SSM - Population Health 23 (2023) 101445

Contents lists available at ScienceDirect

SSM - Population Health

journal homepage: www.elsevier.com/locate/ssmph

Changes in contributions of age- and cause-specific mortality to the widening life expectancy gap between North and South Korea, 1990–2019: An analysis of the Global Burden of Disease Study 2019

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ARTICLE INFO

Keywords:
Life expectancy
Decomposition analysis
North Korea
South Korea

ABSTRACT

Background: Life expectancy gaps between North and South Korea have increased but contributions to these gaps remain poorly understood. Using data from the Global Burden of Disease Study (GBD) 2019, we examined how much death from specific diseases contributed to these gaps in different age groups over three decades.
Methods: Data for death numbers and population by sex and 5-year age groups in both North and South Korea from 1990 to 2019 were extracted from the GBD 2019 to calculate life expectancy. Joinpoint regression analysis was conducted to investigate changes in life expectancy in North and South Korea. We used decomposition analysis to partition differences in life expectancy within and between the two Koreas into changes in age- and cause-specific death contributions.
Results: Life expectancy increased in two Koreas from 1990 to 2019, but North Korea experienced a marked decline in life expectancy during the mid-1990s. The life expectancy gaps between the two Koreas were greatest in 1999, with a difference of 13.3 years for males and 14.9 years for females. The main contributors to these gaps were higher under-5 mortality from nutritional deficiencies for males (4.62 years) and females (4.57 years) in North Korea, accounting for about 30% of the total gap in life expectancy. After 1999, the life expectancy gaps reduced but persisted with differences of about ten years by 2019. Notably, chronic diseases contributed to about 8 out of 10 years of life expectancy gap between the two Koreas in 2019. Differential cardiovascular disease mortality in the older groups was the main contributor to the life expectancy gap.
Conclusions: The contributors to this gap have shifted from nutritional deficiencies in children younger than five years to cardiovascular disease among elderly people. Efforts for strengthening social and healthcare systems are needed to curb this large gap.

1. Introduction

Life expectancy at birth is an essential measure that can be used to monitor trends in national population health, track the impact of socio-environmental threats such as economic shock or famine on population health, and, particularly, investigate absolute and relative differences between countries (Dicker et al., 2018). These differences in life expectancy reflect differential increases or decreases in cause-specific death rates and the living conditions of the population during infancy, childhood, adolescence, working age, and older age during certain periods (Chisumpa & Odimegwu, 2018).

Korea was divided into two separate states after the Korean War in 1953; the Democratic People's Republic of Korea and the Republic of Korea, hereafter called North and South Korea, respectively. Although North and South Korea share the same language and ethnic background, these ethical and cultural backgrounds were followed by over a half-century of life under different political and social systems (Khang, 2013), which may result in entirely different health conditions. Since the division of Korea, the gap in life expectancy between the two Koreas had not been large, but after the mid-1990s, when North Korea suffered severe economic hardship and famine, called 'the great famine' (Schwekendiek, 2015), the gap widened significantly and is estimated not to have decreased due to a worsening public health sector in North Korea (Owen-Davies, 2001).

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https://doi.org/10.1016/j.ssmph.2023.101445
Received 14 February 2023; Received in revised form 8 May 2023; Accepted 5 June 2023
Available online 7 June 2023

Research for cross-national differences in the life expectancy gap between North and South Korea provides a valuable opportunity to study the impact of sociopolitical changes on health (Bahk et al., 2018), but several studies have reported life expectancy in North and South Korea, separately (Bahk et al., 2019; Goodkind & West, 2001; Khang et al., 2016; Kim et al., 2020; Spoorenberg & Schwekendiek, 2012; Yang et al., 2010, 2012). Only one study has been undertaken to provide detailed information on the life expectancy gap and the decomposition of the life expectancy gap (Bahk et al., 2018). This study that examined the cause-specific contributions to the life expectancy gap between the two Koreas assumed that the cause-specific mortalities in North Korea in the past were the same as those in South Korea, and it reported that cardiovascular disease, digestive diseases, and infant mortality contributed greatly to the approximately 10-year life expectancy gap (Bahk et al., 2018). Although this previous study addressed the life expectancy gap and cause-specific contribution to this gap in single years with the lack of primary data, more information on the long-term trends in the contributors to the life expectancy gap using improved health metrics is needed because health status in both Koreas was changed (Smith, 2016, pp. 7–34; Yang et al., 2010). Thus, examining how age- and cause-specific contributions to life expectancy gap have changed over time may identify which diseases and age groups more explain life expectancy gap.

In a situation where primary data on life expectancy in North Korea are not available (Khang, 2013), data from international organisations, such as the World Bank and the United Nations, are usually used as estimates. However, none of these sources estimates detailed cause-specific deaths by age group and uses standardised statistical methods in two countries. The Global Burden of Disease, Injuries, and Risk Factor Study (GBD) provides estimates for the death rates of 369 diseases by age group in North and South Korea with coherent estimation methods and is well suited to investigating changes in life expectancy gap between two Koreas and their contributors.

The objectives of this study were to 1) investigate trends in the life expectancy gap between North and South Korea and 2) estimate age- and cause-specific contributions to the life expectancy gap between the two Koreas from 1990 to 2019.

2. Methods

2.1. Data sources and processing

We obtained annual data on the population and death numbers of men and women from 1990 through 2019 for North and South Korea from the estimates of the GBD 2019, conducted by the Institute for Health Metrics and Evaluation. The GBD 2019 provides several health metrics, such as incidence, prevalence, mortality, and disability-adjusted life-years (DALYs), for 369 cause-specific diseases and injuries, including 286 causes of death; 23 age groups; males, females, and both sexes; and 204 countries and territories for 1990 and 2019 (Vos et al., 2020). The estimation methods used in GBD 2019 are detailed in the previous publications (Vos et al., 2020; Wang et al., 2020). Briefly, the GBD 2019 used a set of standardised estimation methods, including Cause of Death Ensemble model (CODEm), spatiotemporal Gaussian process regression (ST-GPR), and DisMod-MR, and a coherent measurement statistical analysis with multiple data sources, including vital statistics, disease registries and other sources, providing opportunities for comparative health assessments between the countries (Vos et al., 2020). CODEm is for analysing the cause of death data with an ensemble of different modellings for rates and causes fractions. ST-GPR is a three-step regression modelling tool by weighting and adding residuals proximal in location and time to refine a linear prior for single health metrics of interest. DisMod-MR is a hierarchical Bayesian meta-regression to allow correcting differences in all available data-collection methods for the disease (Vos et al., 2020). All data used in this study were extracted using the GBD global health data exchange tool (https://ghdx.healthdata.org/).

2.2. Categories for age- and cause-specific groups

Age group was categorised into the following groups: 0–9, 10–24, 25–49, 50–69, and ≤70 years. Moreover, we also classified age groups into 5-year groups except for those younger than one year and older than 90 years (e.g., <1, 1–4, 5–9, 10–14, …, 85–89, and ≥90 years). The causes of death in the GBD 2019 are organised into a 4-level cause hierarchy ranging from the three broadest causes, including communicable, maternal, neonatal, and nutritional diseases (CMNNs), and non-communicable diseases (NCDs), and injuries in level 1 to specific causes consisting of 119 causes in level 4 (https://ghdx.healthdata.org/). We selected level 1 and level 2 causes encompassing 21 causes, which were coded according to the International Classification of Diseases (ICD-9) from 1990 to 1995 and the ICD-10 from 1996 to 2019 (see Supplementary Appendix 1) as these disease categories, such as neoplasm, cardiovascular disease, and respiratory infection and tuberculosis, were generally used in the previous study (Ni et al., 2021) and a sufficient number of deaths from these causes may increase the power of the analyses.

2.3. Life expectancy estimation and assessment of trends from 1990 to 2019

We constructed abridged life tables for 5-year age groups for men and women separately and calculated the life expectancy at birth in North and South Korea. As a descriptive analysis of changes in life expectancy trends, we plotted the annual life expectancy for North and South Korean men and women separately to visualise the trends in life expectancy in North and South Korea between 1990 and 2019. We also performed a joinpoint regression analysis to identify significant changes in the temporal trends. This method estimates the number of linear segments and joinpoints where statistically significant changes during the entire period occur with an estimated annual percentage change (APC) in each identified trend (Martinez et al., 2020). Joinpoint regression analysis provides a detailed picture of what is happening during a specific period than a summary trend in life expectancy (H. Chen et al., 2018). We carried out joinpoint regression analyses with estimates of life expectancy and standard error, extracted from GBD 2019 in each year. Joinpoint Regression Program was used for these analyses (version 4.9.1.0, National Cancer Institute, Bethesda, MD, USA).

2.4. Decomposition by age- and cause-specific mortality contribution to the gap in the life expectancy

To estimate the age and cause-specific contributions to the life expectancy differences within and between North and South Korea, we used Arriaga's decomposition method (Arriaga, 1984). This method estimates how much changes in mortality in each age and cause group contribute to life expectancy differences (Arriaga, 1984). The total contribution to life expectancy differences was obtained by adding the number of years contributed by death across different age groups and causes (Karanikolos et al., 2012). In this study, the analysis examined differences in life expectancy in North and South Korea over 30 years in two parts. The first part was to estimate the age- and cause-specific contributions to the changes in life expectancy over each 10-year interval period (1990–1999, 2000–2009, and 2010–2019) in North and South Korea with the reference year of 1990, 2000, and 2010, respectively. Since the sum of the values shows the change in life expectancy between periods, positive values indicate positive contributions to increasing life expectancy, whereas negative values represent contributions to decreasing life expectancy. The second part was to analyse the decomposition of life expectancy gap between North and South Korea in 1990, 1999, 2009, and 2019. The sum of values represents the life expectancy gap between North and South Korea. Since we chose North Korea as a reference country, negative values indicate the advantage of South Korea in increasing the life expectancy gap, whereas positive values indicate the advantage of North Korea in closing the life expectancy gap. We used SAS 9.4 and Microsoft Excel to determine decomposing differences in life expectancy by adapting the decomposition syntax and spreadsheet provided by Auger et al., 2014.

3. Results

3.1. Trends in life expectancy in North and South Korea

Fig. 1 shows that life expectancy increased in both North and South Korea from 1990 to 2019, except for the period between 1994 and 1997 in North Korea (see Supplementary Appendix 2). Life expectancy in North Korea increased at an average annual percent change (AAPC) of 0.3% for both men and women from 1990 to 2019, but life expectancy fluctuated substantially from the mid-1990s to the early 2000s. In particular, between 1994 and 1997, the life expectancy of men fell from 65.24 in 1994 to 58.17 years in 1995 and that of women from 70.80 in 1994 to 64.15 years in 1995. Following this period, North Korea saw a sharp rebound in life expectancy to 66.3 years in men and 72.17 years in women in 2003, and life expectancy gradually increased until 2019 (APC in both men and women between 2003 and 2019: 0.3% and 0.4%, respectively) (see Supplementary Appendix 3).

South Korea experienced a steady improvement in life expectancy from 1990 to 2019 with an average gain of about 0.6% per year in men and 0.4% per year in women and the life expectancy reached 80.03 years for men and 85.72 years for women in 2019. However, gains in life expectancy have stagnated in both sexes with no statistically significant increases since 2015 (see Supplementary Appendix 3).

3.2. Age and cause-specific contributions of changes in life expectancy in North Korea

Fig. 2 presents the contribution of cause-specific deaths at different age groups to the changes in life expectancy in North Korea. Over the past three decades, under 5 deaths consistently affected changes in life expectancy in North Korea in both sexes. About 58% of these changes (3.11 of 5.36 years for males and 3.00 of 5.19 years for females) were due to increases in the death rate among children younger than five years between 1990 and 1999, in which life expectancy decreased by 5.36 years for males and 5.19 years for females. As the leading cause of death, nutritional deficiencies contributed to declines in life expectancy by 6.58 years among males and 6.68 years among females.

In contrast to the previous period (1990–1999), a substantial increase in life expectancy was observed in the following ten years (2000–2009), with gains of 7.05 years for males and 7.08 years for females, which was primarily due to the decreasing number of deaths from nutritional deficiencies among children younger than five years (contributing 2.1 years for males and 2.04 years for females). Between 2010 and 2019, contributions to increasing life expectancy emerged among those aged 65 years and older from decreased mortality due to cardiovascular diseases and chronic respiratory diseases. Contributions from children under five years were still observed, but they were smaller than in the previous period, with an increased life expectancy of 0.88 and 0.80 years for men and women, respectively (see Supplementary Appendix 4).

3.3. Age and cause-specific contributions of changes in life expectancy in South Korea

In South Korea, the contributions to life expectancy gains in older adults over the past three decades have been identified (Fig. 3). Between 1990 and 1999, the life expectancy gains were 4.14 years for men and

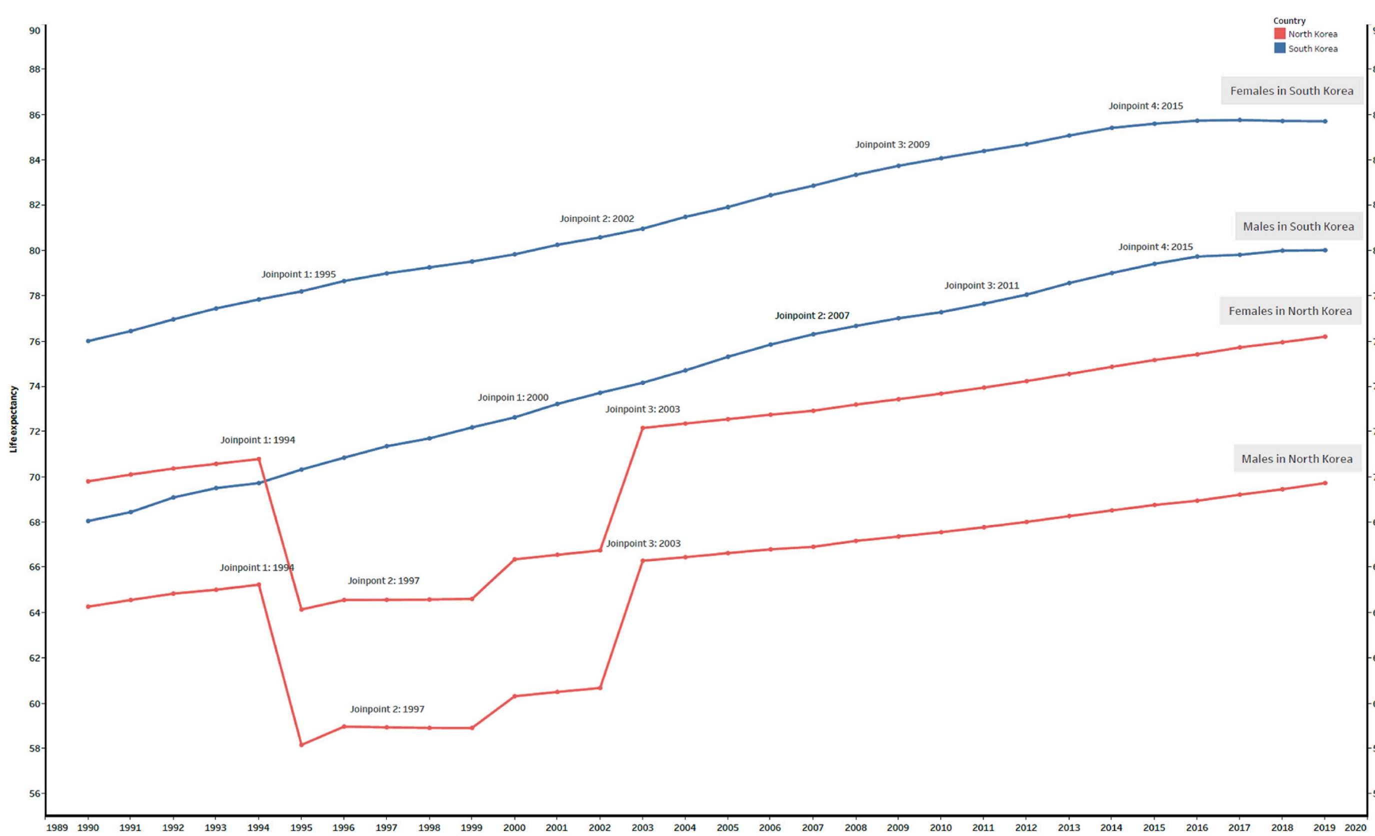

Fig. 1. Trends in life expectancy at birth in North and South Korea by sex from 1990 to 2019.

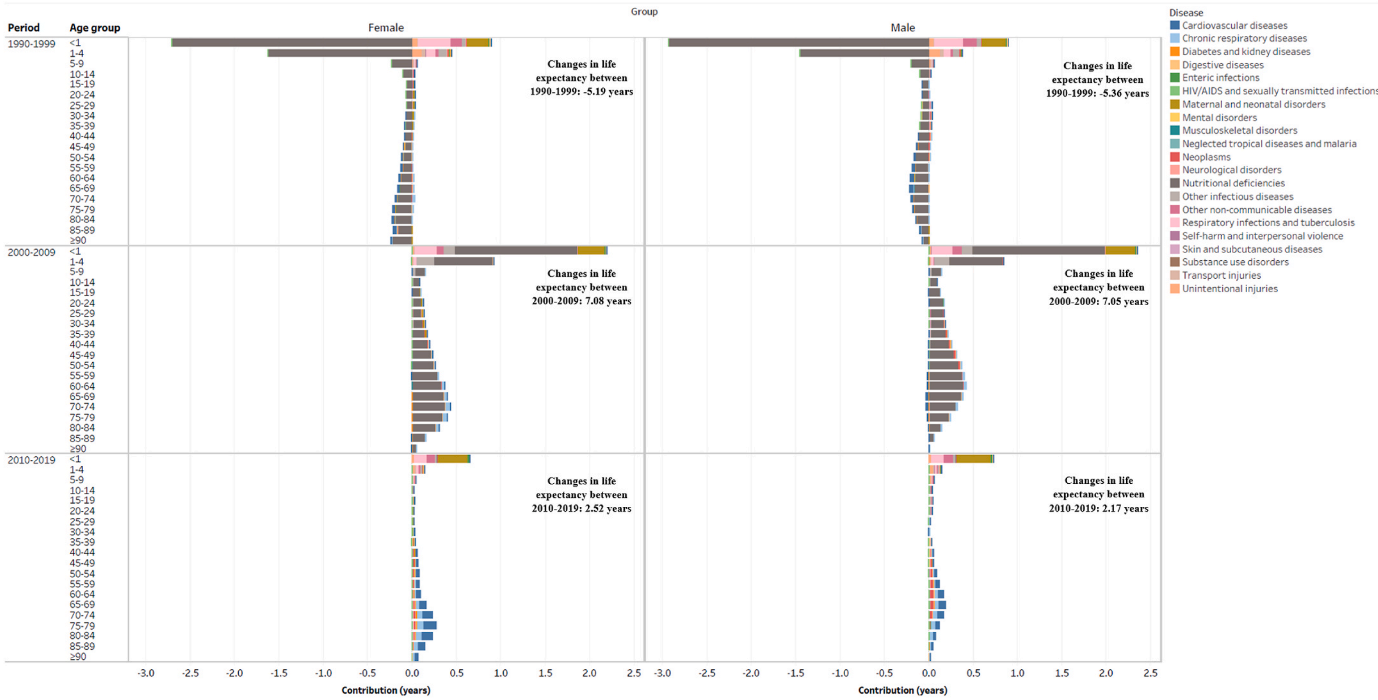

Fig. 2. Contribution of age- and cause-specific death to the changes in life expectancy at birth in North Korea. Note: The sum of values represents the changes in life expectancy at birth, and positive values indicated positive contributions to increasing life expectancy, whereas negative values represent contributions to decreasing life expectancy.

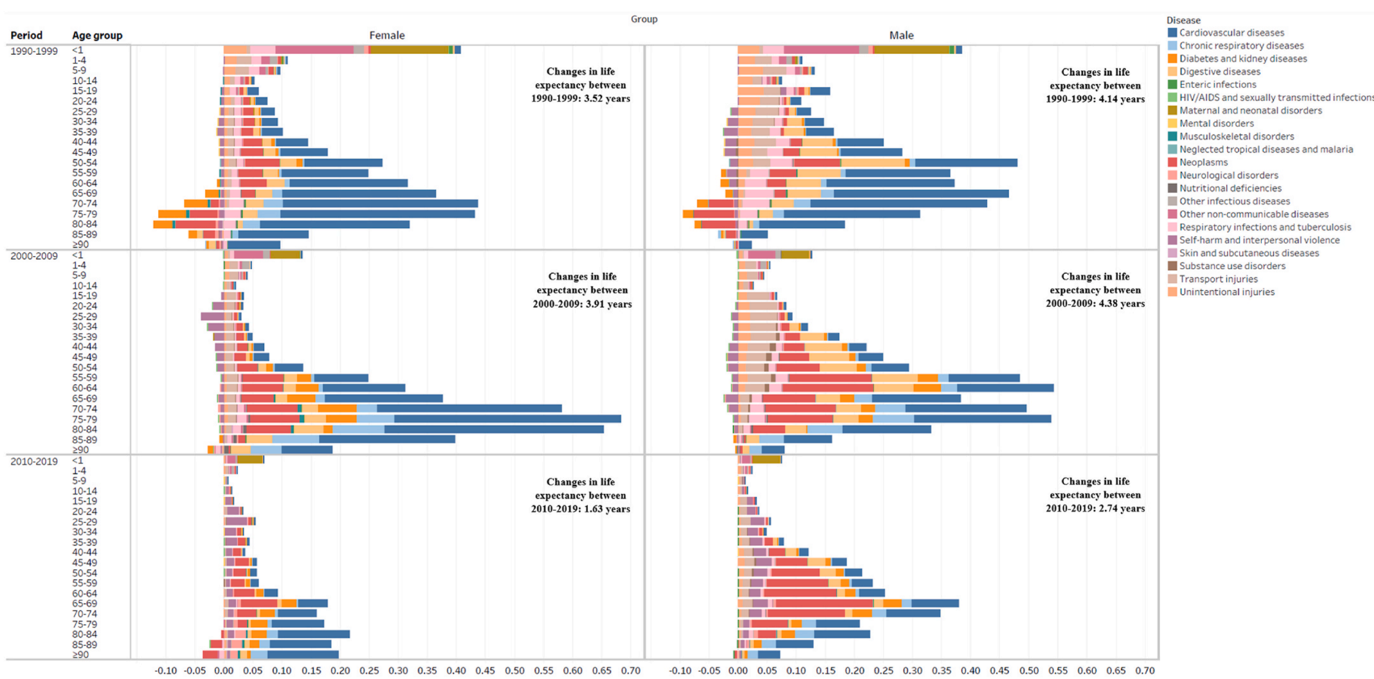

Fig. 3. Contribution of age- and cause-specific death to the changes in life expectancy at birth in South Korea Note: The sum of values represents the changes in life expectancy at birth, and positive values indicated positive contributions to increasing life expectancy, whereas negative values represent contributions to decreasing life expectancy.

3.52 years for women, and the contributions of children younger than five years and older adults were larger than those of other age groups in both sexes. The main cause-specific contributors to these life expectancy gains were decreased death rates for cardiovascular disease, digestive diseases, and respiratory infections and tuberculosis, accounting for the majority of life expectancy gains in both males and females (71.9% for males and 76.9% for females). The contributions to decreasing life expectancy were increasing diabetes and kidney disease and neoplasm death rates in older ages (≥70 years) and self-harm and interpersonal violence among middle-aged adults.

Between 2000 and 2009, South Korea experienced an increase in life expectancy, resulting in increases of 4.38 and 3.91 years in men and women, respectively. This increased life expectancy was mainly due to decreased deaths by cardiovascular diseases, digestive diseases, and neoplasms among older adults in both sexes. Therefore, the decreasing death rate from chronic diseases, including cardiovascular diseases, digestive diseases, and neoplasms, contributed to increasing life expectancy, but with a smaller contribution than between 1990 and 1999 (see Supplementary Appendix 5).

3.4. Life expectancy gap between the two Koreas and age and cause-specific contributions to the gap

Regarding the gap in life expectancy between North and South Korea, both South Korean men and women had higher life expectancies than their North Korean counterparts. The life expectancy gap was 3.78 and 6.20 years for men and women, respectively, in 1990, and the life expectancy gap was largest at 13.27 years in men and 14.91 years in women in 1999 (see Supplementary Appendix 2). Although the life expectancy gaps between North and South Korea decreased to 7.87 years in men and 8.81 years in women by 2003, these gaps widened and persisted to 10.29 years in men and 9.51 years in women in 2019 (Fig. 1) (see Supplementary Appendix 2).

Table 1 shows the contribution years by age group and level 1 disease category to life expectancy gap between North and South Korea from 1990 to 2019. CMNNs among children aged 0–9 years were the most significant contributors to the increasing life expectancy gap before 2000. When the gap between the two Koreas was largest in males (13.27 years) and females (14.91 years) in 1999, CMNNs among children aged 0–9 years accounted for over 45% of this life expectancy gap among males (−6.86 years) and females (−6.77 years). However, the contribution years of NCDs increased after 2000. Notably, NCDs contributed to about 8 out of 10 years of life expectancy gap between the two Koreas in 2019.

More specifically, Fig. 4 shows the age-specific contributions to the life expectancy gap between North and South Korea in 1990, 1999, 2009, and 2019, respectively. The contribution to the life expectancy gap between the two Koreas has shifted from children to older groups over the past three decades. In 1990, the main age-specific contributors were deaths among children under one year and 1–4 years, accounting for over 50% of the life expectancy gap in both males and females, as the mortality gap between the two Koreas among those age groups was relatively higher than in the other age groups. When the largest life expectancy gap between the two Koreas occurred in 1999, the years contributed by these age groups were substantially greater (e.g., contributed years of under-1 age group: -5.11 years (percentage of the life expectancy gap: 38.5%) for males and −4.70 years (percentage of the life expectancy gap: 31.5%) for females). In 2009 and 2019, the contribution to the gap of age less than one year rapidly decreased by −1.21 years (percentage of the life expectancy gap: 11.7%), −0.57 years (percentage of the life expectancy gap: 6.0%) for females and −1.35 years (percentage of the life expectancy gap: 14.0%), −0.63 years (percentage of the life expectancy gap: 6.2%) for males in 2009 and 2019, respectively (see Supplementary Appendix 6). On the contrary, the contribution to the life expectancy gap among those aged over 50 years gradually increased from 1990 to 2009. Notably, the contributed years to the life expectancy gap among women aged 70–74 years changed from −0.34 years (percentage of the life expectancy gap: 5.5%) to −1.15 years (percentage of the life expectancy gap: 12.0%) from 1990 to 2019. The contribution years of the corresponding male also changed from 0.02 years (percentage of the life expectancy gap: -0.6%) to −1.18 years (percentage of the life expectancy gap: 11.5%) (see Supplementary Appendix 6).

The contributors to the life expectancy gap between the two Koreas shifted from communicable, maternal, neonatal, and nutritional diseases to non-communicable diseases over the past three decades (Fig. 5). The major cause-specific contributors to increasing the life expectancy gap were chronic respiratory diseases, maternal and neonatal disorders,

Table 1
Contribution years to life expectancy gap between the two Koreas by disease and age group from 1990 to 2019.

Year	Age group	Female				Male			
		Total	CMNNs	NCDs	Injuries	Total	CMNNs	NCDs	Injuries
		Year (%)	Year (%)	Year (%)	Year (%)	Year (%)	Year (%)	Year (%)	Year (%)
1990	0–9	−3.64 (58.7)	−2.90 (46.8)	−0.4 (6.5)	−0.34 (5.5)	−3.75 (99.3)	−2.91 (77.0)	−0.48 (12.6)	−0.36 (9.6)
	10–24	−0.21 (3.4)	−0.12 (1.9)	−0.02 (0.4)	−0.07 (1.1)	−0.18 (4.8)	−0.06 (1.46)	−0.04 (0.9)	−0.09 (2.4)
	25–49	−0.71 (11.4)	−0.22 (3.6)	−0.347 (5.6)	−0.13 (2.2)	−0.07 (1.9)	−0.04 (1.2)	−0.00 (0.1)	−0.02 (0.6)
	50–69	−1.22 (19.6)	−0.10 (1.6)	−1.11 (18.0)	−0.01 (0.1)	0.04 (-1.1)	0.03 (-0.8)	−0.11 (2.9)	0.13 (-3.3)
	Over 70	−0.43 (6.9)	−0.04 (0.6)	−0.43 (6.9)	0.04 (-0.6)	0.19 (-4.9)	0.08 (-2.2)	0.05 (-1.2)	0.06 (-1.5)
	Total	−6.20 (100)	−3.38 (54.4)	−2.31 (37.3)	−0.51 (8.3)	−3.78 (100)	−2.90 (76.8)	−0.58 (15.3)	−0.30 (7.9)
1999	0–9	−7.26 (48.7)	−6.77 (45.4)	−0.31 (2.1)	−0.18 (1.2)	−7.46 (56.2)	−6.86 (51.7)	−0.33 (2.5)	−0.24 (1.81)
	10–24	−0.53 (3.6)	−0.39 (2.6)	−0.09 (0.6)	−0.06 (0.4)	−0.73 (5.5)	−0.35 (2.6)	−0.12 (0.9)	−0.27 (2.0)
	25–49	−1.50 (10.0)	−0.64 (4.3)	−0.71 (4.8)	−0.14 (1.0)	−1.26 (9.5)	−0.68 (5.1)	−0.42 (3.2)	−0.14 (1.1)
	50–69	−2.70 (18.1)	−0.73 (4.9)	−1.9 (13.0)	−0.03 (0.2)	−2.29 (17.2)	−0.86 (6.5)	−1.46 (11.0)	0.06 (-0.5)
	Over 70	−2.92 (19.6)	−1.60 (10.7)	−1.4 (9.2)	0.05 (-0.3)	−1.54 (11.6)	−0.95 (7.2)	−0.68 (5.1)	0.05 (-0.4)
	Total	−14.91 (100)	−10.13 (68.0)	−4.41 (29.6)	−0.36 (2.4)	−13.27 (100)	−9.68 (72.9)	−3.1 (23.3)	−0.5 (3.8)
2009	0–9	−1.56 (15.1)	−1.10 (10.7)	−0.28 (2.7)	−0.18 (1.8)	−1.73 (17.9)	−1.18 (12.2)	−0.31 (3.2)	−0.23 (2.4)
	10–24	−0.25 (2.4)	−0.07 (0.6)	−0.11 (1.1)	−0.07 (0.6)	−0.63 (6.5)	−0.05 (0.5)	−0.15 (1.6)	−0.4 (4.2)
	25–49	−1.06 (10.2)	−0.15 (1.4)	−0.83 (8.1)	−0.08 (0.8)	−1.28 (13.3)	−0.13 (1.4)	−0.8 (8.3)	−0.33 (3.4)
	50–69	−3.13 (30.4)	−0.15 (1.4)	−2.90 (28.1)	−0.08 (0.8)	−3.23 (33.5)	−0.17 (1.8)	−2.96 (30.7)	−0.03 (0.3)
	Over 70	−4.32 (41.9)	−0.23 (2.3)	−4.16 (40.3)	0.07 (-0.7)	−2.81 (29.1)	−0.09 (0.9)	−2.84 (29.4)	0.1 (-1.0)
	Total	−10.31 (100)	−1.70 (16.5)	−8.28 (80.3)	−0.34 (3.3)	−9.65 (100)	−1.66 (17.2)	−7.11 (73.7)	−0.88 (9.1)
2019	0–9	−0.742 (7.8)	−0.50 (5.3)	−0.15 (1.6)	−0.09 (0.9)	−0.83 (8.1)	−0.55 (5.3)	−0.14 (1.4)	−0.11 (1.1)
	10–24	−0.234 (2.5)	−0.05 (0.5)	−0.11 (1.14)	−0.08 (0.8)	−0.59 (5.7)	−0.03 (0.3)	−0.16 (1.6)	−0.37 (3.6)
	25–49	−1.06 (11.2)	−0.11 (1.2)	−0.81 (8.5)	−0.14 (1.4)	−1.6 (15.6)	−0.15 (1.5)	−0.98 (9.5)	−0.47 (4.6)
	50–69	−3.27 (34.4)	−0.13 (1.3)	−3.03 (31.9)	−0.11 (1.2)	−3.76 (36.5)	−0.16 (1.6)	−3.44 (33.4)	−0.13 (1.3)
	Over 70	−4.20 (44.1)	−0.11 (1.2)	−4.15 (43.6)	0.06 (-0.6)	−3.5 (34.0)	−0.02 (0.2)	−3.56 (34.6)	0.09 (-0.9)
	Total	−9.51 (100)	−0.9 (9.5)	−8.26 (86.8)	−0.36 (3.8)	−10.29 (100)	−0.95 (9.2)	−8.33 (81.0)	−1.02 (9.9)

Note: Since the estimates, calculated using unrounded data, were rounded to two (one) decimal points, this may produce a situation where some total values are not equal to sums.
CMNNs: Communicable, maternal, neonatal, and nutritional diseases.
NCDs: Non-communicable diseases.

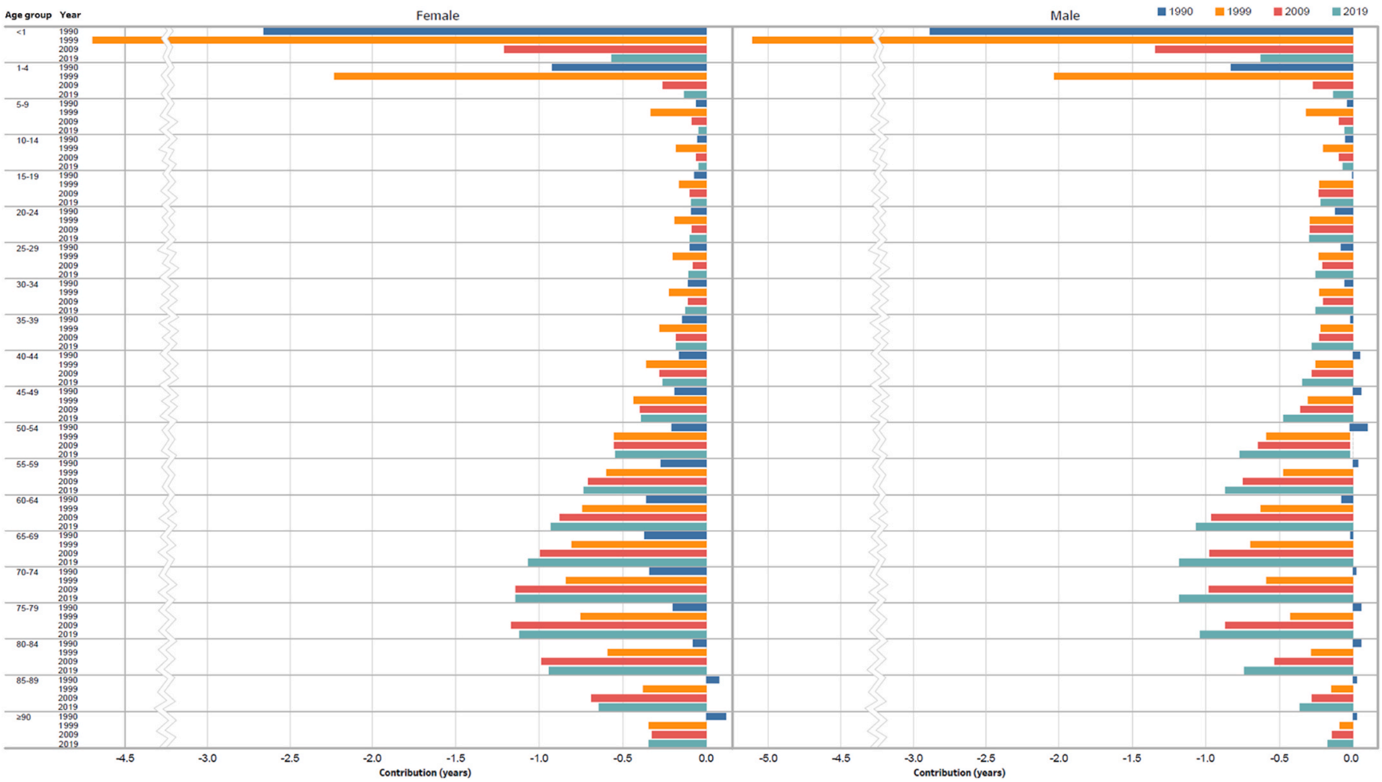

Fig. 4. Age-specific contribution to the gap in life expectancy at birth between North and South Korea in 1990, 1999, 2009, and 2019. Note: The sum of values represented the life expectancy gap. Negative values indicated the advantage of South Korea in increasing the life expectancy gap, whereas positive values indicated the advantage of North Korea in closing the life expectancy gap.

and respiratory infections and tuberculosis in 1990. When the largest life expectancy gap was observed around 1999, nutritional deficiencies were the first leading cause of death, and the contribution years increased substantially from −0.17 (percentage of the life expectancy gap: 4.6%) and −0.17 (percentage of the life expectancy gap: 2.7%) years in 1990 to −7.28 (percentage of the life expectancy gap: 54.9%) and −7.59 (percentage of the life expectancy gap: 50.9%) years in 1999 for male and female, respectively. However, in 2009, cardiovascular diseases (contribution year: -4.65 years, percentage of the life expectancy gap: 48.2% for men; contribution year: 5.14 years, percentage of the life expectancy gap: 49.8% of the life expectancy gap for women) and chronic respiratory diseases (contribution year: 1.88 years, percentage of the life expectancy gap: 19.5% for men; contribution year: -2.02 years, percentage of the life expectancy gap: 19.6% for women) mainly contributed to persisting the life expectancy gap despite rapid reductions in contribution years for nutritional deficiencies (−0.05 years for both men and women). In 2019, the North-South life expectancy gap of 10.29 years for men and 9.51 years for women was also mainly caused by the mortality gap of cardiovascular diseases, contributing 5.45 years (percentage of the life expectancy gap: 53.0%) for males and 5.42 years (percentage of the life expectancy gap: 56.9%) for females in favour of South Korea (see Supplementary Appendix 6).

Fig. 6 shows the age- and cause-specific contribution to the life expectancy gap between the two Koreas from 1990 to 2019. Red shades indicate mortality in North Korea was higher than in South Korea, grey shades indicate little difference, and blue shades indicate mortality in South Korea was higher than in North Korea. Over the three decades, most of the cause-specific death rates were higher in North Korea among children and young and middle-aged adults as shades of red were dominantly presented. In 1990, contributions to the life expectancy gap were mainly concentrated in communicable diseases among those under five years in both sexes. Particularly, the darker red indicates that the contribution of nutritional deficiencies among those under 1 year was 3.06 years (percentage of the life expectancy gap: 23.0%) in males and 2.83 years (percentage of the life expectancy gap: 19.0%) in females in 1999. The contribution of this age group has gradually attenuated since 2000. However, the large gap in life expectancy has remained and is mostly attributable to increasing mortality differences between the two countries among elderly people due to cardiovascular diseases, indicated by the change in colour of cardiovascular diseases and chronic respiratory diseases among those aged over 70 years from light blue in 1990 to red in 2019. The contribution of cardiovascular diseases among those over 70 years was 0.24 years (percentage of the life expectancy gap: -6.5%) in males and 0.37 years (percentage of the life expectancy gap: -6.0%) in females in 1990, indicated by light blue colour. However, the contribution of corresponding disease and age group was changed to −2.72 years (percentage of the life expectancy gap: 26.4%) in males and −3.21 years (percentage of the life expectancy gap: 33.9%) in females in 2019, indicated by light red colour (see Supplementary Appendix 6).

4. Discussion

Through the analysis of GBD data, this study investigated trends in life expectancy in North and South Korea and analysed the contributions of different age- and cause-specific deaths to the life expectancy gap between the two Koreas over the past 30 years. Life expectancy increased steadily over the study years in both North and South Korea. However, the gap in life expectancy widened during this period. Particularly, in the mid-1990s, as death rates due to nutritional deficiencies among North Korean children increased, life expectancy in North Korea decreased rapidly. As a result, the gap in life expectancy between the two Koreas widened rapidly and significantly. Since the 2000s, North Korea's death rates attributable to nutritional deficiencies have decreased, and life expectancy has increased, but the gap in life expectancy between the two Koreas has continued to widen. This is because South Korea has steadily reduced mortality from chronic

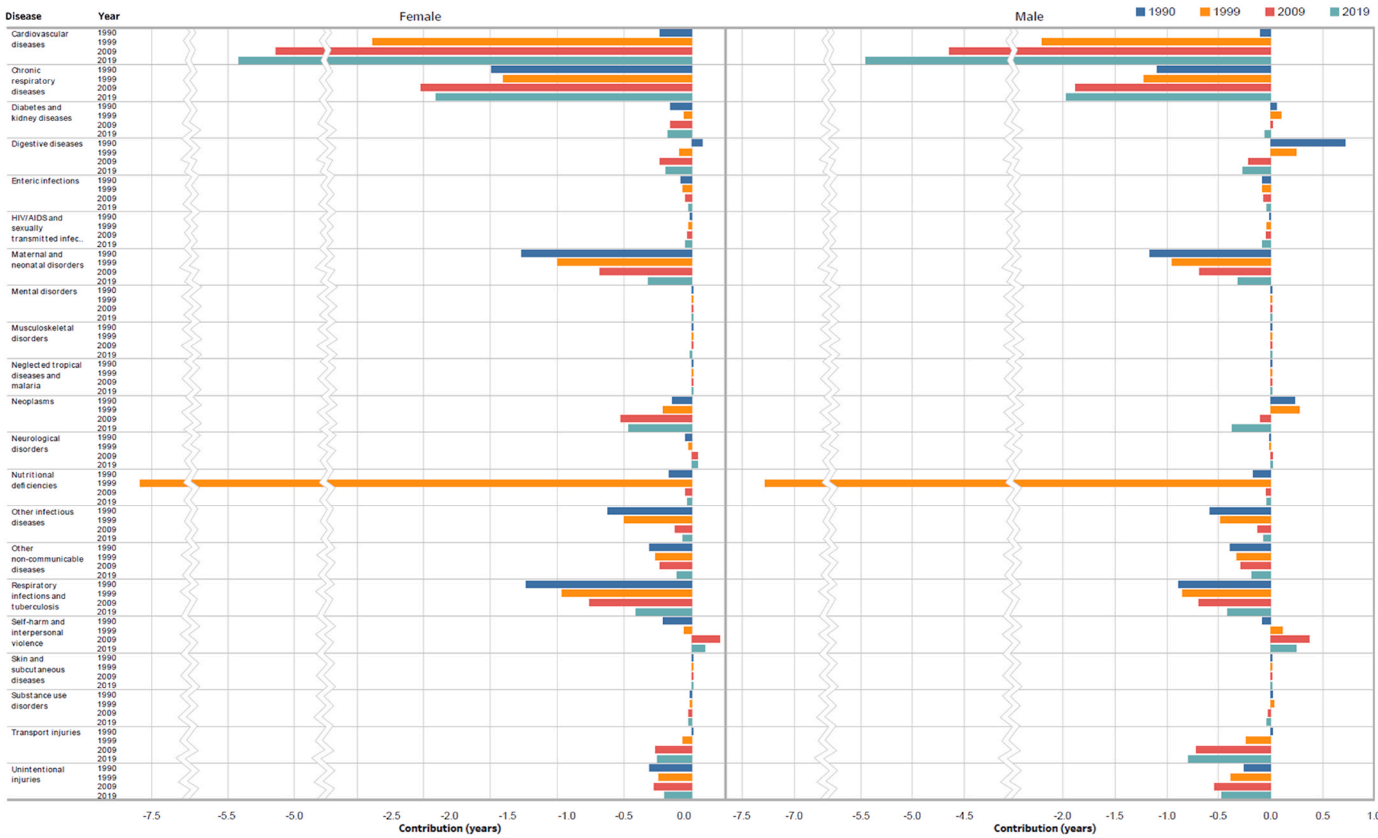

Fig. 5. Cause-specific contribution to the gap in life expectancy at birth between North and South Korea in 1990, 1999, 2009, and 2019. The sum of values represented the life expectancy gap. Negative values indicated the advantage of South Korea in increasing the life expectancy gap, whereas positive values indicated the advantage of North Korea in closing the life expectancy gap.

diseases, particularly in the middle-aged and older age group, while North Korea has not (E. H. Lee et al., 2022).

Before we discuss our findings, some limitations of this study should be mentioned. There is a concern related to the use of GBD data. Since this study used modelled data, estimates may heavily rely on the quality of primary and modelling processes. Although GBD 2019 was a high-quality study in a comparative setting, as a general limitation of GBD studies that have been reported elsewhere (Murray, 2022), estimates for certain countries, including North Korea, are mostly based on modelling by substituting data from similar regions due to the paucity of high-quality primary data (Clarsen et al., 2022). Very limited primary data underpin the estimates of the North Korean burden of diseases in the GBD 2019. We searched the GBD 2019 data input sources (components: mortality and population and causes of death; locations: Democratic People's Republic of Korea) and found eight sources of data from North Korea used by the GBD 2019 (see Supplementary Appendix 7). Most of these data sources from North Korea were reported after the 2000s, and larger uncertainty was observed during the 1990s compared to the 2000s. Variations in trends in the life expectancy of North Koreans were reported among different international organisations, such as the World Bank and the UN, and showed that discordance in life expectancy was higher in earlier periods. However, concordance has increased in recent time periods (see Supplementary Appendix 8), suggesting that differences in life expectancy may have resulted from data availability.

A variety of international organisations, including the World Health Organization (WHO), World Bank, and the UN, have databases with population and death statistics, but these sources vary in quality and completeness according to measurement and estimation methods (Wang et al., 2020). For example, the WHO provides mortality for all member countries in 5-year periods but does not generate estimates of the population by age group (World Health Organization, 2022), and the World Bank and UN Population Division provide data on both population and number of deaths by age group in each year (United Nations, 2022; World Bank, 2022). Although these sources provide diverse estimates, none of them except the GBD 2019 generated cause-specific death numbers for 5-year age groups starting in 1990, which is essential for decomposing life expectancy. Furthermore, the GBD 2019 used a set of standardised estimation methods, and a coherent statistical analysis measure with multiple data sources, including censuses, vital statistics, disease registries, and other sources, and adhered to the Guidelines for Accurate and Transparent Health Estimates Reporting (GATHER) standards, which enables the comparison of health statuses between countries (Murray et al., 2020). With these benefits of using GBD data, which remains the best available data to date, our findings informed age- and cause-specific contributions to the life expectancy gap between the two Koreas. Even though direct validation of GBD estimates in North Korea was limited due to a lack of primary data, Bahk and colleagues (Bahk et al., 2018) assumed that the patterns of cause-specific deaths in North Korea would be similar to those of the past in South Korea, and this assumption was verified using GBD estimates. However, estimates made due to the lack of primary data remain a major limitation of this study and the findings should be cautiously interpreted, particularly with respect to the fluctuation in life expectancy in North Korea during the 1990s. Thus primary research on measuring various health outcomes in the real world should be conducted to fill in the gaps in this sparse evidence (C. Chen et al., 2022).

The life expectancy gap between the two Koreas has grown by about ten years over the three decades, which is consistent with a previous study (Bahk et al., 2018). Importantly, this is an alarming estimate because none of the countries that experienced division saw such a large life expectancy gap between newly formed states. In Germany, for example, the life expectancy in West and East Germany was almost

Fig. 6. Fig. 5. Age- and cause-specific contribution to the life expectancy gap between North and South Korea in 1990, 1999, 2009, and 2019. Note: Red shades indicate where the contribution of the age group and cause of death to mortality in North Korea was higher than in South Korea, grey shades indicate little difference, and blue shades indicate instances in which mortality in South Korea was higher than in North Korea. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

identical in 1960, but the difference in life expectancy between West and East Germany had grown to about three years before German unification due to political instability and economic downturns in East Germany (Mackenbach, 2013). We also posit that a key explanation for the large life expectancy gap between the two Koreas is a complex interplay of two major factors, the differences in economic and political circumstances and healthcare systems.

Our findings demonstrated a large life expectancy gap between the two Koreas for 30 years. From the mid-1990s to the early 2000s, in particular, life expectancy gap between the two Koreas was the largest because life expectancy in North Korea substantially reduced with the highest annual percent changes. In contrast, life expectancy in South Korea increased with higher annual percentage changes during these periods. Increased mortality due to nutritional deficiency among those aged under five was one of the major contributors to this gap from the mid-1990s to the early 2000s, consistent with previous study (McMichael et al., 2004). A possible explanation is that severe economic deterioration occurred during these periods in North Korea as the Soviet Union collapsed and began to cut financial aid, and in the wake of massive floods and drought, thereby harming health infrastructure and food production and resulting in poor living conditions and widespread famine over a decade (Bhatia & Thorne-Lyman, 2002; Goodkind & West, 2001; Spoorenberg & Schwekendiek, 2012). Other evidence also demonstrated that 15.6% of children less than seven years of age were acutely malnourished, a third of whom had severe malnutrition (Bhatia & Thorne-Lyman, 2002) and the prevalence of child malnutrition peaked in 1998, which may be related to higher under-5 mortality from nutritional deficiencies in North Korea during the famine. North Korea appealed to the international community, including the World Food Programme (WFP) and the United Nations Children's Fund (UNICEF), for assistance and received food and other subsidies from WFP and other donor countries for vulnerable groups, such as children and adolescents and pregnant and lactating women (Bhatia & Thorne-Lyman, 2002). Such international aid had a positive effect on a rebound in life expectancy as acute and chronic malnutrition among North Korean children has steadily reduced (S.-K. Lee, 2017). and deaths for nutritional deficiencies in childhood, particularly infants under 1 year, decreased due to improvements in socioeconomic conditions and better nutrition. However, gains in life expectancy in North Korea are still lower than in South Korea after early-2000s, suggesting that this situation in North Korea might remain precarious in the long term due to continuously poor living conditions and social infrastructure even though the worst impact of the deteriorating economic conditions on health subsided in the short term.

The persisting gap in life expectancy has primarily been driven by differences in the mortality rates of chronic diseases after the early 2000s. Notably, chronic diseases contribute to about 8 out of 10 years of life expectancy gap between the two Koreas. According to the World Health Organization, over 80% of all deaths in North Korea have been caused by chronic diseases, and half were reported to have been caused by cardiovascular disease (World Health Organization, 2018). Similarly, the GBD 2019 estimated that the age-standardised death rates from chronic diseases in North Korea decreased from 806 to 694 deaths per 100,000 population between 1990 and 2019, which is markedly high compared to 319 deaths due to chronic diseases in South Korea in 2019. (Institute for Health Metrics and Evaluation, 2022) This suggests that the burden of chronic disease in North Korea is quite large and poorly managed. People with poor living conditions may have priorities of trying to achieve economic growth and are less likely to manage their health when faced with an economic crisis, resulting in low quality of life and chronic diseases associated with risky health behaviours, such as smoking and drinking (E. H. Lee et al., 2022). Moreover, the level of chronic malnutrition increased with increasing age. (S.-K. Lee, 2017). Regarding the healthcare system in North Korea, the management of chronic diseases is neglected in North Korea as the government of North Korea has allotted only one research agenda on non-communicable diseases, i.e., mental health, and seven communicable disease-oriented policy agendas among 16 priorities in the Medium Term Strategic Plan 2016–2020 (Park et al., 2019). This is similar to the healthcare system and policy in low- and middle-income countries (Geneau et al., 2010), but demographic trends and population and disease burden composition paradoxically seem to be rather close to those of high-income and upper-middle-income countries (Hong & Kim, 2021; E. H. Lee et al., 2022) (see Supplementary Appendix 9), which implies that an inadequate response to non-communicable diseases may cause a considerable disease burden. Insufficient healthcare system for management of chronic diseases and poor living conditions may lead to lower gains in life expectancy in North Korea than in South Korea after 2000. Thus, the sustainable development of social infrastructure and economic growth should be pursued for further improvements in population health and embracing a proactive approach to chronic disease management should be also considered in North Korea.

In contrast, South Korea experienced a considerable improvement in life expectancy, shown to be attributable to decreases in deaths from chronic diseases, including cardiovascular disease and neoplasms among older people. One previous study demonstrated that decreased mortality among middle- and old-aged people made the most significant contribution to the rapid increase in life expectancy, accounting for approximately 70% of the total increasing life expectancy after the early-2000s (Kim et al., 2020). Other studies (Yang et al., 2010) showing that increasing life expectancy was mainly due to decreased mortality from chronic diseases support our findings. South Korea is one of the countries that has experienced rapid growth in life expectancy over the past five decades and is likely to have the highest life expectancy by 2030 (Kontis et al., 2017). The increased life expectancy is attributable to improvements in the standard of living and universal access to high-quality healthcare services under national health insurance (Kwon, 2009). Particularly, South Korea introduced compulsory health insurance for workers in large corporations in 1977 and gradually extended it to the self-employed, achieving universal coverage for its population in 1989 (Kwon, 2009). Moreover, national and community-based health promotion programmes have been provided to reduce risky health behaviours. Male smoking prevalence decreased by about half, from 71.7% in 1992 to 39.7% in 2016 (Chang et al., 2019), and the highest treatment and control rates, as well as the lowest prevalence of hypertension, were observed in 2019 (Zhou et al., 2021). However, in accordance with previous findings (Kim et al., 2020), South Korea has faced a stagnation of life expectancy from declines in the contribution of cardiovascular disease in recent years. It is difficult to identify whether this stagnating life expectancy will remain and warrants further investigation.

This study may contribute to a better understanding of the life expectancy gaps between North and South Korea, and age- and cause-specific contributions to these gaps can be seen more clearly over the last three decades. The major contributors to the gaps changed from communicable, maternal, neonatal, and nutritional diseases among children to non-communicable diseases among older people. Although further research is needed to understand the factors related to the trends in life expectancy gaps, one possible explanation for the life expectancy gap between the two Koreas might be related to differences in their socioeconomic, political, and cultural environments and health system. Improvement in these socioeconomic environments and health policies may increase life expectancy in North Korea and reduce the life expectancy gap between the two Koreas. Thus, government and international communities, including North and South Korea, should devote additional resources to these areas, and sustained and coordinated action is needed.

Author contributions

Minjae Choi and Yo Han Lee devised the study concept. Minjae Choi and Joshua Kirabo Sempungu did data analysis and produced a table and figures. Minjae Choi and Yo Han Lee wrote the first draft of the

manuscript and all authors contributed to editing and commenting on the final version of the manuscript and figures. The corresponding author had full access to all the data in this study and had final responsibility for the decision to submit for publication.

Financial disclosure statement

Yo Han Lee was supported by grants from the National Research Foundation (NRF) of Korea funded by the Ministry of Science and ICT [grant number: NRF-2021R1G1A1095517], Korea Institute for Health and Social Affairs, and Korea University. Minjae Choi was supported by grants from the National Research Foundation (NRF) of Korea funded by the Ministry of Education [grant number: NRF-2022R1A6A3A01086222]. These funding bodies played no role in the design, collection, analysis and interpretation of the data.

Declaration of competing interest

The authors declare no competing interests. The funding body played no role in the design, data collection, analysis, and interpretation of the data.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssmph.2023.101445.

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