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Cardiovascular Mortality of 40–70-year-olds in Sri Lanka from 1980 - 2010; an age-period-cohort analysis

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3 **Abstract**

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6 **Introduction**

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9 Cardiovascular diseases (CVDs) are the leading cause of death globally; in Sri Lanka which has a

10 rapidly ageing population, CVDs contribute to over 34% of deaths and is increasing. The objective

11 of this study was to compare cardiovascular mortality of 40–70-year-old Sri Lankans from 1980-

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16 2010 by age, birth cohorts and sex.

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19 **Methods**

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22 A comparative retrospective study was done using secondary data of cardiovascular deaths due to

23 ischemic heart disease (IHD), hypertensive disease (HTN) and cerebrovascular disease (CeVD)

24 among 40-70-year-old Sri Lankans from 1980-2010. Data were extracted from the WHO mortality

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done by age, birth cohort and by sex.

34 **Results**

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37 Mortality due to IHD increased with age but decreased with birth cohorts with time (range 3.7-390

38 per 100,000 population); there was a spike in the IHD mortality rates in both age-groups and birth

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cohorts in 2000. Deaths due to HTN markedly increased after 55 years; however, mortality

decreased in the younger cohorts (range 2.8-204.81 per 100,000 population). CeVD mortality

linearly increased with age (range 3.3-153.3 per 100,000 population); birth cohorts of 1926-1930 and

1931-1935 had a spike in mortality among 60-64 and 65-69 age groups, respectively. Changes were

seen among both males and females; mortality rates were higher in males than in females.

Conclusions: All cardiovascular mortality rates increase with age and are higher in males than in females. Age specific cardiovascular mortality rates are lower in the younger birth cohorts as compared to the older birth cohorts. The increase in cardiovascular deaths in Sri Lanka is due to the ageing population. Though the mortality rates are decreasing, the number of cardiovascular events will increase due to the ageing population.

Keywords: Cardiovascular mortality, 1980-2010, 40-70-year-olds, Sri Lanka

Data availability statement

All data extracted are given in the supplementary tables and in the tables.

What is already known in this topic

- Cardiovascular diseases (CVDs) are the leading cause of death globally. WHO estimated that there were 17.9 million deaths due to CVDs accounting for 32% of all global deaths in 2019.
- Various studies across multiple countries have shown a relationship between cardiovascular disease mortality and age periods, indicating that mortality rates vary significantly with different age groups and time periods, influenced by both early life exposures and concurrent changes in risk factors.
- The mortality from CVDs in Sri Lanka is estimated to be 524 deaths per 100,000 which is higher than that observed in many high-income countries

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What this study adds

- Despite increase in mortality due to cardiovascular diseases with time, we have shown that mortality rates due to cardiovascular diseases is decreasing with time, age and birth cohorts.
- The results of this study can be used to project mortality rates due to cardiovascular diseases in Sri Lanka.

How this study might affect research, practice or policy

- Although the mortality rates due to cardiovascular diseases are decreasing, the burden of cardiovascular diseases will still be high with the increase in the number of events, both fatal and non-fatal due to the ageing population. This will have implications in the future on providing preventive, curative and rehabilitative healthcare services.

Introduction

Cardiovascular diseases (CVDs) are the leading cause of death globally. They comprise a group of diseases of the heart and blood vessels including coronary heart disease (CHD), cerebrovascular disease (CeVD), peripheral artery disease, rheumatic heart disease, congenital heart disease, deep vein thrombosis and pulmonary embolism.¹

In 2019, it was estimated that there were 17.9 million deaths due to CVDs accounting for 32% of all global deaths; of these deaths, 85% were due to heart attack and stroke. More than 75% of all CVD deaths occur in low- and middle-income countries; CVD deaths comprised 38% of premature deaths (under the age of 70) due to non-communicable diseases.¹

Hypertension is a leading risk factor for cardiovascular disease with a heavy public health burden worldwide.² It is defined as having a blood pressure above 140/90; poorly controlled or uncontrolled blood pressure increases the risk of hypertensive disease (HTN) giving rise to microscopic and macroscopic cardiac remodeling and functional alterations.³ It is estimated that 1.28 billion adults aged 30–79 years worldwide have hypertension with two-thirds living in low- and middle-income countries.⁴ 46% of hypertensives are unaware they have the condition and less than 42% are diagnosed and treated; only 21% of adults with hypertension have it controlled.⁴ It is a major cause of premature death worldwide.⁴

The number of CVD deaths has been increasing over time; in 2000, around 14 million people died from cardiovascular diseases globally, while in 2019, close to 18 million died.⁵ It was estimated that CVDs would account for >23 million deaths by 2030.⁶ Almost all countries experienced a significant decline in mortality from 1990 to 2017.⁷ The global mean trend of CVD incidence increased from 1990 to 1996 followed by a decline since then.⁷ The decline in

incidence and mortality rates for developed countries was significantly higher than that for developing countries from 1990–2017 ($p < 0.05$); developing nations had a less-steep decline.⁷

As for all non-communicable diseases, risk factors for cardiovascular diseases include age, sex and other modifiable lifestyle risk factors.⁷ The rising death toll is largely due to a growing and ageing global population. Death rates have been declining due to implementation of preventive programmes; large declines in smoking, improvements in screening, diagnosis, and monitoring; and advances in medical treatments, public health initiatives, emergency care, and surgical procedures have all helped to reduce the impact of cardiovascular diseases on people’s lives.⁷

The large disparities that still exist can be further reduced.

South Asia has a disproportionately high burden of cardiovascular disease, with higher rates of CVD incidence, mortality, and risk factor prevalences than many other regions.⁸ Cardiovascular diseases account for 3.9 million deaths in the WHO South-East Asia Region every year, comprising a quarter of all deaths from non-communicable diseases (NCDs), with most of them being preventable.⁹ Global research studies related to healthcare have shown that even though South Asians comprise only 25% of the world’s population, they account for more than 50% of the world’s cardiovascular deaths.⁸

Sri Lanka, a country having one of the fastest ageing populations in Asia, is in the midst of an epidemiological and demographic transition. For 2022, WHO estimated that over 80% of the mortality in Sri Lanka is due to major non-communicable diseases. Among them, CVDs contribute to over 34% of deaths, impacting both life expectancy and quality of life for the past four decades. The mortality from CVDs in Sri Lanka is estimated to be 524 deaths per 100,000 which is higher

than that observed in many high-income countries.¹⁰ Coronary artery disease (CAD) is the leading cause of death in Sri Lanka while stroke is the third highest cause of death.^{11, 12}

There is evidence that childhood risk factors such as obesity, exposure to indoor and outdoor tobacco smoke, dyslipidaemia and diabetes impact cardiovascular disease in adulthood¹³; these risk factors are now being targeted for prevention of cardiovascular disease.

Birth cohort analyses have been used to determine the causal relationship between potential risk factors during the prenatal and postnatal period and the health status of the newborn up to childhood. There has been an increase in the use of birth cohort analyses.¹⁴ They allow description of associations between early exposures and subsequent outcomes¹⁵; in addition, they are able to identify the risk and environmental exposure factors shared by a given generation.¹⁶ Cohort analyses are often used to investigate disease trends¹⁷ and for testing a wide range of hypotheses.¹⁴

As cardiovascular diseases are a heavy health burden in Sri Lanka, the aim of this study was to find out whether there are variations in mortality of selected cardiovascular diseases (ischaemic heart disease, hypertensive disease and cerebrovascular disease) separately for males and females over time and birth cohort among 40 – 70-year-old Sri Lankans over the period 1980-2010.

Methods

Study design and data sources

This comparative retrospective study was conducted from August 2022 to January 2024 using secondary data available in the public domain. Mortality data for Sri Lankan were extracted from the World Health Organization mortality database from 1980 through 2010 (country code 3365).¹⁸

Mortality data are reported annually to the WHO from the civil registration system of the country (Registrar General’s department). Mortality data included the number of deaths for 5-year age groups and coded as per the International Classification of Diseases (ICD) versions 9 (1979 up to 1992) and 10 (1993 to 2021). The 10th revision of the ICD was used in Sri Lanka from 1997 onwards.¹⁹ Separate ICD codes are given for different causes of deaths falling under cardiovascular diseases. The ICD codes used for deaths due to ischaemic heart disease, hypertensive disease and cerebrovascular diseases in the 9th and 10th revisions used in this study are given in Supplementary Table 1.

For each disease category, deaths of 5-year age groups (40-44, 45-49, 50-54, 55-59, 60-64 and 65-69) were extracted from the database for the codes and subcodes given in Supplementary Table 1 from 1980 to 2010.

The birth cohorts for different age groups corresponding to the selected years of data extraction are given in Supplementary Table 2. For example, the age group 40-44 years in 1980 belonged to the 1936-1940 birth cohort. Likewise, the age group 65-69 years in 1980 belonged to the 1911-1915 birth cohort. For each birth cohort, the number of deaths for each group of ICD codes were summed for the age group studied. For example, for the birth cohort of 1936-1940, deaths coded as B27 (9th revision) were summed for the 40-44 year age group in 1980 (birth cohort of 1936-1940).

Mortality data from 1987 to 1995 were not available on the WHO website. Mortality data for 1990 was obtained by linear interpolation of the number of deaths separately for males and females in the different age groups considered. Mortality data for 1995 were obtained from the vital statistics section of the Registrar General’s Department, Sri Lanka by age group and sex.

Population data by age group and sex were obtained from the database displayed in the UN population website²¹, Sri Lanka being coded as 144. Population data are displayed as estimates for inter-censal years as estimated by the Department of Census and Statistics of Sri Lanka and reported to the UN; during the census years, the actual figures are provided. Population data are reported for 5-year age groups as done for mortality data by sex.

Extracted mortality and population data were tabulated to yield six, five-year age groups from 40–44 to 65–69 years, and seven quinquennial demographic profiles from 1980 to 2010 for the 12 birth cohorts.

Data analysis

Data were entered in Excel worksheets. Mortality rates for each of the three cardiovascular diseases for each age category of both sexes were calculated based on the following formula.

$$\text{Mortality rate for each age-sex category} = (\text{deaths} / \text{population}) * 100,000$$

Using the calculated mortality rates for each age group and birth cohort, trends were determined to identify birth cohort and age effects by sex. Data are presented as tables and graphs.

To compare sex differences in specific mortality rates of 40–70-year-old Sri Lankans from 1980–2010, mortality rates of the 1936–1940 birth cohort for which all age groups were included in the analyses were plotted against the age groups; using multiple regression analysis, the slopes of the regression lines using mortality rates as the dependent variable and age as the independent variable between males and females were compared.

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3 **Ethics statement**

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6 As secondary data were used in this study, the Ethics Review Committee of the Faculty of

7 Medicine, University of Kelaniya, Sri Lanka, exempted this study from ethics review (Ref No.

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9 P/149/11/2022).

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14 **Patient and public involvement**

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17 Patients and the public were not specifically involved in the design, conduct, reporting or

18 dissemination plans of our research.

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25 **Results**

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28 The mortality rates due to ischaemic heart disease, hypertensive disease and cerebrovascular

29 disease by age group, birth cohort and sex are given in Figures 1-3 and supplementary tables 3-5,

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36 Mortality rates due to ischaemic heart disease increased with age among both males and females

37 in each birth cohort (Figure 1 and Supplementary Table 3), the rates being higher in males than

38 in females for each age group in each birth cohort. The mortality rates due to ischaemic heart

39 disease for each age group was higher among the early birth cohorts as compared to the younger

40 birth cohorts among both males and females. In each age group, the mortality rates of each birth

41 cohort peaked corresponding to year 2000 in both males and females after which there is a

42 gradual decline; a spike in the mortality rates due to ischaemic heart disease seen in all birth

43 cohorts in different age groups in year 2000 progressively declines with each subsequent birth

44 cohort.

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Similar to mortality rates due to ischaemic heart disease, mortality rates due to hypertensive disease increased with age among both males and females (Figure 2 and Supplementary Table 4); the mortality rates were higher in males than in females for each birth cohort. The highest mortality rates due to hypertensive disease for each age group was higher among the early birth cohorts as compared to the younger birth cohorts among both males and females, the rates in the males being higher than in the females. Among both males and females, the mortality rates due to hypertensive disease of the 65-69 age group increased from the 1911-1915 to the 1941-1945 birth cohorts; again spikes are seen in the mortality rates corresponding to year 2000. In the 1936-1940 birth cohort, the mortality rate due to hypertensive disease increased from 8.4 per 100,000 population in the 40-44 year age group to 167.1 per 100,000 population in the 65-69 age group. Similar to the trends in ischaemic heart disease, a spike in the mortality rates due to hypertensive disease is seen in all birth cohorts in different age groups corresponding to year 2000.

Similar to ischaemic heart disease and hypertensive disease, mortality due to cerebrovascular disease (CeVD) increased with age among both males and females (Figure 3 and Supplementary Table 5) with the mortality rates being higher in males than in females for each birth cohort; the mortality rates due to CeVD for each age group was higher among the early birth cohorts as compared to the younger birth cohorts among both males and females. Unlike the distinct spike in mortality rates due to ischaemic heart disease and hypertensive disease corresponding to year 2000 data, the spike for CeVD mortality rates was less marked. The mortality rates due to cerebrovascular diseases among males of the earlier cohorts for the older age groups (the 65-69 year age group of the 1926-1930 cohort and the 60-64 year age group of the 1931-1935 cohort)

peaked corresponding to year 1995; among females, this peak was less distinct for the same year. In subsequent birth cohorts, the mortality rates have been declining for each age group.

Figure 4 shows the mortality rates due to IHD, HTN and CeVD among 40–70-year-old Sri Lankans of birth cohort 1936-1940 by sex. Mortality rates for all three causes show an increasing trend in both sexes and the mortality rates of males are higher than that of females; there is a significant difference in the mortality rates for all three causes with age between males and females ($p<0.05$).

Discussion

The findings of this study show age, sex and 5-year birth cohort effects of selected cardiovascular deaths in 40-70-year-old Sri Lankans from 1980-2010. As expected, cardiovascular mortality rates due to IHD, HTN and CeVD increased with age; in each age group, mortality rates were higher among men. In the older age groups, the mortality rates due to HTN increased in the early cohorts till about 2000; in the subsequent cohorts, age group mortality continued to decrease over time. Mortality rates to CeVD in males peaked in the older age groups (65-69 and 60-64) corresponding to 1995 with a decline in younger cohorts and over time; among females, the trend was less marked. Although the number of deaths increased with time for different age groups due to an ageing population, the mortality rates decreased with each birth cohort.

An age-period-cohort study of CVD in Japan using data from 1995-2018 showed that mortality rates of both sexes increase with age²², similar to what we report here. The Japanese study also revealed the association between other co-morbidities with advancing age, such as diabetes mellitus, and atherosclerosis and age-related changes in the cardiovascular system such as reduced elasticity in blood vessels, increased arterial stiffness and hypertrophy of the heart etc.

could be probable causes for the higher mortality in older age.²² Another Japanese study on mortality due to IHD from 1955 to 2000 showed non-linear birth cohort effects with an initial increase and then a decreasing trend in both sexes.¹⁶

Our findings suggest that mortality rates due to HTN starts to rise after about 50 years of age. Again, there are birth cohort effects with younger cohorts having lower mortality rates; the mortality rates for males are higher than that for females.²³ In Mexico, mortality due to hypertension affected more women than men. In recent cohorts, the risk of dying from hypertension is two times higher in men compared to women. Hypertensive kidney disease is the main underlying cause, with an average increase throughout the study period.²³

Similar to the trends of HTN, CeVDs, mortality rates are relatively constant in younger birth cohorts up to about 50 years. After 1985, there is a declining trend in mortality across the birth cohorts. Similar findings were reported from China where age-standardized stroke mortality rates started declining in every age group.²⁴ In Japan, age-standardized stroke mortality rates have declined from 98 in 1990, to 74 in 2000, to 50 in 2010, and to 33 in 2019 in males; among females, the decline was from 69 in 1990, to 46 in 2000, 27 in 2010, and to 18 in 2019.^{25, 26}

In this study, the overall mortality rates of males are higher than that of females for all three cardiovascular diseases. Similar results were reported from southern Spain²⁷ and China.²⁸ The differences in mortality between males and females are partly due to biological differences including the protective effect of oestrogen in females; after menopause this effect gradually declines but the prevalences of other risk factors are lower than that of males. Other factors such as healthcare-seeking behaviour and social determinants also influence these differences. In Sri Lanka, females are subjected to routine screening at different ages during their lifetime from birth

including antenatal and postnatal care clinics and well woman clinics; female attendance at healthy lifestyle centres where screening for CVD risk factors is done is much higher than that of males.

An interesting feature in our analysis is the spikes seen in mortality rates of all three cardiovascular deaths. For IHD and HTN the spikes corresponded to data of year 2000; for CeVD the spike was less conspicuous. A possible reason for this observation is the change of the ICD coding from version 9 to 10 in 1997 despite ICD-10 being released in 1995¹⁹; ICD version 10 had more specific cause of death codes and had more causes of death for each disease which is likely to have increased the mortality rates for each cause of death. The subsequent decrease in the mortality rates may be due to the natural decrease in the mortality rates seen with successive birth cohorts.

Mortality rates of all three cardiovascular diseases considered show similar trends; like all non-communicable diseases, these disease entities share distinct common characteristics that are influenced by a broader range of lifestyle factors such as smoking, diet, physical activity, and obesity.

Decline in mortality rates in successive birth cohorts may be due to many factors. Firstly, it may be due to differences in exposures *in utero*, childhood and even adulthood. Implementation of screening programmes, advances in medical and surgical procedures have contributed largely to early diagnosis and secondary prevention increasing the life expectancy of those diagnosed with cardiovascular diseases.⁷ In addition, large declines in smoking due to increased public awareness and regulation, including heavy taxation, are now considered a “best buy” for reduction of cardiovascular disease.⁷ Ma et al. (2008) suggested that lower mortality in younger birth cohorts in Japan was probably a result of improvements in lifestyle factors, including the

national hypertension control prevention programme and improved nutrition in Japan during the previous few decades.¹⁶

Over several decades the Sri Lanka's health system has improved tremendously in all aspects achieving impressive health indicators comparable to those of developed countries but at a much lower cost. This achievement is attributable to an excellent preventive health service originally initiated in 1926; though initially concentrating on maternal and child health, the service has been extended to cover environmental health and later to non-communicable diseases after the inclusion of prevention and control of non-communicable diseases in the first national health policy based on primary health care and subsequently revised with a focus on universal health coverage.²⁹ Simultaneously, clinical services were improved and expanded with an increase in the number of hospital beds, advancements in technology and other related services. The number of doctors per 10,000 population has increased from 1401 in 1991 to 11,924 in 2021³⁰. Initially, general physicians in medical wards treated cardiology patients; subsequently since the early 1970's cardiology as a specialty emerged in Sri Lanka. Specialisation in cardiology and cardiothoracic surgery followed and special units were created; in 2020, there were 644 inward beds for cardiology compared to 470 in 2008^{31,32}. The improvement and expansion of healthcare services and the emergence of cardiology as a specialty beginning in the 1970's explains the high mortality rates in older age groups of early cohorts.

In Sri Lanka, health promotion activities carried out by the Ministry of Health at national level are likely to have contributed to improvements in cardiovascular health among the younger generations: these include, tobacco control measures (both policy and legislation); nutrition and food policies to address obesity and high lipid levels; and health promotion to raise awareness about the importance of cardiovascular health and the prevention of CVDs.³³

Data for 1990 and 2008 were not available and data were interpolated separately for males and females. We acknowledge the fact that the validity of our results is dependent on the accuracy and reliability of mortality data and the vital statistics registration system of the country. Studies have reported that cause of death certification is not 100% accurate, as expected.^{34, 35} However, given the CVD causes of death that we investigated it is unlikely to have adversely impacted on our results; the rates were calculated based on large denominators that would have little or no effect on the overall mortality rates.

Conclusions

There are age, period and birth cohort effects on mortality due to IHD, HTN and CeVD among 40-70-year-old male and female Sri Lankans between 1980 and 2010. Mortality increased with age and declined in younger cohorts over time as compared to older cohorts. Males had higher mortality rates than females for each age group in each birth cohort.

It is likely that age-sex specific mortality rates due to cardiovascular diseases will decline further, but at a much lower rate, provided that prevention and control measures for CVD risk factors are enhanced and sustained; however, the number of deaths due to cardiovascular diseases will increase due to the increasing ageing population for which adequate care facilities should be improved, expanded and provided.

Contributors

DTHDeS, EDSMDeA, DMDDeM, AHDDDeS and ARW contributed to the conceptualisation and developing the methodology. ARW supervised data collection. All authors were involved in data curation, data analysis, writing the original draft, and reviewing and editing the final draft. ARW accepts full responsibility for the work and conduct of the study.

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Competing interests

All authors have no competing interests to declare.

Patient and public involvement

Patients and the public were not specifically involved in the design, conduct, reporting or dissemination plans of our research.

Data availability statement

All data extracted are given in the supplementary tables and in the tables.

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Legend for figures

Figure 1. Mortality rates due to Ischaemic Heart disease among 40-70-year-old Sri Lankans by age groups, birth cohort and sex. (Panel 1a₁-Mortality rates by age for different birth cohorts in males; Panel 1a₂-Mortality rates by birth cohorts for different age groups in males; Panel 1b₁-Mortality rates by age for different birth cohorts in females; Panel 1b₂-Mortality rates by birth cohorts for different age groups in females)

Figure 2. Mortality rates due to Hypertensive disease among 40-70-year-old Sri Lankans by age groups, birth cohort and sex. (Panel 2a₁-Mortality rates by age for different birth cohorts in males; Panel 2a₂-Mortality rates by birth cohorts for different age groups in males; Panel 2b₁-Mortality rates by age for different birth cohorts in females; Panel 2b₂-Mortality rates by birth cohorts for different age groups in females)

Figure 3. Mortality rates due to Cerebrovascular disease among 40-70-year-old Sri Lankans by age groups, birth cohort and sex. (Panel 3a₁-Mortality rates by age for different birth cohorts in males; Panel 3a₂-Mortality rates by birth cohorts for different age groups in males; Panel 3b₁-Mortality rates by age for different birth cohorts in females; Panel 3b₂-Mortality by birth cohorts for different age groups in females)

Figure 4. Sex differences in mortality rates by age group between males and females in the 1936-1940 birth cohort.

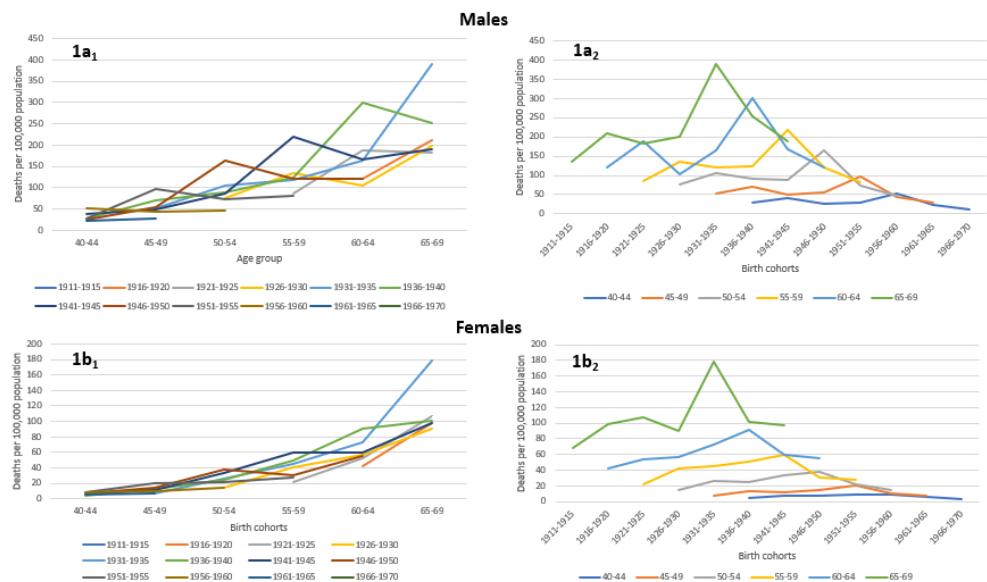


Figure 1. Mortality rates due to Ischaemic Heart disease among 40-70-year-old Sri Lankans by age groups, birth cohort and sex. (Panel 1a1-Mortality rates by age for different birth cohorts in males; Panel 1a2- Mortality rates by birth cohorts for different age groups in males; Panel 1b1-Mortality rates by age for different birth cohorts in females; Panel 1b2-Mortality rates by birth cohorts for different age groups in females)

588x344mm (38 x 38 DPI)

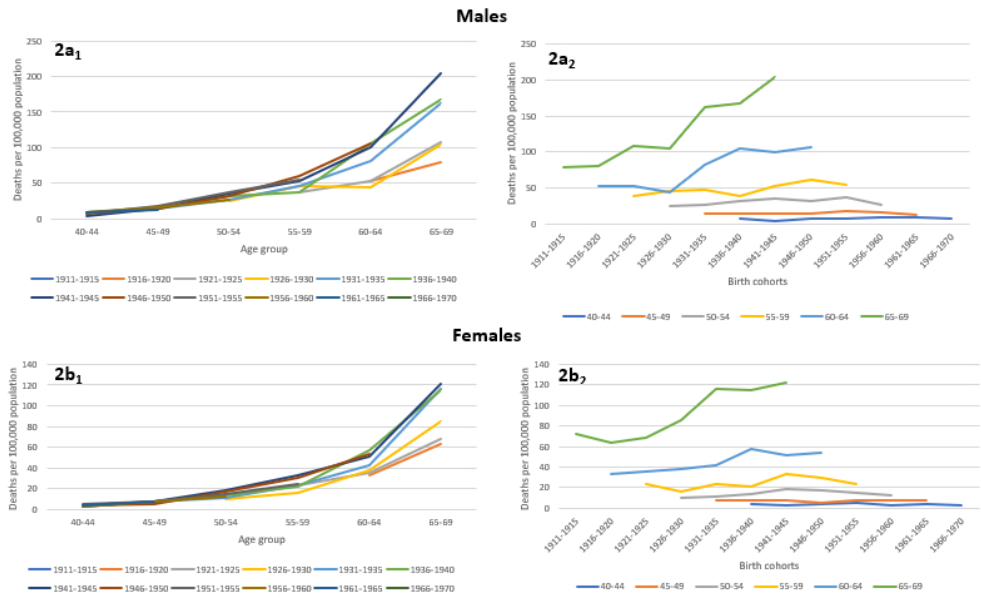


Figure 2. Mortality rates due to Hypertensive disease among 40-70-year-old Sri Lankans by age groups, birth cohort and sex. (Panel 2a1-Mortality rates by age for different birth cohorts in males; Panel 2a2-Mortality rates by birth cohorts for different age groups in males; Panel 2b1-Mortality rates by age for different birth cohorts in females; Panel 2b2-Mortality rates by birth cohorts for different age groups in females)

534x315mm (38 x 38 DPI)

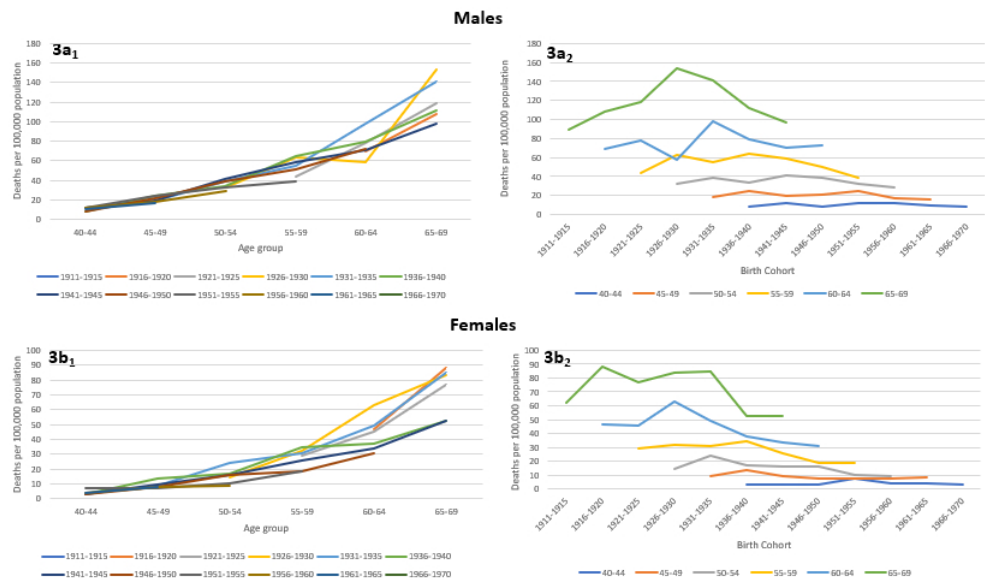


Figure 3. Mortality rates due to Cerebrovascular disease among 40-70-year-old Sri Lankans by age groups, birth cohort and sex. (Panel 3a1-Mortality rates by age for different birth cohorts in males; Panel 3a2-Mortality rates by birth cohorts for different age groups in males; Panel 3b1-Mortality rates by age for different birth cohorts in females; Panel 3b2-Mortality by birth cohorts for different age groups in females)

556x319mm (38 x 38 DPI)

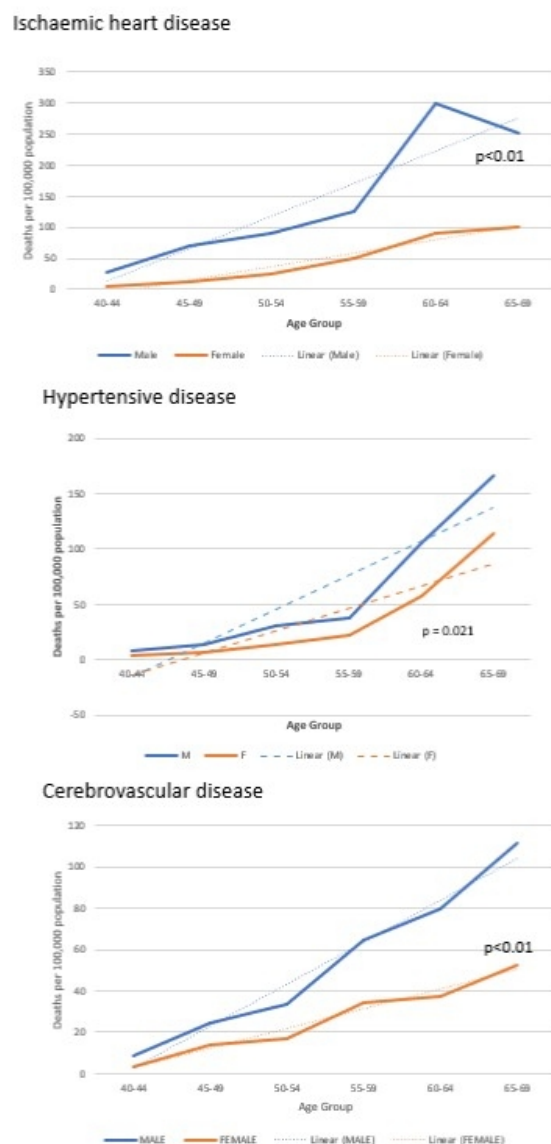


Figure 4. Sex differences in mortality rates by age group between males and females in the 1936-1940 birth cohort.

111x203mm (96 x 96 DPI)

Supplementary Table 1. Cause of death codes of selected conditions of the International Classification of Diseases versions 9 and 10

Cause of death	ICD-9		ICD-10	
	Code	Subcode	Code	Subcode
Ischaemic Heart Disease	B27		1067	I20-I25
Acute myocardial infarction		B270		I21
Remainder		B279		I20, I22, I23, I24, I25
Hypertensive Disease	B26		1066	I10-I13
Hypertensive heart disease		B260		I11
Remainder		B269		I10, I12, I13
Cerebrovascular disease	B29		1069	I60-I69
Subarachnoid hemorrhage		B290		I60
Intracerebral and other intracranial hemorrhage		B291		I61
Cerebral infarction		B292		I63
Others		B293, B294, B299		I62, I64-I69

Source: WHO. Mortality database²⁰

Supplementary Table 2. Birth cohorts corresponding to different age groups 1980-2010

Age Group	Year						
	1980	1985	1990	1995	2000	2005	2010
40-44	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965	1966-1970
45-49	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965
50-54	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960
55-59	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955
60-64	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950
65-69	1911-1915	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945

Supplementary Table 3. Deaths due to Ischaemic Heart Disease per 100,000 population in Sri Lanka by birth cohort and age group

Age group (years)	Year											
	1911-1915	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965	1966-1970
Males												
40-44						28.42	40.02	25.58	28.23	52.84	23.41	13.03
45-49					51.52	70.20	50.26	55.83	96.02	42.97	28.85	
50-54				75.26	105.89	90.60	87.68	164.23	73.50	47.65		
55-59			85.97	135.67	119.64	124.77	219.60	120.39	81.31			
60-64		120.35	187.19	104.35	163.57	300.37	167.23	122.23				
65-69	136.73	210.55	182.50	199.57	389.99	252.12	189.32					
Females												
40-44						3.77	6.77	7.53	9.22	8.68	5.86	3.71
45-49					7.76	12.95	11.28	14.97	20.53	10.41	6.91	
50-54				14.87	25.59	24.69	33.07	37.18	22.29	15.02		
55-59			21.37	41.48	45.29	50.24	60.21	30.40	27.42			
60-64		42.14	53.13	57.32	72.83	91.09	59.50	55.25				
65-69	68.17	98.12	106.77	90.38	177.83	100.98	97.80					

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Supplementary Table 4. Deaths due to Hypertensive Disease per 100,000 population in Sri Lanka by birth cohort and age group

Age group (years)	Year											
	1911-1915	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965	1966-1970
Males												
40-44						8.44	4.23	7.40	7.44	8.81	8.61	7.04
45-49					14.40	14.28	15.03	14.34	17.48	15.63	12.39	
50-54				24.28	27.24	31.35	35.23	31.63	36.95	27.15		
55-59			38.21	45.84	46.91	38.24	53.28	60.80	54.55			
60-64		52.62	52.80	44.06	82.18	105.20	99.89	106.07				
65-69	78.76	80.00	108.50	104.23	162.42	167.07	204.82					
Females												
40-44						4.06	2.51	3.77	4.71	2.95	3.81	2.28
45-49					7.08	7.23	7.95	5.77	8.13	7.65	7.06	
50-54				9.53	11.57	13.58	18.37	17.16	14.55	12.60		
55-59			23.64	16.35	23.19	21.62	33.36	29.96	23.93			
60-64		33.36	35.26	38.08	42.27	57.18	50.96	53.51				
65-69	71.96	63.49	68.23	85.46	116.66	114.62	121.64					

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Supplementary Table 5. Deaths due to Cerebrovascular Disease per 100,000 population in Sri Lanka by birth cohort and age group

Age group (years)	Year											
	1911-1915	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965	1966-1970
Males												
40-44						8.44	12.18	8.67	11.63	12.29	10.12	8.84
45-49					18.88	24.39	19.69	21.18	24.51	17.83	16.46	
50-54				32.95	38.48	33.54	41.24	39.13	32.11	28.73		
55-59			43.39	62.99	54.55	64.40	58.58	50.67	39.23			
60-64		69.19	77.67	57.97	98.14	79.55	70.24	72.48				
65-69	89.47	108.33	118.50	153.30	141.01	111.52	97.43					
Females												
40-44						3.48	3.51	3.35	7.34	3.93	3.81	3.42
45-49					9.10	13.55	9.49	7.70	7.36	7.65	7.94	
50-54				14.49	23.84	16.98	16.01	15.84	10.39	8.88		
55-59			29.10	31.91	30.80	34.66	26.04	18.81	18.59			
60-64		46.82	45.41	62.76	49.44	37.56	33.88	31.01				
65-69	62.11	87.86	77.08	83.67	85.07	52.33	52.26					

BMJ Open

Cardiovascular Mortality of 40–70-year-olds in Sri Lanka from 1980 -2010; a birth cohort analysis by age and sex

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Keywords:	Cardiac Epidemiology < CARDIOLOGY, Cardiovascular Disease, EPIDEMIOLOGIC STUDIES, Mortality, PUBLIC HEALTH, EPIDEMIOLOGY

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1 Cardiovascular Mortality of 40–70-year-olds in Sri Lanka from 1980 - 2 2010; a birth cohort analysis by age and sex

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30Abstract

31Objectives

32To compare cardiovascular mortality (ischaemic heart disease (IHD), hypertensive disease (HTN)
33and cerebrovascular disease (CeVD)) of 40–70-year-old Sri Lankans from 1980-2010 by age, birth
34cohort and sex.

35Design

36A comparative retrospective study

37Setting

38Sri Lanka

39Participants

4040-70-year-old Sri Lankans from 1980-2010.

41Primary and secondary outcome measures

42Cardiovascular deaths due to IHD, HTN and CeVD.

43Results

44Mortality due to IHD increased with age but decreased with birth cohorts with time (range 3.7-390
45per 100,000 population); there was a spike in the IHD mortality rates in both age-groups and birth
46cohorts in 2000. Deaths due to HTN markedly increased after 55 years; however, mortality
47decreased in the younger cohorts (range 2.8-204.81 per 100,000 population). CeVD mortality
48linearly increased with age (range 3.3-153.3 per 100,000 population); birth cohorts of 1926-1930 and

1931-1935 had a spike in mortality among 60-64 and 65-69 age groups, respectively. Changes were seen among both males and females; mortality rates were higher in males than in females.

Conclusions

All cardiovascular mortality rates increase with age and are higher in males than in females. Age specific cardiovascular mortality rates are lower in the younger birth cohorts as compared to the older birth cohorts. The increase in cardiovascular deaths in Sri Lanka is due to the ageing population.

Keywords: Cardiovascular mortality, 1980-2010, 40-70-year-olds, Sri Lanka

Strengths and limitations of this study

- The study aimed to compare cardiovascular mortality (ischaemic heart disease (IHD), hypertensive disease (HTN) and cerebrovascular disease (CeVD)) of 40–70-year-old Sri Lankans from 1980-2010 by age, birth cohort and sex, the first such analysis done in the country.
- Birth cohort analysis of mortality due to cardiovascular diseases by age and sex show trends in mortality and allows comparisons over time.
- The results depend on the accuracy and reliability of mortality data over time.
- Inability to determine the relationship between mortality and economic indicators due to lack of data is a limitation of the study.

Data availability statement

All data extracted are given in the supplementary tables and in the tables.

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70 Introduction

71 Cardiovascular diseases (CVDs) are the leading cause of death globally. They comprise a group
72 of diseases of the heart and blood vessels including coronary heart disease (CHD), cerebrovascular
73 disease (CeVD), peripheral artery disease, rheumatic heart disease, congenital heart disease, deep
74 vein thrombosis and pulmonary embolism.¹

75 In 2019, it was estimated that there were 17.9 million deaths due to CVDs accounting for 32% of
76 all global deaths; of these deaths, 85% were due to heart attack and stroke. More than 75% of all
77 CVD deaths occur in low- and middle-income countries; CVD deaths comprised 38% of premature
78 deaths (under the age of 70) due to non-communicable diseases.¹

79 Hypertension, defined as having a blood pressure above 140/90, is a leading risk factor for
80 cardiovascular disease with a heavy public health burden worldwide.² Poorly controlled or
81 uncontrolled blood pressure increases the risk of hypertensive disease (HTN) giving rise to
82 microscopic and macroscopic cardiac remodeling and functional alterations.³ It is estimated that
83 1.28 billion adults aged 30–79 years worldwide have hypertension with two-thirds living in low-
84 and middle-income countries.⁴ 46% of hypertensives are unaware they have the condition and less
85 than 42% are diagnosed and treated; only 21% of adults with hypertension have it controlled.⁴ It
86 is a major cause of premature death worldwide.⁴

87 The number of CVD deaths has been increasing over time; in 2000, around 14 million people
88 died from cardiovascular diseases globally, while in 2019, close to 18 million died.⁵ It is
89 estimated that CVDs would account for >23 million deaths by 2030.⁶ The decline in incidence
90 and mortality rates for developed countries was significantly higher than those for developing
91 countries from 1990–2017 ($p < 0.05$); developing nations had a less-steep decline.⁷

92 Risk factors for cardiovascular diseases include age, sex and other modifiable lifestyle risk
93 factors.⁷ The rising death toll is largely due to a growing and ageing global population.
94 Death rates have been declining due to implementation of preventive programmes; large declines
95 in smoking, improvements in screening, diagnosis, and monitoring; and advances in medical
96 treatments, public health initiatives, emergency care, and surgical procedures have all helped to
97 reduce the impact of cardiovascular diseases on people's lives.⁷ The large disparities that still
98 exist can be further reduced.

99 South Asia has a disproportionately high burden of cardiovascular disease, with higher rates of
100 CVD incidence, mortality, and risk factor prevalences than many other regions.⁸ Cardiovascular
101 diseases account for 3.9 million deaths in the WHO South-East Asia Region every year,
102 comprising a quarter of all deaths from non-communicable diseases (NCDs), with most of them
103 being preventable.⁹ Even though South Asians comprise only 25% of the world's population, they
104 account for more than 50% of the world's cardiovascular deaths.⁸

105 Sri Lanka, a country having one of the fastest ageing populations in Asia, is in the midst of an
106 epidemiological and demographic transition. In 2022, WHO estimated that over 80% of the
107 mortality in Sri Lanka is due to major non-communicable diseases with CVDs contribute to over
108 34% of deaths, impacting both life expectancy and quality of life. The mortality from CVDs in Sri
109 Lanka is estimated to be 524 deaths per 100,000 which is higher than that observed in many high-
110 income countries.¹⁰ Coronary artery disease (CAD) is the leading cause of death in Sri Lanka
111 while stroke is the third highest cause of death.^{11, 12}

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112 There is evidence that childhood risk factors such as obesity, exposure to indoor and outdoor
113 tobacco smoke, dyslipidaemia and diabetes impact cardiovascular disease in adulthood¹³; these
114 risk factors are now being targeted for prevention of cardiovascular disease.

115 Birth cohort analyses have been used to determine the causal relationship between potential risk
116 factors during the prenatal and postnatal period and the health status of the newborn up to
117 childhood. Birth cohort analyses allow description of associations between early exposures and
118 subsequent outcomes^{14, 15}; in addition, they are able to identify the risk and environmental exposure
119 factors shared by a given generation, are used to investigate disease trends and test a wide range
120 of hypotheses.¹⁴⁻¹⁷ Birth cohort analyses of CVDs have not been conducted in Sri Lanka. The aim
121 of this study was to find out whether there are variations in age and sex specific mortality rates of
122 selected cardiovascular diseases (ischaemic heart disease, hypertensive disease and
123 cerebrovascular disease) among 40-70-year-old Sri Lankans from 1980-2010 by birth cohort.

125 **Methods**

126 **Study design and data sources**

127 This comparative retrospective study was conducted from August 2022 to January 2024 using
128 secondary data available in the public domain. Mortality data of Sri Lanka were extracted from
129 the World Health Organization mortality database from 1980 through 2010 (country code 3365).¹⁸
130 Mortality data are reported annually to the WHO from the civil registration system of the country
131 (Registrar General's department). Mortality data included the number of deaths for 5-year age
132 groups and coded as per the International Classification of Diseases (ICD) versions 9 (1979 up to

1992) and 10 (1993 to 2021). The 10th revision of the ICD was used in Sri Lanka from 1997 onwards.¹⁹ Separate ICD codes are given for different causes of deaths falling under cardiovascular diseases. The ICD codes used for deaths due to ischaemic heart disease, hypertensive disease and cerebrovascular diseases in the 9th and 10th revisions used in this study are given in Supplementary Table 1.

For each disease category, deaths of 5-year age groups (40-44, 45-49, 50-54, 55-59, 60-64 and 65-69) were extracted from the database for the codes and subcodes given in Supplementary Table 1 from 1980 to 2010.

The birth cohorts for different age groups corresponding to the selected years of data extraction are given in Supplementary Table 2. For example, the age group 40-44 years in 1980 belonged to the 1936-1940 birth cohort. Likewise, the age group 65-69 years in 1980 belonged to the 1911-1915 birth cohort. For each birth cohort, the number of deaths for each group of ICD codes were summed for the age group studied. For example, for the birth cohort of 1936-1940, deaths coded as B27 (9th revision) were summed for the 40-44 year age group in 1980 (birth cohort of 1936-1940).

Mortality data from 1987 to 1995 were not available on the WHO website. Mortality data for 1990 was obtained by linear interpolation of the number of deaths separately for males and females in the different age groups considered. Mortality data for 1995 were obtained from the vital statistics section of the Registrar General's Department, Sri Lanka by age group and sex.

Population data by age group and sex were obtained from the database displayed in the UN population website²¹, Sri Lanka being coded as 144. Population data are displayed as estimates for inter-censal years as estimated by the Department of Census and Statistics of Sri Lanka and

155 reported to the UN; during the census years, the actual figures are provided. Population data are
156 reported for 5-year age groups as done for mortality data by sex.

157 Extracted mortality and population data were tabulated to yield six, five-year age groups from 40–
158 44 to 65–69 years, and seven quinquennial demographic profiles from 1980 to 2010 for the 12
159 birth cohorts.

160 Data analysis

161 Data were entered in Excel worksheets. Mortality rates for each of the three cardiovascular
162 diseases for each age category of both sexes were calculated based on the following formula.

163
$$\text{Mortality rate for each age-sex category} = (\text{deaths} / \text{population}) * 100,000$$

164 Using the calculated mortality rates for each age group and birth cohort, trends were determined
165 to identify birth cohort and age effects by sex. Data are presented as tables and graphs. Mortality
166 rates of IHD, HTN and CeVD were plotted by age group, birth cohort and year by age and sex.

167 To compare sex differences in specific mortality rates of 40–70-year-old Sri Lankans from 1980–
168 2010, mortality rates of the 1936-1940 birth cohort for which all age groups were included in the
169 analyses were plotted against the age groups; using multiple regression analysis, the slopes of the
170 regression lines using mortality rates as the dependent variable and age as the independent variable
171 between males and females were compared.

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175 Ethics statement

176 The Ethics Review Committee of the Faculty of Medicine, University of Kelaniya, Sri Lanka,
177 exempted this study from ethics review (Ref No. P/149/11/2022).

178 Patient and public involvement

179 Patients and the public were not specifically involved in the design, conduct, reporting or
180 dissemination plans of our research.

182 Results

183 The mortality rates due to ischaemic heart disease, hypertensive disease and cerebrovascular
184 disease by age group, birth cohort and sex are given in Figures 1-6 and supplementary tables 3-5,
185 respectively.

186 Insert figure 1 here

187 Mortality rates due to ischaemic heart disease increased with age among both males and females
188 in each birth cohort (Figures 1 and 2, and Supplementary Table 3), the rates being higher in
189 males than in females for each age group in each birth cohort each year. The mortality rates due
190 to ischaemic heart disease for each age group was higher among the early birth cohorts as
191 compared to the younger birth cohorts among both males and females. In each age group, the
192 mortality rates of each birth cohort peaked corresponding to year 2000 in both males and females
193 after which there is a gradual decline; a spike in the mortality rates due to ischaemic heart
194 disease seen in all birth cohorts in different age groups in year 2000 and progressively declines
195 with each subsequent birth cohort.

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196 Insert figure 2 here

197 Similar to mortality rates due to ischaemic heart disease, mortality rates due to hypertensive

198 disease increased with age among both males and females (Figures 3 and 4, and Supplementary

199 Table 4); the mortality rates were higher in males than in females for each birth cohort and age

200 group. The highest mortality rates due to hypertensive disease for each age group was higher

201 among the early birth cohorts as compared to the later birth cohorts among both males and

202 females, the rates being higher in males. Among both males and females, the mortality rates due

203 to hypertensive disease of the 65-69 age group increased from the 1911-1915 to the 1941-1945

204 birth cohorts; spikes are seen in the mortality rates corresponding to year 2000. In the 1936-1940

205 birth cohort, the mortality rate due to hypertensive disease increased from 8.4 per 100,000

206 population in the 40-44-year age group to 167.1 per 100,000 population in the 65-69-year age

207 group. Similar to the trends in ischaemic heart disease, a spike in the mortality rates due to

208 hypertensive disease is seen in all birth cohorts in different age groups corresponding to year

209 2000.

210 Insert figures 3 and 4 here

211 Similar to ischaemic heart disease and hypertensive disease, mortality due to cerebrovascular

212 disease (CeVD) increased with age among both males and females (Figures 5 and 6, and

213 Supplementary Table 5) with the mortality rates being higher in males than in females for each

214 birth cohort; the mortality rates due to CeVD for each age group was higher among the early

215 birth cohorts as compared to the later birth cohorts among both males and females. Unlike the

216 distinct spike in mortality rates due to ischaemic heart disease and hypertensive disease

217 corresponding to year 2000 data, the spike for CeVD mortality rates was less marked. The

218 mortality rates due to cerebrovascular diseases among males of the earlier cohorts for the older

age groups (the 65-69 year age group of the 1926-1930 cohort and the 60-64 year age group of the 1931-1935 cohort) peaked corresponding to year 1995 (Figure 6); among females, this peak was less distinct for the same year. In subsequent birth cohorts, the mortality rates have been declining for each age group.

Insert figures 5 and 6 here

Mortality rates due to IHD, HTN and CeVD among 40–70-year-old Sri Lankans of birth cohort 1936-1940 by sex are given in Supplemental figures 1-3, respectively. Mortality rates due to all three causes show an increasing trend in both sexes and the mortality rates of males being higher than that of females; there is a significant difference in the mortality rates for all three causes with age between males and females ($p<0.05$).

Discussion

The findings of this study show age, sex and 5-year birth cohort effects of selected cardiovascular deaths in 40-70-year-old Sri Lankans from 1980-2010. As expected, cardiovascular mortality rates due to IHD, HTN and CeVD increased with age; in each age group, mortality rates were higher among men. In the older age groups, the mortality rates due to HTN increased in the early cohorts till about 2000; in the subsequent cohorts, age group mortality continued to decrease over time. CeVD mortality rates in males peaked in the older age groups (65-69 and 60-64) corresponding to year 1995 with a decline in younger cohorts and over time; among females, the trend was less marked. Although the number of deaths increased with time for different age groups due to an ageing population, the mortality rates decreased with each birth cohort.

240 An age-period-cohort study of CVD in Japan using data from 1995-2018 showed that mortality
241 rates of both sexes increased with age²², similar to what is reported here. The Japanese study also
242 revealed the association between other co-morbidities with advancing age, such as diabetes
243 mellitus, and atherosclerosis and age-related changes in the cardiovascular system such as
244 reduced elasticity in blood vessels, increased arterial stiffness and hypertrophy of the heart etc.
245 could be probable causes for the higher mortality in older age.²² Another Japanese study on
246 mortality due to IHD from 1955 to 2000 showed non-linear birth cohort effects with an initial
247 increase and then a decreasing trend in both sexes.¹⁶

248 The findings of this study suggest that mortality rates due to HTN starts to rise after about 50 years
249 of age. Again, there are birth cohort effects with younger cohorts having lower mortality rates; the
250 mortality rates for males are higher than that for females.²³ In Mexico, mortality due to
251 hypertension affected more women than men. In recent cohorts, the risk of dying from
252 hypertension is two times higher in men compared to women. Hypertensive kidney disease is the
253 main underlying cause, with an average increase throughout the study period.²³

254 Similar to the trends of HTN, CeVDs, mortality rates are relatively constant in younger birth
255 cohorts up to about 50 years. After 1985, there is a declining trend in mortality across the birth
256 cohorts. Similar findings were reported from China where age-standardized stroke mortality rates
257 started declining in every age group.²⁴ In Japan, age-standardized stroke mortality rates per 100,000
258 population have declined from 98 in 1990, to 74 in 2000, to 50 in 2010, and to 33 in 2019 in males;
259 among females, the decline was from 69 in 1990, to 46 in 2000, 27 in 2010, and to 18 in 2019.²⁵

260 ²⁶

261 In this study, the overall mortality rates of males are higher than that of females for all three
262 cardiovascular diseases. Similar results were reported from southern Spain²⁷ and China.²⁸ The
263 differences in mortality between males and females are partly due to biological differences
264 including the protective effect of oestrogen in females; after menopause this effect gradually
265 declines but the prevalences of other risk factors are lower than that of males. Other factors such
266 as healthcare-seeking behaviour and social determinants also influence these differences. In Sri
267 Lanka, females are subjected to routine screening at different ages during their lifetime from birth
268 including antenatal and postnatal care clinics and well woman clinics; female attendance at healthy
269 lifestyle centres where screening for CVD risk factors is done is much higher than that of males.

270 An interesting feature in this analysis is the spikes seen in mortality rates of all three cardiovascular
271 deaths. For IHD and HTN the spikes corresponded to data of year 2000; for CeVD the spike was
272 less conspicuous. A possible reason for this observation is the change of the ICD coding from
273 version 9 to 10 in 1997 despite ICD-10 being released in 1995¹⁹; ICD version 10 had more specific
274 cause of death codes and had more causes of death for each disease which is likely to have
275 increased the mortality rates for each cause of death. The subsequent decrease in the mortality
276 rates may be due to the natural decrease in the mortality rates seen with successive birth cohorts.

277 Mortality rates of all three cardiovascular diseases considered show similar trends; like all non-
278 communicable diseases, these disease entities share distinct common characteristics that are
279 influenced by a broader range of lifestyle factors such as smoking, diet, physical activity, and
280 obesity.

281 Decline in mortality rates in successive birth cohorts may be due to many factors. Firstly, it may
282 be due to differences in exposures *in utero*, childhood and even adulthood. Implementation of

screening programmes, advances in medical and surgical procedures have contributed largely to early diagnosis and secondary prevention increasing the life expectancy of those diagnosed with cardiovascular diseases.⁷ In addition, large declines in smoking due to increased public awareness and regulation, including heavy taxation, are now considered a “best buy” for reduction of cardiovascular disease.⁷ Ma et al. (2008) suggested that lower mortality in younger birth cohorts in Japan was probably a result of improvements in lifestyle factors, including the national hypertension control prevention programme and improved nutrition in Japan during the previous few decades.¹⁶ It is also likely to be due to improved economic status over time. The per capita GNI in Sri Lanka was current dollars 2510 in 1990; in 2010 it was 8150.

Over several decades the Sri Lanka’s health system has improved tremendously in all aspects achieving impressive health indicators comparable to those of developed countries but at a much lower cost. This achievement is attributable to an excellent preventive health service originally initiated in 1926; though initially concentrating on maternal and child health, the service has been extended to cover environmental health and later to non-communicable diseases after the inclusion of prevention and control of non-communicable diseases in the first national health policy based on primary health care, and subsequently revised with a focus on universal health coverage.²⁹ Simultaneously, clinical services were improved and expanded with an increase in the number of hospital beds, advancements in technology and other related services. The number of doctors per 10,000 population has increased from 1401 in 1991 to 11,924 in 2021³⁰. Initially, general physicians in medical wards treated cardiology patients; subsequently since the early 1970’s cardiology as a specialty emerged in Sri Lanka. Specialisation in cardiology and cardiothoracic surgery followed and special units were created; in the public sector in 2020, there were 644 inward beds for cardiology compared to 470 in 2008^{31, 32}. The improvement and expansion of healthcare

services and the emergence of cardiology as a specialty beginning in the 1970's probably explains the high mortality rates in older age groups of early cohorts.

In Sri Lanka, preventative activities carried out by the Ministry of Health at national level are likely to have contributed to improvements in cardiovascular health among the younger generations: these include, tobacco control measures (both policy and legislation); nutrition and food policies to address obesity and high lipid levels; and health promotion to raise awareness about the importance of cardiovascular health and the prevention of CVDs.³³

Data for 1990 and 2008 were not available and data were interpolated separately for males and females. The fact that the validity of our results is dependent on the accuracy and reliability of mortality data and the vital statistics registration system of the country is acknowledged. Studies have reported that cause of death certification is not 100% accurate, as expected.^{34, 35} However, given the CVD causes of death that were investigated it is unlikely to have adversely impacted on our results; the rates were calculated based on large denominators that would have little or no effect on the overall mortality rates.

Relating the differences in mortality rates to economic indicators was not attempted. The GNI was available from 1990 onwards and requires a more detailed analysis that should be conducted in the future.

Conclusions

There are age, period and birth cohort effects on mortality due to IHD, HTN and CeVD among 40-70-year-old male and female Sri Lankans between 1980 and 2010. Mortality increased with age and declined in younger cohorts over time as compared to older cohorts. Males had higher mortality rates than females for each age group in each birth cohort.

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328 It is likely that age-sex specific mortality rates due to cardiovascular diseases will decline further, but at a
329 much lower rate, provided that prevention and control measures for CVD risk factors are enhanced and
330 sustained; however, the number of deaths due to cardiovascular diseases will increase due to the
331 increasing ageing population for which adequate care facilities should be improved, expanded and
332 provided.

333 **Contributors**

334 DTHDeS, EDSMDeA, DMDDeM, AHDDDeS and ARW contributed to the conceptualisation and
335 developing the methodology. ARW supervised data collection. All authors were involved in data
336 curation, data analysis, writing the original draft, and reviewing and editing the final draft. ARW
337 is the guarantor and accepts full responsibility for the work and conduct of the study.

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340 The authors received no funding for this study.

341 **Competing interests**

342 All authors have no competing interests to declare.

343 **Patient and public involvement**

344 Patients and the public were not specifically involved in the design, conduct, reporting or
345 dissemination plans of our research.

346 **Data availability statement**

347 All data extracted are given in the supplementary tables and in the tables.

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Figure legends

Figure 1. Mortality rates due to Ischaemic Heart disease among 40-70-year-old Sri Lankans by age groups, birth cohort and sex. (panel a₁-mortality rates by age for different birth cohorts among males; panel a₂-mortality rates by birth cohorts for different age groups among males; panel b₁-mortality rates by age for different birth cohorts among females; panel b₂-mortality rates by birth cohorts for different age groups among females)

Figure 2. Mortality rates due to Ischaemic Heart disease among 40-70-year-old Sri Lankans by year by age groups and sex. (panel a- for males; panel b for females)

Figure 3. Mortality rates due to Hypertensive disease among 40-70-year-old Sri Lankans by age groups, birth cohort and sex. (panel a₁-mortality rates by age for different birth cohorts in males; panel a₂-mortality rates by birth cohorts for different age groups in males; panel b₁-mortality rates by age for different birth cohorts in females; panel b₂-mortality rates by birth cohorts for different age groups in females)

Figure 4. Mortality rates due to Hypertensive Disease (HTN) among 40-70-year-old Sri Lankans by year by age groups and sex. (panel a- for males; panel b for females)

Figure 5. Mortality rates due to Cerebrovascular disease among 40-70-year-old Sri Lankans by age groups, birth cohort and sex. (panel a₁-mortality rates by age for different birth cohorts in males; panel a₂-mortality rates by birth cohorts for different age groups in males; panel b₁-mortality rates by age for different birth cohorts in females; panel b₂-mortality by birth cohorts for different age groups in females)

Figure 6. Mortality rates due to Cerebrovascular disease (CeVD) among 40-70-year-old Sri Lankans by year by age groups and sex. (panel a- for males; panel b for females)

Supplemental figure 1. Sex differences in mortality rates due to IHD by age group in males and females of the 1936-1940 birth cohort.

Supplemental figure 2. Sex differences in mortality rates due to HTN by age group in males and females of the 1936-1940 birth cohort.

466 **Supplemental figure 3.** Sex differences in mortality rates due to CeVD by age group in males
467 and females of the 1936-1940 birth cohort.

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For peer review only

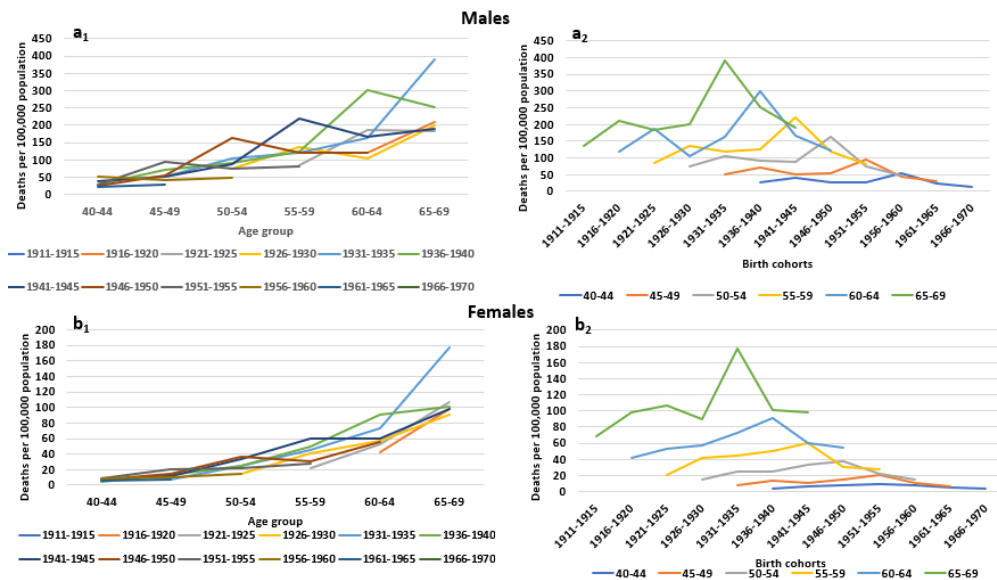


Figure 1. Mortality rates due to Ischaemic Heart disease among 40-69-year-old Sri Lankans by age groups, birth cohort and sex. (panel a1-mortality rates by age for different birth cohorts among males; panel a2-mortality rates by birth cohorts for different age groups among males; panel b1-mortality rates by age for different birth cohorts among females; panel b2-mortality rates by birth cohorts for different age groups among females)

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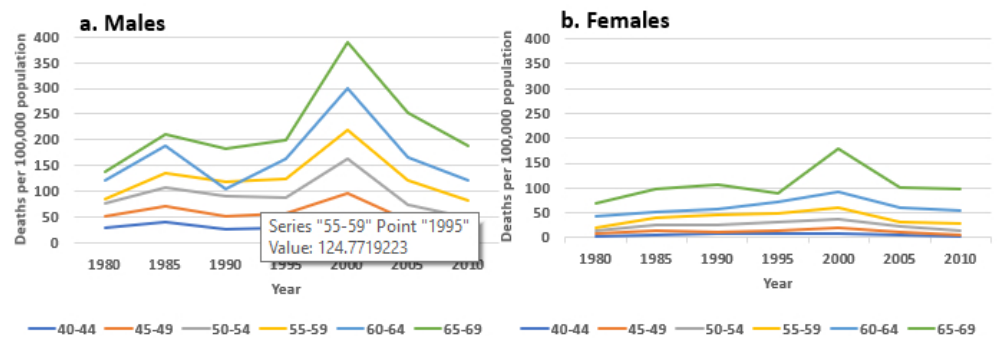


Figure 2. Mortality rates due to Ischaemic Heart disease among 40-70-year-old Sri Lankans by year by age groups and sex. (panel a- for males; panel b for females)

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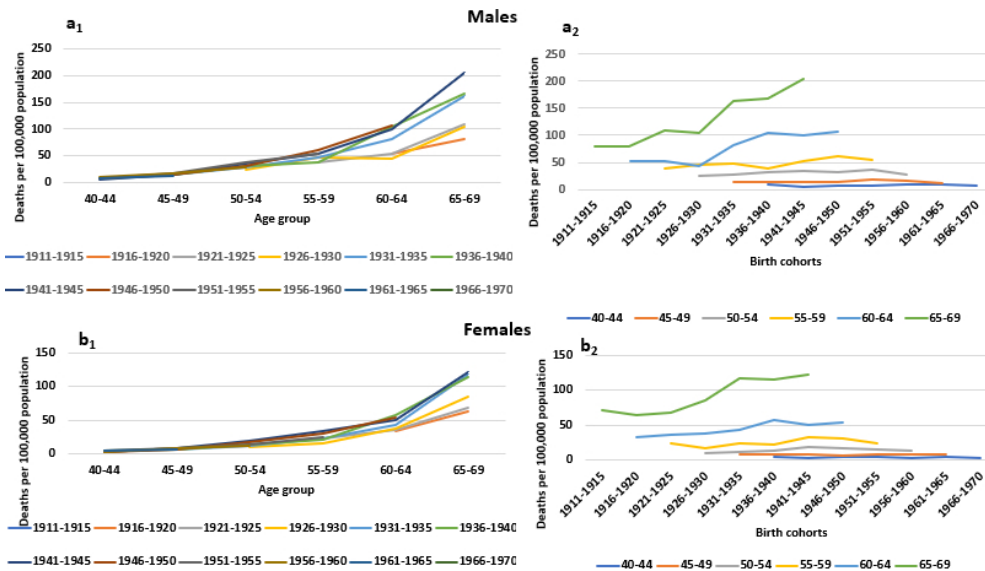


Figure 3. Mortality rates due to Hypertensive disease among 40-69-year-old Sri Lankans by age groups, birth cohort and sex. (panel a1-mortality rates by age for different birth cohorts in males; panel a2-mortality rates by birth cohorts for different age groups in males; panel b1-mortality rates by age for different birth cohorts in females; panel b2-mortality rates by birth cohorts for different age groups in females)

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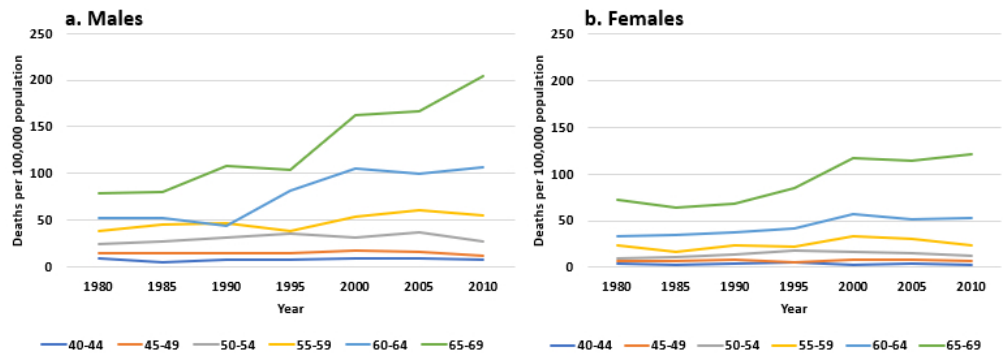


Figure 4. Mortality rates due to Hypertensive Disease (HTN) among 40-69-year-old Sri Lankans by year by age groups and sex. (panel a- for males; panel b for females)

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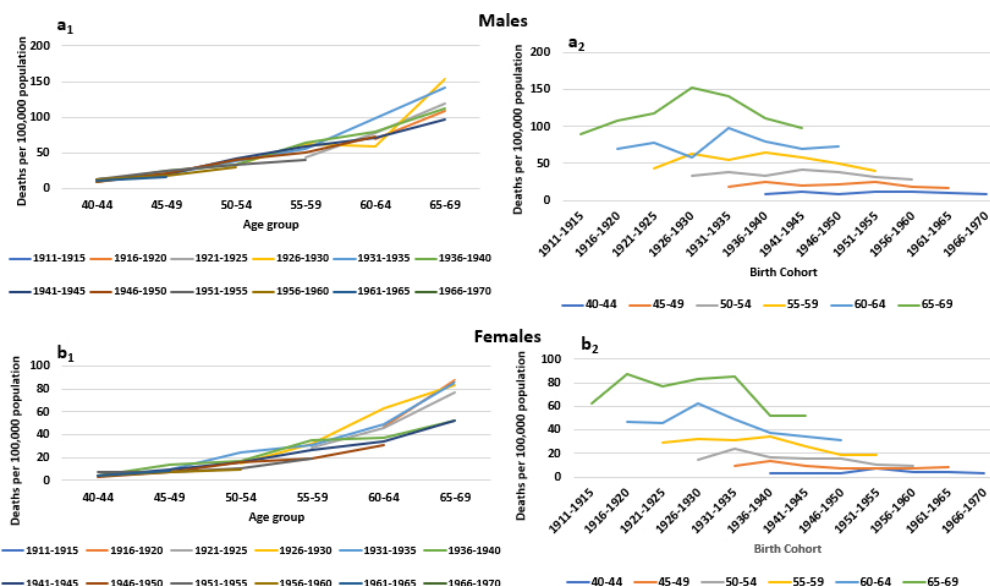


Figure 5. Mortality rates due to Cerebrovascular disease among 40-69-year-old Sri Lankans by age groups, birth cohort and sex. (panel a1-mortality rates by age for different birth cohorts in males; panel a2-mortality rates by birth cohorts for different age groups in males; panel b1-mortality rates by age for different birth cohorts in females; panel b2-mortality by birth cohorts for different age groups in females)

546x316mm (38 x 38 DPI)

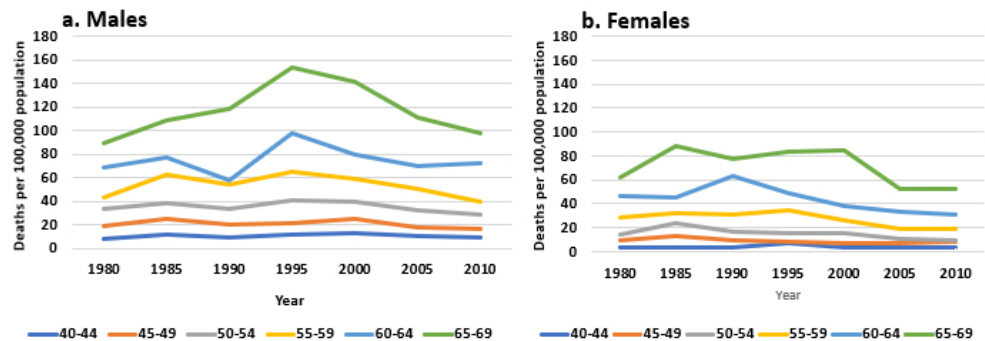


Figure 6. Mortality rates due to Cerebrovascular disease (CeVD) among 40-69-year-old Sri Lankans by year by age groups and sex. (panel a- for males; panel b for females)

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Supplementary Table 1. Cause of death codes of selected conditions of the International Classification of Diseases versions 9 and 10

Cause of death	ICD-9		ICD-10	
	Code	Subcode	Code	Subcode
Ischaemic Heart Disease	B27		1067	I20-I25
Acute myocardial infarction		B270		I21
Remainder		B279		I20, I22, I23, I24, I25
Hypertensive Disease	B26		1066	I10-I13
Hypertensive heart disease		B260		I11
Remainder		B269		I10, I12, I13
Cerebrovascular disease	B29		1069	I60-I69
Subarachnoid hemorrhage		B290		I60
Intracerebral and other intracranial hemorrhage		B291		I61
Cerebral infarction		B292		I63
Others		B293, B294, B299		I62, I64-I69

Source: WHO. Mortality database²⁰

Supplementary Table 2. Birth cohorts corresponding to different age groups 1980-2010

Age Group	Year						
	1980	1985	1990	1995	2000	2005	2010
40-44	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965	1966-1970
45-49	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965
50-54	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960
55-59	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955
60-64	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950
65-69	1911-1915	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945

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Supplementary Table 3. Deaths due to Ischaemic Heart Disease per 100,000 population in Sri Lanka by birth cohort and age group

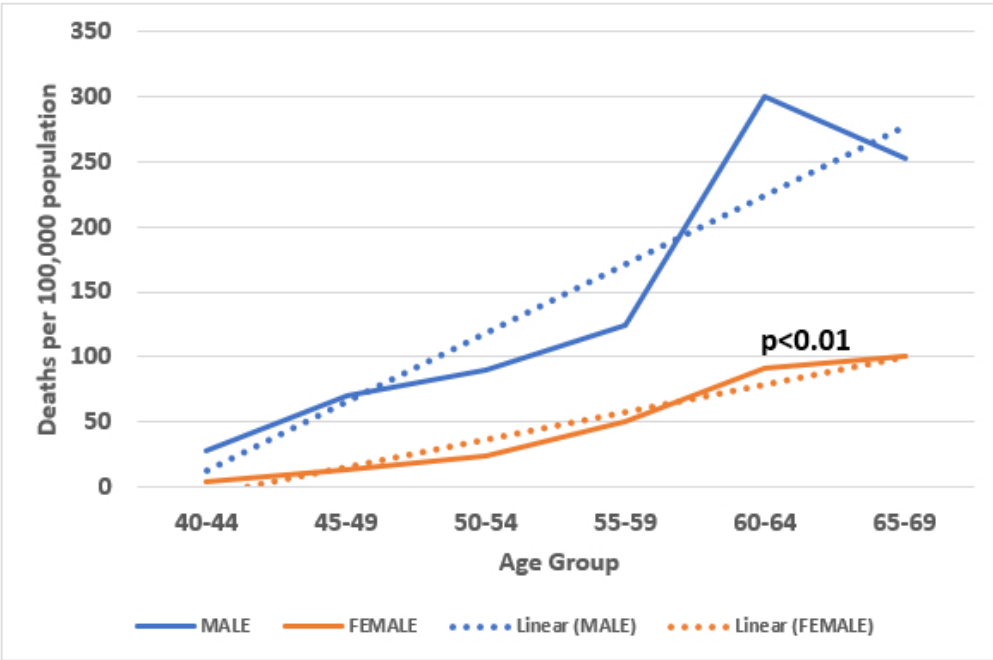
Age group (years)	Year											
	1911-1915	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965	1966-1970
Males												
40-44						28.42	40.02	25.58	28.23	52.84	23.41	13.03
45-49					51.52	70.20	50.26	55.83	96.02	42.97	28.85	
50-54				75.26	105.89	90.60	87.68	164.23	73.50	47.65		
55-59			85.97	135.67	119.64	124.77	219.60	120.39	81.31			
60-64		120.35	187.19	104.35	163.57	300.37	167.23	122.23				
65-69	136.73	210.55	182.50	199.57	389.99	252.12	189.32					
Females												
40-44						3.77	6.77	7.53	9.22	8.68	5.86	3.71
45-49					7.76	12.95	11.28	14.97	20.53	10.41	6.91	
50-54				14.87	25.59	24.69	33.07	37.18	22.29	15.02		
55-59			21.37	41.48	45.29	50.24	60.21	30.40	27.42			
60-64		42.14	53.13	57.32	72.83	91.09	59.50	55.25				
65-69	68.17	98.12	106.77	90.38	177.83	100.98	97.80					

Supplementary Table 4. Deaths due to Hypertensive Disease per 100,000 population in Sri Lanka by birth cohort and age group

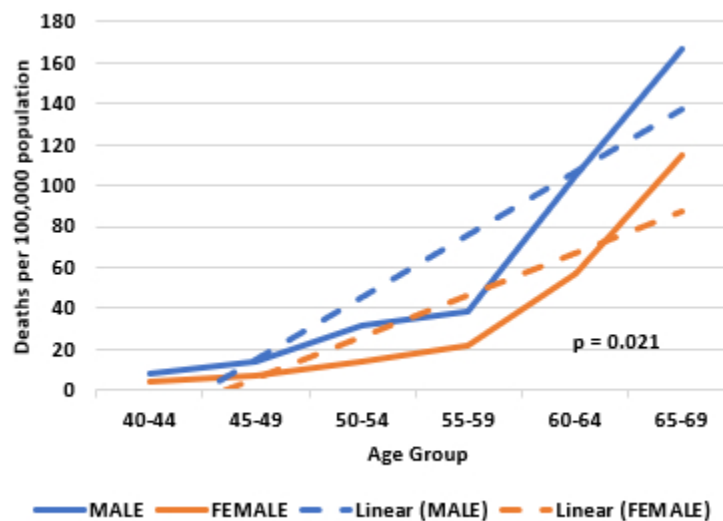
Age group (years)	Year											
	1911-1915	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965	1966-1970
Males												
40-44						8.44	4.23	7.40	7.44	8.81	8.61	7.04
45-49					14.40	14.28	15.03	14.34	17.48	15.63	12.39	
50-54				24.28	27.24	31.35	35.23	31.63	36.95	27.15		
55-59			38.21	45.84	46.91	38.24	53.28	60.80	54.55			
60-64		52.62	52.80	44.06	82.18	105.20	99.89	106.07				
65-69	78.76	80.00	108.50	104.23	162.42	167.07	204.82					
Females												
40-44						4.06	2.51	3.77	4.71	2.95	3.81	2.28
45-49					7.08	7.23	7.95	5.77	8.13	7.65	7.06	
50-54				9.53	11.57	13.58	18.37	17.16	14.55	12.60		
55-59			23.64	16.35	23.19	21.62	33.36	29.96	23.93			
60-64		33.36	35.26	38.08	42.27	57.18	50.96	53.51				
65-69	71.96	63.49	68.23	85.46	116.66	114.62	121.64					

Supplementary Table 5. Deaths due to Cerebrovascular Disease per 100,000 population in Sri Lanka by birth cohort and age group

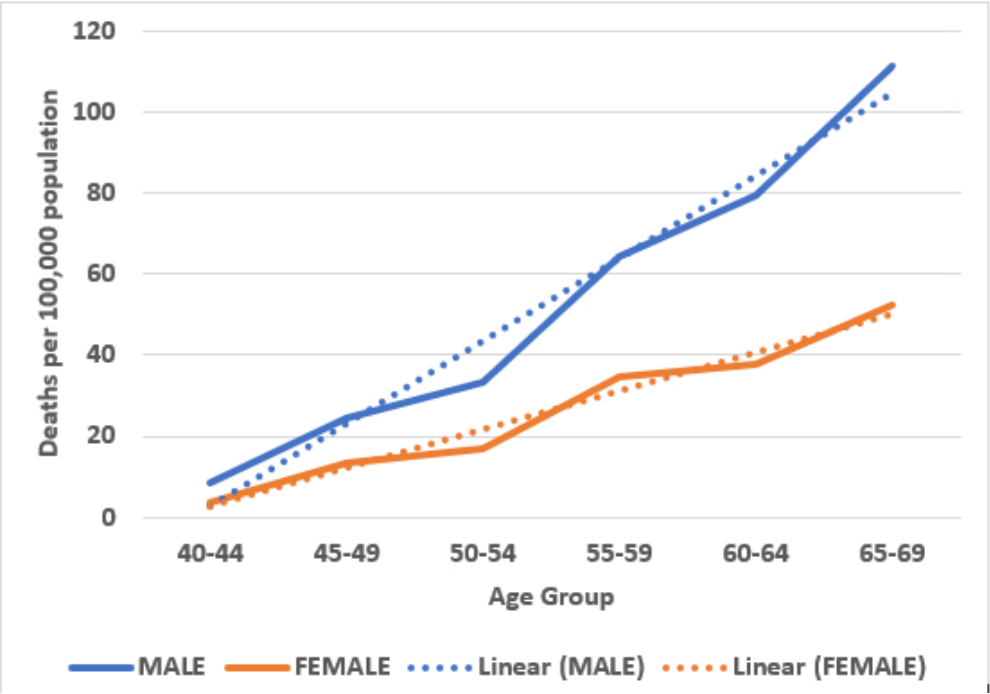
Age group (years)	Year											
	1911-1915	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965	1966-1970
Males												
40-44						8.44	12.18	8.67	11.63	12.29	10.12	8.84
45-49					18.88	24.39	19.69	21.18	24.51	17.83	16.46	
50-54				32.95	38.48	33.54	41.24	39.13	32.11	28.73		
55-59			43.39	62.99	54.55	64.40	58.58	50.67	39.23			
60-64		69.19	77.67	57.97	98.14	79.55	70.24	72.48				
65-69	89.47	108.33	118.50	153.30	141.01	111.52	97.43					
Females												
40-44						3.48	3.51	3.35	7.34	3.93	3.81	3.42
45-49					9.10	13.55	9.49	7.70	7.36	7.65	7.94	
50-54				14.49	23.84	16.98	16.01	15.84	10.39	8.88		
55-59			29.10	31.91	30.80	34.66	26.04	18.81	18.59			
60-64		46.82	45.41	62.76	49.44	37.56	33.88	31.01				
65-69	62.11	87.86	77.08	83.67	85.07	52.33	52.26					



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Cardiovascular Mortality of 40–69-year-olds in Sri Lanka from 1980 -2010; a birth cohort analysis by age and sex

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1 Cardiovascular Mortality of 40–69-year-olds in Sri Lanka from 1980 - 2 2010; a birth cohort analysis by age and sex

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Abstract

Objectives

To compare cardiovascular mortality (ischaemic heart disease (IHD), hypertensive disease (HTN) and cerebrovascular disease (CeVD)) of 40–69-year-old Sri Lankans from 1980-2010 by age, birth cohort and sex.

Design

A comparative retrospective study.

Setting

Sri Lanka

Participants

40-69-year-old Sri Lankans from 1980-2010.

Primary and secondary outcome measures

Cardiovascular deaths due to IHD, HTN and CeVD.

Results

Mortality due to IHD increased with age but decreased with birth cohorts with time (range 3.7-390 per 100,000 population); there was a spike in the IHD mortality rates in both age-groups and birth cohorts in 2000. Deaths due to HTN markedly increased after 55 years; however, mortality decreased in the younger cohorts (range 2.8-204.81 per 100,000 population). CeVD mortality linearly increased with age (range 3.3-153.3 per 100,000 population); birth cohorts of 1926-1930 and

1931-1935 had a spike in mortality among 60-64 and 65-69 age groups, respectively. Changes were seen among both males and females; mortality rates were higher in males than in females.

Conclusions

All cardiovascular mortality rates increased with age and are higher in males than in females. Age specific cardiovascular mortality rates were lower in the younger birth cohorts as compared to the older birth cohorts. The increase in cardiovascular deaths in Sri Lanka is due to the ageing population.

Keywords: Cardiovascular mortality, 1980-2010, 40-69-year-olds, Sri Lanka

Strengths and limitations of this study

- Birth cohort analysis of mortality due to cardiovascular diseases by age and sex show trends in mortality and allows comparisons over time.
- Data used for the analysis have been published by the Registrar General's Department of Sri Lanka.
- Inability to determine the relationship between mortality and economic indicators due to lack of data is a limitation of the study.

Data availability statement

All data extracted are given in the supplementary tables and in the tables.

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69 **Introduction**

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70 Cardiovascular diseases (CVDs) are the leading cause of death globally. They comprise a group

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71 of diseases of the heart and blood vessels including coronary heart disease (CHD), cerebrovascular

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72 disease (CeVD), peripheral artery disease, rheumatic heart disease, congenital heart disease, deep

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73 vein thrombosis and pulmonary embolism.¹

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74 In 2019, 17.9 million deaths due to CVDs accounting for 32% of all global deaths were estimated;

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75 85% were due to heart attack and stroke. More than 75% of all CVD deaths occur in low- and

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76 middle-income countries; CVD deaths comprised 38% of premature deaths (under the age of 70)

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77 due to non-communicable diseases.¹

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78 Hypertension, a blood pressure above 140/90, is a leading risk factor for cardiovascular disease

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79 with a heavy public health burden worldwide.² Poorly controlled or uncontrolled blood pressure

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80 increases the risk of hypertensive disease (HTN) giving rise to microscopic and macroscopic

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81 cardiac remodeling and functional alterations.³ It is estimated that 1.28 billion adults aged 30–79

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82 years worldwide have hypertension with two-thirds living in low- and middle-income countries.⁴

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83 46% of hypertensives are unaware they have the condition and less than 42% are diagnosed and

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84 treated; only 21% of adults with hypertension have it controlled.⁴

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85 The number of CVD deaths has been increasing over time; in 2000, around 14 million died of

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86 CVDs globally, while in 2019, close to 18 million died.⁵ CVD deaths are estimated to be >23

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87 million by 2030.⁶ The decline in incidence and mortality rates for developed countries was

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88 significantly higher than those for developing countries from 1990–2017 ($p < 0.05$); developing

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89 nations had a less-steep decline.⁷

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Risk factors for cardiovascular diseases include age, sex and other modifiable lifestyle risk factors.⁷ The rising death toll is largely due to a growing and ageing global population. Death rates have been declining due to implementation of preventive programmes; large declines in smoking, improvements in screening, diagnosis, and monitoring; and advances in medical treatments, public health initiatives, emergency care, and surgical procedures have all helped to reduce the impact of cardiovascular diseases on people's lives.⁷ The large disparities that still exist can be further reduced.

South Asia has a disproportionately high burden of cardiovascular disease, with higher rates of CVD incidence, mortality, and risk factor prevalences than many other regions.⁸ CVDs account for 3.9 million deaths in the WHO South-East Asia Region every year, comprising a quarter of all deaths from non-communicable diseases (NCDs), with most of them being preventable.⁹ Even though South Asians comprise only 25% of the world's population, they account for more than 50% of the world's cardiovascular deaths.⁸

Sri Lanka, a country having one of the fastest ageing populations in Asia, is in the midst of an epidemiological and demographic transition. In 2022, WHO estimated that over 80% of the mortality in Sri Lanka is due to major non-communicable diseases with CVDs contributing to over 34% of deaths, impacting both life expectancy and quality of life. The mortality from CVDs in Sri Lanka is estimated to be 524 deaths per 100,000 which is higher than that observed in many high-income countries.¹⁰ Coronary artery disease (CAD) is the leading cause of death in Sri Lanka while stroke is the third highest cause of death.^{11, 12}

Childhood risk factors such as obesity, exposure to indoor and outdoor tobacco smoke, dyslipidaemia and diabetes impact cardiovascular disease in adulthood¹³ and are now being targeted for prevention of cardiovascular disease.

Birth cohort analyses have been used to determine the causal relationship between potential risk factors during the prenatal and postnatal period and the health status of the newborn up to childhood. Birth cohort analyses allow description of associations between early exposures and subsequent outcomes^{14, 15}; in addition, they are able to identify the risk and environmental exposure factors shared by a given generation, are used to investigate disease trends and test a wide range of hypotheses.¹⁴⁻¹⁷ Birth cohort analyses of CVDs have not been conducted in Sri Lanka. The aim of this study was to find out whether there are variations in age and sex specific mortality rates of selected CVDs (ischaemic heart disease, hypertensive disease and cerebrovascular disease) among 40-69-year-old Sri Lankans from 1980-2010 by birth cohort.

Methods

Study design and data sources

This comparative retrospective study was conducted from August 2022 to January 2024 using secondary data available in the public domain. Mortality data of Sri Lanka were extracted from the World Health Organization mortality database from 1980 through 2010 (country code 3365).¹⁸ Mortality data are reported annually to the WHO from the civil registration system of the country (Registrar General's department). Mortality data included the number of deaths for 5-year age groups and coded as per the International Classification of Diseases (ICD) versions 9 (1979 up to

1992) and 10 (1993 to 2021). The 10th revision of the ICD was used in Sri Lanka from 1997 onwards.¹⁹ Separate ICD codes are given for different causes of deaths falling under cardiovascular diseases. The ICD codes used for deaths due to ischaemic heart disease, hypertensive disease and cerebrovascular diseases in the 9th and 10th revisions used in this study are given in Supplementary Table 1.

For each disease category, deaths of 5-year age groups (40-44, 45-49, 50-54, 55-59, 60-64 and 65-69) were extracted from the database for the codes and subcodes given in Supplementary Table 1 from 1980 to 2010.

The birth cohorts for different age groups corresponding to the selected years of data extraction are given in Supplementary Table 2. For example, the age group 40-44 years in 1980 belonged to the 1936-1940 birth cohort. Likewise, the age group 65-69 years in 1980 belonged to the 1911-1915 birth cohort. For each birth cohort, the number of deaths for each group of ICD codes were summed for the age group studied. For example, for the birth cohort of 1936-1940, deaths coded as B27 (9th revision) were summed for the 40-44-year age group in 1980 (birth cohort of 1936-1940).

Mortality data from 1987 to 1995 were not available on the WHO website. Mortality data for 1990 was obtained by linear interpolation of the number of deaths separately for males and females in the different age groups considered. Mortality data by age and sex for 1995 were obtained from the Registrar General's Department, Sri Lanka.

Population data by age group and sex were obtained from the database displayed in the UN population website²¹, Sri Lanka being coded as 144. Population data are displayed as estimates for inter-censal years as estimated by the Department of Census and Statistics of Sri Lanka and

153 reported to the UN; during the census years, the actual figures are provided. Population data are
154 reported for 5-year age groups as done for mortality data by sex.

155 Extracted mortality and population data were tabulated to yield six, five-year age groups from 40–
156 44 to 65–69 years, and seven quinquennial demographic profiles from 1980 to 2010 for the 12
157 birth cohorts.

158 Data analysis

159 Data were entered in Excel worksheets. Mortality rates for each of the three cardiovascular
160 diseases for each age category of both sexes were calculated based on the following formula.

161
$$\text{Mortality rate for each age-sex category} = (\text{deaths} / \text{population}) * 100,000$$

162 Using the calculated mortality rates for each age group and birth cohort, trends were determined
163 to identify birth cohort and age effects by sex. Data are presented as tables and graphs. Mortality
164 rates of IHD, HTN and CeVD were plotted by age group, birth cohort and year by age and sex.

165 To compare sex differences in specific mortality rates of 40–70-year-old Sri Lankans from 1980–
166 2010, mortality rates of the 1936-1940 birth cohort for which all age groups were included in the
167 analyses were plotted against the age groups; using multiple regression analysis, the slopes of the
168 regression lines using mortality rates as the dependent variable and age as the independent variable
169 between males and females were compared.

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173 Ethics statement

174 The Ethics Review Committee of the Faculty of Medicine, University of Kelaniya, Sri Lanka,
175 exempted this study from ethics review (Ref No. P/149/11/2022).

176 Patient and public involvement

177 Patients and the public were not specifically involved in the design, conduct, reporting or
178 dissemination plans of our research.

180 Results

181 The mortality rates due to ischaemic heart disease, hypertensive disease and cerebrovascular
182 disease by age group, birth cohort and sex are given in Figures 1-6 and supplementary tables 3-5,
183 respectively.

184 Insert figure 1 here

185 Mortality rates due to ischaemic heart disease increased with age among both males and females
186 in each birth cohort (Figures 1 and 2, and Supplementary Table 3), the rates being higher in
187 males than in females for each age group in each birth cohort each year. The mortality rates due
188 to ischaemic heart disease for each age group was higher among the early birth cohorts as
189 compared to the younger birth cohorts among both males and females. In each age group, the
190 mortality rates of each birth cohort peaked corresponding to year 2000 in both males and females
191 after which there is a progressive decline -in each subsequent birth cohort.

192 Insert figure 2 here

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193 Similar to mortality rates due to ischaemic heart disease, mortality rates due to hypertensive
194 disease increased with age among both males and females (Figures 3 and 4, and Supplementary
195 Table 4); the mortality rates were higher in males than in females for each birth cohort and age
196 group. The highest mortality rates due to hypertensive disease for each age group was higher
197 among the early birth cohorts as compared to the later birth cohorts among both males and
198 females, the rates being higher in males. Among both males and females, the mortality rates due
199 to hypertensive disease of the 65-69 age group increased from the 1911-1915 to the 1941-1945
200 birth cohorts; spikes are seen in the mortality rates corresponding to year 2000. In the 1936-1940
201 birth cohort, the mortality rate due to hypertensive disease increased from 8.4 per 100,000
202 population in the 40-44-year age group to 167.1 per 100,000 population in the 65-69-year age
203 group. Similar to the trends in ischaemic heart disease, a spike in the mortality rates due to
204 hypertensive disease is seen in all birth cohorts in different age groups corresponding to year
205 2000.

206 Insert figures 3 and 4 here

207 Similar to ischaemic heart disease and hypertensive disease, mortality due to cerebrovascular
208 disease (CeVD) increased with age among both males and females (Figures 5 and 6, and
209 Supplementary Table 5) with the mortality rates being higher in males than in females for each
210 birth cohort; the mortality rates due to CeVD for each age group was higher among the early
211 birth cohorts as compared to the later birth cohorts among both males and females. Unlike the
212 distinct spike in mortality rates due to ischaemic heart disease and hypertensive disease
213 corresponding to year 2000 data, the spike for CeVD mortality rates was less marked. The
214 mortality rates due to cerebrovascular diseases among males of the earlier cohorts for the older
215 age groups (the 65-69 year age group of the 1926-1930 cohort and the 60-64 year age group of

the 1931-1935 cohort) peaked corresponding to year 1995 (Figure 6); among females, this peak was less distinct for the same year. In subsequent birth cohorts, the mortality rates have been declining for each age group.

Insert figures 5 and 6 here

Mortality rates due to IHD, HTN and CeVD among 40–69-year-old Sri Lankans of birth cohort 1936-1940 by sex are given in Supplemental figures 1-3, respectively. Mortality rates due to all three causes show an increasing trend in both sexes and the mortality rates of males being higher than that of females; there is a significant difference in the mortality rates for all three causes with age between males and females ($p<0.05$).

Discussion

The findings of this study show age, sex and 5-year birth cohort effects of selected cardiovascular deaths in 40-70-year-old Sri Lankans from 1980-2010. As expected, cardiovascular mortality rates due to IHD, HTN and CeVD increased with age; in each age group, mortality rates were higher among men. In the older age groups, the mortality rates due to HTN increased in the early cohorts till about year 2000; in the subsequent cohorts, age group mortality continued to decrease over time. CeVD mortality rates in males peaked in the older age groups (65-69 and 60-64) corresponding to year 1995 with a decline in younger cohorts and over time; among females, the trend was less marked. Although the number of deaths increased with time for different age groups due to an ageing population, the mortality rates decreased with each birth cohort.

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236 An age-period-cohort study of CVD in Japan using data from 1995-2018 showed that mortality
237 rates of both sexes increased with age²², similar to what is reported here. The Japanese study also
238 revealed an association between other co-morbidities with advancing age, such as diabetes
239 mellitus, and atherosclerosis and age-related changes in the cardiovascular system such as
240 reduced elasticity in blood vessels, increased arterial stiffness and hypertrophy of the heart etc.
241 which could be probable causes for the higher mortality in older age.²² Another Japanese study
242 on mortality due to IHD from 1955 to 2000 showed non-linear birth cohort effects with an initial
243 increase followed by a decreasing trend in both sexes.¹⁶

244 The findings of this study suggest that mortality rates due to HTN starts to rise after about 50 years
245 of age. Again, there are birth cohort effects with younger cohorts having lower mortality rates with
246 males having higher rates. ²³ In Mexico, mortality due to hypertension affected more women than
247 men; in the recent cohorts, the risk of dying from hypertension is two times higher in men
248 compared to women. Hypertensive kidney disease was the main underlying cause, with an average
249 increase throughout the study period.²³

250 Similar to the trends of HTN, CeVDs, mortality rates are relatively constant in younger birth
251 cohorts up to about 50 years. After 1985, there is a declining trend in mortality across the birth
252 cohorts. Similar findings were reported from China where age-standardized stroke mortality rates
253 started declining in every age group.²⁴ In Japan, age-standardized stroke mortality rates per 100,000
254 population have declined from 98 in 1990, to 74 in 2000, to 50 in 2010, and to 33 in 2019 in males;
255 among females, the decline was from 69 in 1990, to 46 in 2000, 27 in 2010, and to 18 in 2019. ²⁵,
256 ²⁶

257 In this study, the overall mortality rates of males are higher than that of females for all three
258 cardiovascular diseases. Similar results were reported from southern Spain²⁷ and China.²⁸ The
259 differences in mortality between males and females are partly due to biological differences
260 including the protective effect of oestrogen in females; after menopause this effect gradually
261 declines but the prevalences of other risk factors are lower than that of males. Other factors such
262 as healthcare-seeking behaviour and social determinants also influence these differences. In Sri
263 Lanka, females are subjected to routine screening at different ages during their lifetime from birth
264 including antenatal and postnatal care clinics and well woman clinics; female attendance at healthy
265 lifestyle centres where screening for CVD risk factors is done is much higher than that of males.

266 An interesting feature in this analysis is the spikes seen in mortality rates of all three cardiovascular
267 deaths. For IHD and HTN the spikes correspond to data of year 2000; for CeVD the spike was less
268 conspicuous. A possible reason for this observation is the change of the ICD coding system used
269 from version 9 to 10 in 1997 despite ICD-10 being released in 1995¹⁹; ICD version 10 had more
270 specific cause of death codes and had more causes of death for each disease which is likely to have
271 increased the mortality rates for each cause of death. The subsequent decrease in the mortality
272 rates may be due to the natural decrease in the mortality rates seen with successive birth cohorts.

273 Mortality rates of all three cardiovascular diseases considered show similar trends; like all non-
274 communicable diseases, these disease entities share distinct common characteristics that are
275 influenced by a broader range of lifestyle factors such as smoking, diet, physical activity, and
276 obesity which have been targeted in preventive programmes.

277 Decline in mortality rates in successive birth cohorts may be due to many factors. Firstly, it may
278 be due to differences in exposures *in utero*, childhood and even adulthood. Implementation of

screening programmes, and advances in medical and surgical procedures have contributed largely to early diagnosis and secondary prevention increasing the life expectancy of those diagnosed with cardiovascular diseases.⁷ In addition, large declines in smoking due to increased public awareness and regulation, including heavy taxation, are now considered a “best buy” for reduction of cardiovascular disease.⁷ Ma et al. (2008) suggested that lower mortality in younger birth cohorts in Japan was probably a result of improvements in lifestyle factors, including the national hypertension control prevention programme and improved nutrition in Japan during the previous few decades.¹⁶ It is also likely to be due to improved economic status over time. The per capita GNI in Sri Lanka was current dollars 2510 in 1990; in 2010 it was 8150.

Over several decades the Sri Lanka’s health system has improved tremendously in all aspects achieving impressive health indicators comparable to those of developed countries but at a much lower cost. This achievement is attributable to an excellent preventive health service originally initiated in 1926; though initially concentrating on maternal and child health, the service has been extended to cover environmental health and later to non-communicable diseases after the inclusion of prevention and control of non-communicable diseases in the first national health policy based on primary health care, and subsequently revised with a focus on universal health coverage.²⁹ Simultaneously, clinical services were improved and expanded with an increase in the number of hospital beds, advancements in technology and other related services. The number of doctors per 10,000 population has increased from 1401 in 1991 to 11,924 in 2021³⁰. Initially, general physicians in medical wards treated cardiology patients; subsequently since the early 1970’s cardiology as a specialty emerged in Sri Lanka. Specialisation in cardiology and cardiothoracic surgery followed and special units were created; in the public sector in 2020, there were 644 inward beds for cardiology compared to 470 in 2008^{31, 32}. The improvement and expansion of healthcare

services and the emergence of cardiology as a specialty beginning in the 1970's probably explains the high mortality rates in older age groups of early cohorts.

In Sri Lanka, preventative activities carried out by the Ministry of Health at national level are likely to have contributed to improvements in cardiovascular health among the younger generations: these include, tobacco control measures (both policy and legislation); nutrition and food policies to address obesity and high lipid levels; and health promotion to raise awareness about the importance of cardiovascular health and the prevention of CVDs.³³

Limitations

Data for 1990 and 2008 were not available and data were interpolated separately for males and females. The fact that the validity of our results is dependent on the accuracy and reliability of mortality data and the vital statistics registration system of the country is acknowledged. Studies have reported that cause of death certification is not 100% accurate, as expected.^{34, 35} However, given the CVD causes of death that were investigated it is unlikely to have adversely impacted on our results; the rates were calculated based on large denominators that would have little or no effect on the overall mortality rates.

Relating the differences in mortality rates to economic indicators was not attempted. The GNI was available from 1990 onwards and requires a more detailed analysis that should be conducted in the future.

Conclusions

There are age, period and birth cohort effects on mortality due to IHD, HTN and CeVD among 40-70-year-old male and female Sri Lankans between 1980 and 2010. Mortality increased with

1
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3 323 age and declined in younger cohorts over time as compared to older cohorts. Males had higher
4
5 324 mortality rates than females for each age group in each birth cohort.
6
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8 325 It is likely that age-sex specific mortality rates due to cardiovascular diseases will decline further, but at a
9
10 326 much lower rate, provided that prevention and control measures for CVD risk factors are enhanced and
11
12 327 sustained; however, the number of deaths due to cardiovascular diseases will increase due to the
13
14 328 increasing ageing population for which adequate care facilities should be improved, expanded and
15
16 329 provided.
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20 330 **Contributors**

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23 331 DTHDeS, EDSMDeA, DMDeM, AHDDeS and ARW contributed to the conceptualisation and
24
25 332 developing the methodology. ARW supervised data collection. All authors were involved in data
26
27 333 curation, data analysis, writing the original draft, and reviewing and editing the final draft. ARW
28
29 334 is the guarantor and accepts full responsibility for the work and conduct of the study.
30
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32

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34
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36
37
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39
40

41 338 **Competing interests**

42
43
44 339 All authors have no competing interests to declare.
45
46

47 340 **Patient and public involvement**

48
49
50 341 Patients and the public were not specifically involved in the design, conduct, reporting or
51
52 342 dissemination plans of our research.
53
54

55 343 **Data availability statement**

344 All data extracted are given in the supplementary tables and in the tables.

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348

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Figure legends

Figure 1. Mortality rates due to Ischaemic Heart disease among 40-69-year-old Sri Lankans by age groups, birth cohort and sex. (panel a₁-mortality rates by age for different birth cohorts among males; panel a₂-mortality rates by birth cohorts for different age groups among males; panel b₁-mortality rates by age for different birth cohorts among females; panel b₂-mortality rates by birth cohorts for different age groups among females)

Figure 2. Mortality rates due to Ischaemic Heart disease among 40-69-year-old Sri Lankans by year by age groups and sex. (panel a- for males; panel b for females)

Figure 3. Mortality rates due to Hypertensive disease among 40-69-year-old Sri Lankans by age groups, birth cohort and sex. (panel a₁-mortality rates by age for different birth cohorts in males; panel a₂-mortality rates by birth cohorts for different age groups in males; panel b₁-mortality rates by age for different birth cohorts in females; panel b₂-mortality rates by birth cohorts for different age groups in females)

Figure 4. Mortality rates due to Hypertensive Disease (HTN) among 40-69-year-old Sri Lankans by year by age groups and sex. (panel a- for males; panel b for females)

Figure 5. Mortality rates due to Cerebrovascular disease among 40-69-year-old Sri Lankans by age groups, birth cohort and sex. (panel a₁-mortality rates by age for different birth cohorts in males; panel a₂-mortality rates by birth cohorts for different age groups in males; panel b₁-mortality rates by age for different birth cohorts in females; panel b₂-mortality by birth cohorts for different age groups in females)

Figure 6. Mortality rates due to Cerebrovascular disease (CeVD) among 40-69-year-old Sri Lankans by year by age groups and sex. (panel a- for males; panel b for females)

Supplemental figure 1. Sex differences in mortality rates due to IHD by age group in males and females of the 1936-1940 birth cohort.

Supplemental figure 2. Sex differences in mortality rates due to HTN by age group in males and females of the 1936-1940 birth cohort.

Supplemental figure 3. Sex differences in mortality rates due to CeVD by age group in males and females of the 1936-1940 birth cohort.

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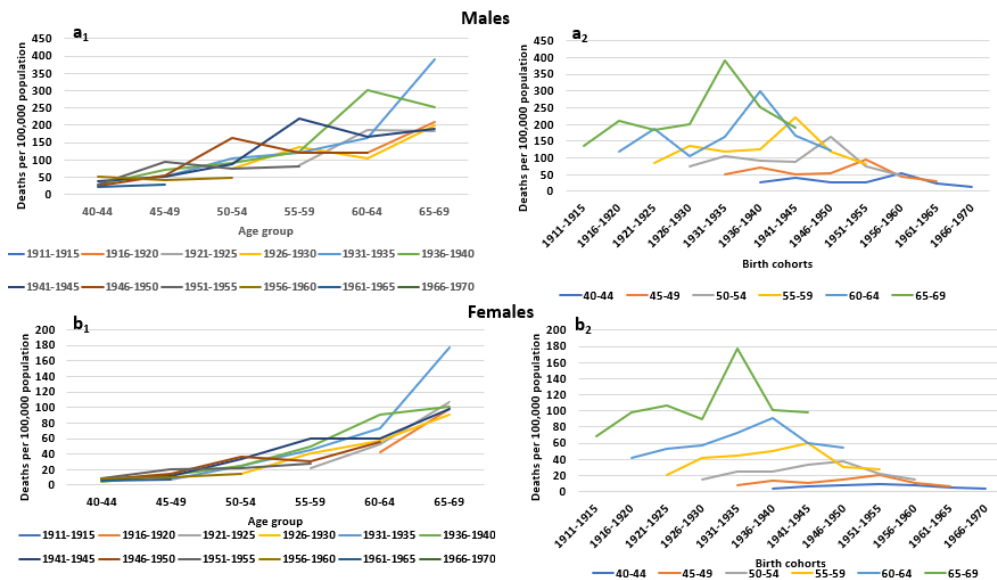


Figure 1. Mortality rates due to Ischaemic Heart disease among 40-69-year-old Sri Lankans by age groups, birth cohort and sex. (panel a1-mortality rates by age for different birth cohorts among males; panel a2-mortality rates by birth cohorts for different age groups among males; panel b1-mortality rates by age for different birth cohorts among females; panel b2-mortality rates by birth cohorts for different age groups among females)

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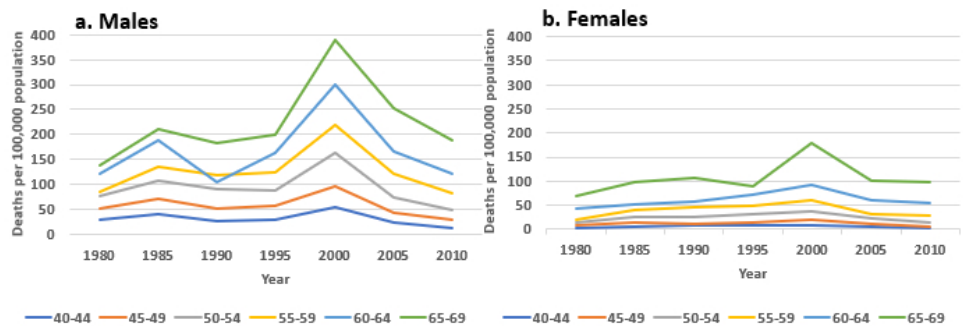


Figure 2. Mortality rates due to Ischaemic Heart disease among 40-69-year-old Sri Lankans by year by age groups and sex. (panel a- for males; panel b for females)

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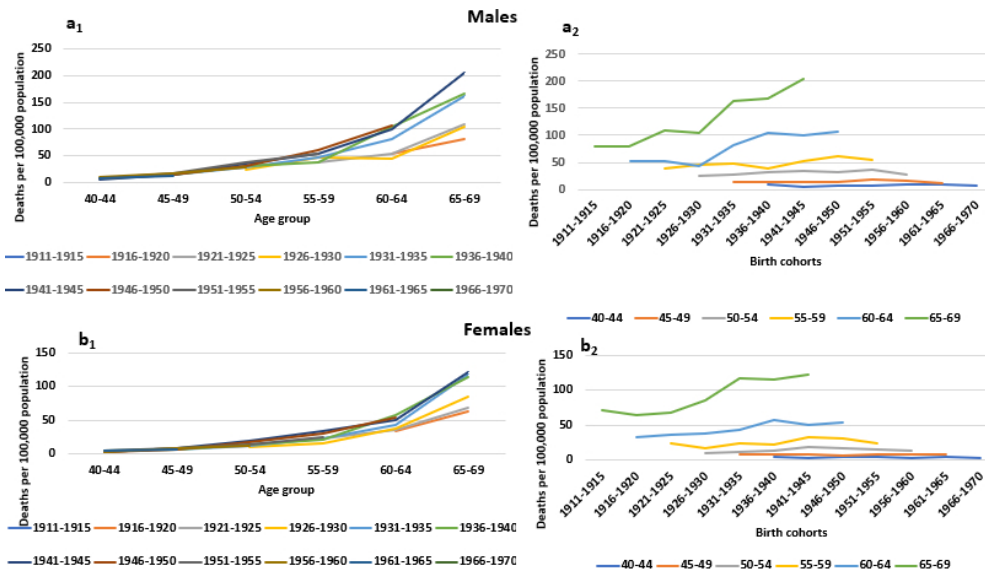


Figure 3. Mortality rates due to Hypertensive disease among 40-69-year-old Sri Lankans by age groups, birth cohort and sex. (panel a1-mortality rates by age for different birth cohorts in males; panel a2-mortality rates by birth cohorts for different age groups in males; panel b1-mortality rates by age for different birth cohorts in females; panel b2-mortality rates by birth cohorts for different age groups in females)

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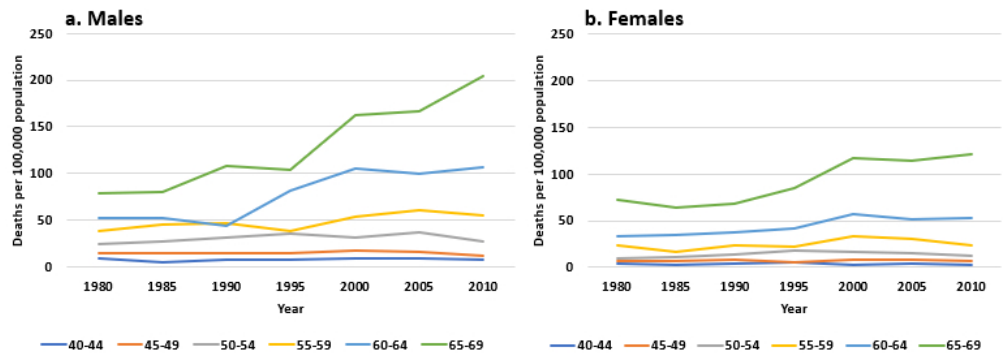


Figure 4. Mortality rates due to Hypertensive Disease (HTN) among 40-69-year-old Sri Lankans by year by age groups and sex. (panel a- for males; panel b for females)

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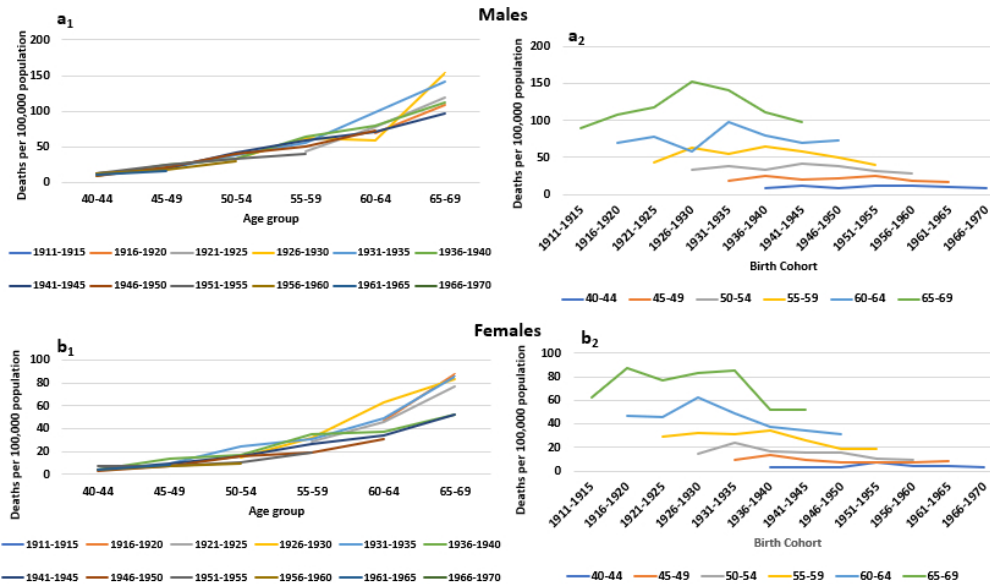


Figure 5. Mortality rates due to Cerebrovascular disease among 40-69-year-old Sri Lankans by age groups, birth cohort and sex. (panel a1-mortality rates by age for different birth cohorts in males; panel a2-mortality rates by birth cohorts for different age groups in males; panel b1-mortality rates by age for different birth cohorts in females; panel b2-mortality by birth cohorts for different age groups in females)

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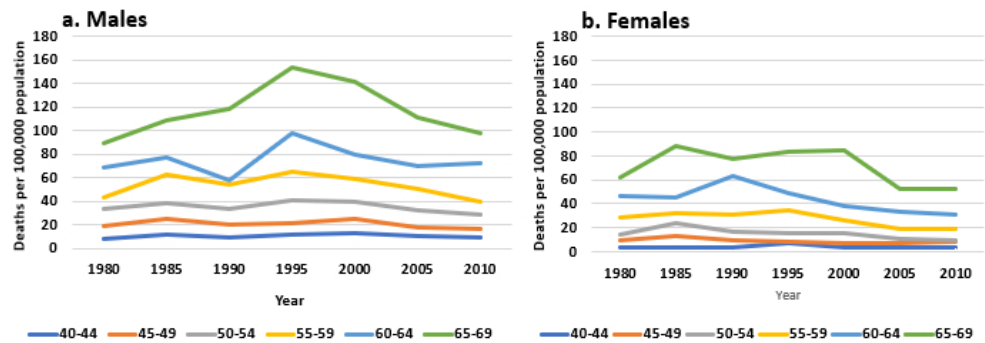


Figure 6. Mortality rates due to Cerebrovascular disease (CeVD) among 40-69-year-old Sri Lankans by year by age groups and sex. (panel a- for males; panel b for females)

468x171mm (38 x 38 DPI)

Supplementary Table 1. Cause of death codes of selected conditions of the International Classification of Diseases versions 9 and 10

Cause of death	ICD-9		ICD-10	
	Code	Subcode	Code	Subcode
Ischaemic Heart Disease	B27		1067	I20-I25
Acute myocardial infarction		B270		I21
Remainder		B279		I20, I22, I23, I24, I25
Hypertensive Disease	B26		1066	I10-I13
Hypertensive heart disease		B260		I11
Remainder		B269		I10, I12, I13
Cerebrovascular disease	B29		1069	I60-I69
Subarachnoid hemorrhage		B290		I60
Intracerebral and other intracranial hemorrhage		B291		I61
Cerebral infarction		B292		I63
Others		B293, B294, B299		I62, I64-I69

Source: WHO. Mortality database²⁰

Supplementary Table 2. Birth cohorts corresponding to different age groups 1980-2010

Age Group	Year						
	1980	1985	1990	1995	2000	2005	2010
40-44	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965	1966-1970
45-49	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965
50-54	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960
55-59	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955
60-64	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950
65-69	1911-1915	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945

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Supplementary Table 3. Deaths due to Ischaemic Heart Disease per 100,000 population in Sri Lanka by birth cohort and age group

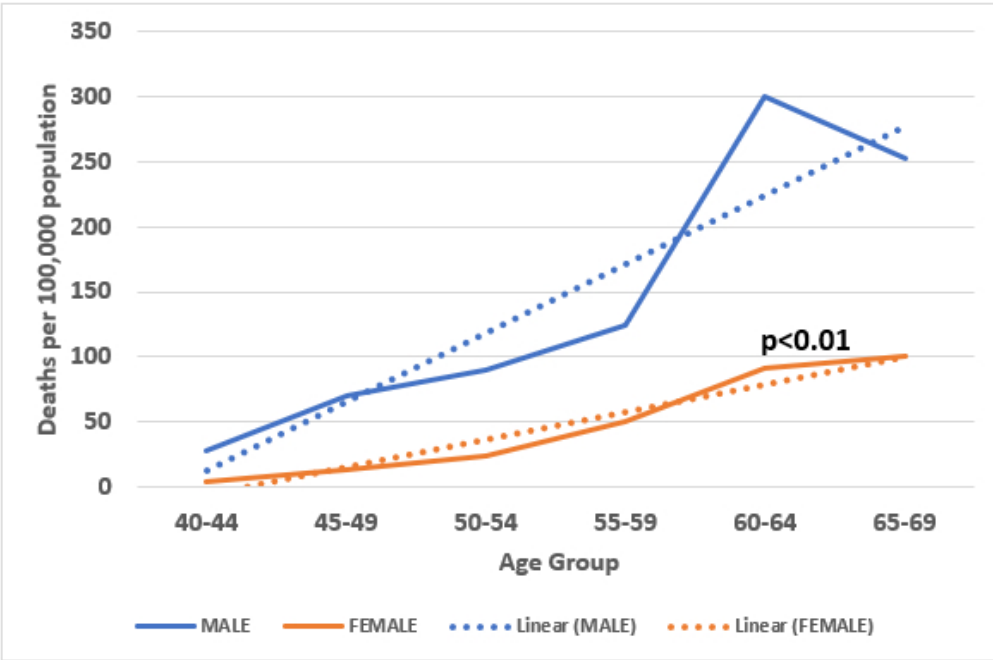
Age group (years)	Year											
	1911-1915	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965	1966-1970
Males												
40-44						28.42	40.02	25.58	28.23	52.84	23.41	13.03
45-49					51.52	70.20	50.26	55.83	96.02	42.97	28.85	
50-54				75.26	105.89	90.60	87.68	164.23	73.50	47.65		
55-59			85.97	135.67	119.64	124.77	219.60	120.39	81.31			
60-64		120.35	187.19	104.35	163.57	300.37	167.23	122.23				
65-69	136.73	210.55	182.50	199.57	389.99	252.12	189.32					
Females												
40-44						3.77	6.77	7.53	9.22	8.68	5.86	3.71
45-49					7.76	12.95	11.28	14.97	20.53	10.41	6.91	
50-54				14.87	25.59	24.69	33.07	37.18	22.29	15.02		
55-59			21.37	41.48	45.29	50.24	60.21	30.40	27.42			
60-64		42.14	53.13	57.32	72.83	91.09	59.50	55.25				
65-69	68.17	98.12	106.77	90.38	177.83	100.98	97.80					

Supplementary Table 4. Deaths due to Hypertensive Disease per 100,000 population in Sri Lanka by birth cohort and age group

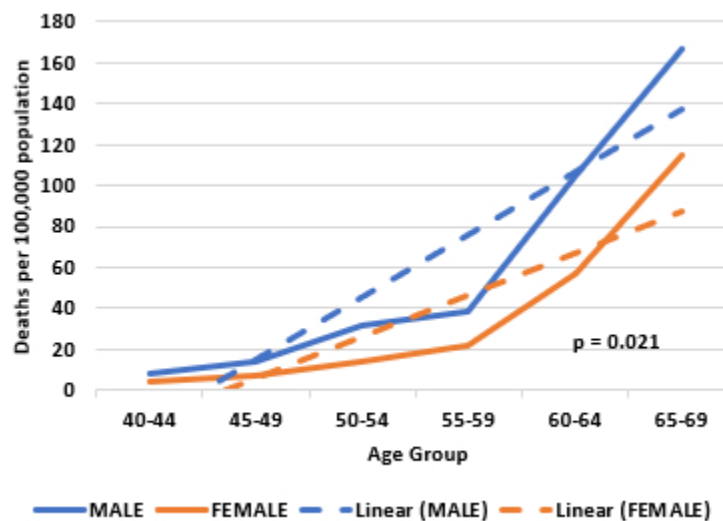
Age group (years)	Year											
	1911-1915	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965	1966-1970
Males												
40-44						8.44	4.23	7.40	7.44	8.81	8.61	7.04
45-49					14.40	14.28	15.03	14.34	17.48	15.63	12.39	
50-54				24.28	27.24	31.35	35.23	31.63	36.95	27.15		
55-59			38.21	45.84	46.91	38.24	53.28	60.80	54.55			
60-64		52.62	52.80	44.06	82.18	105.20	99.89	106.07				
65-69	78.76	80.00	108.50	104.23	162.42	167.07	204.82					
Females												
40-44						4.06	2.51	3.77	4.71	2.95	3.81	2.28
45-49					7.08	7.23	7.95	5.77	8.13	7.65	7.06	
50-54				9.53	11.57	13.58	18.37	17.16	14.55	12.60		
55-59			23.64	16.35	23.19	21.62	33.36	29.96	23.93			
60-64		33.36	35.26	38.08	42.27	57.18	50.96	53.51				
65-69	71.96	63.49	68.23	85.46	116.66	114.62	121.64					

Supplementary Table 5. Deaths due to Cerebrovascular Disease per 100,000 population in Sri Lanka by birth cohort and age group

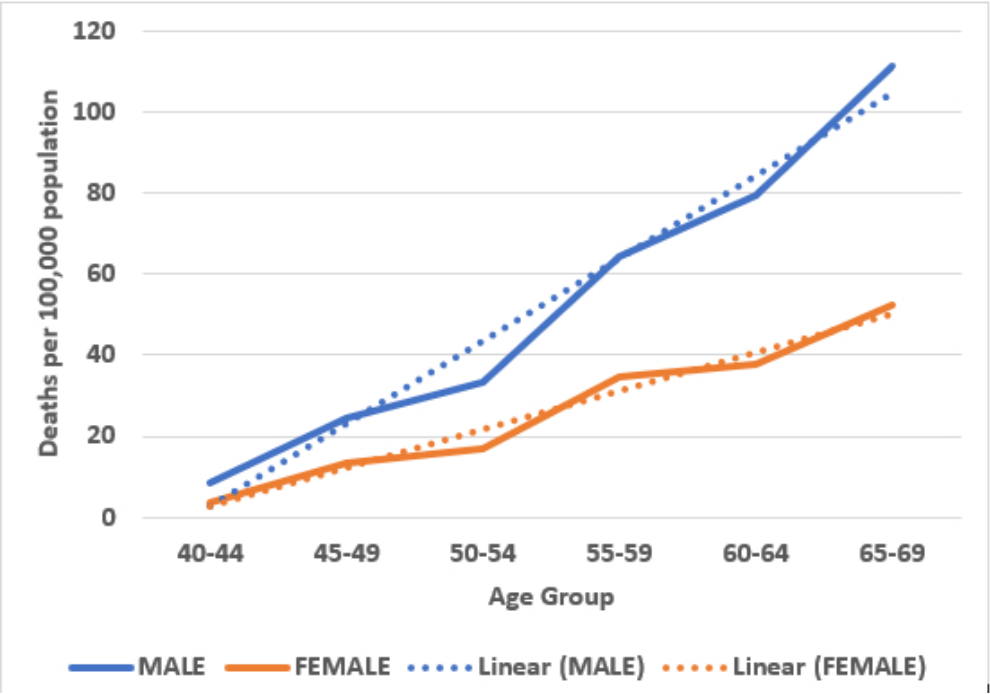
Age group (years)	Year											
	1911-1915	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965	1966-1970
Males												
40-44						8.44	12.18	8.67	11.63	12.29	10.12	8.84
45-49					18.88	24.39	19.69	21.18	24.51	17.83	16.46	
50-54				32.95	38.48	33.54	41.24	39.13	32.11	28.73		
55-59			43.39	62.99	54.55	64.40	58.58	50.67	39.23			
60-64		69.19	77.67	57.97	98.14	79.55	70.24	72.48				
65-69	89.47	108.33	118.50	153.30	141.01	111.52	97.43					
Females												
40-44						3.48	3.51	3.35	7.34	3.93	3.81	3.42
45-49					9.10	13.55	9.49	7.70	7.36	7.65	7.94	
50-54				14.49	23.84	16.98	16.01	15.84	10.39	8.88		
55-59			29.10	31.91	30.80	34.66	26.04	18.81	18.59			
60-64		46.82	45.41	62.76	49.44	37.56	33.88	31.01				
65-69	62.11	87.86	77.08	83.67	85.07	52.33	52.26					



389x274mm (38 x 38 DPI)



266x185mm (38 x 38 DPI)



372x258mm (38 x 38 DPI)