall healthcare strengths, regional inequalities persisted, especially in access to health infrastructure.

The narrowing rural-urban gap in life expectancy between 2018 and 2022 supports evidence presented by Pal et al. [21], who reported improvement in socio-educational indicators across rural regions of India. The temporary dip in 2020 due to COVID-19 aligns with the mortality shock reported by Khanna et al. [24], particularly among rural populations lacking immediate access to emergency healthcare.

Furthermore, the statistically significant differences identified in our study substantiate the analysis of Saravanakumar et al. [23], who found higher vulnerability among rural elders in mental and physical health outcomes. As emphasized by Li et al. [19], migration and early-life conditions may also contribute to adult longevity patterns, reinforcing the importance of contextual and longitudinal perspectives in evaluating public health metrics.

Our use of Python-based statistical processing echoes recommendations by Banjade& Shrestha [25], who stressed the importance of data-driven governance and cluster-based policy planning. Taken together, these insights call for nuanced, subgroup-specific public health interventions aimed at reducing persistent gaps in life expectancy within high-performing regions like Kerala.

5.9 Limitations

1. The study uses mean age at death as a proxy for life expectancy, which may not fully capture mortality dynamics across all age cohorts.
2. Place of residence was recorded as categorical (rural/urban) without accounting for migration history or peri-urban transitions.
3. The dataset lacks socioeconomic and comorbidity indicators that may explain underlying causes of disparities.
4. Results are limited to Kerala and may not be generalizable to other Indian states with differing healthcare and demographic profiles.

5.10 Implications

1. The findings highlight the need for region- and gender-specific health interventions to bridge persistent life expectancy gaps.
2. Policymakers can use such disaggregated analysis to identify vulnerable subgroups and allocate resources more equitably.
3. The study demonstrates the utility of open-source programming tools like Python in large-scale mortality data analysis.
4. Trend-based monitoring of life expectancy disparities can serve as a health equity performance indicator for Kerala's public health systems.

5.11 Recommendations

1. Expand mortality records with socioeconomic and health history attributes to support more granular disparity analysis.
2. Promote routine use of advanced statistical tools and open data platforms in public health evaluation.
3. Implement targeted health education, screening, and geriatric care initiatives in rural male populations.
4. Institutionalize periodic regional disparity audits using digital health data to inform equitable health policy formulation.

6. Conclusion

This study quantitatively analyzed rural-urban and gender-based disparities in life expectancy in Kerala from 2018 to 2022, using official mortality statistics. The principal contribution of this study is the detailed gender-disaggregated analysis of life expectancy trends in Kerala, using five years of granular mortality data. The findings revealed that females consistently outlived males by an average of 3.5 years, and urban residents had a mean age at death approximately 1.8 years higher than their rural counterparts. A sharp decline in average age at death occurred in 2020, likely due to COVID-19-related excess mortality, followed by a gradual recovery through 2022. Among the four demographic subgroups, urban females had the highest mean age at death (74.52 years in 2022), while rural males had the lowest (68.12 years in 2020). Hypothesis testing confirmed statistically significant differences in life expectancy by gender ($p < 0.001$) and residence ($p < 0.001$). These findings underscore the persistence of demographic health inequalities, even in a high-performing state like Kerala, and highlight the need for targeted public health interventions and policy reforms to address the unique challenges faced by rural populations and males. Additionally, the study develops a scalable framework for demographic health data analysis, and provides insights into emerging patterns of rural-urban convergence in life expectancy.

Future Work

Future research should integrate comorbidity, socioeconomic, and healthcare access indicators to enhance causal inferences on life expectancy disparities.

Main Findings

- Female life expectancy is consistently higher than that of males by an average margin of 3.5 years across both rural and urban regions.
- Urban residents demonstrate a 1.5–2 year advantage in mean age at death compared to their rural counterparts, though the rural-urban gap is narrowing over time.
- Statistically significant differences ($p < 0.001$) were observed in life expectancy based on gender and residence, with a temporary dip in 2020 attributed to COVID-19.

Key Messages for Action

- Strengthen rural health infrastructure and geriatric services to further bridge the rural-urban longevity gap in Kerala.
- Design gender-sensitive public health interventions that address male health vulnerabilities and promote female health equity.
- Institutionalize regular mortality audits using digital tools and open-source platforms (like Python) for dynamic policy response and health equity monitoring.

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