

Mortality Patterns in Papua New Guinea

Dr. Urarang Kitur

ORCID Identifier: 0000-0001-9830-0957

Submitted in total fulfilment for the degree of

Doctor of Philosophy

Melbourne School of Population and Global Health

THE UNIVERSITY OF MELBOURNE

February 2020

Abstract

Introduction

Little is known about mortality rates and cause of death (COD) patterns in Papua New Guinea (PNG), because there is a lack of high-quality mortality data. The use of demographic and statistical models which use no local data to estimate mortality has created much uncertainty about actual mortality and COD patterns in PNG. This thesis aims to address this knowledge gap by applying novel demographic and statistical methods to available local data to estimate all-cause mortality (adult mortality, child mortality and life expectancy) and COD by sex for PNG and each of its provinces.

Methods

A range of demographic and statistical methods were used to estimate mortality rates and COD patterns. The adult mortality rate (45q15) was estimated using the orphanhood method applied to data reported in the 2000 and 2011 national censuses. The under-five mortality rate (5q0) was calculated using the maternal age cohort method using summary birth history data from the 2000 and 2011 national censuses. The 45q15 and 5q0 estimates were entered into model life tables to produce estimates of life expectancy at birth. Cause-specific mortality fractions (CSMFs) were calculated as the average of estimates obtained from two methods: the empirical cause method and the expected cause patterns method. A composite index was constructed using the means of education, economic and health access indicators from various data sources to assess the plausibility of mortality and COD estimates.

Results

The 45q15 for PNG in 2011 was estimated as 269 per 1,000 for males and 237 per 1,000 for females with substantial inter-provincial variations in both sexes. The under-five mortality was

estimated as 68 per 1,000 live births for males and 58 per 1,000 live births for females, and life expectancy was 62.0 years for males and 64.3 years for females. Provinces with a low composite index had comparatively high levels of 45q15 and 5q0, and low life expectancy for both sexes. Conversely, provinces with a higher composite index reported lower 45q15 and 5q0, and higher life expectancy.

Both Infectious diseases and noncommunicable diseases (NCDs) accounted for 45% of the deaths each, with the former accounting for more than half the deaths in several provinces (e.g. Gulf and Sandaun). Provinces with higher CSMFs from emerging NCDs (e.g. ischaemic heart disease and stroke) were those in which socioeconomic status was comparatively high.

Conclusion

The major findings of this thesis are that adult mortality in PNG is relatively high compared with other low- and middle-income countries and that provincial variations in all-cause mortality and COD correlate with levels of development as measured by the composite index. The level of epidemiological transition is not uniform across the country with noncommunicable diseases emerging in provinces with higher levels of socioeconomic development. It is recommended that PNG urgently address the major causes of persistently high premature adult and child mortality and strengthen the collection of routine mortality and COD data through verbal autopsies to ensure the availability of reliable and timely data for policymakers to improve PNG's population health.

Declaration

This is to certify that:

- (1) the thesis comprises only my original work towards the PhD except where indicated in the Preface,
- (2) due acknowledgment has been made in the text to all other material used,
- (3) the thesis is less than 100,000 words in length, exclusive of tables, maps, bibliographies and appendices.

Dr. Urarang Kitur, February 2020

Acknowledgements

This research would not have been possible without the support of many people.

Firstly, many thanks to my Supervisors Dr Tim Adair and Professor Alan Lopez for giving me the opportunity to undertake this study within such a stimulating environment. It has been an exceptional experience and I feel privileged to have shared in your wealth of knowledge. I greatly value your patience, interest and insight you have provided towards my professional development. I appreciate the support and encouragement of Professor Ian Riley, and the chair of the Advisory Committee Professor Peter McDonald.

I am grateful for the support of the Australian citizens through the Australian Awards Scholarship (AAS), which paid for my tuition fees, academic support and living allowances during my studies in Australia. Thanks to AAS for engaging the services of Elite editing services to edit my work restricted to Standards D and E of the Australian Standards for Editing Practice.

I thank the National Department of Health (NDoH), the Papua New Guinea Institute of Medical Research (PNGIMR) and the National Statistics Office (NSO) for the data I used in this research, especially to Mr Ila Rouka of NDoH and Mr Benjamin Haichim of NSO.

I appreciate the friendship and support of my fellow graduate research students from the Melbourne School of Population and Global Health. It has been a pleasure studying alongside you and I wish you all the best of luck in completing your studies.

To my family - my wife Joyce and children Julianne and Joshua, thanks for your support in Melbourne in the last four years. To my other two children Grace and Sammy who could not make it to Australia, thanks for your understanding and patience. To all relatives and friends, thank you for your undivided support.

Statement of Contribution to Jointly Published Works

Estimating Adult Mortality in Papua New Guinea, 2011

Kitur, U., Adair, T., & Lopez, A. D. (2019). Estimating adult mortality in Papua New Guinea, 2011. *Population Health Metrics*, 17(1), 1–14. <https://doi.org/10.1186/s12963-019-0184-x>

I conceptualized the research theme and analytical framework, together with TA and ADL. I conducted the data analysis and was responsible for drafting the manuscript. TA and AL critically revised the manuscript. The final draft was approved by all authors.

Patterns of All-Cause Mortality in Papua New Guinea, 2011

Kitur, U., Adair, T., & Lopez, A. D. (2019). Patterns of all-cause mortality in Papua New Guinea, 2011. *Asia Pacific Journal of Public Health*, 31(4), 315–324. <https://doi.org/10.1177%2F1010539519841492>

I conceptualized the research theme and analytical framework, conducted the data analysis and drafted the manuscript. TA and ADL assisted with the research theme and framework and critically revised the manuscript. We all approved the final draft.

Estimating the pattern of causes of death in Papua New Guinea

Kitur, U., Adair, T., Riley, I., & Lopez, A. D. (2019). Estimating the pattern of causes of death in Papua New Guinea. *BMC Public Health*, 19(1), 1322. <https://doi.org/10.1186/s12889-019-7620-5>

I conceptualised the research theme and analytical framework with the help of TA, IR and ADL. I conducted the data analysis with advice from TA and drafted the manuscript. TA, IR and ADL critically revised the manuscript. All authors approved the final draft.

Table of Contents

Abstract	i
Declaration.....	iii
Acknowledgements	iv
Statement of Contribution to Jointly Published Works.....	v
Table of Contents	vi
List of Figures	ix
List of Tables	ix
List of Key Acronyms.....	xi
Chapter 1: Introduction	1
1.1 Introduction	1
1.2 Research Aim and Objectives.....	2
1.3 Significance of this study.....	2
1.4 Outline of the thesis.....	2
1.5 Country Profile	4
1.5.1 Geography	4
1.5.2 Demography	6
1.5.3 Culture and ethnicity	9
1.5.4 Economic development.....	9
1.5.5 Administration	10
1.5.6 Education	11
1.5.7 Health system	12
1.6 Summary of Chapter	13
Chapter 2: Review of Literature on Mortality and Causes of Death in Papua New Guinea	14
2.1 Importance of Mortality and Cause of Death Data	14
2.1.1 Global epidemiological transition	16
2.2 Mortality in Papua New Guinea.....	20
2.2.1 History of disease in Papua New Guinea.....	20
2.2.2 All-cause mortality.....	21
2.2.3 Causes of death	27
2.3 Summary of Mortality and COD Data from PNG	33
Chapter 3: Review of Sources of Mortality and Causes of Death in Papua New Guinea	35
3.1 Population-Based Mortality Datasets	35
3.1.1 Civil registration and vital statistics system	36
3.1.2 National censuses.....	38
3.1.3 Demographic and health surveys	40
3.1.4 Health and demographic surveillance systems	41
3.2 Routine Health Facility-Based Mortality Datasets	43
3.2.1 Discharge Health Information System.....	43
3.2.2 National Health Information System.....	46
3.2.3 Electronic National Health Information System.....	49
3.3 Other Performance Monitoring Research Branch Data.....	52
3.3.1 Maternal mortality register	52
3.3.2 Paediatric Hospital Reporting programme.....	52
3.4 Summary of Sources of Mortality and COD Data in PNG	56

Chapter 4: Estimating Adult Mortality in Papua New Guinea.....	57
4.1 Introduction	57
4.2 Methods Available to Estimate Adult Mortality	73
4.2.1 Assessing the completeness of male adult mortality.....	78
4.2.2 Estimating under-five mortality	81
4.2.3 Projecting orphanhood method–derived estimates of adult mortality to 2011	84
4.2.4 Components of the composite index	85
4.3 Summary of Adult Mortality Estimation in PNG	89
Chapter 5: Estimating the Patterns of All-Cause Mortality in Papua New Guinea	91
5.1 Data Sources	103
5.1.1 Quality assessment of data sources for mortality estimation	103
5.2 Use of Model Life Tables to Generate Complete Life Tables.....	107
5.3 Summary of All-Cause Mortality Estimation in PNG.....	110
Chapter 6: Estimating the Patterns of Causes of Death in Papua New Guinea	111
6.1 Introduction	111
6.2 Summary of Estimating the Pattern of Causes of Death in PNG	142
Chapter 7: Discussion: Mortality and Cause of Death Estimates	145
7.1 Introduction	145
7.2 Mortality Data Sources Used to Estimate Adult Mortality, Under-Five Mortality, Life Expectancy at Birth and Cause-Specific Mortality Fractions	147
7.2.1 Conclusion on data sources.....	151
7.3 Adult Mortality (45q15) Estimates.....	152
7.4 All-Cause Mortality and Life Expectancy.....	154
7.5 Cause of Death Estimates by Province.....	157
7.5.1 Cause-specific mortality fractions	157
7.5.2 Endemic and emerging infectious diseases.....	159
7.5.3 Endemic and emerging non-communicable diseases	160
7.6 Use of Composite Index for Socioeconomic Development and Health Access	162
7.7 Limitations of the Thesis	165
7.8 Summary of Mortality and COD Estimates in PNG	168
Chapter 8: Conclusions and Recommendations.....	171
8.1 Conclusions	171
8.1.1 Chapter 1 Introduction and profile of PNG and its provinces	171
8.1.2 Chapter 2 Literature Review on mortality and COD in PNG.....	171
8.1.3 Chapter 3 Sources of mortality and COD in PNG.....	172
8.1.4 Estimating adult mortality in PNG	172
8.1.5 Estimating the pattern of all-cause mortality in PNG.....	172
8.1.6 Estimating the pattern of causes of death in PNG.	173
8.1.7 Limitations	173
8.2 Policy Recommendations.....	174
8.2.1 Improve notification of deaths linked to the electronic National Health Information System.....	174
8.2.2 Introduce verbal autopsies linked to notifications in the electronic National Health Information System	175
8.2.3 Strengthen medical certification of causes of death.....	176
8.2.4 Improve civil registration legislation to enable verbal autopsies and notifications to feed into registration, improving routine surveillance of mortality and causes of death.....	176
8.2.5 Use mortality surveillance data for health planning and policy.....	177

8.2.6 Address the emergence of non-communicable disease in a country struggling with infectious, maternal, childhood and poverty-related diseases	177
8.3 Recommendations for Ongoing and Future Mortality Research Activities	178
8.3.1 Expand notification of deaths and verbal autopsies for cause of death data.....	178
8.3.2 Introduce STEPS surveys to ascertain non-communicable disease risk factors.....	178
8.4 Limitations of Policy Recommendations.....	178
References	179

List of Figures

Figure 1.1: Map of Provinces in Papua New Guinea	5
Figure 3.1: Deaths by Age in Five Provinces from Electronic National Health Information System (2015–2016)	50
Figure 5.1: Age-Specific Deaths Rate, Log Scale, Papua New Guinea, 2011 (Census Household Deaths)	105

List of Tables

Table 3.3: Deaths Reported Through the Discharge Health Information System by Province and Sex (2007–2013)	45
Table 3.4: Reporting of Age at Death by Province and Sex by the National Health Information System (2010–2015)	48
Table 3.6: Number of Deaths Reported in the Paediatric Hospital Reporting Program (2009–2015)	53
Table 3.7: Reported Deaths by Hospital (2010–2015)	54
Table 3.8: Sources of Mortality Data in Papua New Guinea	55
Table 4.1: Paternal Survivorship by Province (2011)	75
Table 4.2: Maternal Survivorship Rates by Province (2000 and 2011)	76
Table 4.3: Predicted Completeness of Male Adult Death Reporting by Province (2002)	80
Table 4.4: Estimates of Provincial 5q0 by Sex (2000, 2002, 2005 and 2011)	83
Table 4.5: Calculated and Projected Estimates of 45q15 by Sex and Province	85
Table 4.6: Education, Economic and Health Access Indicator Components of the Composite Index	88
Table 5.1: Census Household Deaths and ASDRs in PNG (2011)	104
Table 5.2: DHIS and NHIS Annual Reported Deaths	106
Table 5.3: ASDRs and Life Expectancy at Birth in PNG (2011) Using Model Life Tables	108
Table 5.4: Estimated Life Expectancy at Birth Derived Using the United Nations (UN) Model, Modified Logit Model and Log-Quadratic Model Life Tables Applied to 5q0 and 45q15	109
Table 6.1: Cause Ratios of VA and DHIS Mortality Data from VA Sites	125
Table 6.2: Estimated Annual Deaths and Maximum Annual DHIS Deaths with Proportion Of Facility And Community Deaths By Age, Sex And Province (2011)	126
Table 6.3: CSMFs of Facility and Community Deaths by Age, Sex and Province	129

Table 6.4: Final Empirical Cause-Specific Mortality Fractions by Age, Sex and Province	133
Table 6.5: Expected Cause Pattern Cause-Specific Mortality Fractions Estimates by Age, Sex and Province.....	135
Table 6.6: Final CSMFs (%) Based on Average Empirical and Expected Cause Patterns by Age, Sex and Province, 2011.....	137
Table 6.7: Undetermined Redistribution of Verbal Autopsy Deaths	140

List of Key Acronyms

5q0	Under-five mortality, <i>the probability of dying before the age of 5 years</i>
45q15	Adult mortality, <i>the probability of dying between the ages of 15 and 60 years</i>
ASDR	Age-specific death rate
CEB	Children ever born
CED	Children ever died
COD	Cause of death
CSL	Children still living
CRVS	Civil registration and vital statistics
CSMF	Cause-specific mortality fractions
D4H	Data for Health
DHIS	Discharge Health Information System
DHS	Demographic and health survey
eNHIS	Electronic National Health Information System
GBD	Global Burden of Disease
HDSS	Health and demographic surveillance system
ICD-10	International Classification of Diseases, 10th Revision
IHME	Institute of Health Metrics and Evaluation
NCD	Non-communicable disease
NCDs	Non-communicable diseases
NDoH	National Department of Health
NHIS	National Health Information System
NRI	National Research Institute
NSO	National Statistical Office
PNG	Papua New Guinea
PNGCIR	Papua New Guinea Civil and Identity Registry
PNGIMR	Papua New Guinea Institute of Medical Research
UN	United Nations
UNICEF	United Nations Children's Fund
VA	Verbal autopsy
WHO	World Health Organization

Chapter 1: Introduction

1.1 Introduction

The aim of this thesis is to describe levels and patterns of all-cause mortality and cause of death (COD) by sex and geographical location in Papua New Guinea (PNG). To date, there has been no single high-quality dataset that has comprehensively described mortality levels and patterns in PNG. Civil registration and vital statistics (CRVS) systems, considered the gold standard for routine mortality measurement, are currently non-functional (Montgomery, 2019). Despite the existence of multiple data sources for mortality and COD in PNG, there have been no previous attempts to use these sources to estimate national or provincial mortality or COD (Kitur et al., 2019a).

Previous national mortality estimates have been published by the United Nations Department of Economic and Social Affairs, Population Division (UN) (2017) and the Global Burden of Disease (GBD) (Naghavi et al., 2017) from limited data sources and using statistical and demographic models that have employed little or no local data from PNG, creating much uncertainty about mortality and COD patterns in PNG. Further, subnational studies have focused on either specific locations or diseases without providing a comprehensive assessment of mortality and COD for PNG overall (Gouda et al., 2019; Hetzel et al., 2017; Duke et al., 2016; Mola & Kirby, 2013).

This thesis seeks to fill this knowledge gap by employing demographic and statistical techniques to provide a comprehensive estimate of mortality rates and COD patterns for PNG and each of its provinces using empirical data sources, which has not previously been done.

1.2 Research Aim and Objectives

The broad aim of this research is to describe the mortality and cause of death patterns in PNG.

Specific research objectives are:

1. To review the major sources of mortality and COD data available in PNG;
2. To estimate the all-cause mortality (adult mortality, under-five mortality and life expectancy) in PNG by sex and province;
3. To estimate the major causes of death in PNG by sex and province;
4. To describe how mortality and COD patterns are influenced by geographical location, level of socioeconomic development and health access in PNG.

1.3 Significance of this study

A clear understanding of PNG mortality differentials will provide insights into PNG's epidemiological transition and how it varies throughout the country. It will also help identify priority areas for public health interventions to improve population health. Given the scarcity of comprehensive data, the methodological approaches presented in this thesis were necessary, despite being less than ideal. A strengthened mortality surveillance system would provide more reliable and timely evidence for policymakers, enable scarce resources to be better targeted to areas in greater need and reduce the reliance on the use of demographic and statistical techniques.

1.4 Outline of the thesis

This thesis is structured as follows. The remainder of Chapter 1 presents an overview of PNG's geographic, demographic and socioeconomic characteristics and its government and health system, providing a local context for the levels and variations in mortality and COD. Chapter 2 presents the literature related to mortality and COD in PNG question beginning with the global

situation and epidemiological transitions, before focusing on PNG mortality. Chapter 3 reviews the major sources of mortality data available in PNG, discusses their strengths and weaknesses and assesses the consistency and quality of death reporting. This chapter addresses the first research objective that underpins the selection of methods to estimate all-cause mortality and COD in Chapters 4-6. Each of the following datasets is described in terms of its availability, consistency of reporting and strengths and limitations in generating mortality statistics:

- under-five mortality (5q0): the probability of dying from birth to five years per 1,000 live births;
- adult mortality (45q15): the probability (per 1,000 people) of dying from age 15 years to 60 years;
- all-cause mortality;
- COD.

The characteristics of each of these datasets were used to guide the best available method of estimating all-cause mortality and age-sex-specific COD for PNG and its provinces. It was not possible to conduct analysis at the district level because the average population of the 89 districts is 80,000; hence, the number of deaths at this level is too low to be useful.

Chapter 4 presents the methods used to generate adult mortality (45q15) for PNG by province and sex. It discusses a novel approach based on existing demographic methods that were applied to various data sources, the results for which are discussed collectively in Chapter 7.

Chapter 5 shows how the 45q15 estimates from Chapter 4 and under-five mortality (5q0) estimates from the 2000 and 2011 national censuses were used to determine all-cause mortality, including life expectancy by sex and provinces, using model life tables. Chapters 4-5 address the second research objective.

Chapter 6 presents the estimates for COD patterns in PNG by province, age and sex and links to the third research objective. The COD estimates are derived using statistical techniques based on empirical COD data and mortality estimates presented in Chapters 4 and 5. Chapter 7

briefly presents the major findings established in Chapters 4 to 6 and discusses the overall findings of the thesis. Chapter 8 presents the major conclusions of this thesis which relate directly to the research aim and objectives. Recommendations to improve mortality surveillance and address the high adult mortality and under-five mortality in PNG are proposed.

1.5 Country Profile

PNG is the largest Pacific Island nation and comprises the eastern part of New Guinea, the world's second largest island (the western part of which is the Indonesian province of West Papua or Irian Jaya). On 16 September 1975, PNG gained independence from Australia (Waiko, 2014). With significant variations in its geography, ethnicity and culture, PNG is considered to be one of the most diverse countries in the world (National Statistical Office [NSO], 2015b). Understanding PNG's geographic, cultural and socioeconomic variations is fundamental to analysing deaths and COD differentials (McGehee, 2004). Despite the abundance of natural resources, there are large socioeconomic gaps between provinces and districts, resulting in PNG reporting poorly in terms of development compared with neighbouring countries and countries with similar levels of development (United Nations Development Programme, 2017).

1.5.1 Geography

PNG comprises the eastern part of New Guinea and consists of over 600 separate islands, the largest of which are New Britain, New Ireland, Bougainville and Manus. The country has a total area of 462,840 km² (452,860 km² land and 9,980 km² water). PNG consists of isolated communities separated by steep mountains and gullies, dense tropical forests and scattered islands. With offshore islands to the east, lowland forests and extensive marshes in the northern and southern coastal provinces and dry savannah and temperate highlands in the centre, PNG is one of the most geographically diverse countries in the world (O'Conella & Allan, 2003).

For administrative purposes, PNG is divided into the following four regions based on geography (see Figure 1.1): Southern Region (comprising the southern coastal provinces of Western, Gulf, Central, National Capital District, Milne Bay and Oro), Highlands Region (comprising Southern Highlands, Hela, Enga, Western Highlands, Jiwaka and Eastern Highlands provinces), Momase Region (comprising the northern coastal provinces of Morobe, Madang, East Sepik and Sandaun) and New Guinea Islands Region (comprising Manus, New Ireland, East New Britain and Autonomous Region of Bougainville [Bougainville]). The two newly formed provinces of Hela and Jiwaka were initially part of Southern Highlands and Western Highlands, respectively, before they were nominated as separate provinces in 2012 (Zackery & Elapa, 2012) after a bill for their creation was passed in 2010.

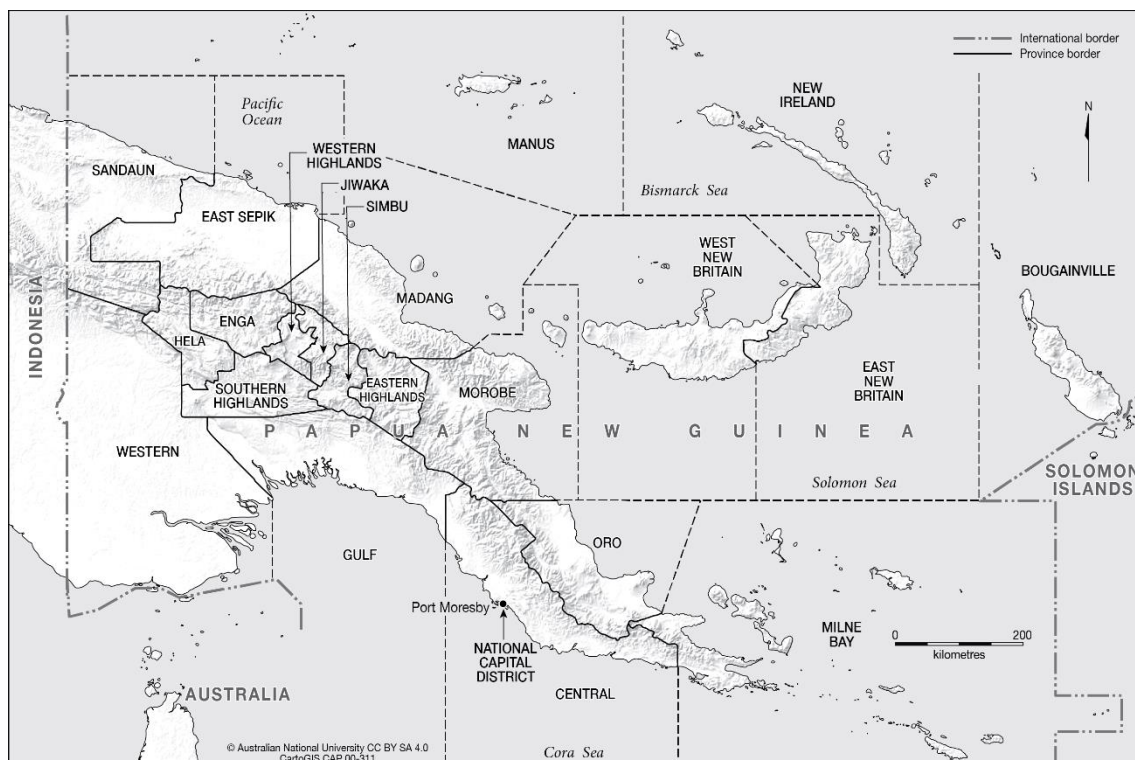


Figure 1.1: Map of Provinces in Papua New Guinea.

Downloaded with permission from ANU Maps Online. ANU College of Asia & the Pacific.

Available at <http://asiapacific.anu.edu.au/mapsonline/base-maps/png-provinces>

For much of the population, accessibility is a challenge, with air and sea transport being the primary modes of transportation between the nation's capital and other provincial centres. On the mainland, the Highlands Highway connects the northern coastal provinces of Morobe and Madang with all seven highland provinces—Eastern Highlands, Simbu, Western Highlands, Jiwaka, Enga, Southern Highlands and Hela (Asian Development Bank, 2015). However, there is no road link between Port Moresby and the Highland or Momase provinces, making transportation a challenge.

1.5.2 Demography

The 2011 census count was 7,275,324 (see Table 1.1). Based on an estimated growth rate of 2.8%, the PNG NSO has predicted the population to reach 9 million by 2020. PNG has a relatively young population, with over one-third of people under the age of 15 years (NSO, 2015b) and over 73% of the population under 35 years (Department of National Planning and Monitoring, 2015). Less than 3% of the population is aged 65 years and above.

The average population of a province is around 330,000 people but varies considerably with Morobe recording the highest population of 673,448 (9%), and Manus with 60,307 (1%), the lowest population equivalent to the size of a district. Over 43% of the population lives in the Highlands Region, 25% in the Momase Region, 18% in the Southern Region and 14% in the Islands Region. The Highlands Region is the most densely populated (52 per km²), followed by the Islands Region (22 per km²), Southern Region (19 per km²) and Momase Region (14 per km²). Apart from the National Capital District (1,366.3 per km²), the highland provinces of Western Highlands (85 per km²), Jiwaka (71 per km²) and Simbu (61 per km²) are the most densely populated. Eighty-eight per cent of the population lives in rural and remote communities, and over 80% of people in all provinces except Morobe (76.1%) live outside of the cities and towns (NSO, 2015b).

Table 1.1: Provincial Profiles for Papua New Guinea

Province	Population (2011)	Population Density (/km ²)	Rural Population (%)	65+ (%)	Literacy Rate (%) 2011	Poverty Rate (%)	Nursing Officers per 1000 pop	Measles Coverage (%) 2011
<i>Papua New Guinea</i>	<i>7,275,324</i>	<i>16.0</i>	<i>87.7</i>	<i>2.6</i>	<i>64.0</i>	<i>36.8</i>	<i>0.4</i>	<i>40</i>
Western	200,200	2.1	79.9	2.1	86.4	52.2	0.8	39
Gulf	157,525	4.6	92.4	2.0	60.7	27.3	0.5	21
Central	269,135	9.1	97.4	2.9	80.1	32.9	0.2	53
National Capital District	361,222	1,366.3	–	1.5	92.4	31.0	0.1	68
Milne Bay	275,932	19.4	94.7	2.9	82.2	32.3	0.7	68
Oro	185,737	8.2	91.7	2.6	78.4	39.5	0.4	43
Southern Highlands	509,488	32.3	97.5	2.5	49.8	41.1	0.3	30
Enga	431,418	36.9	97.8	2.7	49.2	29.5	0.2	34
Western Highlands	362,068	85.5	91.0	3.0	54.1	40.5	0.3	38
Simbu	375,604	61.4	95.5	3.2	60.8	32.3	0.3	51
Eastern Highlands	578,242	52.0	95.0	2.8	60.2	28.3	0.1	49
Morobe	673,448	20.0	76.1	2.6	70.2	34.9	0.5	60
Madang	492,162	17.1	91.8	2.1	68.5	46.8	0.4	44
East Sepik	449,395	10.3	90.6	3.1	65.5	37.1	0.4	42
Sandaun	247,628	6.9	92.1	2.3	62.6	62.6	0.3	51
Manus	60,307	28.3	83.8	3.0	86.4	28.7	0.9	62
New Ireland	193,488	20.3	92.9	2.5	81.4	41.5	0.6	68
East New Britain	327,355	21.5	87.7	2.4	86.6	30.7	0.7	60
West New Britain	263,338	13.0	89.0	2.2	83.5	30.7	0.6	82
Bougainville	248,779	26.5	96.6	2.4	85.7	35.4	0.5	64
Hela	248,838	25.5	98.7	2.6	43.1	–	–	–
Jiwaka	343,133	70.7	98.7	2.7	66.2	–	–	–

Sources: National Department of Health (2011); National Research Institute (2010); National Statistical Office (2011).

1.5.3 Culture and ethnicity

The indigenous population of PNG is one of the most heterogeneous populations in the world, with an estimated 7,000 different cultural groups speaking over 852 different languages (12% of global languages). For convenience, Papua New Guineans may be broadly classified as Papuans and Austronesians; however, Fearon (2003) concludes that the indigenous people belong to very small ethnic groups, which are often differentiated by language giving rise to a country with thousands of cultures (Fearon, 2003).

Despite the wide array of languages in PNG, there are only three official languages in use: English is the official language used in schools and government offices; Tok Pisin is a combination of indigenous languages, mixed with some vocabulary of German and English. Tok Pisin is mainly used by people in the island, northern and highland provinces. Hiri Motu is a simplified trading commonly spoken in the Southern Region of Papua. PNG is ethnically and culturally diverse with thousands of cultural groups speaking over 800 different languages.

1.5.4 Economic development

PNG is a country with abundant natural resources; yet, none of its richness has translated into greater prosperity for its citizens, with poverty increasing at a faster rate than that of neighbouring countries and those with comparable development (United Nations Development Programme, 2017). PNG has a human development index of 0.544, ranking it 153rd out of 189 countries (United Nations Development Programme, 2017).

PNG's economy relies mainly on agriculture, forestry and fishing on one hand and the minerals and energy extraction sector which accounts for most export earnings and GDP on the other. Almost all mining in PNG is for gold, with Porgera (in Enga Province) and Lihir (in New Ireland Province) being the two largest gold mines. In 2009, Hidden Valley gold and silver mine (in Morobe Province) began operations, while the Ramu nickel–cobalt mine (in Madang Province)

commenced a year later (PNG Mining, 2010). Access to employment and business opportunities varies between provinces. For example, Port Moresby is accessible by most people in the Central Province and parts of Gulf Province. The highlands region is linked by the Highlands highway, with access to business, markets for cash cropping and fresh food readily available to people in the central highland provinces of Eastern Highlands, Simbu and Western Highlands (Chang, Mullen, Anjen & B'Soer, 2014). Access to these services are difficult in the remote Highland provinces of Southern Highlands and Enga.

The World Bank (2017) estimated the national poverty rate to be 37%, with the highest level reported for Sandaun Province (63%) and the lowest for Gulf Province (27%). The poverty level in the National Capital District is 31% (see Table 1.1) and is comparable to levels in the Island provinces of Manus, East and West New Britain and Bougainville. The level of poverty is probably higher in Gulf Province given its other correspondingly low socioeconomic indicators shown in Table 1.1.

1.5.5 Administration

PNG became independent from Australia in 1975, but the country first had contact with European explorers as early as the 16th century. The northern part of the country was initially colonised by Germany and was formerly known as German New Guinea, while the southern part was administered by Australia as British New Guinea (Embassy of PNG, Tokyo, 2020). Following World War II, these two territories were combined into the Territory of Papua and New Guinea, which became the independent state of PNG in 1975.

PNG has three levels of government based on the Westminster system: national, provincial and local. There are 22 provinces with 384 local governments, whose roles and functions are determined by two key pieces of legislation: the *Organic Law on Provincial Governments and Local-level Governments 1995* and the *Local-level Governments Administration Act 1997* (Reilley, Brown, & Flower, 2014). These laws were specifically introduced to give more power

to subnational governments at the provincial, district and local levels. However, the decentralisation of administrative power without the provision of financial power has resulted in the disintegration of services in provinces, districts and communities. There is little difference in the functions and responsibilities between the two lower levels of government, with duplication of roles and functions affecting service delivery in areas such as education and health services.

Decentralisation commenced in the late 1970s, with Bougainville and East New Britain provinces attaining provincial governments as a form of autonomy (Day, 2009). This was in response to the citizens' desire to bring decision-making and financial powers closer. However, the consequences of this process were more detrimental than beneficial in terms of service delivery. In 2014, the government introduced the *District Development Authority Act (2014)* to improve service delivery.

1.5.6 Education

PNG's education system is structured as follows: elementary school (prep, Grades 1 and 2), primary school (Grades 3 to 8), lower secondary school (Grades 9 and 10) and upper secondary school (Grades 11 and 12). Despite the accessibility of education in PNG, school attendance is not compulsory at the elementary and primary school levels, resulting in poor education and literacy rates. According to the National Education for All 2015 Review (United Nations Educational, Scientific and Cultural Organization [UNESCO], 2015), PNG has a literacy rate of 64% (62% female, 65% male), ranking it the lowest in Oceania. Despite the introduction of the universal primary education policy under the British decades ago and the further expansion and reforms under the Australian and PNG administrations, basic education in PNG is still poor. The literacy rate in people over 15 years of age has only marginally increased from 57% in 2000 to 64% in 2015 (UNESCO, 2015).

Table 1.1 shows that literacy rates are particularly low in the Highlands (Hela, Southern Highlands and Enga) and Momase (Sandaun and East Sepik) regions. Apart from the National Capital District (92%), East New Britain (87%), Manus (86%) and Milne Bay (82%) have reported the highest literacy rates. A similar pattern is observed in the net enrolment rate as reported by the National Research Institute (NRI, 2010). Oro (38%), Sandaun (40%) and Gulf (42%) achieved the lowest rates between 2007 and 2009. In the same period National Capital District (66%), East and West New Britain (67%) and Bougainville reported the highest rates.

A study on the status of schools and health services between 2002 and 2012 showed a 40% increase in proportion of children attending primary school (Howes, Mako, swan, Walton, Webster & Wilshire, 2014). The study reported enormous provincial variation in proportion of children attending primary school, ranging from a 37% to 90% rise in East New Britain Province to a fall of 63% to 37% in Gulf Province (Howes et al., 2014).

1.5.7 Health system

Health services in PNG are delivered through a structure consisting of community and family care (Level 1), community health posts (Level 2), rural health centres (Level 3), district hospitals (Level 4), provincial hospitals (Level 5), regional hospitals (Level 6) and one tertiary hospital (Level 7) (National Department of Health [NDoH], 2011a). The health system in PNG currently operates under three different Acts, resulting in poor health access and the disintegration of health services (NDoH, 2015a, 2015b). Provincial hospitals operate under the *Provincial Hospitals Act 1994*, while the *National Health Administration Act 1997* covers provincial health offices, health centres and aid posts (NDoH, 2010). Because of the challenges of operating under these two acts, the *Provincial Health Authority Act 2007* was developed to unify the functions of provincial hospitals and provincial health offices.

Health services in PNG are delivered through 19 provincial hospitals provinces (Central Province does not have a hospital). Four provincial hospitals (L5)—Port Moresby General

Hospital in the National Capital District, Angau Hospital in Morobe Province, Mt Hagen Hospital in Western Highlands Province and Nonga Base Hospital in East New Britain Province—also function as regional hospitals (L6) for the Southern, Momase, Highlands and Islands regions, respectively (NDoH, 2011a). Most doctors and nurses are based at these regional hospitals, giving a high nurse-to-population ratio in the provinces in which they are located, while Sandaun and Southern Highlands have the lowest nurse-to-population ratios. In addition, there are over 757 health centres /health-sub centres and clinics and 3,000 aid posts serving the rural population (NDoH, 2016), with half the aid posts closed.

Considerable variations exist between provinces in terms of health access and performance. Table 1.1 shows low vaccination coverage in Gulf (21%), Southern Highlands (30%), and Enga (34%), and higher coverage rates of 68% in National Capital District, Milne Bay and New Ireland provinces. Further, essential medicine was available only 40% of the year in Sandaun Province in contrast to the National Capital District, which had drugs available for 80% of the year (NDoH, 2011b). Other reports show similar provincial variations in health access and performance (NDoH, 2015a, 2015b).

1.6 Summary of Chapter

PNG has significant geographic, demographic and economic diversity, which may cause variations in mortality and COD levels and patterns. Development and access to health services are relatively high in the Island provinces of Manus, New Ireland, East New Britain and Bougainville and in major towns such as Port Moresby in the National Capital District. While all highland provinces are accessible by road, some provinces in Momase Region (e.g. Sandaun and East Sepik) and Southern Region (e.g. Western Province) can only be reached by air.

Chapter 2 reviews the available literature on mortality and COD in PNG, while Chapter 3 reviews the various mortality data sources.

Chapter 2: Review of Literature on Mortality and Causes of Death in Papua New Guinea

This chapter reviews the available literature on mortality and COD in PNG, beginning with a global overview of the importance of mortality and COD data, followed by a review of mortality studies for PNG. This includes all-cause mortality (under-five mortality, adult mortality and life expectancy) and COD studies. The major knowledge gaps with respect to mortality and COD identified in this review conclude the chapter. A comprehensive review of the different data sources available in PNG is presented in Chapter 3.

2.1 Importance of Mortality and Cause of Death Data

The availability of accurate and timely mortality and COD data is critical to guide policy development and monitor public health programs. Further, the significance of mortality and COD extends beyond the domains of public health and epidemiology to include development significance such as a source of identity for relatives to access services and entitlements (AbouZahr & Boerma, 2005). The early experiences of John Snow during the cholera outbreak in England in 1854 (cited in Lawrence, 2004), is hailed as birth of epidemiology. However, without the proper recording of deaths and their places of residence by the local authorities, Snow would not have identified the source of the outbreak that claimed the lives of many of the population on Broad Street, Soho. The use of vital statistics goes far back to the mid-1600s in John Graunt's analyses of the London Bills of Mortality to investigate epidemics of plague (cited in Greenberg, 1997). Other significant values of mortality and COD data include the establishment of a causal relationship between smoking and lung cancer by Doll and Hill (1950), and the demonstration of reduced mortality from coronary heart disease (CHD) in the Australian population due to changes in risk factors (Taylor, Dobson & Mirzaei, 2006).

The establishment of the UN Millennium Development Goals (MDGs) by the United Nations Development Programme (2005) in 2000 is another reason for the keen interest on mortality and COD data to monitor progress against the MDGs (especially MDGs 4-6) between 2000 and 2015. While the MDG era came to an end in 2015, the adoption of the 17 Sustainable Development Goals (SDGs) and 169 targets (United Nations Development Programme, 2015) will continue to put pressure on countries to collect mortality and COD data to monitor the health goal and its 13 targets.

High-quality data on the levels and trends of mortality and COD, including differentials for geographical or subpopulations, social classes and ethnicity, is essential for prioritisation of interventions that are targeted to achieve maximum impact (AbourZahr et al., 2007). With the introduction of sectoral reform programmes especially in low-income countries, mortality and COD data are needed to guide policy formulation and monitor such policies where planning, budgeting and monitoring have been devolved to provinces and districts (AbouZahr & Boerma, 2005). The issue of targeted interventions become more pressing for PNG given the substantial diversity between communities and the current devolvement of power to provinces and districts.

Further, the value of mortality levels and trends extends beyond the health domain. For example, the issuance of legal documents such as the death certificate proves the identity of a person and enables relatives to access entitlements or state services (Abouzahr et al. 2007). Such documents also prevent persons against exploitation or hardship. Mortality and COD data are essential to set priorities, formulate policies and monitor such policies at subnational level to improve the health of the population at these levels, but are also helpful in identifying eligible relatives to access entitlements.

There is continuing interest to improve the quality of data on deaths and COD after past reviews revealed that more than two-thirds of countries reviewed did not have compete and

quality COD data (Mathers et al., 2005; Mahapatra et al., 2007). Several methods of improving mortality and COD data were subsequently developed including an assessment framework by the Health Metrics Network (Rampatige et al., 2013) to assist nations to assess the quality of their mortality data. In their review of COD data from 148 countries from 1980 to 2012, Mikkelsen and co-authors (2015) reported that death registration had marginally improved. This was despite improvements in civil registration systems. Recent evaluations of mortality and COD data sources have reported overall improvements; however, more work is needed to improve mortality data from middle- and low-income countries (Mikkelsen et al., 2015; AbouZahr et al., 2015; Roth et al., 2018), in line with the broader policy on improving vital registrations globally (Lopez & Setel, 2015).

The GBD Study has produced a number of publications comparing deaths and COD globally to inform policies and interventions and improve quality of life (Murray & Lopez, 1996, 1997; Naghavi et al., 2017). These GBD reports, with multiple publications on global mortality, risk factors and COD (Institute for Health Metrics and Evaluations [IHME], 2016) have been invaluable in informing policies and interventions on mortality and COD at global, regional and national levels, since the first publication by Murray and Lopez (1996).

2.1.1 Global epidemiological transition

The overall mortality levels of the global population have improved in the past 40 years. According to the 2015 GBD report (Institute of Health Metrics and Evaluations [IHME], 2016), life expectancy at birth increased from 61.7 years to 71.8 years between 1980 and 2015, a gain of 10.2 years. The increase was higher for females whose life expectancy rose from 63.7 years to 74.8 years over the 35-year period, compared with males whose life expectancy increased by 9.4 years, from 59.6 years in 1980 to 69.0 years in 2015. WHO's estimated global life expectancy at birth for 2016 is 72.0 years. Similarly, females (74.2 years) live longer than males (69.8 years) on average, a difference of 4.4 years which has been constant since 2000.

(WHO, 2016). The average life expectancy at birth ranges from 61.2 years in the WHO African Region to 77.5 years in the WHO European Region. However, the increase in life expectancy at birth is highest in the WHO African Region due to improved child survival and reduction in HIV deaths resulting from access to anti-retroviral for HIV treatment. In addition to the decrease in under-five mortality there was a corresponding decline in mortality rate among adults between the ages of 15 to 60 years (IHME, 2016). The rate of under-five mortality globally dropped by half between 1990 and 2015. WHO estimated adult mortality rate as 142 per 1000 population in 2016, having dropped from 290 per 1000 in 1990. Rates are highest in countries in the WHO African Region. In almost all countries, adult mortality rates for males are higher than for females. The highest ratio is found in the WHO European Region where male adult mortality rate is more than twice that of female.

The GBD 2015 report states that 'between 2005 and 2015 the world has been undergoing an epidemiological transition, with declining communicable disease burdens and increasing life expectancies (IHME, 2016). With the increase in global life expectancy, populations are more likely to suffer and die from non-communicable diseases (NCDs) than from infectious diseases. However, the epidemiological transition is not a new phenomenon. Omran (1971) is credited with originally drawing attention to a shift in the COD structure for different countries at different stages of the epidemiological transition in his 1971 report. He showed evidence using different models to demonstrate this change where 'pandemics of infectious diseases had displaced degenerative and man-made diseases' as the leading causes of death. Omran called for more collaborations to better understand the process of population change through studies linking mortality patterns to social, economic, demographic and epidemiological factors.

McKeown (2009) argues that the theory of epidemiological transition suffers from several limitations despite being useful in explaining changing demographic patterns. These limitations

include a lack of attention paid to the role of poverty in diseases risk and mortality and the oversimplification of the model (McKeown 2009). Mercer (2018) claims that Omran's original model and stages of transition are basically descriptive and not explanatory because they do not focus on the aetiology and morbidity. He further argues that infections have been confirmed as causes of various chronic diseases. For example, human papilloma virus (HPV) has been linked to cervical cancer (Burd, 2003) while other infections are associated with deaths from chronic infections (O'Connor, Taylor & Hughes, 2006). The theory of epidemiological transition will continue to be refined over time as suggested by Omran (1971). Despite the limitations revealed by other researchers, the basic structure and models of the epidemiological transition as developed by Omran have been useful in explaining population changes in different countries (Omran 1971). As the level of development in countries rise, deaths due to communicable, maternal and child health diseases and conditions of poverty decline (IHME, 2016). Consequently, more people live into adulthood and the average age of the population increases. This change creates a shift in disease burden as older adults and young adults die from non-communicable diseases (NCDs) and from diseases of risky behaviour respectively.

In 2015, NCDs were the major COD globally, accounting for 71.3% of deaths (39.8 million), followed by communicable, maternal and perinatal diseases, and nutritional diseases which accounted for 20.2% (11.3 million). Injuries was responsible for 8.5% (4.4 million) of all deaths globally, (IHME, 2016). Conversely, in children under the age of five years, 80.8% of deaths were due to communicable, perinatal diseases and nutritional causes, while NCDs accounted for the remaining 13.8% of deaths. Deaths from injuries comprised 5.4% of all deaths which is about half the proportion of deaths among adults (IHME, 2016). More deaths from NCDs were reported in 2016 (72.3%) and 2017 (73.4%) respectively (Naghavi et al., 2017; Roth et al., 2018). Consequently, there were less deaths from infectious, maternal, neonatal and nutritional diseases in 2016 (19.3%) and even less in 2017 (18.6%).

Allen, Cobiac and Townsend (2017) claim that 82% of premature deaths from NCDs occur to people from low- and middle-income countries suggesting a disproportion of deaths in these countries. However, these countries also account for 82% of the world population hence, it is plausible that a large proportion of premature deaths occur in them.

The top 10 leading CODs were ischaemic heart disease, cerebrovascular disease, lower respiratory infections, neonatal and perinatal conditions, diarrhoea, neonatal encephalopathy, human immunodeficiency virus (HIV) and acquired immunodeficiency syndrome (AIDS), road traffic injuries, malaria and chronic pulmonary disease (GBD, 2016), but the top four causes have been cardiovascular diseases, cancer, diabetes and chronic respiratory diseases (Allen et al. 2017; Naghavi et al., 2017). Despite the inclusion of six diseases from Group I in the top ten causes of death, they collectively contribute only one out of every five deaths and the proportion of deaths from these diseases have declined since 1980. The most notable change was the reduction in deaths from HIV from 1.8 million to 1.2 million between 2005 and 2015 (IHME, 2016; Naghavi et al., 2017). Likewise, deaths from malaria and diarrhoea decreased by 37.4% and 32.3%, respectively, between 2005 and 2015. Overall, NCD deaths increased by 14.3% over the 10-year period, showing the prominence of NCDs over communicable diseases globally.

In low- and middle-income countries there is an emerging trend of a dual burden of diseases as evident in several neighbouring Melanesian countries. For example, in addition to a high proportion of deaths from infection and perinatal conditions, Vanuatu is now faced with increasing deaths from NCDs, including cardiovascular disease, diabetes and cancer, for adults aged 15–49 years (Carter et al., 2016). While Solomon Islands is affected mainly by communicable disease, Fiji has a high burden of NCDs, including diabetes (Carter et al. 2011; Phillip, Carter, Naidu, Linhart, Azim, Rao & Lopez, 2013). Polynesian countries are affected mainly by NCDs, predominantly diabetes and cardiovascular disease (Gani, 2009). The dual

burden of disease from the emergence of NCDs coexisting with communicable diseases will become a major challenge for many countries, including PNG, and requires immediate attention.

2.2 Mortality in Papua New Guinea

2.2.1 History of disease in Papua New Guinea

PNG's population has been affected by a series of epidemics since the country was first inhabited thousands of years ago. However, documentation of disease only goes as far back as the early 1900s after the arrival of missionaries. Traditionally, communities in PNG did not keep written records of vital events such as births and deaths prior to contact with the outside world (Maddocks, 1973). Scragg (1977) reported that only two villages in German New Guinea and another two communities (Mekeo and Yule Island) in Central Province kept records on births and deaths by the 1920s. Early settlers in PNG were highly mobile and free from many communicable diseases because the size of groups was insufficient to sustain acute infections. Therefore, airborne infections such as measles, mumps, smallpox, chickenpox, rubella and the common cold were likely to be non-existent in PNG when people lived exclusively in small isolated communities (Maddocks, 1973).

Exposure to the outside world saw the parasitic intestinal infections from hookworm, roundworm, whipworm and amoebae appear after people began congregating in large communities in the 1900s. In addition, organised societies and cultural practices aided the emergence of pig-bel and kuru in certain communities. Pig-bel (or enteritis necrotica) often emerged following the mass slaughter of pigs and the consumption of partially cooked pig meat (National Department of Health [NDoH], 1986). A type of necrotizing enteritis endemic in the Papua New Guinea highlands caused by the B toxin of *Clostridium perfringens* type C; pig-bel occurred predominantly in children because of poor immunity to type B toxin and a low level of intestinal proteases, resulting from a diet (mostly sweet potatoes) low in protein. PNG

protocols on pig-bel now form the basis of World Health organisation guidelines for the management of sick children in all developing countries. Kuru is an encephalopathy or neuro-degenerative disease found only in the Okapa District of the Eastern Highlands Province of Papua New Guinea (NDoH, 1986). It is always fatal, with a subacute course, on average, of about 12 months from onset to death. Kuru was unknown to the outside world until the 1950s when this area of the highlands was first brought under administrative control by the Australian government. Scientific investigation of kuru began in 1957. From the evidence of oral history, the epidemic began in the early 1900s with a single case of kuru and slowly spread in extent and expanded in number until over 200 people were dying of the disease each year.

Early epidemics of whooping cough, influenza, dysentery, TB and venereal diseases were also consequences of contact with Europeans (Scragg, 1954, 1977). In his studies of depopulation in New Ireland and Bougainville, Scragg (1954) attributed the declining population in New Ireland to venereal disease, particularly gonorrhoea, as he also considered malaria a major factor in the population decline. Communicable diseases have been the major causes of morbidity and mortality since they were first documented in the early 1900s (Bell, 1973; Maddocks, 1973; NDoH 1986, 2010). While communicable diseases predominate, NCDs, including diabetes, heart disease and cervical and hepatic cancer (Gouda et al., 2019) and NCD risk factors (Rarau et al., 2017; 2019) are rapidly emerging issues for PNG, however, NCDs remains largely unreported because of the lack of available data.

2.2.2 All-cause mortality

Studies on under-five mortality in PNG are limited, while there is no available academic literature on adult mortality nor life expectancy nationally (apart from estimates by the GBD (Naghavi et al., 2017) and the United Nations Department of Economic and Social Affairs, Population Division (2017) and subnationally.

Crude death rate (CDR)

The crude death rate measures the number of deaths per 1,000 population. The crude death rate is called 'crude' because it does not take into account age. Data on crude death rate for PNG is limited to those published by the GBD (Naghavi et al., 2017), the UN (2017) and by the National Statistical Office (NSO, 2011). The NSO estimated CDR as 10 nationally, 10 in rural areas and 8 in urban areas for 2011. The UN estimates are lower (8.3) as well as the GBD study at 7.6. Apart from these estimates, there are no publications on CDR for PNG anywhere in the academic literature.

Under-five mortality (5q0)

Data on under-five mortality are available from studies by Scragg (1954), van de Kaa (1971), Riley (1979, 2009), Lagani et al. (2011) Tran, Bauze, Nguyen, Firth and Jimenez-Soto (2011) and Bauze et al. (2012). Several authors (Lagani et al., 2011; Tran et al., 2011; Duke, 1999), using information on children ever born (CEB) and children still living (CSL) collected from female respondents aged 15–49 years in censuses, argue that there has been a drastic decline in child mortality between 1960 and 1980, but the rate has remained stagnant in the last 40 years.

The earliest evidence of under-five mortality post-World War II was reported by Scragg (1954). In his studies of depopulation in New Ireland and Bougainville, Scragg (1954) attributed the declining fertility in New Ireland to venereal disease, particularly gonorrhoea, as he also considered malaria a major factor in the population decline. Scragg showed that 70% of neonatal mortality occurred in the first week of life. Mortality in the first week of life was 63 per 1,000 live births compared with 26 per 1,000 live births in the remainder of the first month. Scragg's study demonstrated that most deaths occurred between 0 and 4 years of age with no significant differences in mortality in older age groups.

Subsequent studies reported by van de Kaa (1971) from four different locations in the country confirmed declines in infant mortality rate over a 20-year period from 1949 to 1971. Following his study in New Ireland, Scragg commissioned and supported similar investigations in Bougainville in the New Guinea Islands, Oro Bay in Oro Province and the Trobrian Islands in Milne Bay Province (in the Southern Region), Angugunak in Sandaun Province (Momase Region) and Baiyer River in Western Highlands Province (Highlands Region). In New Ireland and Bougainville, infant mortality decreased from 189 per 1,000 live births in the 1949–1952 period to 49 per 1,000 live births in the 1962–1967 period. Similarly, results from Angugunak showed declines of 109–134 to 61–87 per 1,000 live births between 1962–1964 and 1969–1971, respectively. All four regional studies, including Scragg's, showed a general decline in infant mortality. However, despite all studies reporting a decline in infant mortality, none used standardised methods to collect mortality data from the study sites. This limitation was partly resolved by the development and use of verbal autopsy (VA) instruments and methods in 1971, after which these became a standard method for collecting data on mortality (Gouda, Lehmann, & Riley, 2013; Lehmann, 1991; Riley, 1979).

Riley (1979) reported a decline in infant mortality rate in Tari (Southern Highlands Province) between 1950 and 1971. Prior to 1950, the infant mortality rate was 160 per 1,000 live births, subsequently falling to 120 per 1,000 live births between 1952 and 1964 and 68 per 1,000 live births between 1965 and 1971. Riley also noted that mortality in Tari did not fit the West model life table (which represents certain age patterns of mortality for a given level of mortality) because mortality was low among children but high for people aged over 40 years. Riley attributed the decline in infant mortality rate in these sites to the introduction of health services, which had a more immediate impact on reducing mortality in the absence of social and economic change.

Duke (1999) claimed that the under-five mortality rate declined by 3% annually over the 20 years between 1960 and 1980 (falling from 204 per 1,000 live births in 1960 to 112 per 1,000 live births in 1980), but that there had been negligible change for the next 20 years. In other studies, infant mortality and under-five mortality rate was higher than the national average (Townsend, 1985; Garner, Heywood, Baea, Lai, & Smith, 1996). Townsend (1985) showed that the infant mortality rate in one remote Sepik district was four times the provincial rate and ten times the national urban average in the mid-1980s. Duke estimated the under-five mortality rate for PNG in 1999 to be 100 per 1,000 live births, which was double the rate for the Asia-Pacific region of 54 per 1,000 live births estimated by the United Nations Children's Fund (UNICEF) (1999). According to a report by UNICEF (1999), PNG was among only four countries, including Myanmar, Niger and Zambia, that failed to improve child mortality between 1980 and 1998.

However, more recent studies by Lagani et al. (2010), Tran et al. (2011) and Bauze et al. (2012) have reported declines in under-five mortality in PNG between 1980 and 2000. Lagani et al. (2010) claimed that child mortality and infant mortality rates declined by 19% and 17% respectively between 1990 and 2006 based on data from three demographic and health surveys (NSO, 1991, 1996, 2006). They argued that improvements in child health programmes such as the expanded programme on immunization (EPI), integrated management of childhood illnesses (IMCI), hospital care and human resources for child health are some of the reasons for the decline in under-five mortality (Matai et al., 2008).

In their report written on behalf of the PNG government evaluating its efforts to reduce childhood mortality in line with UN Millennium Development Goal 4, Tran et al. (2011) confirmed that PNG did achieve a reduction in under-five mortality but would not accomplish a two-thirds reduction by 2015. Tran et al. (2011) estimated that the under-five mortality rate fell from 100 per 1000 live births in 1990 to 83 per 1000 live births in 2000. While it was not

possible for PNG to achieve a two-thirds reduction in child mortality between 2000 and 2015, it was on target to reach its revised target of 72 per 1000 live births. This trend was further confirmed by Bauze et al. (2012), who estimated the under-five mortality for children in PNG using data on childbirth histories from the 2000 census. The under-five mortality rate in 2000 was 78 per 1,000 live births, an average reduction of only 1.7% per annum. Studies by Lagani et al. (2010), Tran et al. (2011) and Bauze et al. (2012) confirm that under-five mortality rate in PNG declined between 1980 and 2000. However, the rate of reduction was clearly insufficient to achieve a two-thirds reduction between 2000 and 2015.

Bauze et al. (2012) also noted that data from the 2006 Demographic and Health Survey (DHS) were of poor quality and, therefore, were not used in their analysis. Possible errors could have resulted from incorrect reporting of birth dates for children and their mothers, omission of children and errors with sampling of the 2006 DHS (Bauze et al. 2012). However, since the sampling frame used was not available to the researchers, it was not possible to ascertain the exact source of error in the 2006 DHS data.

The report by Bauze et al. (2012) went beyond estimating under-five mortality to investigating childhood mortality differentials by geographic location at the district level. Childhood mortality was found to be highest in the northern provinces of Sandaun, Madang and Morobe and lowest in the New Guinea Island provinces of East and West New Britain, New Ireland, Manus and Bougainville. The Momase Region had the highest under-five mortality rate (105 per 1,000 live births), while the Islands Region had the lowest rate (72 per 1,000 live births).

These figures represent average rates and conceal variations within and between provinces and districts. For example, Karimui-Nomane District, which reported one of the worst under-five mortality rates in PNG, is in Simbu Province, one of the best performing provinces in the country (NDoH, 2011). In addition, Goilala District and Kairuku-Hiri District are neighbouring districts in Central Province, but Goilala has one of the worst child mortality indicators, while

Kairuku-Hiri ranks among the best in PNG. Goilala District is mountainous and is only accessible by air with limited land transport while Kairuku-Hiri lies on the outskirts of the capital city of Port Moresby. Bauze et al.'s (2012) analysis showed that the large interprovincial and intra-provincial differences in the under-five mortality rate strongly correlated with access to services and poverty levels at district level. Karimui-Nomane District is one of the remotest districts in PNG and is only accessible by air.

In an earlier analysis of the 1980 census, Bakker (1983) reported differentials in infant mortality rate between neighbouring districts within the same province. In East New Britain Province, the infant mortality rate was 41 per 1,000 in Gazelle Peninsula, while the rate was almost threefold (104 of 1,000 live births) in Pomio District. The variations in mortality that show childhood mortality is affected by geographical location, access to services and socioeconomic development. The differentials in child mortality and their associated factors at subnational at provincial and district level are crucial and must be revealed to guide effective targeted health interventions.

Adult mortality

There are no studies in the academic literature on adult mortality for PNG or its provinces, only national estimates published by the United Nations Department of Economic and Social Affairs, Population Division (2017) and the GBD Study (Naghavi et al. 2017). These studies have reported rates for PNG but nothing for the subnational levels. There have been official reports on adult mortality by NSO (2011) and Bakker (1983, 1986) which have been useful for planning purposes in the country, however, there is no academic literature on adult mortality for PNG.

Life expectancy

The UN and the GBD Study provide regular reports on life expectancy for PNG using demographic and statistical models that rely on socioeconomic covariates and mortality levels

and age patterns of nearby countries to estimate mortality. In-country analyses of census data by Bakker (1983, 1986) and the NSO (2011) have provided national estimates based on adult mortality and child mortality applied to model life tables. The United Nations Department of Economic and Social Affairs, Population Division (2017) estimated life expectancy in 2011 was reported as 62.4 years for males and 67.2 years for females, while the GBD Study (Naghavi et al., 2017) estimated life expectancy as 57.8 years for males and 60.3 years for females. The NSO (2011) reported levels of 56.3 years for males and 57.3 years for females. Both the UN (2017) and the GBD study (Naghavi, 2017) estimates are based on little or no local data, while the NSO report (NSO, 2011) used data on the survival of parents and childbirth histories collected from the 2000 census and 2006 DHS.

2.2.3 Causes of death

Cause of death studies in PNG have mainly focused on specific infectious diseases such as TB, malaria and pneumonia, with small-scale population studies limited to a few conveniently selected sites (Gouda et al., 2019; Gouda et al., 2013; Riley, 2010). Only a handful of population-based studies on COD have been conducted in PNG in recent decades, including those undertaken by the Directorate of Public Health (Scragg, 1954), the Department of Health in Tari and Asaro (Gouda et al., 2013) and the PNG Institute of Medical Research (PNGIMR) in Wosera and Madang (Lehmann, 1998). More recently, the Partnership in Health Project conducted by PNGIMR and ExxonMobil involved the use of a health and demographic surveillance system (HDSS) in which mortality and CODs in four localities were ascertained using the Population Health Metrics Research Consortium VA instrument (Gouda et al., 2019).

The studies by Scragg (1954), the Department of Health and the PNGIMR (except for the Partnership in Health Project) were conducted in response to emerging issues at the selected sites. For instance, Scragg's study was in direct response to claims of depopulation in New Ireland; the Tari and Asaro studies were undertaken to investigate the efficacy of

polysaccharide vaccine against pneumonia; and the Wosera study was set up to investigate the efficacy of the malaria vaccine. These studies have all achieved the goals for which they were established and have since ceased operation.

Scragg's (1954) study on depopulation in New Ireland Province (NIP) and Bougainville provides the earliest available data on COD in PNG. In his studies of depopulation in New Ireland and Bougainville, Scragg (1954) attributed the declining fertility in New Ireland to venereal disease, particularly gonorrhoea, as he also considered malaria a major factor in the population decline. He was able to assign a COD to 105 of 188 deaths (56%) for people between the ages of 10 and 59 years. Although he successfully ascribed a COD to 61 of 102 males and 44 of 86 females, he was unable to do so for the remaining 44% of people (41 males and 42 females). Most deaths occurred from 0 to 4 years, and there were no significant differences in mortality in the older age groups. Scragg concluded that while infant mortality was a COD, it was not the cause of depopulation because the highest mortality rate occurred in areas with increasing numbers.

Mortality in those aged over 60 years was considered insignificant by local people, who firmly believed that death at such an age was normal ("he was too old to live"), (Scragg, 1954, p. 68). While deaths occurring in this age group were believed to be the result of old age, Scragg believed that the major causes were likely to be cardiac and pulmonary diseases and malaria.

TB (30.5%), pneumonia (16.2%) and accidents (13.3%) were the leading CODs accounting for 60% of deaths with known causes. For the remaining 83 deaths for which there was no known cause, malaria and pneumonia were the most likely causes according to Scragg. This ranking is comparable to reports on all deaths in the territory between 1951 and 1952, with pneumonia (34%), malaria (14%), TB (7%), dysentery (5%) and meningitis (3%) being the five leading CODs. These findings show that communicable diseases were the major CODs, while there was also a higher death rate from injuries than current estimates.

Scragg's study has several limitations. Despite assigning a COD to 61 out of 188 (56%) deaths on the north eastern part of New Ireland Province (NIP), his sample of 188 deaths from a population of 2,000 people is too small for the results to be extrapolated to represent mortality across the country. Further, he employed no systematic method of determining the COD in his subjects. However, despite these limitations, Scragg's findings provide the earliest available data on COD since World War II.

Between 1970 and 2001 research sites were set up in four selected communities in PNG. The Department of Health initially established surveillance sites in Tari in the Southern Highlands in 1971 and Asaro in the Eastern Highlands in 1980 for the purpose of pneumococcal polysaccharide vaccine trials (Riley, 1979). A decade later the PNGIMR established malaria surveillance sites in Wosera, East Sepik and Madang in 1982 as part of the Malaria Vaccine Epidemiology and Evaluation Project (Lehmann 1997 cited in Gouda et al, 2013). The Tari and Asaro surveillance sites were later transferred to PNGIMR, which continued to manage them until 1995 and 1989, respectively. More recently, PNGIMR, in partnership with ExxonMobil, established two highland and two coastal sites to monitor the effects of the gas industry along the gas pipeline project (Gouda et al., 2019).

The Tari household surveillance of births and deaths covered a population of approximately 11,000 in 1971, which 20 years later had increased more than threefold to 35,000 (Lehmann et al., 1997, as cited in Gouda et al., 2013). Similarly, the population under surveillance in Asaro increased from 7,000 to 8,840 between 1980 and 1989 (Kakazo et al., 1999), while the study population in Wosera for the malaria study was 4,000 people enrolled from 10 villages.

CODs in these sites were ascertained using VA instruments administered to caregivers or family members of the deceased after four weeks of mourning. The Verbal Autopsy Instrument (VAI) was developed by Riley in 1971 (cited in Gouda, Lehmann and Riley, 2013) to be used by field reporters with minimal schooling in Tari, Southern Highlands Province (SHP). VAIs had

only 18 symptom questions but allowed for the recording of a brief open-ended narrative, the place of death, any treatment by health services, and the type of treatment. The disease classification was based on Lay reporting of health information (WHO 1978) and COD was entered into the international form of the death certificate.

Verbal autopsies (VAs) were physician-coded with reference to diagnostic algorithms. The responses were then transferred to a standard death certificate by a physician, and COD was determined using WHO lay reporting of health information. The VA method was first used primarily in two highland sites (Tari and Asaro) and later in Wosera (East Sepik Province) and Madang.

Based on the data collected on deaths between 1970 and 1995, Gouda et al. (2013) conducted a comparative analysis of 8,489 deaths in Tari, Asaro, Wosera and Madang. As expected, the majority (80%) of deaths occurred in Tari, followed by 9.6% in Asaro, 5.4% in Wosera and 4.8% in Madang. The high proportion of deaths in Tari was attributable to the enrolment of a larger sample over a longer period. The Tari surveillance site had data covering over 25 years, while Asaro, Wosera and Madang had data for only 10, 5 and 2 years, respectively.

For the sixty-five per cent of deaths where a specific cause was assigned, 22% of deaths were due to pneumonia, followed by chronic lung diseases (14%), diarrhoea (8%), injuries (7%) and other fevers (7%). In terms of age distribution, acute respiratory infections and acute abdomen accounted for 41% each in children under 13 years of age. Injuries, febrile illnesses and acute respiratory infections were mainly responsible for deaths in people aged 13–39-years, while chronic respiratory diseases and acute respiratory infections were the major killers of those over 40 years of age. These results show that almost 40% of all deaths with a known cause were due to infections.

Comparing the COD from the different sites with varying populations at different times may not be technically acceptable, because results are prone to biases. However, the authors (Gouda et al., 2013) argue that it was an exercise carried out purposely to validate the use of the VA instrument. In addition, it provided useful insights into the results from the four sites. Despite their views, the COD calculated from the study should be interpreted as specific to each study site and not representative of the mortality experience of the PNG population.

Between 2009 and 2014 the PNGIMR collected data on 1,210 deaths from four integrated health and demographic surveillance sites—Hides in Hela Province, Hiri in Central Province, Asaro in Eastern Highlands Province and Karkar in Madang Province (Gouda et al., 2019). The former two sites were selected as study sites since they are in the liquidified natural gas (LNG) impacted area, while the latter two sites which are located away from the gas project were used as control sites. CODs in all four health surveillance sites were determined using the Population Health Metrics Research Consortium VA instrument (Tariff 2.0 method). This method uses a Smart VA-Analyze Application, which assigns the COD from a list of 34 causes of adult death, 22 causes of child death and six causes of neonatal death (Serina et al., 2015). Using empirical data, the Tariff 2.0 algorithm weighs the signs and criteria for each cause, then sums the weights for each possible cause. All possible causes are ranked and the most probable cause selected. The Tariff 2.0 method has been found to be more accurate than review by a physician (Chowdhury et al, 2019; Murray et al., 2011).

A total of 1,038 VAs were used to calculate cause-specific mortality fractions (CSMFs) after 172 VAs were removed due to refusals and loss to follow up (116), incomplete forms (18) and stillbirths (38). However, for the latest report on the epidemiologic transition in PNG, Gouda et al. (2019) only focused on the COD in 868 adolescents and adults after excluding 170 deaths from children below the age of 12 years of age. Over 40% (40.4%) of deaths were due to NCDs of with chronic obstructive pulmonary diseases (COPD) and diabetes the leading NCDs

accounting for 10.5% and 6.2% of deaths respectively. Infectious diseases, maternal, neonatal and nutritional diseases were responsible for 21.3% of deaths, and injuries accounted for 19.1% of deaths. The COD in one out of five deaths could not be ascertained. These results show doubled the expected proportion of deaths resulting from injuries compared with other publications (IHME, 2016). However, the rate of deaths from NCDs and communicable diseases are comparable to what the GBD study published in 2016. The burden of disease show variations across the four sites. Deaths from emerging NCDs such as diabetes and cardiovascular diseases was higher in Hiri and lower in Hides, while mortality from endemic NCDs was higher in Hides than in Hiri. The differentials in COD is supported by Rarau et al. (2017) who argued that the prevalence of NCD and NCD risk factors was increasing in PNG. Based on studies from three of the four sites (Hiri, Asaro & Karkar) reported that NCD and NCD risk factors varied by ethnicity lifestyle and living environment. The prevalence of central obesity and pre-hypertension was highest in the non-Austronesian population of Asaro, while the prevalence of cardiovascular diseases and diabetes mellitus type II were highest in the Austronesian population of West Hiri. In Karkar, a mixed Austronesian and non-Austronesian population, there was a low prevalence of overweight, obesity and hypertension. In a subsequent publication Rarau et al. (2019) further argued that NCDs and NCD risk factors were associated with the level of socioeconomic development.

These differentials in mortality demonstrate that the epidemiological transition in PNG communities is not uniform and is associated with ethnicity, living environment including socioeconomic development. However, these results on COD and NCD risk factors are based only on four sites from a country with substantial variations in geography, ethnicity and level of development. Although the available evidence is limited to a small number of sites that are not representative of PNG, the findings show that epidemiological transition is evident in PNG. Further, the study by Gouda et al. (2019) has produced valuable information on mortality and

COD using a peer-reviewed VA instrument. The data generated in this study is the only available VA data in the country.

Estimates causes of death in Papua New Guinea from global studies

Existing estimates on COD in PNG have been largely based on indirect estimation and modelling rather than on empirical data. Current estimates by WHO (2018) suggest that 56% of deaths in PNG can be attributed to NCDs. COD estimates by the GBD Study (IHME, 2016) show that infectious diseases, maternal, neonatal and nutritional causes accounts for only 23% of deaths in males and 29% of deaths in males. Lower respiratory infections, ischaemic heart disease, cerebrovascular disease, COPD and diabetes were the top five CODs in 2015. GBD estimates show only one communicable disease among the top five CODs in 2005 and 2015.

PNG is reported to have entered an epidemiological transition, with emerging NCDs, including diabetes, ischaemic heart disease, cerebrovascular disease and cancer, becoming more prominent (IHME, 2012, 2016; Naghavi et al., 2017, Gouda et al., 2019). These estimates are debatable given that they have been derived using models with little empirical data. Estimates by the IHME are likely to be biased towards the global trend because of the use of indirect estimation and modelling. It is likely that not all available data were provided to the IHME team conducting the estimations, resulting in their use of Pacific Island country models to estimate PNG's mortality and COD. The resulting estimates for 2015 are likely to have overestimated the burden of NCDs, including diabetes. There is much uncertainty about the level of mortality and COD given that current estimates employ little or no local data in their estimates.

2.3 Summary of Mortality and COD Data from PNG

The literature has revealed that there is limited published data on mortality and COD from PNG, resulting in the lack of a clear understanding of mortality and COD patterns. Current

estimates of mortality and COD in PNG have been derived using demographic and statistical models with little or no local data. Few studies on under-five mortality were identified, with one study clearly showing substantial variations in under-five mortality in different geographical locations. However, no academic studies on adult mortality and life expectancy estimates for PNG or its provinces have been conducted, only national estimates derived by the UN and the GBD Study.

Few population-based studies have been conducted in small populations since World War II, and those that exist provide little comprehensive information on national mortality rates. While the international literature suggests that PNG is in a stage of epidemiological transition, high-quality data to confirm or dispute this claim are lacking.

Limited empirical data from a recent study (Gouda et al., 2019) show that PNG continues to have a high burden of communicable diseases, with pneumonia, TB, diarrhoea and other infectious diseases being the leading CODs. While COPD and asthma are the major causes of death from NCDs, diabetes, cancer and cardiovascular disease are on the rise. These findings suggest a double burden of infectious diseases and NCDs, similar to that found in other Melanesian countries. Despite these findings being derived from only four sites covering 54,000 of almost 8 million people in PNG, the results provide an insight into deaths and COD. Further, the data generated are the only available VA data for PNG obtained using an internationally approved method.

These limited all-cause and COD estimates reveal that more evidence is needed to provide a comprehensive picture of mortality patterns in PNG. This study aims to determine under-five and adult mortality rates, including life expectancy and CODs for PNG and each of its provinces. However, before proceeding with this analysis, it is necessary to assess the various data sources available in PNG for the estimation process. Hence, a review of the available data sources in PNG is critical to understand the strengths and weakness of data sources and their

consistency in reporting deaths before analysis is conducted. This is the focus of the next chapter.

Chapter 3: Review of Sources of Mortality and Causes of Death in Papua New Guinea

This chapter reviews the different mortality and COD datasets available in PNG. As mentioned, research on population-level mortality and COD in PNG is limited because, despite the availability of multiple datasets, all have significant limitations. This chapter reviews each available dataset for its strengths, weaknesses and consistency in reporting deaths and CODs. Data sources selected for analysis of all-cause mortality are further assessed using high-quality assessment methods in Chapters 4–6.

The various mortality data sources can be broadly categorised into two groups: population-based sources and routine health facility datasets. Population-based sources are reviewed in the following order: the CRVS system, national population censuses, the DHS and health and demographic surveillance systems (HDSS). Routine health facility-based datasets are reviewed in this order: the DHIS, the NHIS, the electronic NHIS (eNHIS), the perinatal register, the maternal mortality register and the paediatrics health reports. A conclusion highlighting the major strengths and weaknesses of data sources is drawn, linking with the following chapter.

3.1 Population-Based Mortality Datasets

Population-based mortality data sources in PNG include the CRVS system, national population censuses, the DHS and HDSS.

3.1.1 Civil registration and vital statistics system

The optimal data source for reliable and high-quality mortality and COD data is a well-functioning CRVS system (AbouZahr & Boerma, 2005). However, as for most middle-and lower-income countries, the CRVS system in PNG is dysfunctional and has failed to collect accurate data on deaths and births (Montgomery, 2017, 2019). PNG's CRVS system comprises three main agencies and is regulated by various regulations and acts creating confusion about the roles and responsibilities of the various agencies and stakeholders in the registration process (Montgomery, 2019). The three main agencies responsible for PNG's CRVS system are the NDoH, the PNG Civil and Identity Registry (PNGCIR) and the NSO, the latter two of which are regulated by the Department of National Planning and Monitoring.

PNG's CRVS system is regulated by the Civil Registration Act 1963 and the Civil Registration Regulations 1967 (cited in Montgomery, 2019, p. 2). An amendment (Civil Registration Amendment Act 2014) was introduced in 2014, leading to the creation of a national register and PNG's national identification system. The Act also provided for the establishment of the Office of the Registrar-General as well as giving power to the Registrar-General to establish an office in each province to be headed by a provincial registrar. Two years later, the Civil Registration (Amendment) Act 2016 was introduced, revoking the power of the Registrar-General to charge fees for civil registration (Montgomery, 2019). These changes have resulted in confusion about whether registration is compulsory and a lack of demarcation of the roles and responsibilities of different agencies and stakeholders.

Each agency in PNG's CRVS system has its own data collection system. For example, the PNGCIR is responsible for registration of births and deaths and the issuing of identity documents pursuant to the Civil Registration Act 1963. The NDoH maintains both the NHIS and DHIS, which collect mortality and morbidity data from health facilities (NDoH, 2016). As the central statistical authority, the NSO is empowered by the Statistical Service Act 1980 to access

data generated by the PNGCIR and NDoH to produce vital statistics. However, this does not occur and is further confounded by the Civil Registration Amendment Act 2016, which authorises the Registrar-General to disseminate vital statistics to government agencies for policy development and planning. Hence, it is unclear which authoritative office is responsible for vital statistics.

The lack of clarity in the Civil Registration Act 1963 and Civil Registration Regulations 1967 has resulted in a lack of coordination and communication between the central agencies responsible for recording and registering mortality data, resulting in a fragmented system. As a result, mortality data are kept in departmental silos and likely never publicly shared. Between 2015 and 2019, PNGCIR recorded less than 2% of estimated deaths, which is clearly insufficient for mortality and COD analysis (Montgomery, 2019). NDoH has the capacity to collect 22% and 28% of estimated deaths from health facilities through the DHIS and NHIS, respectively; however, these deaths are not linked to the PNGCIR database (Kitur, Adair, & Lopez, 2019b). In the past, PNGCIR was highly centralised, restricting the registration of vital events in provinces. Despite the recent establishment of 16 provincial registration offices, these offices focus mainly on retrospective birth registration for the purpose of issuing national identification cards. Further, there is no compelling reason or incentive for most people to register a death. The common misconception that a medical certification must accompany the registration of a death is untrue because registration is possible if the registrar ascertains the identity of the deceased and the fact of death. In the provinces, civil registration officers are focused on adult registration for identification purposes and have little time for death registration. Further, the lack of resources to carry out vital registration activities is another hindrance in the provinces.

Although it is the most important source of mortality and COD data, the CRVS system in PNG does not record accurate mortality data, making the direct estimation of mortality and COD impossible. Therefore, reliance on indirect methods is the only available method for PNG.

3.1.2 National censuses

Since 1966, PNG has conducted six national censuses, two prior to independence (in 1966 and 1971) and four post-independence (in 1980, 1990, 2000 and 2011). All censuses since 1966 have collected information relating to under-five mortality and those since 1971 have included information to estimate adult mortality (NSO, 2011a). To estimate childhood and adult mortality, household deaths in the previous 12 months, the survival status of mothers and fathers of respondents (orphanhood data), the number of births in the previous 12 months and summary birth histories are collected.

The number of household deaths in the previous 12 months was collected in the 2011 national census but not in the 2000 census. A total of 89,982 deaths was reported, well above the total estimated number of deaths (65,000), of which 35% occurred in children under five years (Naghavi et al., 2017). Census data indicate that 51% of deaths occurred in those under 5 years of age and 66% occurred in those under 15 years of age, with approximately 15% of deaths occurring in people between the ages of 15 and 64 years (13% between 15 and 49 years and 2.7% between 50 and 64 years). Only 2.3% of deaths occurred in people aged 65 years and above. Several reasons for this overestimation have been proposed, including errors in coding age groups and reporting of deaths that occurred more than 12 months ago (NSO, 2011a). For 8.8% of deaths, the age of the deceased was not reported.

An investigation into age-specific death rates (ASDRs), presented in Chapter 5, reveals that the ASDRs appear implausible at most ages, revealing an unlikely mortality pattern from household deaths.

Table 3.1: Deaths Occurring in the Previous 12 Months Reported By Five-Year Age Groups And Sex (2011 PNG Census)

Age Group	Total	Percent (%)	Male	Percent (%)	Female	Percent (%)
Total	89,982	100.0	49,835	100.0	40,147	100.0
0–4	45,947	51.1	25,399	51.0	20,548	51.2
5–9	8,734	9.7	4,944	9.9	3,790	9.4
10–14	5,080	5.6	2,918	5.9	2,162	5.4
15–19	4,303	4.8	2,242	4.5	2,061	5.1
20–24	3,301	3.7	1,698	3.4	1,603	4.0
25–29	2,772	3.1	1,432	2.9	1,340	3.3
30–34	2,133	2.4	1,151	2.3	982	2.4
35–39	1,724	1.9	841	1.7	883	2.2
40–44	1,396	1.6	713	1.4	683	1.7
45–49	1,199	1.3	633	1.3	566	1.4
50–54	1,079	1.2	643	1.3	436	1.1
55–59	841	0.9	529	1.1	312	0.8
60–64	893	1.0	569	1.1	324	0.8
65–69	699	0.8	465	0.9	234	0.6
70–74	569	0.6	365	0.7	204	0.5
75–79	436	0.5	283	0.6	153	0.4
80–84	338	0.4	212	0.4	126	0.3
85–89	250	0.3	156	0.3	94	0.2
90+	365	0.4	239	0.5	126	0.3
Not reported	7,923	8.8	4,403	8.8	3,520	8.8

Source: National Statistical Office (2011).

Data on parental survival were collected in 2000 and 2011 for females and in 2011 for males.

The assessment of quality and the use of these data are explored further in the next chapter.

The minimal data on parental survival were generated from the following two questions

requiring a simple yes/no response (NSO, 2000, 2011):

Is the person's own father still alive?

Is the person's own mother still alive?

Information on childbirth and survival was also collected from female respondents aged 15–49 years. Specific questions eliciting this information included:

How many children have you given birth to?

How many children of your own are living in this house?

How many children of your own are living elsewhere?

How many of your children are dead?

The responses to these questions were tabulated by respondents' age (in five-year brackets) to generate numbers for children ever born (CEB), children still living (CSL) and children ever died (CED). These proportions were then used to derive the risk of under-five mortality (5q0). An additional question asked about the number of births for women aged 15–49 years, which provided a proxy for the mean childbearing age, information required for estimating adult mortality (explained further in Chapter 4).

Censuses may not be useful for policy development because they are costly, labour intensive and conducted only once every decade. In addition, there are potential errors in the 2011 census enumeration (Allen, 2014) that could have affected the quality of data on household deaths, parental survival and child birth histories. To assess the plausibility of mortality results from the census, a series of analyses were conducted in Chapter 4 and Chapter 5. However, mortality results based on parental survival and birth histories were found to be plausible, as reported in Chapter 4 and Chapter 5. Despite this, data on household deaths, which showed age-specific death rates (ASDR) with an implausible age pattern (see 5.1), and so were not used in this thesis. Further discussion on the quality of mortality data from the 2011 census is discussed in detail in Chapter 7.2. Despite these shortcomings, censuses have the advantages of collecting data for the entire population, thus were valuable for subnational analyses, and providing orphanhood and birth history data, which were utilised as data sources to estimate adult and childhood mortality in Chapters 4 and 5.

3.1.3 Demographic and health surveys

Since 1991, three DHSs have been conducted (in 1996, 2006 and 2017) for a sample of the PNG population (NSO, 1995, 1997, 2009). While the 1996 and 2006 DHSs both collected data on childhood and adult mortality, Bauze et al. (2012) found the 2006 DHS to be of poor quality for

a number of reasons. Bauze et al (2012) found that the results of the data validation exercise for the 2006 DHS were biased because over half of the confidence intervals did not cover the population parameter measures, a figure much higher than could be attributed to chance alone. They also found that the number of children ever born and the number of dead children were underreported, suggesting that the under-five mortality levels from the DHS 2006 are also underestimated. Furthermore, females surveyed in the DHS 2006 were not representative of the female population of Papua New Guinea because younger females were oversampled while older women were undersampled. Given these reasons, Hence, it was not possible to analyse childhood and adult mortality from the 2006 DHS in this study. Child mortality data were based on detailed birth histories, including date of birth and, if the child was deceased, age at death. Orphanhood data from the 1996 and 2006 DHSs have not been tabulated or published in official reports (NSO, 2011a). Analysis of childhood and adult mortality was not possible at the provincial and district levels because the sample of respondents was insufficient to show any statistically reliable variations in mortality. In addition, the 2017 DHS was not available at the time of this review, thus was not analysed in this study. While DHSs provide more detailed data than censuses, the data collected in PNG were not of sufficient quality to warrant their use as a reliable source of mortality data.

3.1.4 Health and demographic surveillance systems

There have only been two series of population-based studies conducted using verbal autopsy in PNG since 1970. The first study is the 1970-2001 series which included the Tari, Asaro Karkar and Sepik sites discussed in the last chapter (Chapter 2). Recent population-based studies involving HDSS were conducted across four sites in PNG—two study sites (Hides in Southern Highlands Province and Hiri West in Central Province) along a liquefied natural gas pipeline and two control sites (Asaro in Eastern Highlands Province and Karkar in Madang Province). Over 54,000 people were sampled from a population of over 300,000 across these four districts.

Between 2009 and 2014, a total of 1,487 deaths were reported from these four sites (Pham et al. 2015). However, recently Gouda et al. (2019) reported only 1,210 deaths from the four sites, of which 868 adolescents and adult deaths were subsequently analysed in their study.

Table 3.2: Number of Deaths Recorded by Year of Death and Site, HDSSs

Year	Hides	Asaro	Hiri	Karkar	Total
Population sampled	13,253	9,953	12,510	18,623	54,339
2009	0	0	13	0	13
2010	3	57	59	49	168
2011	5	212	69	60	346
2012	56	211	69	122	458
2013	72	132	68	98	370
2014	29	40	27	36	132
Total	165	652	305	365	1,487

Source: Pham et al. 2015

These population-based studies were conducted using the Population Health Metrics Research Consortium SmartVA VA tool (Flaxman, Vahdatpour, Xiao, James & Murray, 2011; Murray et al., 2011; Serina et al., 2015). Deaths were reported by age, sex and village of residence, while physicians verified CODs. Sites were selected purposively to monitor the impact of the liquefied natural gas project. Given the enormous diversity in PNG and the limited number of sites from which mortality data were collected, findings from this study are not likely to be representative of mortality across the country.

The major CODs varied with age and location (Gouda et al., 2019). For example, the leading CODs in Hides were those of infectious origin, with pneumonia predominating, followed by HIV. Accidents and violence were common. Asaro, Karkar and Hiri are relatively well developed in socioeconomic terms and experienced a higher rate of NCDs such as COPD and cancer, although most cancers (cervical and liver) were infectious in origin. Cardiovascular disease and diabetes were also emerging in both Karkar and Hiri. Overall, these results show a mixed burden of infectious and non-infectious disease, requiring further investigation using data from other parts of PNG. These data show that epidemiological transition is evident in PNG but

is not uniform across the country. Despite being collected from only four communities in PNG, the VA data are the only available reliable data on community CODs for PNG.

3.2 Routine Health Facility-Based Mortality Datasets

3.2.1 Discharge Health Information System

Established in 1963, the DHIS is the oldest of all available facility-based mortality reporting in PNG. The first publication on causes of admissions and deaths in government hospitals was the Department of Public Health's *Hospital Disease Statistics 1964–67*, published in 1968. These statistics were limited to public hospitals across the country. A subsequent publication, *Hospital and Health Centre Statistics*, by the Health Planning and Epidemiology Unit in 1973 was expanded to include data from church hospitals and health centres (Department of Public Health, 1973). Because it was more comprehensive than the former publication, data from the 1973 publication provided the basis for the formulation of the first National Health Plan (Bell, 1973; Department of Public Health, 1974). The current DHIS (NDoH, 2016) shows that there are approximately 6,000 deaths reported annually (Kitur, Adair & Lopez, 2019b), with slightly higher numbers of males (52%) than females (48%) (see Table 3.3).

The DHIS is built on the FoxPro program and includes a listing of individual health facility discharges and deaths. Specific information on individual deaths includes information about the patient (name, age and sex), condition (diagnosis on discharge) and outcome (discharged/deceased). Age is available for all deaths and CODs are recorded using the PNG short list from the International Classification of Diseases, 10th Revision (ICD-10). Two-thirds of all deaths are reported from hospitals (Levels 5–7), with the remainder coming from rural health centres and health subcentres (NDoH, 2016).

The non-coding of mortality data in the provinces has resulted in a four-year backlog of data, hence 2013 is the most recent year deaths were reported through the DHIS. (See Table 3.3).

Currently, there are no provincial mortality coders, and all mortality data are sent to the NDoH Performance and Monitoring Branch to be coded and entered into the DHIS database by two people. Further, the use of different programs by hospitals has resulted in inconsistent reporting to the central database. A third of hospitals use FoxPro, a third use FileMaker and a third do not have computers, preventing them from entering data at all. Port Moresby General Hospital is currently using a third system (Instant V software) to record its deaths and discharges (NDoH, 2016).

Death reporting through the DHIS has deteriorated over the past 30 years. For example, in 1986, all hospitals, 96% of health centres and half of the health subcentres reported information relating to patients (name, age and sex), conditions (diagnosis upon discharge) and outcomes (discharged/deceased) (NDoH, 1986). In contrast, in 2012, only 18 out of 21 provincial hospitals reported data on deaths and more than 50% of health centres and subcentres did not report (NDoH, 2016). The lack of coders at provincial level results in a backlog of mortality and COD data that are four years outdated.

Table 3.3: Deaths Reported Through the Discharge Health Information System by Province and Sex (2007–2013)

Province	2007		2008		2009		2010		2011		2012		2013		Total	
	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
<i>Papua New Guinea</i>	1,675	2,101	3,253	3,580	2,872	3,417	3,123	3,667	2,956	3,542	1,097	1,149	2,669	3,202	17,645	20,658
Western	37	44	86	82	51	82	90	84	61	79	67	67	26	36	418	474
Gulf	30	31	53	62	14	19	32	44	44	48	30	30	3	6	206	240
Central	19	59	51	54	10	15	39	37	37	62	32	31	14	28	202	286
National Capital District	9	25	215	287	278	345	209	295	118	188	–	–	324	348	1,153	1,488
Milne Bay	112	138	149	152	25	46	161	197	100	130	80	78	22	18	649	759
Oro	130	149	89	117	78	95	95	98	92	118	24	38	49	58	557	673
Southern Highlands	184	253	172	175	162	168	140	162	157	166	57	68	86	94	958	1,086
Enga	183	194	133	120	121	151	166	164	142	146	23	15	174	182	942	972
Western Highlands	32	26	546	464	321	407	313	369	362	403	320	283	459	455	2,353	2,407
Simbu	58	108	140	171	188	252	172	243	229	263	65	61	197	289	1,049	1,387
Eastern Highlands	244	320	253	322	360	419	48	45	101	117	36	33	49	68	1,091	1,324
Morobe	262	275	389	444	394	450	474	590	395	474	67	86	371	492	2,352	2,811
Madang	44	65	138	159	195	222	248	274	276	335	75	108	259	320	1,235	1,483
East Sepik	106	99	148	167	180	167	230	185	228	225	79	93	148	206	1,119	1,142
West Sepik	25	29	100	97	47	46	131	140	122	139	84	97	66	95	575	643
Manus	34	41	34	26	33	41	39	49	34	39	3	4	44	36	221	236
New Ireland	55	75	107	120	70	102	113	128	80	89	16	15	69	94	510	623
East New Britain	41	48	197	270	122	119	128	177	148	194	–	–	159	208	795	1,016
West New Britain	27	60	148	188	153	175	180	254	112	175	–	–	129	147	749	999
Bougainville	43	62	105	103	70	96	115	132	118	152	39	42	21	22	511	609

3.2.2 National Health Information System

The NHIS was first introduced in 1973 to assess the workload of primary health services in rural health centres to supplement admission and mortality statistics from hospitals (NDoH, 1986). Reviews in 1979 and 1983 enabled modifications and the introduction of a computer-based system, which was upgraded in 1985. Two reporting systems (HS1 and HS2) were introduced between 1994 and 2000 (Cibulskis & Hiawalyer, 2002). The system is mainly paper-based and covers all public and faith-based facilities, including 753 health centres/clinics and 22 hospitals. Data from these facilities are compiled monthly using NHIS reporting forms, which are sent to provincial health offices to be entered into provincial databases. Unfortunately, these databases are not directly linked to the national database at the NDoH, resulting in delays that can take weeks or months (Kitur, 2012). The NHIS continues to use the FoxPro platform, even though it has now become obsolete.

The NHIS currently reports 8,000–15,000 deaths annually, far more than the older DHIS. The reported deaths come from hospitals (Levels 5, 6 and 7) and health centres and clinics (Levels 2, 3, 4). Level 5–7 health facilities are in major towns and cities, while Level 2–4 facilities are mainly rural (NDoH, 2011; Riley, 2009).

Despite more facilities (626) reporting mortality data, only 28% of 41,405 deaths recorded in the NHIS database between 2010 and 2015 showed the age of the deceased (see Table 3.4 below). There was no significant difference in age reporting between males (27%) and females (29%). Of those records showing the age at death, 14% were under five years of age, 78% were 5–14 years and 6% were over the age of 15 years.

COD information in the NHIS is inadequate because diagnosis is recorded according to 26 syndromes listed on the monthly reporting form. This limits the choices of causes, resulting in many diseases being grouped together in a meaningless category denoted as ‘others’.

Reporting of age at death is low for several reasons, including the rigidity of the reporting form in capturing all possible ages and the failure of health workers to record age. In addition, the NHIS monthly reporting form captures a summary of events, including basic demographic data at each health facility every month. Because it does not provide a list of individual deaths, it is impossible to link deaths in the NHIS with those in the DHIS.

Age is recorded for only six diseases (pneumonia, diarrhoea, malaria, malnutrition, meningitis and HIV) on the NHIS form. For all other diseases, there is only the number of deaths and the sex of the deceased. Further, there are no standard age groups across the different disease programmes. Each programme has its own age groups of interest. For example, pneumonia deaths are reported for people aged less than 1 year, 1–4 years and 5 years and older, while the malaria program reports deaths for people aged 5 years, 5–14 years and 15 years and over. Hence, the lack of standardised age groups among different programs is another major reason why age is not reported resulting in difficulties analysing deaths by age (NDoH, 2016).

One of the major weaknesses of the DHIS and NHIS data is that they do not include village level data from aid posts (Ashwell & Barclay, 2010); hence, village level deaths are not reported in any of these two systems.

The NHIS form was designed to capture a monthly summary of events at each health facility. Hence, each month, a summary of outpatient and inpatient data, program coverage rates and other health facility status is provided. Overall, despite it reporting fewer deaths, the DHIS is more accurate than the NHIS as a data source because age at death and CODs in line with ICD-10 coding are reported for all deaths through the DHIS.

Table 3.4: Reporting of Age at Death by Province and Sex by the National Health Information System (2010–2015)

Province	Age recorded		Age not recorded		Total deaths 2010–2015		% age recorded		% age not recorded	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
<i>Papua New Guinea</i>	6,324	5,238	16,849	12,994	23,173	18,232	27	29	73	71
Western	176	122	740	514	916	636	19	19	81	81
Gulf	100	92	360	273	460	365	22	25	78	75
Central	110	117	252	181	362	298	30	39	70	61
National Capital District	176	171	547	435	723	606	24	28	76	72
Milne Bay	275	235	965	713	1,240	948	22	25	78	75
Oro	182	147	579	444	761	591	24	25	76	75
Southern Highlands	213	160	580	397	793	557	27	29	73	71
Enga	446	440	763	631	1,209	1,071	37	41	63	59
Western Highlands	710	638	1,154	1,053	1,864	1,691	38	38	62	62
Simbu	469	411	1,273	827	1,742	1,238	27	33	73	67
Eastern Highlands	683	595	1,410	1,225	2,093	1,820	33	33	67	67
Morobe	701	559	1,501	1,309	2,202	1,868	32	30	68	70
Madang	424	325	1,453	992	1,877	1,317	23	25	77	75
East Sepik	310	246	1,096	1,030	1,406	1,276	22	19	78	81
Weest Sepik	219	181	639	492	858	673	26	27	74	73
Manus	49	56	206	173	255	229	19	24	81	76
New Ireland	156	103	516	369	672	472	23	22	77	78
East New Britain	364	231	1,175	826	1,539	1,057	24	22	76	78
West New Britain	338	241	911	596	1,249	837	27	29	73	71
Bougainville	223	168	729	514	952	682	23	25	77	75

3.2.3 Electronic National Health Information System

The eNHIS dataset, available in eight provinces, is an electronic version of the NHIS monthly reporting system with improvements on the recording of deaths. The eNHIS was trialled in 18 districts of five provinces between 2014 and 2017 before being rolled out to three additional provinces. Provinces initially included in the eNHIS project were Enga and Western Highlands in the Highlands Region, Milne Bay in the Southern Region and West New Britain and Autonomous Region of Bougainville in the New Guinea Islands Region (Matherson, Douglas, & Bhattacharya, 2017).

The eNHIS uses tablets to record and transmit NHIS data electronically from health facilities into a single database. Information on reported deaths includes basic demographic data (sex and age), COD using ICD-10 coding and other background information such as province, district and village of residence.

A total of 1,506 deaths was reported through the eNHIS between 19 March 2015 and 23 January 2017. Most of the deaths (601) were reported in 2016, while 101 deaths were reported in 2015 and 18 in January 2017. The eNHIS project only started compiling death data in late 2015, hence the low number of reported deaths for 2015 (NDoH, 2016).

After removing deaths from other provinces (28) and duplicates (8), 1,470 deaths were analysed and are presented in Table 3.5. All 1,470 deaths were reported from 95 health facilities in 18 districts. The facilities included eight hospitals: one regional (Level 6) hospital in Western Highlands Province, two Level 4 hospitals and one Level 5 hospital in Enga, one Level 4 and one Level 5 hospital in Milne Bay and one Level 5 hospital each in Bougainville and West New Britain Province. These deaths represent only 60% of the total (2,000–3,000) that was expected to be reported from the five provinces annually. Western Highlands Province only recorded 221 (30%) of a potential 700 deaths since it started reporting deaths in 2016.

Table 3.5: Deaths by Province from Electronic National Health Information System (2015–2016)

Province	Hospitals	Health centres	Female	%	Male	%	Total	%
Enga	3	17	160	23	159	21	319	22
Milne Bay	2	21	128	18	145	19	273	19
Bougainville	1	17	111	16	113	15	224	15
West New Britain	1	19	184	26	249	32	433	29
Western Highlands	1	13	119	17	102	13	221	15
Total	8	87	702	100	768	100	1,470	100

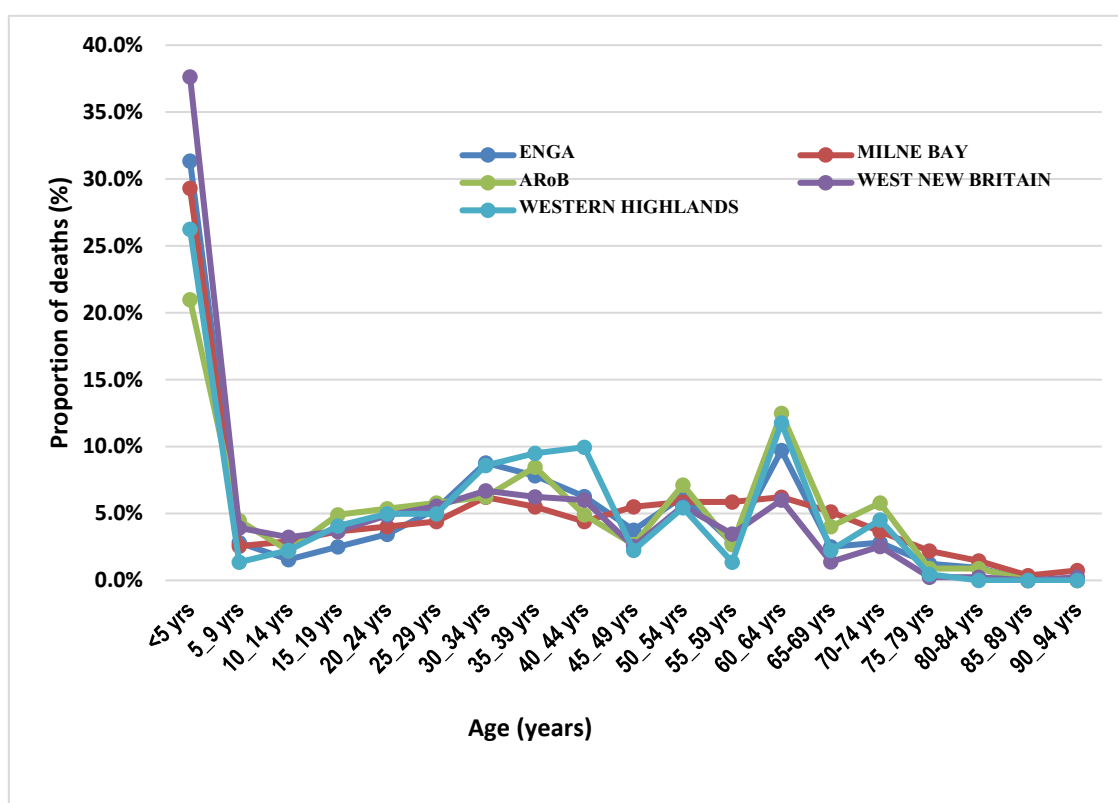


Figure 3.1: Deaths by Age in Five Provinces from Electronic National Health Information System (2015–2016)

The eNHIS shows a young age pattern of mortality, which was expected because it was facility-based. The proportion of deaths in under-five years ranged from 21% in Autonomous Region of Bougainville to 37% in West New Britain Province, while 13.6% of deaths in Milne Bay Province occurred in those aged 65 years and above. The rates for this age group were 11.6% in Bougainville, 7.5% in Enga Province and 7.2% in Western Highlands Province. Age heaping is evident in all provinces (except Milne Bay) for ages 60–64 years. It is more convenient to record an age as 60 years, even if the actual age is greater or less than 60 years.

The eNHIS platform promises to deliver better and timely mortality data than the NHIS once it is fully operational across a greater number of provinces. Data are available in real time; age is recorded for all deaths; and COD is reported using ICD-10 coding. The platform also functions as a monitoring tool to assess the performance of health facilities in terms of reporting and monitoring of disease and death trends.

The top 10 CODs in those under 5 years of age are pneumonia (13.0%), low birth weight (8.3%), birth asphyxia (8.4%), neonatal sepsis (7.7%), malnutrition (5.7%), diarrhoea (4.0%), septicaemia (4.0%), other meningitis (3.5%), bacterial meningitis (3.3%) and TB meningitis (3.1%). These results indicate that over 60% of deaths in children under 5 years of age are caused by infections, mostly occurring in the perinatal period.

For those over 5 years of age, respiratory TB (5.6%) is the leading COD, followed by COPD (5.5%), HIV/AIDS (4.8%), pneumonia (4.3%), stroke (2.9%), anaemia (2.6%), TB meningitis (2.4%), bacterial meningitis (2.2%) and diarrhoea (2.1%). The data show that two NCDs (COPD and stroke) are among the top five COD in those 5 years of age and above in these five provinces.

The eNHIS platform offers a promising source of facility-based data with good mortality and COD data reported by age, sex and place of residence. The data indicate that NCDs, particularly COPD and stroke, are on the rise, confirming similar findings in population-based surveys (Gouda et al., 2019). Like all electronic innovations in PNG, the major limitations are challenges with electricity and internet coverage in most rural areas. Hence, for the intervention to be effective, it must be implemented in phases, starting with health facilities in districts where electricity and internet coverage are available. The use of this technology will improve the efficiency of mortality and COD reporting; however, currently, the number of deaths generated, aside from those in young people, is too few for any meaningful analysis.

3.3 Other Performance Monitoring Research Branch Data

Perinatal death certificates and medical certificates are sent to the NDoH together with mortality and discharge data. However, to date there has been no attempt to analyse these reports.

3.3.1 Maternal mortality register

Approximately, 400 maternal deaths are reported each year from health facilities through the NHIS. Maternal mortality reports containing detailed information about maternal deaths are supposed to be sent to the Performance and Monitoring Branch and the Obstetrics and Gynaecology Department at the University of PNG. Currently, there is no updated database at the NDoH. The number of maternal deaths can be obtained from the NHIS, but details on age and COD are only available in the DHIS. The maternal mortality register was used together with the NHIS and DHIS by Mola and Kirby (2013), to estimate the maternal mortality rate (MMR) in PNG in 2010. Their estimated MMR of around 500 per 100,000 live births is less than what was reported by the 2006 DHS (NSO, 2009), but almost double the UN estimates for maternal mortality rate in 2010 for PNG.

3.3.2 Paediatric Hospital Reporting programme

The Paediatric Hospital Reporting programme enables hospitals to record admissions and calculate mortality rates to monitor trends and outcomes over time. The database was developed in 2007 using the FileMaker Pro platform and was implemented between 2010 and 2015 (Duke et al., 2016).

Between 2010 and 2014, the program was used by 16 hospitals sparingly, with seven hospitals reporting in 2009, 11 in 2010, 11 in 2011, 10 in 2012, 12 in 2014 and 14 in 2015. Between 2009 and 2015, 16 hospitals have released five reports annually (Duke et al., 2016). About 7,128

deaths of 96,998 admissions were reported between 2009 and 2014. By 2015 there were 8,912 deaths from 120,326 hospital admissions.

Table 3.6: Number of Deaths Reported in the Paediatric Hospital Reporting Program (2009–2015)

Year	2009	2010	2011	2012	2013	2014	2015	Total
Admissions	3,456	10,897	20,582	20,546	20,543	20,974	16,278	120,326
Deaths	209	646	1,545	1,660	1,555	1,482	1,247	8,912

Source: Duke et al., 2016.

The data cover more than half the provincial hospitals in the country, with around 1,500 deaths reported annually from over 20,000 annual admissions. Despite sporadic reporting by hospitals, COD diagnoses were of high quality after they were standardised to WHO definitions and the ICD-10. This represents one of the best-maintained datasets available for mortality and COD among children.

The major CODs among children in PNG hospitals between 2009 and 2014 were pneumonia (26%), severe malnutrition (22%), neonatal conditions (22%), meningitis (11%), TB (9%), diarrhoea (4%), malaria (4%) and HIV/AIDS (3%).

The quality of reporting has been affected by hospitals using different versions of the Paediatric Hospital Reporting program (NDoH, 2011). Kerema Hospital did not report for the period 2009–2015. In addition, there is incomplete data reporting—for example, Kavieng, Mendi, Popondetta, Vanimo and Port Moresby hospitals failed to report in 2014.

The PHP is a potential data source capable of generating quality mortality and COD data for children, however, requires consistent annual reporting by all provincial hospitals. This data source was not used in the analyses since it contains data for child deaths only.

Table 3.7: Reported Deaths by Hospital (2010–2015)

Hospital	2010		2011		2012		2013		2014		2015		Total	
	Admissions	Deaths	Admissions	Deaths	Admissions	Deaths	Admissions	Deaths	Admissions	Deaths	Admissions	Deaths	Admissions	Deaths
Daru	–	–	–	–	–	–	–	–	–	–	103	2	103	2
Kerema	–	–	–	–	–	–	–	–	–	–	–	–	0	0
Port Moresby	5,180	431	4,901	373	3,954	300	4,121	238	–	–	–	–	18,156	1,342
Alotau	1,002	28	–	–	–	–	2,013	261	1,490	49	–	–	4,505	338
Popondetta	–	–	–	–	–	–	2,198	163	–	–	899	91	3,097	254
Mendi	2,262	112	–	–	2,143	123	–	–	–	–	–	–	4,405	235
Tari	–	–	–	–	–	–	–	–	–	–	–	–	0	0
Wabag	1,055	89	991	95	–	–	230	16	902	76	818	73	3,996	349
Mt Hagen	–	–	4,198	303	4,232	298	9,435	653	4,002	277	2,788	161	24,655	1,692
Kudjip	–	–	–	–	–	–	–	–	–	–	–	–	0	0
Kundiawa	–	–	–	–	–	–	1,868	132	2,827	210	987	71	5,682	413
Goroka	1,517	90	3,125	114	3,618	279	3,916	205	3,931	198	2,847	153	18,954	1,039
Angau	–	–	2,457	244	2,161	270	–	–	2,041	241	1,547	166	8,206	921
Madang	977	109	1,342	143	1,533	171	1,272	137	1,813	131	1,478	142	8,415	833
Boram	–	–	–	–	–	–	–	–	1,046	50	1,042	95	2,088	145
Vanimo	820	31	668	15	802	50	–	–	–	–	507	39	2,797	135
Lorengau	494	9	–	–	–	–	–	–	266	1	–	–	760	10
Kavieng	378	14	–	–	236	13	–	–	–	–	308	12	922	39
Nonga	720	46	833	61	–	–	–	–	976	78	1,080	65	3,609	250
Kimbe	1,013	72	881	102	1,145	103	999	109	1,204	128	1,153	107	6,395	621
Buka	659	46	574	42	632	53	519	43	476	43	721	70	3,581	297
Papua New Guinea	16,077	1,077	19,970	1,492	20,456	1,660	26,571	1,957	20,974	1,482	16,278	1,247	120,326	8,915

Table 3.8: Sources of Mortality Data in Papua New Guinea

Data source	Institution	Deaths	Strengths	Weaknesses
<i>Population-based</i>				
Civil registration systems	PNG Civil and Identity Registry	612 deaths for 2015–2019 (less than 2% of deaths registered annually)	Potential source of comprehensive mortality data by age and sex	Dysfunctional system; mortality data held in departmental silos; therefore, unable to obtain meaningful and reliable mortality indicators from registered deaths
PNG national censuses (2000 and 2011)	National Statistical Office	Parental survival and summary birth history data; 89,000 household deaths in previous 12 months (2011)	Conducted in entire population. Data on parental survival to estimate adult mortality (45q15). Summary birth histories for under-five mortality (5q0) estimation	Household deaths have age reporting issues; hence, age-specific death rates are implausible. No father survival data in 2000
Demographic and health surveys	National Statistical Office		Potential source of data for adult and child mortality	2006 DHS child survival data were of poor quality. No reliable adult mortality data
Partnership in Health Project	PNG Institute of Medical Research	1,210 deaths (2009–2014)	Relatively complete recording of deaths in HDSS sites	Deaths only from specific sites, so not representative of the whole country to enable all-cause mortality analysis
<i>Facility-based</i>				
National Health Information System	NDoH	41,405 deaths (2010–2015)	Deaths recorded from 636 health centres and 22 hospitals	Age not recorded in 72% of deaths, thus limiting usefulness in mortality analysis. Deaths only for those accessing facilities (28%), thus insufficient for population-level mortality analysis
Electronic National Health Information System	NDoH	2,487 deaths (2015–2017)	Age recorded for all deaths; timeliness and quality of data	Reported deaths from facilities in only eight provinces, insufficient for analysis. Facility-based data insufficient for all-cause mortality analysis
Discharge Health Information System	NDoH	38,303 deaths (2007–2013)	Records deaths by age and sex from all hospitals and health facilities	Reported deaths account for only 22% of all deaths, thus insufficient for population-level mortality analysis
Maternal mortality register	NDoH	3,094 maternal deaths (2010–2018)	Empirical source of estimating maternal mortality rate	Detail information on maternal deaths lacking
Perinatal mortality register	NDoH	Not analysed		
Paediatric health report	Paediatric Society of PNG	8,915 deaths (2009–2015)	Quality source of COD data	Inconsistent reporting from hospitals (16 of 21 provincial hospitals reported). Only available for child deaths

Note: PNG = Papua New Guinea; NDoH = National Department of Health.

The reliability of public health reports as a source of under-five mortality and COD may arise from the stringent process in which deaths are recorded in line with WHO guidelines (Duke et al., 2016).

3.4 Summary of Sources of Mortality and COD Data in PNG

This review clearly confirms that despite the range of sources available, there is no single dataset that comprehensively describes mortality and COD in PNG. A summary of all sources is shown in Table 3.8. The CRVS system is dysfunctional, and most routine health facility-based sources report only a small proportion of deaths weighted towards younger ages and miss most deaths that occur outside of health facilities. The 2006 DHS has been assessed as being of poor quality. The most credible all-cause mortality data sources are the censuses, which are only conducted every 10 years in PNG, and the HDSS VA data from four sites. Therefore, given these shortfalls, estimation of age-specific and all-cause mortality and COD for PNG will continue to be derived using indirect methods in which demographic and statistical models will be used to compensate for poor-quality data. Chapter 4 presents an estimation of adult mortality for PNG and each of its provinces using novel indirect demographic methods from the 2011 and 2000 census data.

Chapter 4: Estimating Adult Mortality in Papua New Guinea

4.1 Introduction

This chapter estimates adult mortality (the probability of dying between the ages of 15 and 60 years per 1,000 population, or $45q_{15}$) by sex for PNG and each of its provinces using demographic and statistical methods applied to data on deaths from the 2000 and 2011 censuses.

In the past, adult mortality in PNG has attracted little attention, despite it being a critical population health indicator (being the most economically productive age span) (WHO, 2016) and its importance as developing countries experience epidemiological transitions (Roth et al., 2018). The emergence of epidemiological transitions in developing countries because of young adults dying from risky health behaviours and older adults dying from lifestyle-related diseases such as cardiovascular disease, diabetes, stroke and cancer makes adult mortality an important indicator for the comprehensive assessment of a population's mortality pattern. Further, inputting adult mortality into model life tables to estimate life expectancy in countries with sparse mortality data makes its estimation even more appealing (WHO, 2016).

Despite the significance of adult mortality (Naghavi et al., 2017), there are no published estimates in the academic literature of adult mortality in PNG, largely because the civil registration system has failed to record accurate data on deaths (Montgomery, 2017). Additionally, routine death reporting from health facilities represent only a small proportion of deaths in the population (Kitur, Adair, & Lopez, 2019b). The lack of empirical local data on deaths has necessitated the use of demographic and statistical models, which are mostly based on model life tables and/or regression modelling with socioeconomic covariates, to estimate adult mortality levels in PNG (Naghavi et al., 2017; United Nations Department of Economic and Social Affairs, Population Division, 2017). According to UN estimates for 2011,

the 45q15 was 206 per 1,000 for females and 266 for males (United Nations Department of Economic and Social Affairs, Population Division, 2017). In the GBD Study, 45q15 estimates were higher at 338 per 1,000 for females and 392 for males (Naghavi et al., 2017). These mortality estimates are limited to the national level, with no estimates at subnational levels, even though significant mortality differentials are likely to exist given the sociodemographic profile of the country (as discussed in Chapter 1).

Given the importance of accurate adult mortality to inform population health policy and facilitate the estimation of other mortality summary indicators, including life expectancy, this chapter estimates adult mortality by sex for PNG at the national and provincial levels using data on parental survival from the 2000 census (for males) and 2011 census (for females) and by extending existing demographic methods (Timaues, 2013a, 1992; Zotnik & Hill, 1981). This chapter also discusses geographic and socioeconomic inequalities and sex differentials in adult mortality risk at the provincial level in comparison to a summary index of education, economic and health access indicators. This composite index was used to assess the plausibility of mortality estimates (Kitur, Adair, & Lopez, 2019a).

This chapter primarily comprises a published paper on these estimates, which is presented next (Kitur, Adair, & Lopez, 2019a). This paper is complemented by additional text and data that provide more detail on the methods of estimating adult and child mortality, the assessment of the completeness of male adult death reporting, the construction of the composite index and additional data that could not be accommodated in the published paper. The chapter finishes with some concluding remarks.

RESEARCH

Open Access

Estimating Adult Mortality in Papua New Guinea, 2011



Urarang Kitur^{*}, Tim Adair and Alan D. Lopez

Abstract

Background: Mortality in Papua New Guinea (PNG) is poorly measured because routine reporting of deaths is incomplete and inaccurate. This study provides the first estimates in the academic literature of adult mortality (45q15) in PNG by province and sex. These results are compared to a Composite Index of provincial socio-economic factors and health access.

Methods: Adult mortality estimates (45q15) by province and sex were derived using the orphanhood method from data reported in the 2000 and 2011 national censuses. Male adult mortality was adjusted based on the estimated incompleteness of mortality reporting. The Composite Index was developed using the mean of education, economic and health access indicators from various data sources.

Results: Adult mortality for PNG in 2011 was estimated as 269 per 1000 for males and 237 for females. It ranged from 197 in Simbu to 356 in Sandaun province among men, and from 164 in Western Highlands to 326 in Gulf province among women. Provinces with a low Composite Index (Sandaun, Gulf, Enga and Southern Highlands) had comparatively high levels of adult mortality for both sexes, while provinces with a higher Composite Index (National Capital District and Manus) reported lower adult mortality.

Conclusions: Adult mortality in PNG remains high compared with other developing countries. Provincial variations in mortality correlate with the Composite Index. Health and development policy in PNG needs to urgently address the main causes of persistent high premature adult mortality, particularly in less developed provinces.

Keywords: Papua New Guinea, Adult mortality, Orphanhood method, Socio-economic inequalities, Sub-national mortality

Introduction

Papua New Guinea (PNG) is a country of eight million people with relatively high mortality and substantial socio-economic and geographic differences [1]. Previous research into mortality in PNG has primarily focused on childhood [2–5] and maternal mortality [6] and in particular infectious diseases such as pneumonia and tuberculosis [7, 8]. Although these have justifiably been topics of considerable and persistent relevance for population health in PNG [9], there has been very little attention paid to the measure of adult mortality, and its causes, despite its importance in overall premature mortality in populations like PNG [10].

The gold standard source for estimating mortality at the national and subnational level is high-quality, complete vital registration data [11]. The lack of empirical data on deaths in PNG to directly measure adult mortality has necessitated the use of demographic and statistical modelling methods that generally use little, if any, local data and instead are driven by model life tables and/or regression modelling with socio-economic covariates [10, 12]. PNG national adult mortality estimates (i.e. the probability of dying between ages 15 and 60 years, or 45q15) for 2011 according to the UN were 266 per 1000 for males and 206 for females,¹ while Global Burden of Disease Study (GBD) estimates were higher, at 392/1000 for males and 338/1000 for females. Moreover, these mortality estimates are limited to the national level; there is no reliable evidence on adult mortality at the sub-national level despite the fact that significant

* Correspondence: u.kitur@student.unimelb.edu.au
Melbourne School of Population and Global Health, University of Melbourne, Melbourne, Carlton, Victoria, Australia



© The Author(s). 2019 **Open Access** This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The Creative Commons Public Domain Dedication waiver (<http://creativecommons.org/publicdomain/zero/1.0/>) applies to the data made available in this article, unless otherwise stated.

mortality differentials are highly likely to exist, given the socio-demographic profile of the country.

Given the critical importance of accurate adult mortality measurement to inform population health policy to reduce premature deaths, we set out to estimate adult mortality (45q15) by sex at the national and provincial level in PNG using demographic methods applied to data on parental survival in the 2000 and 2011 population censuses. The second objective is to discuss geographic inequalities and sex differentials in adult mortality risk at the provincial level with reference to a summary index of education, economic and health access indicators to assess the plausibility of our findings.

Methods

Data sources

There is no single dataset that accurately describes adult mortality in PNG. Multiple disparate data sources exist, the most important of which are described below. A full summary is shown in Table 1.

Civil registration and vital statistics system

The civil registration and vital statistics (CRVS) system in PNG is dysfunctional, and birth and death registration remain very incomplete and inaccurate [13]. The system is fragmented as data are kept in departmental silos with little or no coordination and communication between the agencies involved at the central level, including the Civil and Identity Registry Office (CIRO), National Department of Health (NDOH), Department for Provincial and Local Government Affairs, Department of National Planning and Monitoring, and the National Statistics Office (NSO). Given the deficiencies in the CRVS system, it is not possible to obtain statistically meaningful and reliable mortality indicators from registered deaths.

Census Data in 2000 and 2011

The 2000 and 2011 population censuses collected data on the survival status of the mother of each household respondent, and the 2011 census also collected data on the survival status of the father of each household respondent. These are known as maternal and paternal

Table 1 Sources of adult mortality data, PNG

Data Source	Institution	Deaths	Strengths	Weaknesses
Population-Based				
Civil Registration System	Civil and Identity Registry Office (CIRO)	Less than 1% registered annually	Potential source of comprehensive mortality data by age and sex	Dysfunctional system, mortality data held in departmental silos so unable to obtain meaningful and reliable mortality indicators from registered deaths
PNG National Censuses (2000 and 2011)	National Statistics Office (NSO)	Parental survival and summary birth history (SBH) data; 89,000 reported deaths in household in last 12 months (2011)	Data on parental survival to estimate adult mortality (45q15). Summary Birth Histories (SBH) for under 5 mortality (5q0) estimation.	Household deaths have age reporting issues; hence, age-specific death rates are implausible. No father's survival data in 2000.
Demographic & Health Surveys	National Statistics Office		Potential source of data for adult and child mortality	2006 child survival data is of poor quality. No reliable adult mortality data.
Health and Demographic Surveillance System (HDSS) sites (Partnership in Health Project, Hiri-West, Hides, Asaro and Karkar)	Papua New Guinea Institute of Medical Research (PNGIMR)	1,308 deaths (2009-2014)	Relatively complete recording of deaths within HDSS sites.	Deaths only from specific sites, so not representative of the whole country to enable all-cause mortality analysis
Facility-Based				
National Health Information System (NHIS)	National Department of Health	41,405 deaths (2010–2015)	Deaths recorded from 636 health centres and 22 hospitals	Age is not recorded in 72% of deaths limiting its usefulness in mortality analysis. Deaths for only those accessing facilities (28%) of all deaths, not sufficient for mortality analysis.
eNHIS	National Department of Health	2487 deaths (2015–2017)	Age recorded for all deaths, timeliness and quality of data	Reported deaths from facilities in only 5 provinces, insufficient for analysis. Facility-based data insufficient for all-cause mortality analysis
Discharge Health Information System (DHIS)	National Department of Health	38,303 deaths (2007–2013)	Records deaths by age and sex from all hospitals and health facilities	Reported deaths account for only 22% of all deaths, so insufficient for mortality analysis.

orphanhood questions and require a “yes” or “no” response [14, 15]. The proportion of respondents with their mother still alive or father still alive can be tabulated by sex and 5-year age group of the respondent and then used together with the orphanhood method to estimate adult mortality [16]. The 2011 census also collected data on the number of household deaths in the previous 12 months; however, analysis of these data revealed highly implausible age patterns making them unsuitable for analysis of adult mortality. The 2000 and 2011 censuses collected data on summary birth histories (SBHs); that is, women were asked how many children they had ever given birth to and how many had survived. Such data can be used to estimate child mortality [17, 18]. The 2011 census also asked women how many children they had given birth to in the last 12 months, which can be used to generate a proxy for the mean age at child birth for women. Between the 2011 and 2000 censuses, two new provinces were created: Hela (formerly part of Southern Highlands) and Jiwaka (formerly part of Western Highlands). Due to data for these provinces not being available in both censuses, all analyses are based on provinces as at the 2000 census; Hela as part of Southern Highlands and Jiwaka as part of Western Highlands.

Demographic and health surveys in 1996 and, 2006

The Demographic and Health Surveys (DHS) in 1996 and 2006 included questions on the survival of mothers and fathers, as well as SBHs. Although the 1996 and 2006 DHS included the paternal as well as maternal orphanhood question, this data was never tabulated and published in any official survey reports [19]. Moreover, Bauze et al. [2] reported that child mortality data from the 2006 DHS were of poor quality, and so they were not analysed in this study.

DHIS, NHIS, and eNHIS

The NDOH collects detailed information on births, deaths and causes of deaths using two paper-based parallel and independent systems comprising of the National Health Information System (NHIS) and Discharge Health Information System (DHIS) [20]. The DHIS is the older of the two systems and reports around 6000–11,000 individual deaths annually primarily from provincial hospitals. The NHIS annually reports a summary of 8000–15,000 deaths annually from mainly health centres, but also from hospitals. The reporting of deaths across the two systems is not independent, with several deaths being included in both systems. Moreover, these data are unsuitable for estimating population-level adult mortality because they only include deaths in facilities; the DHIS only captures an estimated 22% and the NHIS 28% of all deaths in PNG [21]. Furthermore, the NHIS does not report the age at

death in 72% of these reported deaths, thus further limiting their value for analysis.

An electronic version of the NHIS was trialled in five provinces between 2014–2017 [22], with deaths recorded via mobile phone and transferred to a central server. However, the coverage of this system is still too low for meaningful analysis.

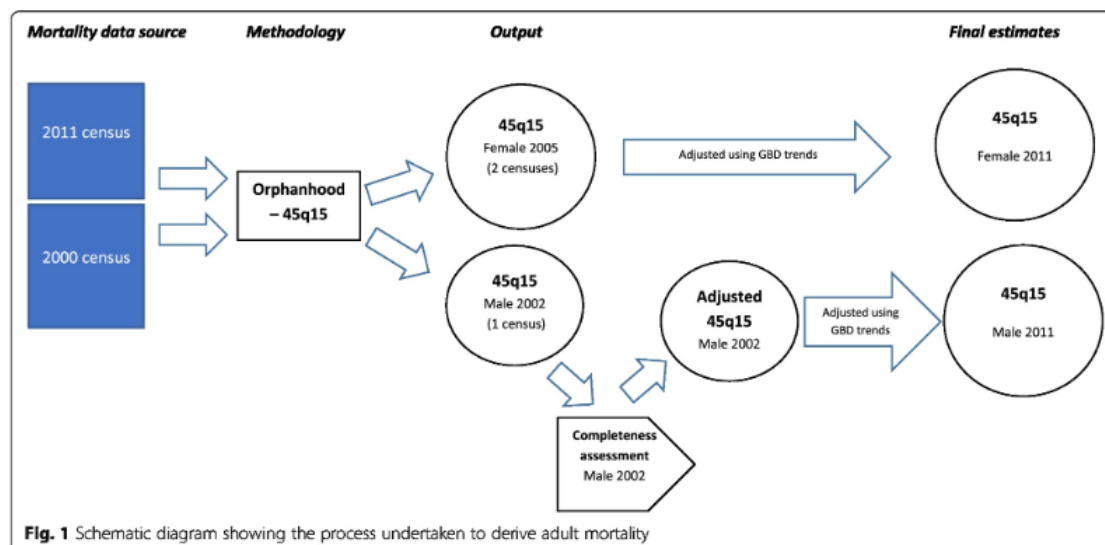
Analytical methods

Since it is not possible to directly obtain statistically valid measures of male and female adult mortality using data from the CRVS system or facility-based sources, adult mortality estimates for PNG and its provinces were derived using the orphanhood method applied to data from the 2000 and 2011 censuses. Estimates of adult mortality were made for 2011 because it was the year of the most recent census; other analyses were then based around this reference date.

A schematic diagram of the process undertaken to derive adult mortality by province and sex is illustrated in Fig. 1. In summary, 45q15 was estimated for males using orphanhood data from the 2011 census and for females using orphanhood data from the 2000 and 2011 censuses. The completeness of the estimated 45q15 for males was measured using the Adair-Lopez method [23], and this completeness estimate was used to adjust the original 45q15 estimates upwards. The reference date for the male 45q15 was 2002 (an average of the date for each 5-year age group) and for the female 45q15 was 2005; these values were then projected forward to 2011 by applying the trend in PNG 45q15 estimated from the GBD Study [10].

Estimating Adult Mortality using the Orphanhood Method

The orphanhood method, first developed by Brass and Hill [24] and refined by Timaeus [25], is a widely used method to indirectly estimate adult mortality. The method estimates male and female 45q15 based on the proportion of respondents with a surviving father or surviving mother, respectively, tabulated by 5-year age group of the respondent. The age of the respondents is used as the duration over which the mother or father has been exposed to the risk of dying and helps to convert the proportion of mothers alive or fathers alive to an estimate of 45q15 [16]. For female adult mortality, the data on the proportion of mothers alive are converted to an estimate of $\frac{l_{5+}^{s,15}}{l_{25}^{s,15}}$ (where n is the age of respondent) using the mean age at child-bearing of mothers (calculated from reported births in the last year by age of the mother in the census) and a set of provided coefficients. The relationship of $\frac{l_{5+}^{s,15}}{l_{25}^{s,15}}$ to $l_{s, 25+n}$ of a standard population in a chosen model life table² is then used to estimate the female adult mortality rate for each age group of respondents. For male adult mortality, the



same process is followed except that the relationship of $\frac{I_{35+n}}{I_{35}}$ to I_{35} is used because men on average tend to be older than their wives. The reference date for the adult mortality for each age group of respondents is calculated based on the mean age of childbearing.

Data on parental survival may be prone to selection bias due to their being based only on reports by surviving children, and if parental and child mortality are strongly correlated then adult mortality would be underestimated [16]. However, such selection bias only arises in populations affected by a generalised HIV epidemic or a severe economic catastrophe, both of which are not the case in PNG [26], and therefore any selection biases are assumed to be minimal. The orphanhood method excludes adults with no living children; however, this is a very low proportion in PNG with only 11% of women aged 40–44 years not having borne any children [15]. Also, if a significant proportion of a provincial population is recent migrants, such as in many subnational populations, then the resultant adult mortality level may also be biased. However, aside from the capital Port Moresby, inter-provincial migration in PNG is relatively low [1] and would not be expected to substantially affect the 45q15 estimates.

The method described above was used to estimate male adult mortality from the 2011 census. Mean age at childbearing of fathers was calculated as mean age at childbearing of mothers plus the difference in median age of currently married males to currently married females [25]. Estimates of male 45q15 and the reference date of the estimates were derived from the average results of respondents aged 10–14 to 30–34 years. Respondents from older

age groups were excluded from the calculation because it would have resulted in the reference date being too many years prior to the reference year of 2011.

A variation of the orphanhood method is to use parental survival data by 5-year age group from two censuses and to construct a hypothetical cohort of respondents to estimate adult mortality based on changes in the survival status of each cohort's parents [27, 28]. This can be done using female mortality in PNG from the 2000 and 2011 censuses. This method provides more accurate estimates of adult mortality than derived from one census alone because it is based on the survival of parents of hypothetical cohorts during an intercensal period; the same information is being asked of the same cohorts of respondents at two points in time, and so any bias introduced by systematic under-reporting of mothers' mortality would be minimal. The 45q15 is estimated as the average of the 45q15 of each age group 20–24 to 45–49. The reference date for the 45q15 estimates is the geometric mean of the two census dates. The method relies upon the calculation of the mean age of childbearing of the mothers in each census using births in the previous year; these data are only available in the 2011 census and so the mean age at childbearing in 2011 was assumed to apply in 2000 as well.

Assessment of completeness of male adult mortality

As mentioned above, there may be under-reporting of male adult mortality derived from applying the orphanhood method to just one census. Under-reporting may occur due to respondents who were adopted not reporting on the survival status of their biological father; adoption of orphaned children by other family members is a

common practice in PNG. The completeness of male adult mortality in 2002, the reference date for the male 45q15 estimate, was estimated using a recently developed empirical method [23]. Other widely used methods to estimate the completeness of mortality reporting (death distribution methods and capture-recapture methods) cannot be used in this study because of their data requirements and assumptions of population dynamics [23]. The empirical method requires the following data inputs: the crude death rate based on reported deaths as the numerator, the true under-five mortality rate (5q0; the probability of death from live birth to 5 years) and the proportion of the population aged 65 years and over. The estimated number of reported deaths was calculated using model life tables,³ with the 45q15 taken from the orphanhood data and 5q0 for 2002. The 5q0 was obtained by using the 5q0 calculated for each sex and province from the 2000 census from the Maternal Age Cohort method, scaling it to the provincial 5q0 as estimated by Bauze and others, and then scaling these estimates to national 5q0 as estimated by the UN Inter-agency Group for Child Mortality Estimation (IGME) for 2002 [2, 17, 29]. The resultant age-specific death rates were multiplied by the population and summed across all age groups to generate an estimated total number of reported deaths. Population data by age and sex for 2002 were estimated by interpolating between the 2000 and 2011 censuses using a geometric growth rate for the total population and linearly interpolating the age-sex distribution of the population [30]. The 45q15 estimated by the orphanhood method was divided by the estimate of completeness of male adult mortality to produce an adjusted male 45q15 in 2002.

Projection of 45q15 estimates to 2011

To adjust both male 2002 and female 2005 45q15 estimates forward to 2011, we used published estimates of 45q15 from the GBD [10]. That is, the ratio of the 2011 to 2002 45q15 as estimated by the GBD was multiplied by the 2002 estimate of male 45q15 to produce 2011 male 45q15, and the ratio of 2011 to 2005 GBD 45q15 was multiplied by the estimate of female 2005 45q15 to produce 2011 female 45q15. The GBD estimates were developed using data and methods independent of the data sources we used in our estimates [10].

Data to describe geographic and socio-economic differentials—Composite Index

Variations in mortality may be associated with social, economic and health system characteristics including ethnic group, marital status, education attainment, occupation, income and socio-economic class, as well as

access to health services [31]. Disaggregation by socio-economic indicators is likely to provide a more informative basis for policy action to reduce mortality differentials than simply using rural and urban or provincial classifications [32]. In PNG, which has significant geographic diversity, the use of an index to measure variation in socio-economic and other characteristics is important to interpret and assess differences in mortality. A sociodemographic index (SDI) identified by the GBD [32] has been previously used for comparison of mortality differentials [33, 34]. In PNG, it is possible to rank provinces and districts using a Composite Index derived from socio-economic indicators to interpret differences in mortality at the subnational level. Previous studies [35–40] in PNG have utilised indicators to rank districts and improve targeting of interventions. This study uses a Composite Index calculated as the arithmetic mean of education, economic and health access indicators. The education indicator measures the net admission rate (percentage of children aged 6 years who were admitted to elementary prep school) and female literacy rate [41]; the economic indicator is an average of poverty levels as assessed by the World Bank based on basic food and non-food expenditure [37] and the proportion of people engaged in paid work activities from the 2011 census [15]; the health access index was computed based on information about the number of health workers per population and the immunisation rates from the 2010–2011 Sector Performance Annual Review [42]. The results for each indicator were adjusted to be a normally distributed percentage ranging from 0 to 100%.⁴ We present scatterplots of male and female 45q15 against the Composite Index and show the *r*-squared of these relationships.

Results

Adult mortality (45q15)

Table 2 shows the estimated completeness of male 45q15 based on the 2011 census data. Overall, 83% of estimated male deaths in PNG between ages 15–60 were reported in the census, ranging from 62% in Enga to 93% in Central province. The 2011 national male 45q15 was estimated at 269 per 1000, varying from 197 in Simbu province to 356 in Sandaun province. Gulf (346), Southern Highlands (326), Enga (300), Morobe (299), Madang (298), and East Sepik (297) are among the provinces with the highest male 45q15. Conversely, National Capital District (207), Western Highlands (223), Eastern Highlands (228), together with three island provinces (Manus 235, New Ireland 239 and West New Britain 258) reported the lowest male 45q15 for 2011. The estimate of 269 is very similar to the UN's estimate of 262/1000, but well below the GBD estimate for the same year of 392.

Table 2 Male adult mortality (45q15 per 1000) by province, PNG 2011

Province	45q15 2011 is Census (reference year 2002)	Estimated completeness (%)	45q15 Adjusted for completeness (reference year 2002)	45q15 projected to 2011
Western	251	81	291	281
Gulf	322	90	358	346
Central	269	93	293	283
National Capital District	173	81	214	207
Milne Bay	241	87	275	266
Oro	239	85	278	269
Southern Highlands/Hela	229	64	337	326
Enga	206	62	310	300
Western Highlands/Iwaka	172	71	231	223
Simbu	161	75	204	197
Eastern Highlands	189	79	236	228
Morobe	266	85	309	299
Madang	270	88	308	298
East Sepik	272	85	307	297
Sandaun	336	91	368	356
Manus	215	90	243	235
New Ireland	217	87	247	239
East New Britain	243	85	278	269
West New Britain	227	84	267	258
Bougainville	248	81	292	282
PNG	230	83	278	269
GBD				392
UN				262

For females, the national estimate of 45q15 in 2011 was 237 per 1000, about 12% lower than for males (see Table 3). Provincial estimates vary from 164 in Western Highlands to 326 in Gulf province. Sandaun (305), Morobe (287), Simbu (274) and Enga (272) are estimated to have the highest levels of 45q15 for females. Western Highlands (186), National Capital District (171), Western (181), Bougainville (200), Milne Bay (206) and Manus (211) reported the lowest female 45q15. The national estimate is higher than the UN's estimate of 202, but again much lower than the GBD's estimate of 338 [10].

Figures 2 and 3 show the variation in adult mortality levels by the province for males and females respectively. Among males, there is a belt of comparatively high adult mortality rates running through the central provinces of the country, although interestingly this is not the case in some neighbouring provinces such as Eastern Highlands. The comparatively low levels of adult male mortality prevailing in the eastern coastal (Oro and Milne Bay) and island provinces (Manus, West New Britain, New Ireland) is also clear, with the exception of Bougainville. The northern region (Morobe, Madang, East Sepik) and Bougainville reported moderately high levels of male

45q15. Bougainville was affected by a 10-year-long civil war between 1989 and 1998 which resulted in 15,000–20,000 deaths, mostly men [43]. Central province, despite surrounding the National Capital District, includes Goilala and Rigo, two of the most remote and least developed districts in the country [15, 38].

The national picture for female 45q15 is quite different, however, with much more geographical variation across provinces, although the comparatively low rates in the eastern coastal and island provinces is also apparent for women.

Sex differences in adult mortality were generally low in PNG as might be expected for a country at an early stage of its NCD epidemic. In general, as female 45q15 increases there is a corresponding rise in male adult mortality ($R^2 = 0.3407$) (Fig. 4). In all except two provinces, male 45q15 is higher than for females; these provinces are Simbu, where 45q15 is 274 for females against 197 per 1000 for males, and Eastern Highlands where 45q15 is 228 for males and 253 for females. Particularly, large differences in male versus female adult mortality were found in Western, Southern Highlands/Hela and Bougainville. While the civil war on Bougainville could

Table 3 Female adult mortality (45q15 per 1000) by province, PNG 2011

Province	45q15 2011 and 2000 Census (reference year 2005)	45q15 projected to 2011
Western	191	181
Gulf	344	326
Central	281	266
National Capital District	181	171
Milne Bay	218	206
Oro	233	221
Southern Highlands/Hela	224	212
Enga	287	272
Western Highlands/Iwaka	196	186
Simbu	289	274
Eastern Highlands	267	253
Morobe	303	287
Madang	273	259
East Sepik	253	240
Sandaun	322	305
Manus	223	211
New Ireland	230	218
East New Britain	262	248
West New Britain	249	236
Bougainville	211	200
PNG	250	237
UN		202
GBD		338

have resulted in high male than female adult mortality, high rates of violence and tribal conflicts in Hela and Southern Highlands could be the reason for the comparatively high excess male mortality compared with females [43, 44].

Composite Index by province, PNG, 2011

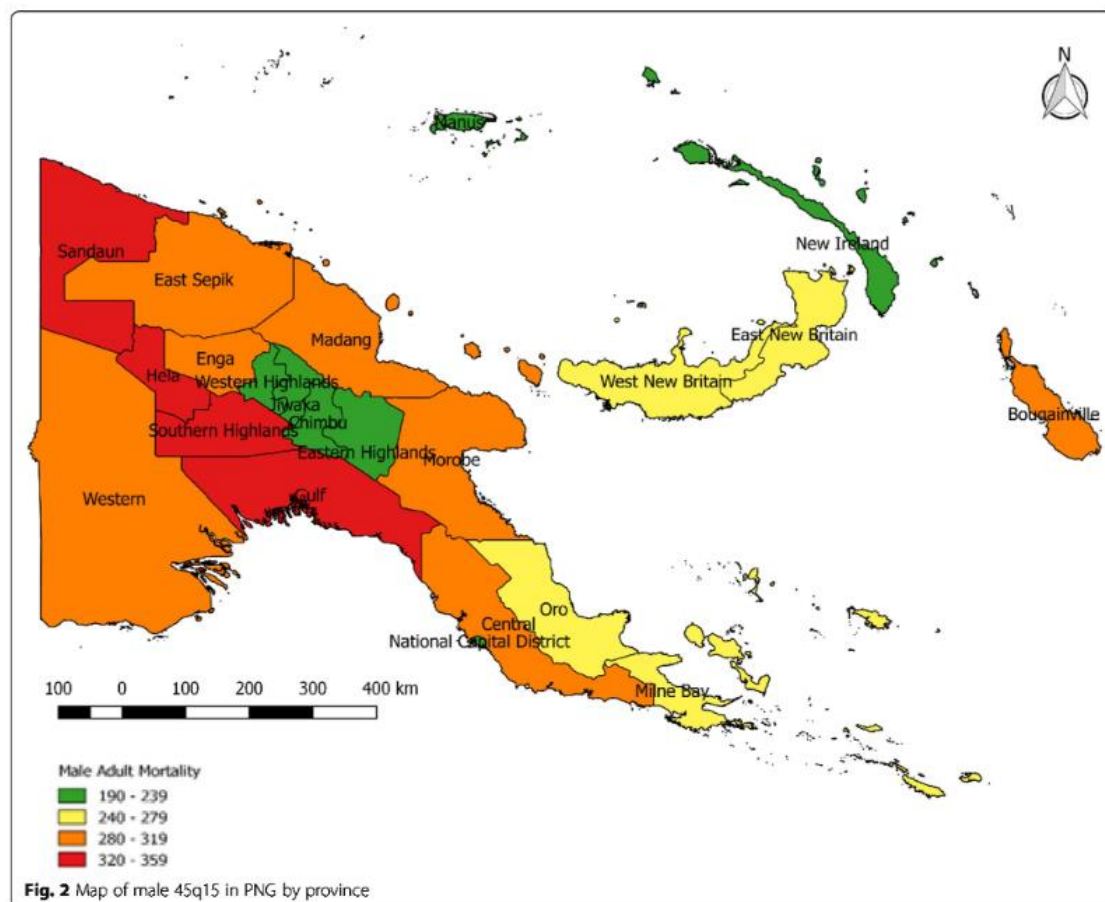
Table 4 and Figs. 5 and 6 show the provincial comparison of adult mortality estimates against the Composite Index. In general, provinces with higher composite index (e.g. National Capital District) have correspondingly lower adult mortality, and provinces with lower composite index (e.g. Sandaun, Madang) show higher levels of adult mortality, as expected. The relationship between 45q15 and socioeconomic development is stronger in men (Fig. 5 male $R^2 = 0.5363$) than women (Fig. 6, female $R^2 = 0.2163$). For male mortality, there are no clear anomalies; however, for females, the 45q15 for Western is the third lowest while its Composite Index is the fifth lowest.

The lower correlation between 45q15 and socioeconomic status observed for females compared with males could well reflect the fact that men at these ages are more susceptible to the potential negative effects of

development than women. These include higher risk factor exposure for non-communicable diseases, less health care seeking behavior, and a reduced risk of violent death [45]. Further research on this male-female variation in mortality responses to development is needed, although interestingly a study by Nikoi and Odimegwu [46] in South Africa found no association between socioeconomic status and adult mortality. Further, our composite index is an aggregate of male and female socioeconomic status and may have concealed important sex differences.

Discussion

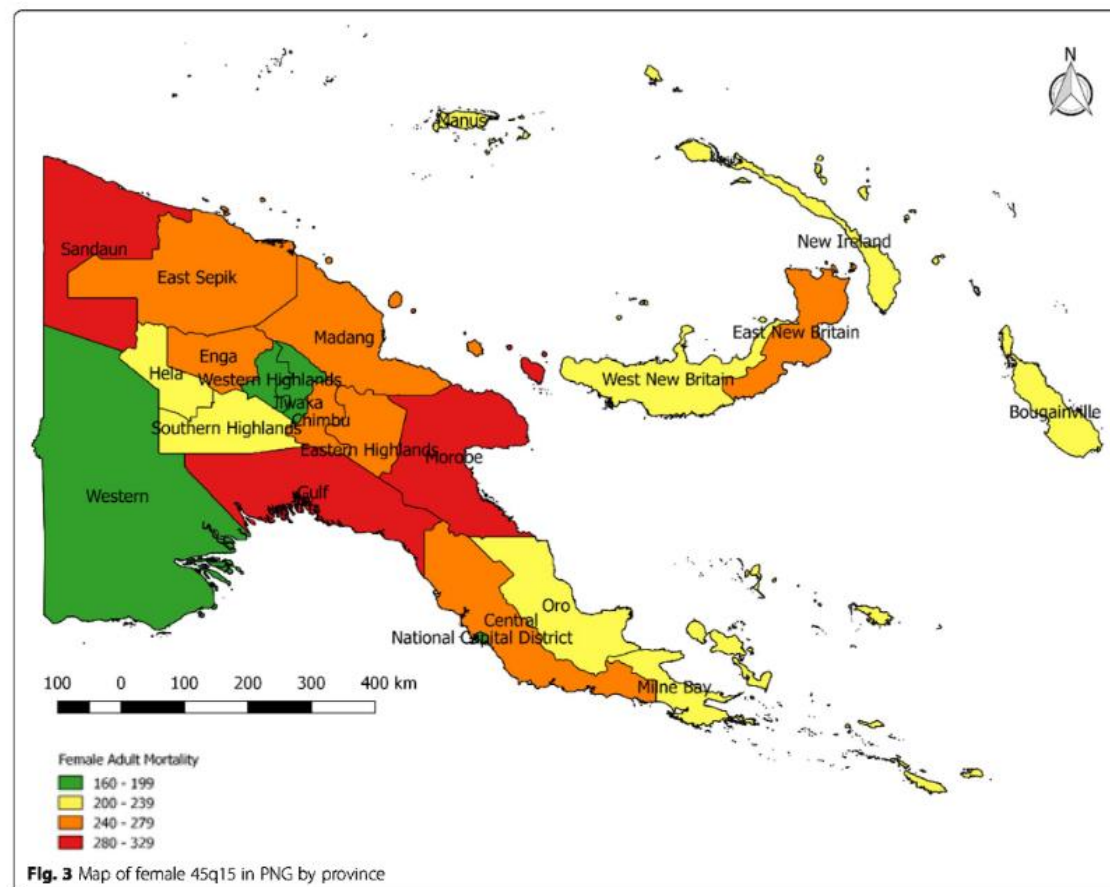
We have estimated adult mortality (45q15) in Papua New Guinea (PNG) by province and sex based primarily on the application of the orphanhood method to 2000 and 2011 census data. To our knowledge, these are the first subnational adult mortality estimates for provinces in PNG derived directly from empirical data. The provincial adult mortality estimates for 2011 show substantial variation, ranging from 197 per 1000 in Simbu to 356 in Sandaun for males and 171 in National Capital District to 326 in Gulf for females. Provinces with the highest 45q15 are found in the Highlands region (Enga and, for males only,



Southern Highlands/Hela), Momase (northern) region (Sandaun, East Sepik, Morobe and Madang) and the Gulf in the southern region. These provinces contain some of the most remote communities with very limited access to health services and low socio-economic status; this is reflected by Sandaun, Enga, Southern Highlands/Hela and Gulf having the lowest Composite Index scores. The lowest adult mortality is found in the National Capital District, the island provinces of Manus and New Ireland and the Highlands provinces of Western Highlands/Jiwaka and, for males only, Eastern Highlands. These findings are consistent with the relatively high Composite Index for these provinces, which reflects that they are relatively highly developed provinces with relatively good levels of education and access to services, as well as their low levels of child mortality [2]. More generally, provinces with disparate estimates of adult mortality and child mortality of Bauze et al. are minimal, and there is a stronger relationship between these two indicators for males than there is for females [2].

One province where the findings about 45q15 merit closer inspection is Simbu, which has the lowest male 45q15 (197) and very high female 45q15 (274). While lower male compared with female 45q15 is not implausible, the extent of the difference in Simbu is so large that it is likely due to issues with the relative quality of reporting of female mortality in the 2000 and 2011 censuses or the accuracy of reporting of completeness of male mortality. The Composite Index in Simbu is comparatively high, at 60%, and child mortality is below the national level, which suggests that the relatively low male 45q15 is more plausible than high female 45q15, and so relative quality of reporting of female mortality is more likely the reason [2].

Our estimates of male and female 45q15 in PNG derived from empirical data are broadly consistent with modelled estimates. Existing published estimates of adult mortality levels in PNG are very limited. Our 45q15 estimates for 2011 are 269 for males and 237 for females at the national level; the GBD's estimates for 2011 were



much higher, at 392 for males and 338 for females, based on demographic and statistical modelling that heavily relies on the mortality experience of nearby countries [10]. The UN estimates are 266 and 202 for males and females respectively, based on adult mortality estimated from the parental survival data from the 2000 census, child mortality data from the DHS and the use of model life tables [12]. Our estimates are closer to the UN than GBD, likely because the UN used more local data than the GBD. The high estimates of the GBD may be because it is driven by model life tables based on other Pacific countries with higher mortality due to non-communicable diseases (e.g. diabetes) and it uses modifiers in models to account for the effect of HIV; this could be the reason for the high adult mortality estimates by Rajaratnam and colleagues [47]. We did not include any effect modifiers for HIV or any other diseases since our estimates were based purely on empirical data and because HIV prevalence is relatively low (less than 1% of 15–24-year-olds according to antenatal

surveillance) [48]. The National Statistics Office census report estimated 45q15 of 335 for males and 316 for females, based on the use of the hypothetical cohort orphanhood method from the 2006 DHS and 2011 census together with two parameter life tables [19]. However, we did not use the 2006 DHS because of concerns over data quality described by Bauze et al. [2]. Closer assessment of the maternal survival data by cohort in the 2000 census, 2006 DHS and 2011 census showed that the 2006 DHS maternal survival probabilities were much closer to the 2000 census than 2011 census figure, suggesting that estimates for the period 2006–2011 (as used by the National Statistics Office) provide estimates of mortality that are too high.

Our estimates rank male 45q15 in PNG as 142nd out of 195 countries in the GBD and rank female 45q15 as 154th [10]. These are highly consistent with health and development measures for PNG; the UN IGME ranks PNG's 5q0 as 156th out of 195 countries and the UN's Human Development Index ranks PNG as PNG 154th

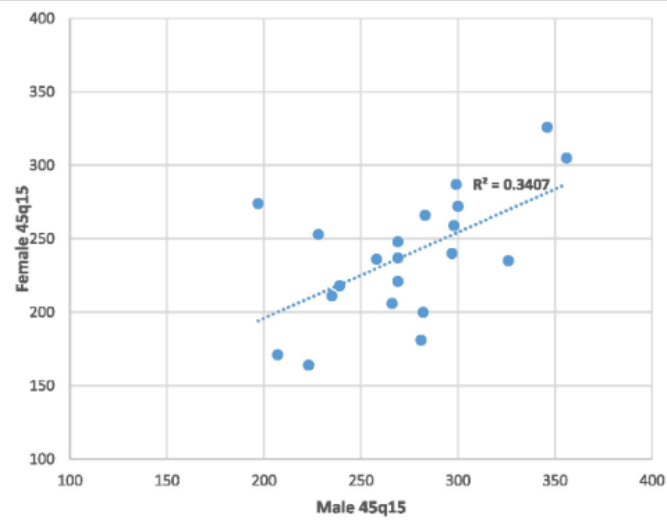


Fig. 4 Scatter plot of male 45q15 against female 45q15 in PNG

Table 4 Comparison of 45q15 and Composite Index by province, PNG 2011

Province	Male 45q15	Female 45q15	Composite Index (%)
National Capital District	207	171	95
East New Britain	269	248	73
Eastern Highlands	228	253	62
Simbu	197	274	60
Morobe	299	287	60
New Ireland	239	218	60
West New Britain	258	236	60
Bougainville	282	200	60
Western Highlands/Jiwaka	223	164	59
Milne Bay	266	206	55
Manus	235	211	55
East Sepik	297	240	53
Central	283	266	50
Madang	298	259	49
Oro	269	221	47
Western	281	181	41
Gulf	346	326	38
Southern Highlands/Hela	326	235	36
Enga	300	272	36
Sandaun	356	305	31
PNG	269	237	50

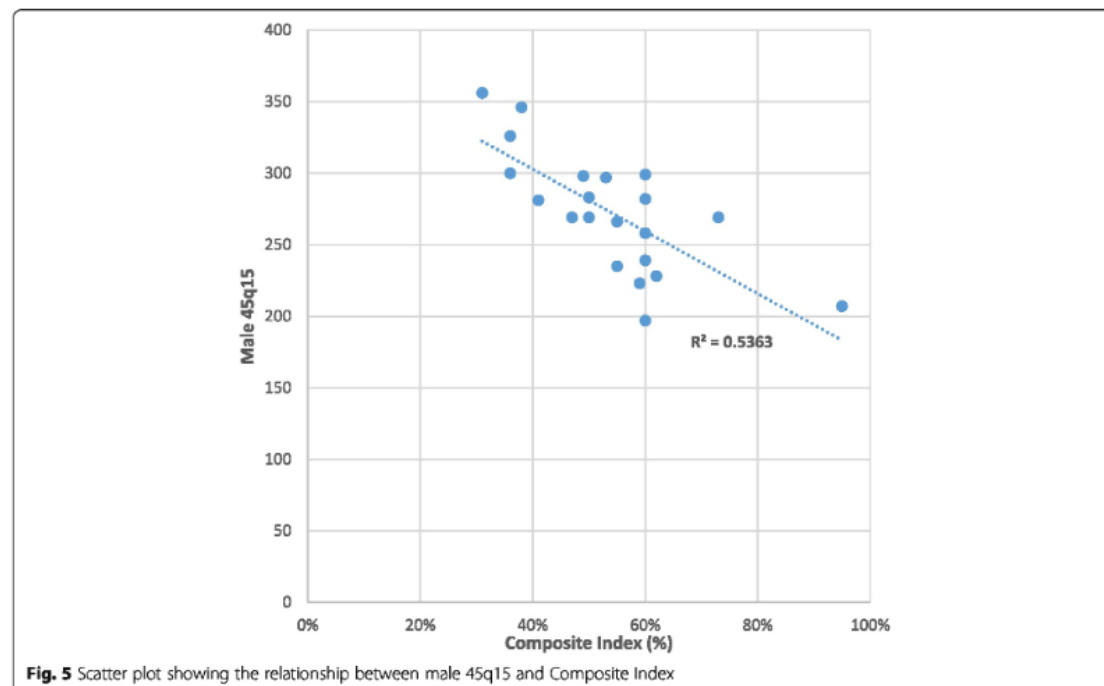


Fig. 5 Scatter plot showing the relationship between male 45q15 and Composite Index

out of 188 countries [29, 49]. The ratio of national male to female 45q15 in our study is 1.13; while this is among the lowest (8th) out of 31 countries that the GBD measures as having male 45q15 of between 240 and 300, it is not implausibly low.

In a country lacking an accurate and complete vital registration system, it is not yet possible to measure adult mortality directly [11, 50]. Due to the dysfunctional state of the CRVS [13] in PNG, the civil registration system could not be used for any of the analyses in this paper. This has always been the case with past estimates [2, 19, 51, 52] and will remain so in the foreseeable future given the current status of the CRVS in the country. To use data from the very incomplete and deficient system would portray a very misleading picture of the mortality situation in the country. The NHIS and DHIS, the two most developed death reporting systems in the country, each only report about one-quarter of all deaths in PNG, and these are not representative because they are only facility deaths. Similarly, the 2011 census household deaths yielded low mortality estimates with an implausible age pattern and so were not used for further mortality analysis. It is envisaged that reporting of deaths will improve in the next 2–3 years following the roll out of the eNHIS and with support from the Bloomberg Data for Health Initiative in the country [53].

Strengths and Limitations

Our estimates have been derived using information from specific questions on parental survival in the 2000 and 2011 censuses. This approach is undesirable in the long term because the census is only held every decade and hence does not provide the timely data that policy-makers require. However, at present, there is no viable alternative to estimate provincial-level adult mortality in PNG. The Composite Index shows a moderately strong correlation with mortality estimates. Although it has limited utility to accurately predict adult mortality, it does assist in identifying implausible levels of adult mortality at the provincial level.

A limitation of our methods is that they do not permit the measurement of uncertainty in the mortality estimates. This is likely to be substantial, given the sources of data used, their provenance, and the reliance on GBD estimated age-sex and trend data to project our estimates forward. It is unlikely that the uncertainty around our estimates would be any less than that associated with the GBD estimates, namely $\pm 20\%$ [10]. It is important that this uncertainty is communicated to users of the data to remind them that while these estimates can provide important policy-relevant insights into comparative levels of mortality, they would be even more useful if significant steps were taken to reduce uncertainty

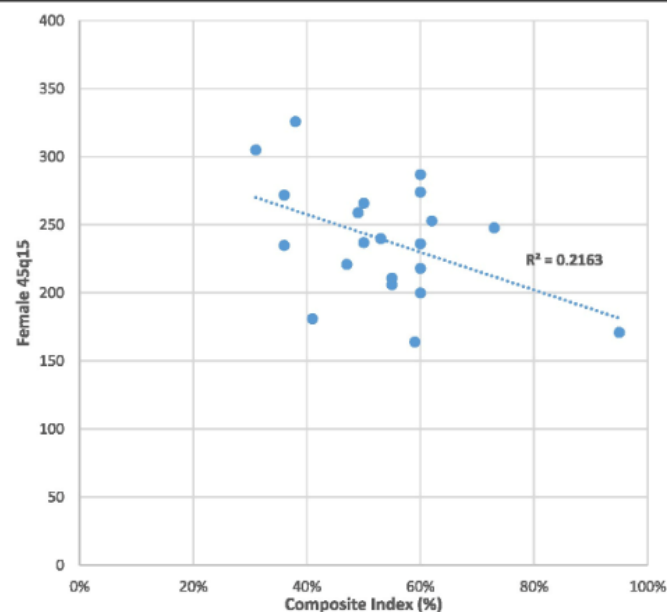


Fig. 6 Scatter plot showing the relationship between female 45q15 and Composite Index

through the establishment of better data systems for the country.

Conclusion

This study provides, to our knowledge, the first estimates of adult mortality (45q15) at the provincial level in PNG. These show substantial geographic inequalities and sex differentials in adult mortality risk at the provincial level, consistent with provincial differences in socio-economic development and tribalism. These findings provide policymakers with valuable evidence about levels and patterns of adult population health in a country with limited data and suggest that health and development policy in PNG need to urgently address the large, avoidable causes of premature adult mortality in the country. As a first and critical step in such a policy response, the development of a reliable national mortality surveillance system should be given high priority.

Endnotes

¹UN 45q15 figures for 2011 were calculated by interpolating the UN's 2005–2010 and 2010–2015 figures assuming an arithmetic rate of change.

²In this study, the UN General model life table is used.

³The average number of reported household deaths from the UN General, Modified Logit and Log-Quad model life tables was used.

⁴Each value was adjusted to a normally distributed percentage ranging from 0 to 100% calculated using the mean and standard deviation of all values in that particular indicator.

Abbreviations

CIRO: Civil Identity and Registry Office; CRVS: Civil registration and vital statistics; DHIS: Discharge Health Information System; DHS: Demographic and Health Survey; GBD: Global Burden of Disease Study; NDoH: National Department of Health; NHIS: National Health Information System; NSO: National Statistics Office; PNG: Papua New Guinea; SBH: Summary Birth Histories; SDI: Sociodemographic index; UN: United Nations; UNIGME: United Nations Inter-agency Group for Child Mortality

Acknowledgements

The authors wish to thank the National Statistician Mr. Roko Koloma and Mr. Benjamin Haichim from the PNG National Statistics Office for access to the 2011 and 2000 census data used in this study. The authors also acknowledge Professor Ian Riley for his assistance with the literature review and initial conceptualization of the study.

Funding

This research was conducted as part of Urarang Kitur's PhD, funded by the Australia Award Scholarship. The funder had no influence on the final results.

Availability of data and materials

Request for data access should be directed to the corresponding author and will be granted subject to approval by the National Statistics Office of Papua New Guinea.

Declarations

We declare that the content of this manuscript has not been published or submitted for publication elsewhere.

Authors' contributions

UK, TA and AL conceptualised the research theme and analytical framework. UK conducted the data analysis and was responsible for drafting the

manuscript. TA and AL critically revised the manuscript. The final draft was approved by all authors.

Ethics approval and consent to participate

Only secondary data were used so ethics considerations are not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Received: 30 May 2018 Accepted: 6 March 2019

Published online: 18 April 2019

References

1. National Statistics Office. Papua New Guinea 2011 National report. Port Moresby: National Statistics Office; p. 2015.
2. Bauze AE, Tran LN, Nguyen K-H, Firth S, Jimenez-Soto E, Dwyer-Lingren, Hodge A, Lopez AD. Equity and geography: the case of child mortality in Papua New Guinea. *PLoS One* 2012; 7(5): e37861. <https://doi.org/10.1371/journal.pone.0037861>. Accessed 12 June 2016.
3. Tran L, Bauze A, Nguyen K, Firth S, Jimenez-Soto E. Under-five mortality analysis for Papua New Guinea. Investment Case MDGs 4 & 5. Brisbane: The University of Queensland School of Population Health; 2011.
4. Lagani W, Mokela D, Saweri W, Kiromat M, Ripa P, Vince J, Pameh W, Tefuarani N, Hwaihwanjee I, Subhif R, Duke T. Papua New Guinea: real progress towards MDG 4 and real challenges. *Int Health*. 2010;2:186–96.
5. Duke T, Edison Y, Hutchinson A, Hwaihwanjee I, Alpit J, Tovilu M, Uluik T, Rongap T, Vetuna B, Lagani W, Amini J. Large-scale data reporting of paediatric morbidity and mortality in developing countries: it can be done. *Arch Dis Child*. 2016;101:392–7.
6. Mola G, Kirby B. Discrepancies between national maternal mortality data and international estimates: the experience of Papua New Guinea. *Reproductive Health Matters*. 2013;21(42):191–202.
7. Douglas R. Pneumonia in Papua New Guinea, from the past to the future. *PNG Med Journal*. 2010;53(3–4):99–105.
8. Riley I. Demography and the epidemiology of disease in Papua New Guinea. *PNG Med J*. 2009;52(3–4):83–95.
9. Papua New WHO. Guinea Statistical Profile. Papua New Guinea: WHO; 2015.
10. GBD 2016 Causes of Death Collaborators. Global, regional, and national age-sex specific mortality for 264 causes of death, 1980–2016: a systematic analysis for the global burden of disease study 2016. *Lancet*. 2017;390:1151–210.
11. Abou Zhar C, de Savigny D, Mikkelsen L, Setel PW, Lozano R, Nichols E, Notzon F, Lopez AD. CRVS progress in data revolution for counting and accountability. *Lancet*. 2015;386:1373–85.
12. United Nations, Department of Economic and Social Affairs, Population Division. World Mortality Report 2017. CD-ROM Edition - Datasets in Excel formats (POP/DB/MORT/2017); 2017. <http://www.un.org/en/development/desa/population/publications/mortality/world-mortality-cdrom-2017.asp>. Accessed 15 Dec 2017.
13. Montgomery J. Foundations for a successful CRVS eco-system in Papua New Guinea. Port Moresby: National Department of Health; 2017.
14. National Statistics Office. The National Population and housing census for Papua New Guinea for 2000. Port Moresby; 2000.
15. National Statistics Office. The National Population and housing census for Papua New Guinea for 2011. Port Moresby; 2011.
16. Timaeus I. Indirect estimation of adult mortality from orphanhood, in Moultrie, T. Et al. tools for demographic estimation, Paris: IUSSP, 2013; pp. 222–243.
17. Rajaratnam J, Tran LN, Lopez AD, Murray CML. Measuring under-five mortality: validation of New low-cost methods. *PLoS Med*. 2010a;7(4):e1000253. <https://doi.org/10.1371/journal.pmed.1000253>. Accessed 15 July 2017.
18. Silva R. Child mortality estimation: consistency of under-five mortality rate estimates using full birth histories and summary birth histories. *PLoS Med*. 2010;9(8):1013. <https://doi.org/10.1371/journal.pmed.1001296>. Accessed 10 Dec 2017.
19. National Statistics Office. Mortality situation, trend and differentials in Papua New Guinea based on the analysis of data from censuses and demographic and health surveys: 2011 census research monograph NR 1; 2011. p. 1–176.
20. Kitur U. Health information challenges for Papua New Guinea. *Pacific Health Dialogue*. 2012;27–31.
21. Kitur U, Adair T, Lopez A. Patterns of all-cause mortality in Papua New Guinea, 2011. *Asia Pac J Public Health* (forthcoming); 2019.
22. Matherson D, Douglas M, Bhattacharya S. Independent review of the PNG NHIS for rural primary health services delivery. NDOH Port Moresby. 2017;1–40.
23. Adair T and Lopez AD. Estimating completeness of death registration: an empirical method. *PLoS one* 2018; 13(5):e0197047. <https://doi.org/10.1371/journal.pone.0197047>. Accessed 19 Dec 2018.
24. Brass W, Hill K. Estimating adult mortality in Africa from orphanhood. In: International Population Conference Liege; 1973. p. 3111–23.
25. Timaeus I. Estimation of adult mortality from paternal orphanhood: a reassessment of a new approach. *Popul Bull UN*. 1992;30–3.
26. Cogan B, Milan J, Malau C, Kaldor J, Toole M. The HIV epidemic in Papua New Guinea. *J Acquir Immune Defic Syndr*. 2011;58(2):e48–51.
27. Zotnik H, Hill K. The use of hypothetical cohorts in estimating demographic parameters under conditions of changing fertility and mortality. *Demography*. 1981;18:103–22.
28. Timaeus I. Indirect estimation from orphanhood in multiple inquiries, in Moultrie, T. Et al. tools for demographic estimation, Paris: IUSSP, 2013; pp. 293–308.
29. United Nations Inter-agency for Group for Child Mortality Estimates; 2017. <https://www.childmortality.org>. Accessed 21 Sept 2017.
30. Bryan T. Estimates. In: Siegel JS, Swanson DA, editors. The methods and materials of demography. 2nd ed. San Diego California: Elsevier academic press; 2004. p. 523–60.
31. McGehee M. Mortality. In: Siegel JS, Swanson DA, editors. The methods and materials of demography. 2nd ed. San Diego California: Elsevier academic press; 2004. p. 265–300.
32. GBD Global Collaborators. Measuring the health-related sustainable Development goals in 188 countries: a baseline analysis from the global burden of disease study 2015. *Lancet*. 2016;388:1813–50.
33. Alijanzadeh M, Asefzadeh S, Zare SAM. Correlation between human development index and infant mortality rate worldwide. *Biotech Health Science*. 2016;3(1):1–5. https://doi.org/10.17955/bhs_35330.
34. Moradi-Lakeh M, Sepanlou SG, Karimi SM, et al. Trends of socio-demographic index and mortality estimates in Iran and its neighbours, 1990–2015; findings of the global burden of diseases 2015 study. *Arch Iran Med*. 2017;20(7):419–25.
35. National Research Institute. Review of NEFC's less developed provinces and districts. Port Moresby: National Research Institute; 2001.
36. Rural Development. Rural Development handbook. Port Moresby: Office of Rural Development; 2001.
37. World Bank. Papua New Guinea poverty assessment (English). Washington, DC: World Bank; 2017. <http://documents.worldbank.org/curated/en/500511468082129284/Papua-New-Guinea-poverty-assessment>. Accessed 15 Jan 2017.
38. National Economic & Fiscal Commission. Review of intergovernmental financing arrangements (RIGFA). NEFC less developed district index. NEFC. In: Port Moresby; 2004.
39. Gibson J and Rozelle, S. Poverty and access to infrastructure in Papua New Guinea. 2002; Working Paper 02-008.
40. Gibson J, Datt G, Allen B, Hwang V, Bourke MR, Parajuli D. Mapping Poverty in Rural Papua New Guinea; 2014.
41. National Research Institute. Papua New Guinea District and Provincial profiles. March 2010: 1–182. Port Moresby: National Research Institute; 2010.
42. National Department of Health. 2011 Sector Performance Annual Review Assessment of Sector Performance 2006–2010. National Report. Port Moresby. Port Moresby: National Department of Health; 2011.
43. Tierney D, Bolton P, Matanu B, Barnabas E, Garasu L, Silove D. The mental health and psychosocial impact of the Bougainville crisis: a synthesis of available information. *Int J Ment Health Syst*. 2016;10:1752–4458.
44. Gouda H, Maraga S, Flaxman A, Stewart A, Joseph J, Serina P, Phuanukoonnon S, Pam B, Rarau P, Wanganapi R, Poka H, Vano M, Lupiwa S, Sie A, Kave H, Kave P, Lehmann D, Siba P, Lopez A, Riley I. The epidemiological transition in Papua New Guinea: new evidence from verbal autopsy studies. *Int J Epid* (forthcoming); 2019.
45. Beltran-Sanchez H, Finch C, Crimmins E. Twentieth century surge of excess adult male mortality. *PNAS*. 2015;112(29):8993–8.

46. Nikoi C, Odimegwu C. (2013). The association between socioeconomic status and adult mortality in rural Kwazulu-Natal, South Africa. *Oman Med J*. 2013;28(2):102–7.
47. Rajaratnam JK, Marcus JR, Levin-Rector A, Chalupka AN, Wang H, Dwyer L, Costa M, Lopez AD, Murray CJK. Worldwide mortality in men and women aged 15–59 years from 1970 to 2010: a systematic analysis. *Lancet*. 2010b; 375:1704–20.
48. National Department of Health. 2017 Sector Performance Annual Review Assessment of Sector Performance 2013. Port Moresby: National Report; 2017. National Department of Health, Port Moresby; 2011.
49. UNDP. Human Development report 2016: human development for everyone. New York: UNDP; 2017.
50. Mikkelsen L, Phillips DE, AbouZahr C, Setel W, de Savigny D, Lozano R, Lopez AD. Counting births and deaths 3: a global assessment of civil registration and vital statistics systems: monitoring data quality and progress. *Lancet*. 2015;386:1395–406.
51. Bakker ML. The mortality situation in Papua New Guinea: levels, differentials, patterns and trends. Port Moresby: National Statistic Office; 1986.
52. Bakker ML. Spatial differentiation of mortality in Papua New Guinea. A classification based on the results of the 1980 census. Working paper no 4. Port Moresby: National Statistics Office; 1983.
53. Lopez AD, Setel PW. Better health intelligence: a new era for civil registration and vital statistics? *BMC Med*. 2015; <https://doi.org/10.1186/s12916-015-0333-4>. Accessed 12 May 2018.

Ready to submit your research? Choose BMC and benefit from:

- fast, convenient online submission
- thorough peer review by experienced researchers in your field
- rapid publication on acceptance
- support for research data, including large and complex data types
- gold Open Access which fosters wider collaboration and increased citations
- maximum visibility for your research: over 100M website views per year

At BMC, research is always in progress.

Learn more biomedcentral.com/submissions



4.2 Methods Available to Estimate Adult Mortality

This section elaborates on the methods and results of the measurement of adult mortality and the completeness of mortality data reporting. For countries in which civil registration is non-functional, various data sources to measure adult mortality exist. National censuses can collect data on adult mortality by including questions about recent household deaths or survival of parents (orphanhood data) or siblings of household members.

In PNG, the 2011 national population census included a question about the deaths of household members in the previous 12 months (NSO, 2011). However, census-reported deaths were not used because of poor age reporting (Kitur, Adair, & Lopez, 2019b), resulting in implausible ASDRs. These data are explored in more detail in Chapter 5.

Although there were no data on sibling survival in PNG, data collected from adults on the survival of their adult siblings and tabulated by age group of respondents could be used to indirectly estimate adult mortality (Timaheus, 2013b). Information on the survival of brothers is used to estimate the mortality of men, and information on the survival of sisters is used to estimate the mortality of women. Fewer respondents are required for the sibling method than for household deaths to generate mortality estimates that are sufficiently precise to be useful. However, results from the sibling survival method may not be representative of subnational populations with large in- and out-migration and may be biased by families with high mortality rates or those in which there are no siblings. Further, the 2000 or 2011 censuses had no questions on sibling survival, excluding the use of the sibling survivorship method for estimating adult mortality in PNG.

Adult mortality estimates were derived using the orphanhood method applied to parental survival data from the 2000 census for males and the 2000 and 2011 censuses for females. The orphanhood method is described comprehensively in the paper. Table 4.1 presents paternal

survivorship rates (that is, the percentage of respondents' fathers who were still alive) for ages 5–9 years to 40–44 years used in estimating adult male mortality for PNG and each of its provinces. Similarly, Table 4.2 presents the maternal survivorship rates for 2000 and 2011 used in the synthetic cohort to estimate female adult mortality.

Parental survival data from the census may be prone to bias if people not enumerated in the census had significantly different mortality risk compared with those who were enumerated. However, the provincial adult mortality rates generated from the parental survivorship rates were found to be plausible after adjusting for the reporting completeness of each province, where necessary, comparing provincial adult mortality rates against a composite index of socioeconomic and health access, and comparing the national adult mortality rank against health and development measures for PNG (Kitur, Adair & Lopez 2019a).

Table 4.1: Paternal Survivorship by Province (2011)

Province	Paternal survivorship (%)								
	Mean age at childbearing (yrs)	5–9	10–14	15–19	20–24	25–29	30–34	35–39	40–44
<i>Papua New Guinea</i>	34.2	0.9477	0.9317	0.8971	0.8288	0.7292	0.5901	0.4507	0.2960
Western	34.0	0.9518	0.9288	0.8862	0.8088	0.7146	0.5615	0.4314	0.2787
Gulf	34.9	0.9235	0.8949	0.8393	0.7498	0.6359	0.4893	0.3595	0.2143
Central	33.6	0.9417	0.9204	0.8757	0.7958	0.6950	0.5766	0.4452	0.2985
National Capital District	34.0	0.9521	0.9401	0.9064	0.8523	0.7937	0.6816	0.5491	0.3798
Milne Bay	33.8	0.9605	0.9404	0.8975	0.8165	0.7180	0.5734	0.4302	0.2945
Oro	34.0	0.9518	0.9262	0.8858	0.8143	0.7211	0.5925	0.4601	0.3244
Southern Highlands	34.5	0.9285	0.9232	0.8907	0.8311	0.7357	0.5918	0.4538	0.2855
Enga	34.8	0.9446	0.9347	0.9045	0.8497	0.7517	0.5997	0.4411	0.2752
Western Highlands	34.2	0.9549	0.9430	0.9219	0.8745	0.7863	0.6561	0.5243	0.3722
Simbu	35.7	0.9579	0.9451	0.9278	0.8576	0.7419	0.5883	0.4338	0.2867
Eastern Highlands	34.3	0.9596	0.9493	0.9196	0.8547	0.7514	0.6218	0.4916	0.3279
Morobe	34.1	0.9457	0.9244	0.8816	0.7999	0.6903	0.5532	0.4126	0.2542
Madang	34.3	0.9492	0.9266	0.8835	0.8026	0.6855	0.5314	0.3943	0.2465
East Sepik	33.3	0.9562	0.9349	0.8931	0.8077	0.6977	0.5527	0.4050	0.2593
Sandaun	34.0	0.9345	0.9101	0.8551	0.7500	0.6334	0.4722	0.3458	0.1973
Manus	34.1	0.9430	0.9398	0.9049	0.8346	0.7386	0.6105	0.4471	0.3109
New Ireland	34.3	0.9349	0.9341	0.9000	0.8360	0.7409	0.6029	0.4710	0.3105
East New Britain	34.5	0.9411	0.9320	0.8971	0.8194	0.7080	0.5626	0.4108	0.2601
West New Britain	34.1	0.9574	0.9404	0.8967	0.8174	0.7253	0.5877	0.4503	0.2956
Bougainville	33.7	0.9526	0.9290	0.8822	0.8124	0.7192	0.5926	0.4344	0.2936

Table 4.2: Maternal Survivorship Rates by Province (2000 and 2011)

Province	Maternal survivorship (%)										
	Age group (years)	0–4	5–9	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49
<i>Papua New Guinea</i>	2011	0.985	0.964	0.955	0.930	0.878	0.798	0.681	0.555	0.397	0.290
	2000	0.983	0.968	0.948	0.908	0.831	0.736	0.612	0.500	0.369	0.284
Western	2011	0.985	0.971	0.960	0.936	0.888	0.823	0.700	0.598	0.438	0.322
	2000	0.986	0.971	0.948	0.906	0.824	0.730	0.606	0.515	0.391	0.306
Gulf	2011	0.980	0.947	0.925	0.884	0.804	0.718	0.583	0.465	0.315	0.230
	2000	0.980	0.952	0.923	0.854	0.746	0.627	0.514	0.412	0.287	0.211
Central	2011	0.985	0.956	0.943	0.914	0.854	0.771	0.667	0.556	0.412	0.301
	2000	0.980	0.964	0.941	0.900	0.821	0.727	0.607	0.507	0.398	0.312
National Capital District	2011	0.988	0.964	0.960	0.935	0.899	0.848	0.763	0.650	0.502	0.374
	2000	0.986	0.979	0.969	0.934	0.866	0.790	0.676	0.579	0.460	0.371
Milne Bay	2011	0.989	0.972	0.956	0.932	0.878	0.805	0.708	0.573	0.441	0.317
	2000	0.986	0.969	0.941	0.896	0.823	0.735	0.620	0.527	0.410	0.306
Oro	2011	0.985	0.970	0.953	0.926	0.870	0.790	0.670	0.558	0.414	0.312
	2000	0.976	0.960	0.933	0.900	0.814	0.721	0.602	0.492	0.386	0.285
Southern Highlands	2011	0.970	0.946	0.942	0.919	0.878	0.797	0.675	0.539	0.366	0.271
	2000	0.980	0.964	0.949	0.920	0.860	0.759	0.625	0.481	0.341	0.266
Enga	2011	0.982	0.962	0.956	0.930	0.882	0.798	0.658	0.506	0.324	0.223
	2000	0.976	0.962	0.950	0.917	0.840	0.720	0.565	0.426	0.285	0.214
Western Highlands	2011	0.985	0.971	0.965	0.947	0.904	0.826	0.712	0.586	0.434	0.322
	2000	0.984	0.972	0.955	0.914	0.839	0.751	0.629	0.501	0.351	0.269
Simbu	2011	0.984	0.970	0.964	0.947	0.899	0.809	0.680	0.544	0.378	0.276
	2000	0.983	0.969	0.950	0.916	0.849	0.757	0.643	0.535	0.377	0.291
Eastern Highlands	2011	0.988	0.972	0.966	0.945	0.888	0.798	0.676	0.557	0.397	0.301
	2000	0.983	0.969	0.954	0.909	0.833	0.739	0.623	0.514	0.386	0.312

Province	Maternal survivorship (%)										
	Age group (years)	0–4	5–9	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49
Morobe	2011	0.984	0.961	0.946	0.913	0.849	0.761	0.643	0.520	0.364	0.263
	2000	0.984	0.966	0.942	0.893	0.810	0.711	0.589	0.480	0.367	0.282
Madang	2011	0.986	0.968	0.953	0.923	0.858	0.765	0.638	0.514	0.362	0.260
	2000	0.984	0.963	0.936	0.886	0.794	0.695	0.558	0.453	0.323	0.238
East Sepik	2011	0.987	0.971	0.958	0.931	0.870	0.794	0.684	0.553	0.402	0.290
	2000	0.986	0.971	0.949	0.910	0.823	0.723	0.603	0.487	0.351	0.275
Sandaun	2011	0.984	0.954	0.937	0.897	0.814	0.718	0.592	0.462	0.318	0.213
	2000	0.976	0.953	0.919	0.854	0.747	0.639	0.496	0.396	0.285	0.210
Manus	2011	0.992	0.953	0.962	0.944	0.897	0.827	0.742	0.616	0.440	0.315
	2000	0.982	0.970	0.953	0.925	0.858	0.779	0.651	0.540	0.402	0.308
New Ireland	2011	0.990	0.951	0.954	0.934	0.885	0.830	0.719	0.606	0.444	0.331
	2000	0.987	0.974	0.960	0.928	0.860	0.779	0.666	0.554	0.428	0.323
East New Britain	2011	0.990	0.958	0.957	0.936	0.886	0.812	0.701	0.579	0.430	0.314
	2000	0.987	0.975	0.958	0.931	0.859	0.763	0.647	0.555	0.435	0.332
West New Britain	2011	0.989	0.976	0.962	0.933	0.873	0.805	0.698	0.579	0.417	0.297
	2000	0.988	0.973	0.953	0.910	0.835	0.757	0.642	0.541	0.409	0.314
Bougainville	2011	0.989	0.976	0.962	0.933	0.873	0.805	0.698	0.579	0.417	0.297
	2000	0.988	0.973	0.953	0.910	0.835	0.757	0.642	0.541	0.409	0.314

4.2.1 Assessing the completeness of male adult mortality

This section elaborates on the methods and results of the measurement of adult mortality and the completeness of mortality data reporting. For countries in which civil registration is non-functional, various data sources to measure adult mortality exist. National censuses can collect data on adult mortality by including questions about recent household deaths or survival of parents (orphanhood data) or siblings of household members.

In PNG, the 2011 national population census included a question about the deaths of household members in the previous 12 months (NSO, 2011b). However, census-reported deaths were not used because of poor age reporting (Kitur, Adair, & Lopez, 2019b), resulting in implausible ASDRs. These data are explored in more detail in Chapter 5.

Although there were no data on sibling survival in PNG, data collected from adults on the survival of their adult siblings and tabulated by age group of respondents could be used to indirectly estimate adult mortality (Timaues, 2013b). Information on the survival of brothers is used to estimate the mortality of men, and information on the survival of sisters is used to estimate the mortality of women. Fewer respondents are required for the sibling method than for household deaths to generate mortality estimates that are sufficiently precise to be useful. However, results from the sibling survival method may not be representative of subnational populations with large in- and out-migration and may be biased by families with high mortality rates or those in which there are no siblings. Further, the 2000 or 2011 censuses had no questions on sibling survival, excluding the use of the sibling survivorship method for estimating adult mortality in PNG.

Adult mortality estimates were derived using the orphanhood method applied to parental survival data from the 2000 census for males and the 2000 and 2011 censuses for females. The orphanhood method is described comprehensively in the paper. Table 4.1 presents paternal

survivorship rates (that is, the percentage of respondents' fathers who were still alive) for ages 5–9 years to 40–44 years used in estimating adult male mortality for PNG and each of its provinces. Similarly, Table 4.2 presents the maternal survivorship rates for 2000 and 2011 used in the synthetic cohort to estimate female adult mortality.

Table 4.3: Predicted Completeness of Male Adult Death Reporting by Province (2002)

Province	Deaths*	Mid-Year Population	Registered Crude Death Rate (Per 1,000)	Registered Crude Death Rate (Per 1,000) ²	65+ (%)	True Under-Five Mortality Rate	ln (Under-Five Mortality Rate)	Model Equation	(%) Predicted Completeness
<i>Papua New Guinea</i>	22,314	2,979,109	7.5	56.1	2.7	0.081	-2.513	1.961	83
Western	612	80,741	7.6	57.5	1.7	0.101	-2.293	1.838	81
Gulf	439	59,330	7.4	54.8	1.9	0.100	-2.303	1.751	90
Central	567	102,916	5.5	30.4	3.1	0.060	-2.813	1.406	93
National Capital District	407	144,483	2.8	7.9	1.2	0.040	-3.219	0.802	81
Milne Bay	898	114,874	7.8	61.0	2.9	0.092	-2.386	1.871	87
Oro	541	74,024	7.3	53.4	2.6	0.088	-2.430	1.780	86
Southern Highlands	1,426	295,935	4.8	23.2	2.5	0.068	-2.688	0.958	64
Enga	965	163,933	5.9	34.7	2.8	0.084	-2.477	1.154	62
Western Highlands	1,363	244,478	5.6	31.1	3.2	0.067	-2.703	1.267	71
Simbu	878	144,401	6.1	37.0	4.4	0.063	-2.765	1.397	75
Eastern Highlands	1,224	234,609	5.2	27.2	2.9	0.064	-2.749	1.193	79
Morobe	3,146	291,018	10.8	116.9	2.2	0.150	-1.897	2.283	85
Madang	1,247	200,448	6.2	38.7	2.1	0.084	-2.477	1.443	88
East Sepik	1,635	180,313	9.1	82.3	2.9	0.110	-2.207	2.090	85
Sandaun	1,070	100,284	10.7	113.9	2.0	0.143	-1.945	2.359	91
Manus	107	23,703	4.5	20.4	3.0	0.048	-3.037	1.234	90
New Ireland	366	68,293	5.4	28.7	3.1	0.057	-2.865	1.400	87
East New Britain	723	123,266	5.9	34.4	2.7	0.068	-2.688	1.478	85
West New Britain	557	104,841	5.3	28.2	2.0	0.065	-2.733	1.378	84
Bougainville	541	95,745	5.7	31.9	2.6	0.069	-2.674	1.361	81

*Calculated from age-specific death rates estimated from 5q0, 45q15 and model life tables and multiplied by age-specific population.

4.2.2 Estimating under-five mortality

A key input of the empirical method is the under-five mortality rate (5q0). The optimal means of measuring child mortality is through a vital registration system that captures all births and deaths. However, in countries without comprehensive vital registration systems, 5q0 is indirectly measured using surveys that ask women to report the births and deaths of their children (Rajaratnam, Tran, et al., 2010; Silva, 2010). Two common forms of retrospective data exist: complete birth histories and summary birth histories. Complete birth histories are collected via household surveys and contain detailed information on each live birth, the date of birth, whether the child has died and date of death. Although complete birth histories are the preferred method and are used widely in ongoing DHSs, they are costly and labour intensive to administer, making them unsuitable (Rajaratnam, Tran, et al., 2010).

Summary birth histories are mostly collected through population censuses or household surveys in which women are asked to report summary information on the numbers of CEB and CSL as well as maternal age as a proxy for exposure to the risk of dying (Silva, 2010). Although methods to estimate child mortality from CEB and CSL data were first proposed over 60 years ago by Myburg (1956, as cited in Rajaratnam, Tran, et al., 2010), it was Brass who pioneered the current method after observing a strong relationship between the proportion of CEB for a particular age group of mothers and population-level child mortality rates. Despite being widely used to estimate under-five mortality using CEB tabulated by maternal age, summary birth histories have some limitations (Rajaratnam, Tran, et al., 2010). First, responses from younger women (15–24 years of age) overestimate the risk of child deaths for older mothers (25–34 years) for the most recent period; hence, reliable estimates of child mortality are normally derived 3–6 years prior to data collection. Additionally, estimates based on small numbers of deaths can have considerable uncertainty.

Given the non-functioning of the civil registration system in PNG, under-five mortality was indirectly estimated using birth history data from the 2000 and 2011 censuses. The 2006 DHS was found to be of poor quality by Bauze et al. (2012), thus was not analysed in this thesis. It has been reported that because of the length of the questionnaire on child mortality, interviewers opted to truncate the questionnaire to reduce the workload, thus compromising the quality of the data collected (NSO, 2011a).

Using the maternal age cohort method, 5q0 was estimated using summary birth histories in the 2000 and 2011 censuses with respect to CEB and CED. The averages of CEB and CED were calculated from maternal responses, followed by a calculation of the CEB/CED ratio.

Table 4.4 shows the 5q0 estimates for 2000, 2002, 2005 and 2011. Estimates of 5q0 by sex for 2000 (Columns 2 and 3) are consistent with estimates published by Bauze et al. (2012).

However, 5q0 estimates for 2011 (Columns 8 and 9)—40 (males) and 38 (females)—were much lower than the levels of 68 and 58, respectively, estimated by the UN Inter-Agency Group for Child Mortality Estimation (2017) based on modelling of estimate trends from censuses and DHSs. The final 5q0 estimates for 2011 (Columns 10 and 11) were calculated by multiplying the ratio of provincial sex-specific 5q0 to national sex-specific 5q0 by the sex-specific 5q0 for PNG estimated by UN Inter-Agency Group for Child Mortality Estimation.

For the empirical method, estimates of 5q0 for 2002 for males were used in model life tables together with orphanhood method adult mortality estimates to generate ASDRs. The ASDRs were then multiplied to the interpolated age structure in 2002 for males to estimate the expected total deaths by age. From the estimated total deaths, reported crude death rates were then used as the input in the empirical method to assess the completeness of death reporting in male adults.

Table 4.4: Estimates of Provincial 5q0 by Sex (2000, 2002, 2005 and 2011)

Province	5q0 2000		5q0 2002 Estimated		5q0 2005 Estimated		5q0 2011		5q0 2011 Scaled Against United Nations Inter-Agency Group for Child Mortality Estimation	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
<i>Papua New Guinea</i>	83	73	81	70	76	66	40	35	68	58
Western	101	82	101	80	87	71	38	34	64	57
Gulf	100	104	100	101	103	100	64	58	109	97
Central	60	65	60	63	58	56	32	26	55	44
National Capital District	40	33	40	32	38	29	18	14	34	23
Milne Bay	92	82	92	79	87	74	46	38	78	64
Oro	88	97	88	94	82	83	41	38	69	64
Southern Highlands	68	64	68	62	68	61	40	35	70	59
Enga	84	83	84	80	79	75	41	39	69	66
Western Highlands	67	54	67	52	58	44	24	19	40	33
Simbu	63	53	63	52	54	46	24	21	40	35
Eastern Highlands	64	62	64	60	60	55	31	27	53	45
Morobe	150	137	150	133	124	108	49	42	84	71
Madang	84	89	84	87	82	80	46	41	78	69
East Sepik	110	100	110	97	106	91	58	47	100	79
Sandaun	143	150	143	146	139	136	77	71	131	119
Manus	48	61	48	59	58	64	49	44	83	75
New Ireland	51	68	51	66	54	59	36	28	62	48
East New Britain	68	63	68	62	67	60	38	33	65	56
West New Britain	65	61	65	60	61	54	31	27	54	45
Bougainville	69	59	69	57	64	52	32	25	54	43

4.2.3 Projecting orphanhood method–derived estimates of adult mortality to 2011

Adult mortality estimates were calculated from the 2000 and 2011 censuses for females (reference date 2005) and from the 2011 census for males (reference date 2002). Table 4.5 shows the estimated and projected 45q15 estimates for PNG and each of its provinces. The rate of completeness described in the earlier section was used to adjust the provincial male 45q15 calculated from the 2011 census upwards.

The adjusted male 45q15 (reference date 2002) and female 45q15 (reference date 2005) were projected to 2011 using the GBD rate of decline of 0.97 over the period. The GBD rate of decline was considered more plausible than the UN's reduction rate of 0.87. For males, the ratio of 2011 45q15 to 2002 45q15 was multiplied by the 2002 adjusted estimates to project male 45q15 to 2011. For females, the final female 45q15 estimates in 2011 were derived by multiplying the GBD ratio of 2011 45q15 to 2005 45q15 by the 2005 45q15 estimates.

Table 4.5: Calculated and Projected Estimates of 45q15 by Sex and Province

Province	Male 45q15			Female 45q15	
	2011 Census (Ref. 2002)	Adjusted (Ref. 2002)	Projected (Ref. 2011)	2000 and 2011 Censuses (Ref. 2005)	Projected (Ref. 2011)
Western	251	291	281	191	181
Gulf	322	358	346	344	326
Central	269	293	283	281	266
National Capital District	173	214	207	181	171
Milne Bay	241	275	266	218	206
Oro	239	278	269	233	221
Southern Highlands	229	337	326	224	212
Enga	206	310	300	287	272
Western Highlands	172	231	223	196	186
Simbu	161	204	197	289	274
Eastern Highlands	189	236	228	267	253
Morobe	266	309	299	303	287
Madang	270	308	298	273	259
East Sepik	272	307	297	253	240
Sandaun	336	368	356	322	305
Manus	215	243	235	223	211
New Ireland	217	247	239	230	218
East New Britain	243	278	269	262	248
West New Britain	227	267	258	249	236
Bougainville	248	292	282	211	200
<i>Papua New Guinea</i>	<i>230</i>	<i>278</i>	<i>269</i>	<i>250</i>	<i>237</i>

Note: Ref. =reference date.

4.2.4 Components of the composite index

Given the absence of reliable data sources on adult mortality for PNG, a composite index based on socioeconomic and health access indicators was used to assess the plausibility of provincial 45q15 estimates.

The composite index was calculated by taking the arithmetic means of education, economic and health access indicators, as explained in the paper (Kitur, Adair, & Lopez, 2019a). Similar socioeconomic indicators developed by Lim et al. (2016) and others (Alijanzadeh, Asefzadeh, & Zare, 2016; Moradi-Lakeh et al., 2017) have taken the average of education, economic and total fertility rate indicators. However, given that there were no available total fertility rates by

province, this study used a health indicator comprising the number of health workers per population and immunisation coverage rate.

The education indicator was the average of the net enrolment rate and the female adult literacy rate. The net enrolment rate has been used to measure students' participation in basic education because it shows the actual proportions of pupils of related ages (6–14-year-olds) who are in school and not in school. In addition, the UN prefers this indicator because it shows a province's level of progress towards the attainment of universal basic education. As shown in Table 4.5, Milne Bay Province had the highest net enrolment rate (69%), while Oro Province had the lowest (38%). The link between maternal education and child mortality has been well documented; therefore, the female adult literacy rate is justified as an education indicator to predict mortality (Caldwell, 1979; Caldwell, J., & Caldwell, P., 1993; Desai & Alva, 1998).

The economic indicator comprised the proportion of people aged 10 years and over involved in money-making activities from the 2011 national population census (NSO, 2011) and poverty levels reported by the World Bank on food and non-food items. The World Bank report is a synthesis of several national studies by the NRI (2001), Hanson (2001) and the National Economic and Fiscal Commission (2004), which showed consistent results in the rankings of provinces and districts in PNG in terms of poverty levels (Gibson et al., 2005; Gibson & Rozelle, 2002).

Health access indicators included information on the ratio of health staff to population and the measles immunisation coverage rate for 2011 as reported by the NDoH (2011). Immunisation rates correlate negatively with mortality, thus are a useful predictor of mortality (Breiman et al., 2004; McGovern & Canning, 2015).

The education, economic and health access indicators were normalised around a mean of 50%, then the composite index was constructed by averaging these indicators (Kitur, Adair, & Lopez,

2019a, 2019b). All three indicators were used in the composite index to provide a more comprehensive picture of socioeconomic and health access conditions than what would have been provided by just one indicator. The data required to construct the composite index are presented in Table 4.6. Although the composite index cannot accurately predict mortality levels, it was useful in assessing the plausibility of provincial 45q15 estimates.

Table 4.6: Education, Economic and Health Access Indicator Components of the Composite Index

Province	Education			Economic				Health Access				Composite Index (%)
	Net Enrolment Rate (%)	Female Literacy Rate (%)	Education Component (%)	Poverty Ranking	Poverty Normalised (%)	% Involved in Money-Making Activities	Economic Component (%)	Nursing Officers per 1000 Population	Doctors per 1000 Population	Measles Coverage Rate (%)	Health Component (%)	
National Capital District	66	89	94	109	100	33	99	0.1	0.55	68	91	95
East New Britain	67	81	90	60	76	21	65	0.7	0.09	60	69	75
New Ireland	62	76	85	30	35	18	49	0.9	0.04	68	47	60
Bougainville	68	75	82	38	40	19	50	0.5	0.03	64	47	60
Eastern Highlands	50	37	22	59	79	25	77	0.3	0.03	49	78	59
Morobe	50	57	54	48	60	23	62	0.1	0.08	43	60	59
Western Highlands	47	33	28	32	40	28	78	0.3	0.05	38	68	58
Simbu	60	35	28	54	67	26	62	0.3	0.02	51	82	57
West New Britain	67	67	72	64	78	23	53	0.6	0.05	82	44	56
Milne Bay	69	76	81	54	68	12	12	0.7	0.05	68	59	51
Manus	66	84	96	63	78	17	43	0.9	0.03	62	10	50
East Sepik	51	46	57	45	56	19	52	0.4	0.04	42	38	49
Madang	45	49	55	22	20	19	51	0.5	0.05	44	37	48
Central	58	69	65	45	52	16	34	0.2	0.00	53	38	45
Oro	38	66	72	36	43	14	24	0.4	0.03	43	34	43
Western	61	66	82	28	17	14	26	0.8	0.03	39	13	41
Sandaun	40	44	49	4	1	17	30	0.3	0.02	51	9	29
Southern Highlands	40	32	15	39	48	13	26	0.3	0.02	30	44	28
Gulf	42	51	47	67	82	13	18	0.5	0.03	21	15	27
Enga	51	30	25	59	74	14	25	0.2	0.02	34	25	25

4.3 Summary of Adult Mortality Estimation in PNG

This chapter provided estimates of adult mortality by province in PNG. These were high by global standards and varied substantially by province according to the level of development as measured by socioeconomic development and health access. As expected in a country lower in the epidemiological transition, sex differentials were low. This thesis has greatly benefited from the extension of an existing demographic method to estimate adult mortality, the use of an empirical method to assess the completeness of male adult death reporting and the upward readjustment of derived estimates. Further, the use of a socioeconomic and health access index (composite index) informed the plausibility of provincial adult estimates for males and females.

These estimates will provide policymakers in PNG with valuable evidence on the levels and patterns of mortality in the adult population when mortality data are limited. PNG must urgently address this high level of premature death by investing in a national mortality surveillance system that will generate accurate and timely data to inform population health policy.

45q15 and 5q0 estimated in this chapter were used to estimate all-cause mortality, including life expectancy, for PNG and each of its provinces, presented in Chapter 5.

Chapter 5: Estimating the Patterns of All-Cause Mortality in Papua New Guinea

This chapter presents complete life tables and key mortality indicators for PNG and each of its provinces. Chapters 3 and 4 reported that high-quality data on deaths are not available in PNG because the CRVS system has failed to collect accurate data on mortality. Hence, a comprehensive analysis and understanding of mortality levels and patterns in PNG in the academic literature is lacking, despite PNG's adult mortality being among the highest in the world (Naghavi et al., 2017; United Nations Department of Economic and Social Affairs, Population Division, 2017). This chapter aims to address the gap in knowledge by estimating life expectancy at birth for PNG and its provinces to provide an insight into the demographic and epidemiological complexities surrounding mortality levels and patterns in the country. Specifically, 5q0 and 45q15 calculated in Chapter 4 were used in model life tables to generate complete life tables and estimate life expectancy at birth for PNG and each of its provinces (Moultrie & Timaeus, 2013; Murray et al., 2003; UN, 2013; Wilmoth, Zureick, Canudas-Romo, Inoue, & Sawyer, 2012). These results were then compared against a composite index (discussed in detail in Chapter 4) that measured socioeconomic status and health care access differentials across provinces in PNG to assess the plausibility of mortality estimates (Kitur, Adair, & Lopez, 2019b).

The methods used to calculate 5q0 and 45q15 were presented in Chapter 4, and methods used to calculate life expectancy at birth are provided in the paper below. Additional data and text not included in the paper because of space limitations are also provided. These complementary data include quality assessment of census household deaths collected in the 2011 census, the calculated ASDRs from these deaths and the maximum number of deaths from routine health data collected via the DHIS and NHIS. A review of the three model life

tables together with the main input data (5q0, 45q15) and results (ASDRs, life expectancy) are presented. The chapter ends with a conclusion.

Patterns of All-Cause Mortality in Papua New Guinea, 2011

Asia Pacific Journal of Public Health
2019, Vol. 31(4) 315–324
© 2019 APJPH
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/1010539519841492
journals.sagepub.com/home/aph



Urarang Kitur, MBBS¹ , Tim Adair, PhD¹,
and Alan D. Lopez, PhD¹

Abstract

Existing estimates of mortality for Papua New Guinea (PNG) have primarily been based on models using little empirical data, and without estimation of life expectancy at subnational level. We used data on deaths from the 2000 and 2011 censuses and indirect demographic methods to estimate under-5 mortality (5q0), adult mortality (45q15), and life expectancy by province and sex. A Socioeconomic Composite Index was constructed to assess the plausibility of life expectancy estimates. We generated 5q0 estimates (68 per 1000 live births for males and 58 for females), 45q15 (269 per 1000 for males and 237 for females), and life expectancy (62.0 years for males and 64.3 for females) in PNG in 2011. Provinces with low life expectancy had correspondingly low levels of development as measured by the Composite Index, and vice versa. These subnational estimates of mortality levels and patterns maybe useful at the provincial level to improve population health in PNG.

Keywords

life expectancy, under-5 mortality, adult mortality, Papua New Guinea, socioeconomic inequalities, subnational mortality

Introduction

Papua New Guinea (PNG) is a country with significant geographic, cultural, and economic diversity, with 88% of its 8 million population living in rural and remote communities where access is often difficult resulting in significant challenges to improving population health.¹ To our knowledge, no comprehensive analyses of mortality in PNG and its provinces have been published in the academic literature, primarily because the civil registration system is dysfunctional and there is no other routine source of reliable mortality data.² Previous mortality studies in PNG have focused on specific infectious diseases, particularly malaria, pneumonia, and TB (tuberculosis), and population-based mortality studies have been limited to small populations in few selected sites.^{3–7}

Mortality Studies in PNG

Between the 1950s and 1970s, studies on early age mortality in a few sites in PNG indisputably showed long-term declines.^{3–5} Subsequent analysis by Gouda et al⁶ on deaths collected

¹University of Melbourne, Carlton, Victoria, Australia

Corresponding Author:

Urarang Kitur, Melbourne School of Population and Global Health, University of Melbourne, Melbourne, Carlton, Victoria 3010, Australia.
Email: u.kitur@student.unimelb.edu.au

through verbal autopsies from 4 sites between 1970 and 2000 reported under-5 mortality rates (U5MR) of 104.7 per 1000 in Tari, Southern Highlands province; 91.2 in Asaro, Eastern Highlands; and 65.6 in Karkar, Madang. More recently, Gouda and colleagues⁷ reported U5MR that were half those from the verbal autopsies series suggesting decline in child mortality in these sites.

The only representative mortality estimates for PNG have been derived from censuses and surveys. Bauze et al⁸ reported U5MR as 78 per 1000 in 2000, with large inter- and intra-provincial variations. These patterns are similar to those reported by Bakker⁹ and the National Statistics Office (NSO).¹⁰

Publications on life expectancy at birth for PNG are provided by the United Nations¹¹ and the Global Burden of Disease Study (GBD),¹² using different model life tables. The UN life expectancy estimates of 62.4 for males and 67.2 for females are substantially higher than those reported by the GBD of 57.8 for males and 60.3 for females. Aside from under-5 mortality, the GBD does not use empirical data but relies on socioeconomic covariates and mortality levels and age patterns of nearby countries to estimate mortality. Furthermore, these sources provide only national estimates without subnational estimates for PNG.

Given the limited information on mortality in PNG, there is very little understanding of mortality levels and patterns at national and subnational levels. This study seeks to address this knowledge gap by estimating key mortality indicators in PNG by province and sex, using available data sources and a range of demographic methods. Specifically, the study estimates the risk of dying below 5 years (U5MR [5q0]), the risk of adult mortality (45q15, or the probability of dying from age 15 to 60 years), and life expectancy at birth. These results are then compared with a Composite Index that measures socioeconomic status, and health care access differences among provinces in PNG, to assess the plausibility of the mortality findings.

Methods

Data Sources

PNG lacks reliable data sources from which to accurately measure mortality.¹³ Information on deaths is fragmented because civil registration is dysfunctional. The National Department of Health collects data on 6000 to 11 000 individual deaths annually, primarily from provincial hospitals through the Discharge Health Information System (DHIS), and approximately 8000 to 15 000 deaths per year from health centers and hospitals via the National Health Information System (NHIS). However, these sources exclude deaths outside facilities, making the data unsuitable for estimating population-level mortality indicators. The 2000 and 2011 censuses collected summary birth histories (SBHs; i.e., number of children ever born and still living), parental survival or orphanhood data, and household deaths (by age and sex) in the last 12 months. SBHs and parental survival data from the 2006 Demographic Health Survey (DHS) were found to be of poor quality by Bauze et al⁸ and so were not analyzed further in this study. Approval was obtained from the Director of NSO for the use of the census and DHS data.

Estimating Under-5 Mortality

SBH data calculated from the 2011 census, tabulated by 5-year age groups of women aged 15 to 49 years, were used to estimate 5q0 for each sex and province using the maternal age cohort method.¹⁴ The resulting 5q0 from the 2011 census, however, was estimated as 39, much lower than the level of 63 estimated by the United Nations Inter-Agency Group for Child Mortality Estimation (UNIGME) based on modeling of trends of estimates from censuses and DHSs.¹⁵

Final 5q0 estimates by sex and province were calculated by scaling to UNIGME estimates; the ratio of provincial sex-specific 5q0 to national sex-specific 5q0 was multiplied by the sex-specific 5q0 estimated by UNIGME.

Estimating Adult Mortality

Adult mortality in this study was estimated based on the parental survival data from the 2000 and 2011 censuses using the orphanhood method.^{16,17} Male and female 45q15 were estimated based on the proportion of respondents with a surviving father or surviving mother, respectively, tabulated by the 5-year age group of the respondent, using data from both the 2000 and 2011 censuses for females, and 2011 census only for males since no question on paternal survival was asked in the 2000 census. For females, parental survival data by 5-year age group of respondent from 2 censuses allowed us to construct a hypothetical cohort of respondents to estimate adult mortality based on changes in the survival status of each cohort's parents.^{18,19}

The completeness of the estimated 45q15 for males for each province (ie, the estimated 45q15 divided by the actual 45q15) was measured using an empirical completeness method developed by Adair and Lopez.²⁰ The estimated number of reported deaths was calculated using a model life table for 2002 (the reference date of the male orphanhood estimate), with the 45q15 taken from the orphanhood estimate and the 5q0 from Bauze et al provincial estimates scaled to the IGME estimate for 2002.⁸ This completeness estimate was then used to adjust the original male 45q15 estimate upward. No adjustment of female 45q15 estimate for completeness was made because the hypothetical cohort method uses the same questions of the same cohorts of respondents at 2 points in time, so any bias due to systematic underreporting of mortality would be minimal. Each of these estimates was then projected from the reference date (2002 males and 2005 females) to 2011 by using the trend in PNG 45q15 over the ensuing period estimated by the GBD.¹³

The quality of the 2011 census household deaths, NHIS, and DHIS data were evaluated to assess their suitability for use in estimating adult mortality. The natural logarithm of age-specific death rates based on 2011 census household death and population data was first calculated followed by assessment of the NHIS and DHIS actual provincial deaths captured for completeness.²⁰ For both the NHIS and DHIS, the provincial level number of reported deaths was the sum of the maximum annual number of deaths reported in each facility from 2007 to 2013.

Use of Model Life Tables to Generate Complete Life Tables

Three model life tables, the UN General Life Table System, the Modified Logit System, and the Log Quadratic System, were assessed for their appropriateness to generate age-specific death rates (ASDRs) across all ages.^{14,21,22} Each model life table relies on 5q0 and 45q15 as inputs. Life expectancy of males and females for PNG and its provinces was taken as the average of all 3 models.

Composite Index

A Composite Index to measure provincial differences in socioeconomic and health characteristics was developed to assess the plausibility of provincial mortality levels and patterns.¹³ The Composite Index is derived from the arithmetic mean of education, economic, and health access indicators.²³⁻²⁵ Each indicator was adjusted to be a normally distributed percentage with mean of 50%.

Results

Quality Assessment of Data Sources for Adult Mortality

We assessed the NHIS and DHIS for completeness of death reporting and the 2011 census for plausibility of ASDRs. Despite taking the maximum number of deaths reported by each health facility in the period 2007 to 2013, the NHIS and DHIS reported only 28% and 22% of deaths, respectively (Table 1A, available online), making these data sources unsuitable to derive mortality statistics because they are unrepresentative of the mortality experience of the population of each province.

The pattern of ASDRs (Figure 1A, available online) is highly implausible, as the lowest ASDR for both sexes occurs at ages 40 to 44 years (instead of ages 5-14 years), and the next lowest ASDRs are in surrounding ages. Furthermore, the ASDR at ages 0 to 4 and 5 to 9 years are similar to that reported for ages 80 to 84 and 85 to 89 years, again highly implausible given established age patterns of mortality.¹² This pattern of mortality, therefore, cannot be used to estimate summary mortality measures in PNG despite showing a relatively low sex differences in mortality at all ages, a phenomenon not commonly observed.

Under-5 and Adult Mortality

Table 1 summarizes levels of childhood and adult mortality, life expectancy at birth, and Composite Index by province and sex in 2011. The national 5q0 was estimated at 63 per 1000, (68 for males, 58 for females), ranging from 27 in National Capital District (NCD) to 126 in Sandaun province. East Sepik (ESP) 90, Morobe 78, and Madang 74 reported the highest 5q0. Conversely, Western Highlands (WHP; 33 per 1000), Simbu (38), and Bougainville (49) had the lowest 5q0 estimates for both sexes. These findings are consistent with Bauze et al⁸ who found the highest levels of 5q0 in Sandaun, Morobe, and ESP, with NCD and Bougainville showing the lowest 5q0 in 2000.

Provinces with the highest 5q0 estimates also exhibited high 45q15 estimates. Sandaun (356 per 1000 for males, 305 for females), Gulf (346 for males, 326 for females), and Morobe (299 for males, 287 for females) reported the highest adult mortality estimates, while NCD (207 for males, 171 for females), WHP (223 for males, 186 for females), and New Ireland (239 for males, 218 for females) recorded the lowest 45q15. Interestingly, in Simbu and Eastern Highlands province (EHP) female 45q15 was significantly higher for women than men.

For both sexes, 5q0 and 45q15 are linearly related (Figure 2A, available online), but stronger for males ($R^2 = 0.65$) than females ($R^2 = 0.38$). No province has clearly disparate 5q0 and 45q15 estimates in males, while Simbu (5q0 35, 45q15 274) and Central (5q0 44, 45q15 266) have relatively low 5q0 and relatively high 45q15 in females. Simbu's female 45q15 is relatively high given its Composite Index score.

Life Expectancy

Life expectancy at birth in PNG in 2011 was estimated as 62.0 years for males and 64.3 years for females, similar to the United Nations¹¹ estimate of 62.4 for males but different for females (67.2 years) and the GBD¹² estimate of 57.8 for males and 60.3 for females.

Male life expectancy in provinces varied from 54.4 years in Sandaun to 67.2 years in Simbu, and from 56.8 years in Sandaun to 70.3 years in NCD for females. Simbu and EHP are the only provinces that have higher male than female life expectancy.

Figures 1 and 2 show variations in life expectancy levels by province and sex. Among males, there is a belt of comparatively low life expectancy running through the northern provinces of the country and further south in Gulf province. The comparatively high levels of male life expectancy

Table 1. Under-5 Mortality, Adult Mortality, and Life Expectancy at Birth and Composite Index, by Province and Sex, PNG 2011.

Province	Under-5 Mortality (per 1000 Live Births)		Adult Mortality (per 1000)		Life Expectancy (Years)		Composite Index (%)
	Male	Female	Male	Female	Male	Female	All
Western	64	57	281	181	61.8	67.2	41%
Gulf	109	97	346	326	56.2	57.4	27%
Central	55	44	283	266	62.4	63.8	45%
National Capital District	34	23	207	171	67	70.3	95%
Milne Bay	78	64	266	206	61.5	65.4	51%
Oro	69	64	269	221	62.0	64.6	43%
Southern Highlands/Hela	70	59	326	212	59.6	65.4	28%
Enga	69	66	300	272	60.7	62.0	25%
Western Highlands/Jiwaka	40	33	223	186	65.9	68.7	58%
Simbu	40	35	197	274	67.2	64.2	57%
Eastern Highlands	53	45	228	253	64.9	64.4	59%
Morobe	84	71	299	287	59.7	61.0	59%
Madang	78	69	298	259	60.2	62.4	48%
East Sepik	100	79	297	240	58.8	62.6	49%
Sandaun	131	119	356	305	54.4	56.8	29%
Manus	83	75	235	211	62.6	64.4	50%
New Ireland	62	48	239	218	63.8	65.9	60%
East New Britain	65	56	269	248	62.2	63.9	75%
West New Britain	54	45	258	236	63.4	65.2	56%
Bougainville	54	43	282	200	62.4	67.2	60%
PNG	68	58	269	237	62.0	64.3	50%
UN	—	—	262	202	62.4	67.2	—
GBD	—	—	383	338	57.8	60.3	—

Abbreviations: PNG, Papua New Guinea; UN, United Nation; GBD, Global Burden of Disease Study.

prevailing in WHP, Simbu and EHP and NCD, is also illustrated by female life expectancy including Bougainville and Western provinces.

Composite Index

NCD (95%), East New Britain (75%), Bougainville (60%), and New Ireland (60%) reported the highest score, while Enga (25%), Gulf (27%), SHP (28%), and Sandaun (29%) were the least developed provinces as measured by the Composite Index (Table 1). Detailed information is available in supplementary Table 2A and Figure 3A.

Life expectancy is moderately linearly related to the Composite Index, showing an R^2 of 0.48 for males and 0.38 for females (Figure 3). Outliers include a high Composite Index and relatively low life expectancy in Morobe (59%, 59.7 years for males, 61.0 years for females).

Discussion

We used empirical data from the 2011 and 2000 censuses to estimate summary measures of mortality by sex, for PNG, and, for the first time, provinces for 2011. Households deaths reported in

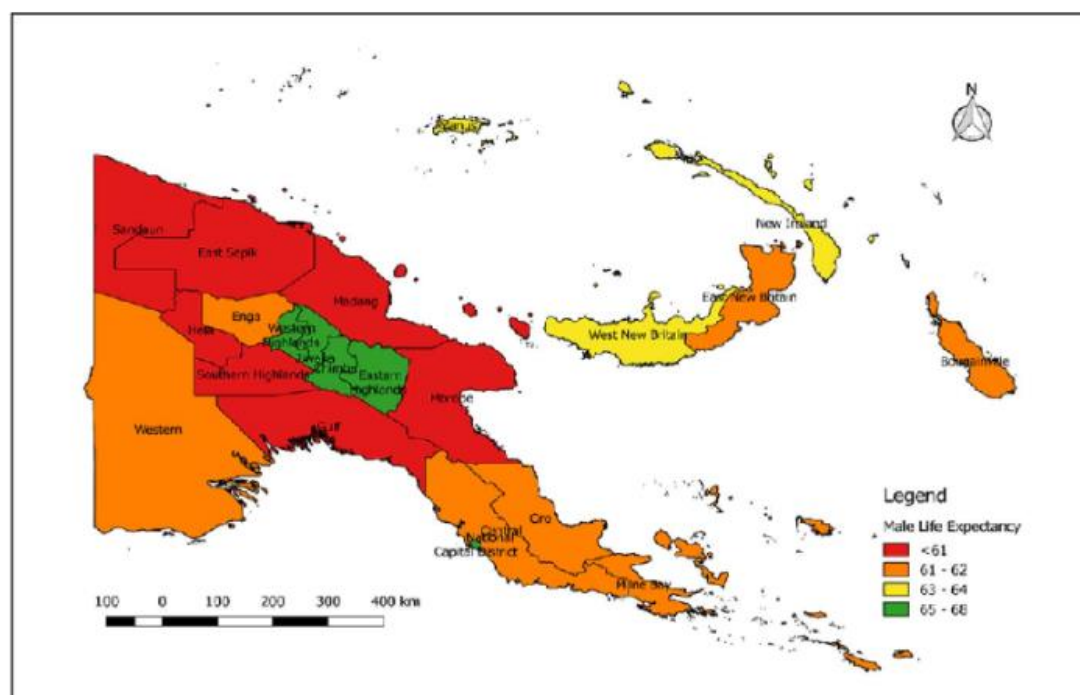


Figure 1. Male life expectancy by province, PNG, 2011.

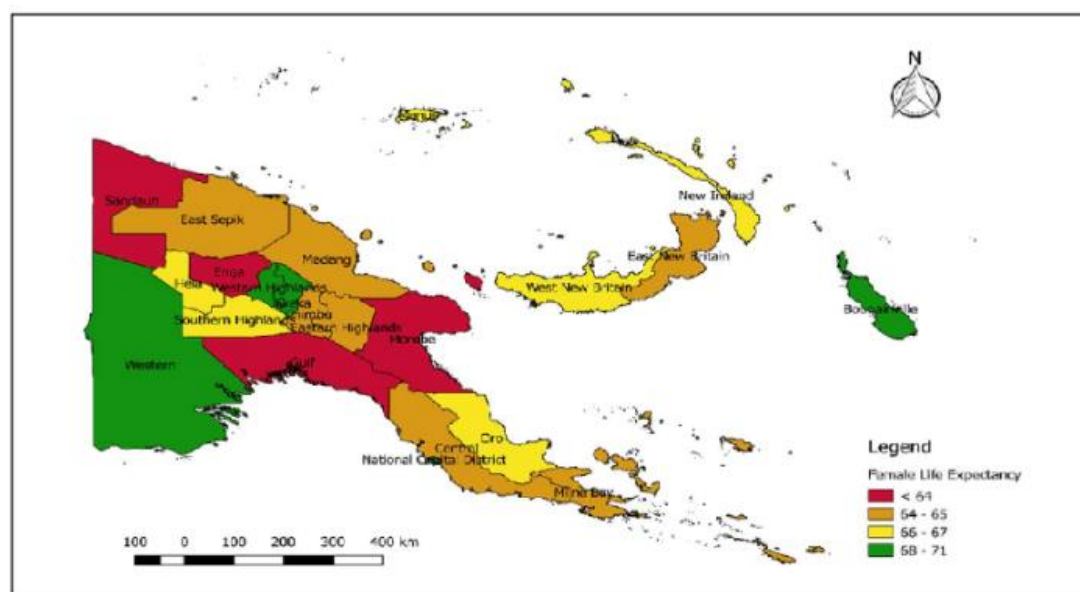


Figure 2. Female life expectancy by province, PNG, 2011.

the 2011 census as well as the NHIS and DHIS data systems were of little use for this analysis because of problems of age misreporting and completeness.

Estimated 5q0 of 68 for males and 58 for females in PNG in 2011 indicated a moderate decline from the estimates of Bauze and colleagues in 2000.⁸ Gulf, Sandaun, and Morobe reported the highest 5q0 estimates, corresponding to some of the remotest and least developed districts in

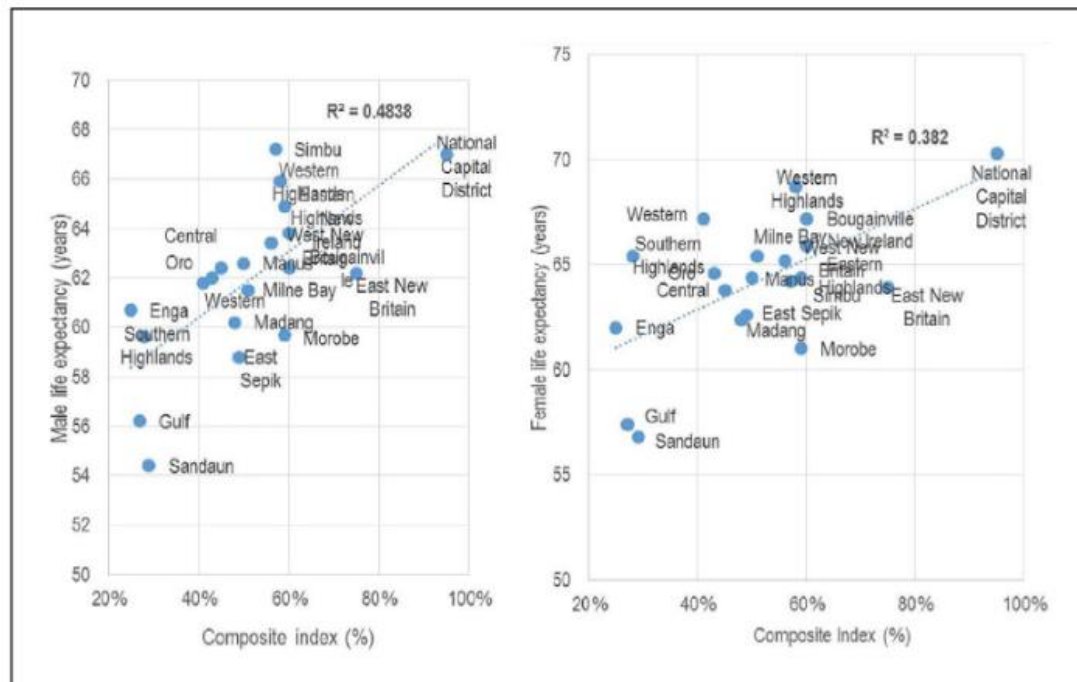


Figure 3. Life expectancy and Composite Index, by province, PNG, 2011.

PNG with very poor access to health services.²⁴ NCD, EHP, and Simbu were found to have the lowest 5q0, which are consistent with the relatively high Composite Index for these provinces, reflecting relatively good levels of education and access to services.¹³ Provincial 5q0 also correlate quite strongly with 45q15 estimates for males and moderately for females indicating high mortality due to communicable diseases.

The 2011 45q15 estimates for PNG of 269 for males and 237 for females are higher than the largely model life table-based estimates of the United Nations¹¹ (266, 202) but much lower than the GBD estimates¹² (392, 338). The GBD's estimates were based on demographic and statistical modeling that relies heavily on the mortality experience of nearby countries, while the United Nations estimates were largely based on child mortality data from the DHS and the use of model life tables. Our estimates are closer to the United Nations than the GBD, likely because the United Nations used more local data than the GBD. Furthermore, the high GBD estimates resulted from employing underlying models that were biased toward other Pacific countries with higher mortality from noncommunicable diseases (eg, diabetes), and its use of modifiers in models to account for the effect of HIV. Conversely, we did not find any compelling evidence to use any effect modifiers for HIV or any other diseases in our estimates, which were largely based on empirical data.²⁶

Life expectancy at birth in 2011 was estimated at 62.0 for males and 64.3 for females. These are moderately similar to the United Nations estimates of 62.4 for males but significantly different from their estimates of 67.2 for females and the GBD estimates of 57.8 for males and 60.3 for females. Our estimates differ substantially from those of the NSO (56 for males and 57 for females), although they suggest a comparably minor sex difference in mortality.¹⁰ The relatively small sex differential in life expectancy is due to low sex differentials in 45q15 and suggests infectious diseases are still a prominent cause of deaths in adulthood. The sex difference in life expectancy is expected to widen when noncommunicable diseases replace infectious diseases as the leading causes of death.²⁷

Using the Composite Index to rank each province by socioeconomic development status provides a more informative basis for policy action to reduce mortality differentials than using rural and urban classification.²⁸ Thus, provinces like Sandaun, Madang, and Gulf with low Composite Indices of development display high levels of mortality and low life expectancy compared with NCD, Bougainville, and WHP with higher indices. This index has been helpful in interpreting provincial mortality differences given the significant geographic and topographical diversity in PNG.

Our mortality estimates have benefited from the use of more empirical data (2000 and 2011 censuses) using appropriate tools to assess data quality and adjust the estimates accordingly. For example, our 2011 5q0 estimates were initially low compared to Bauze et al's estimates but were made more plausible using adjustments based on the UNIGME estimates.^{8,15} Application of the empirical completeness model guided the upward adjustment of male adult mortality for 2002 before projecting it forward using the GBD trend analysis to derive the 2011 estimates.²⁰ Advantages of this model are that it does not rely on implausible assumptions and has been validated against global standards. This method revealed NHIS and DHIS data unsuitable for estimating mortality in this study and identified areas in urgent need for improving mortality surveillance for PNG.

Limitations

We have identified a number of limitations in our study. First, the only available reliable data we could use were retrospectively reported data from the 2011 and 2000 censuses for both adult and child mortality, which meant that the data used are not timely and we have been reliant on projecting estimates forward to 2011 (adult mortality) or scaling them to national 2011 estimates (child mortality). This is an unavoidable situation in PNG, where reliable mortality data are scarce.

Second, due to the methods employed we are unable to measure uncertainty in our estimates, which is likely to be substantial given retrospective reporting, the need to adjust data to a later reference date, and the scarcity of available data. However, is unlikely that the uncertainty around our estimates would be any less than that associated with the GBD estimates, that is, $\pm 20\%$.¹³ Finally, the small numbers of reported deaths in districts in the censuses does not allow for more refined mortality patterns at district level, which might have been more informative for guiding policy reform in the country. However, such level of analysis may have introduced more uncertainty to our analyses.

Conclusion

We have estimated childhood and adult mortality, and life expectancy at birth, by province and sex by using available data and applying established and novel demographic methods. While these data and tools allow us to develop some understanding of how mortality patterns and levels vary in PNG, there is some uncertainty around our results due to the lack of good-quality mortality statistics for the country. If PNG is to reliably measure progress with national and global development goals, the development and maintenance of a reliable and continuous national mortality surveillance system is a developmental priority. It is envisaged that non-facility death reporting will improve in future through improved notification methods being trialed as part of a broader verbal autopsy initiative to measure causes of death in communities but at present little is known about mortality outside of facilities.²⁹

Authors' Note

Request for data access should be directed to the corresponding author and will be granted subject to approval by the National Statistics Office of Papua New Guinea.

Acknowledgments

The authors wish to thank the National Statistician Mr. Roko Koloma and Mr. Benjamin Haichim from the PNG National Statistics Office for access to the 2011 and 2000 census data used in this study. We would also like to thank Ila Rouka for access to the National Department of Health NHIS and DHIS datasets. The authors also acknowledge Professor Ian Riley for his assistance with the literature review and initial conceptualization of the study.

Authors' Contributions

UK, TA, and AL conceptualized the research theme and analytical framework. UK conducted the data analysis and was responsible for drafting the manuscript. TA and AL critically revised the manuscript. The final draft was approved by all authors.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This research was conducted as part of UK's PhD, funded by the Australia Award Scholarship. The funder had no influence on the final results.

Ethics Approval

Only secondary data were used so ethics considerations are not applicable.

Informed Consent

Prior approval for the use of census and DHS data was sought from National Statistics Office of Papua New Guinea.

Supplemental Material

Supplemental material for this article is available online.

ORCID iD

Urarang Kitur  <https://orcid.org/0000-0001-9830-0957>

References

1. National Statistics Office. *The National Population and Housing Census for Papua New Guinea for 2011: Count Me In*. Port Moresby, Papua New Guinea: National Statistics Office, Government of Papua New Guinea; 2015.
2. Montgomery J. *Foundations for a Successful CRVS Eco-system in Papua New Guinea*. National Department of Health. Port Moresby, Papua New Guinea; 2017.
3. Scragg R. *Depopulation in New Ireland: A Study of Demography and Fertility* (MD thesis; University of Adelaide). Port Moresby, Papua New Guinea: Administration of Papua New Guinea; 1954.
4. Van de Kaa DJ. *The Demography of Papua New Guinea's Indigenous Population*. Canberra, ACT: The Australian National University; 1971.
5. Riley ID. Pneumonia research in Papua New Guinea: 1967-1986. *PNG Med J*. 2010;53:106-118.
6. Gouda H, Lehmann D, Riley I. *Measurement of Cause of Death in Papua New Guinea Populations Using a Locally Developed Verbal Autopsy Instrument: 1970-2001* (Working Paper Number 36). Brisbane, Queensland, Australia: Health Information Systems Knowledge Hub, University of Queensland; 2013.

7. Gouda HN, Maraga S, Flaxman A, et al. The epidemiological transition in Papua New Guinea: new evidence from verbal autopsy studies. *Int J Epidemiol*. In press.
8. Bauze AE, Tran LN, Nguyen KH, et al. Equity and geography: the case of child mortality in Papua New Guinea. *PLoS One*. 2012;7(5):e37861. doi:10.1371/journal.pone.0037861
9. Bakker ML. *The Mortality Situation in Papua New Guinea: Levels, Differentials, Patterns, and Trends*. Port Moresby, Papua New Guinea: National Statistics Office; 1986.
10. National Statistics Office. *Mortality Situation, Trend and Differentials in Papua New Guinea Based on the Analysis of Data from Censuses and Demographic and Health Surveys* (2011 Census Research Monograph NR 1). Port Moresby, Papua New Guinea: National Statistics Office; 2011.
11. United Nations Department of Economic and Social Affairs, Population Division. World Mortality Report 2017. <http://www.un.org/en/development/desa/population/publications/mortality/world-mortality-cdrom-2017.shtml>. Accessed June 15, 2018.
12. Global Burden of Disease Study (GBD) 2016 Global Collaborators. Global, regional, and national age-sex specific mortality for 264 causes of death, 1980-2016: a systematic analysis for the Global Burden of Disease Study 2016. *Lancet*. 2017;390:1151-1210.
13. Kitur U, Adair T, Lopez AD. Estimating adult mortality in Papua New Guinea. *Population Health Metrics*. In press.
14. Moultrie TA, Timaeus IA. Introduction to model life tables. In: Moultrie T, et al, eds. *Tools for Demographic Estimation*. Paris, France: IUSSP; 2013:341-347.
15. United Nations Inter-Agency for Group for Child Mortality Estimates. Child mortality estimates 2017. <http://www.childmortality.org>. Accessed March 20, 2018.
16. Timaeus I. Estimation of adult mortality from paternal orphanhood: a reassessment of a new approach. *Popul Bull United Nations*. 1992;33:47-63.
17. Brass W, Hill K. Estimating adult mortality in Africa from orphanhood. Paper presented at: International Population Conference; Liege, Belgium; 1973.
18. Zotnik H, Hill K. The use of hypothetical cohorts in estimating demographic parameters under conditions of changing fertility and mortality. *Demography*. 1981;18:103-122.
19. Timaeus I. Indirect estimation from orphanhood in multiple enquiries. In: Moultrie T, et al, eds. *Tools for Demographic Estimation*. Paris, France: IUSSP; 2013:293-308.
20. Adair T, Lopez AD. Estimating the completeness of death registration: an empirical method. *PLoS One*. 2018;13:e0197047. doi:10.1371/journal.pone.0197047
21. Murray CJ, Ferguson BD, Lopez AD, Guillot M, Salomon J, Ahmad O. Modified logit life table system: principles, empirical validation, and application. *Popul Stud*. 2003;57:165-182.
22. Wilmoth JR, Zureick S, Canudas-Romo V, Inoue M, Sawyer C. A flexible two-dimensional mortality model for use in indirect estimation. *Popul Stud*. 2012;66:1-28.
23. National Research Institute. *Papua New Guinea District and Provincial Profiles*. Port Moresby, Papua New Guinea: National Research Institute; 2010.
24. World Bank. *Papua New Guinea: Poverty Assessment (English)*. Washington, DC: World Bank. <http://documents.worldbank.org/curated/en/500511468082129284/Papua-New-Guinea-poverty-assessment>. Accessed July 25, 2018.
25. National Department of Health. *Sector Performance Annual Review 2007-2011*. Port Moresby, Papua New Guinea: National Department of Health; 2011.
26. Coghlan B, Milan J, Malau C, Kaldor J, Toole M. The HIV epidemic in Papua New Guinea. *J Acquir Immune Defic Syndr*. 2011;58:e48-e51.
27. Beltran-Sanchez H, Finch C, Crimmins E. Twentieth century surge of excess adult male mortality. *Proc Natl Acad Sci U S A*. 2015;112:8993-8998.
28. Global Burden of Disease Study (GBD) 2015 Global Collaborators. Measuring the health-related Sustainable Development Goals in 188 countries: a baseline analysis from the Global Burden of Disease Study 2015. *Lancet*. 2015;388:1813-1850.
29. Lopez AD, Setel PW. Better health intelligence: a new era for civil registration and vital statistics? *BMC Med*. 2015;13:73. doi:10.1186/s12916-015-0333-4

5.1 Data Sources

Potential data sources to estimate adult mortality were identified through a review of data sources presented in Chapter 3 and in the paper presented in Chapter 4. These included data on household deaths collected through the national population census and routine health data on deaths collected by the NDoH via the DHIS and NHIS (NDoH, 2016).

Population-based censuses and DHSs have collected summary birth histories on the number of CEB and CSL as well as parental survival data and household deaths in the previous 12 months (NSO, 2000, 2011b). The 2000 and 2011 censuses included summary birth histories and parental survival data, but child history data collected in the 2006 DHS were not analysed further in this study because they were found to be of poor quality by Bauze et al. (2012). The 2011 census gathered information on maternal and paternal survival, while the 2000 census gathered data on maternal survival only. Similarly, data on household deaths in the previous 12 months was only collected in the 2011 census and not in the 2000 census. Data on deaths from the 2000 and 2011 national population censuses and routinely collected health data via the DHIS and NHIS were the only potential data sources for which to estimate adult mortality. Both sources of data were assessed for quality prior to use.

5.1.1 Quality assessment of data sources for mortality estimation

The ASDRs for both sexes in PNG in 2011, calculated from the number of household deaths per total population for each age group, showed a highly implausible mortality pattern (see Table 5.1 and Figure 5.1). According to the Gompertz law (Preston, Heuveline, & Guillot, 2001), mortality declines from a high rate in the 0–4-year-old category to its lowest rate in the 10–14-year-old category, before it begins to increase exponentially after the age of 30–34 years. Figure 5.1 shows that the lowest ASDR is between the ages of 35 and 49 years instead of 10–14 years and that the mortality rate of 5–9-year-olds is similar to that for 65–69-year-olds. This pattern of mortality is highly implausible, thus could not be used to estimate summary

mortality measures in PNG. The implausible ASDR pattern from census household deaths confirms findings by Allen (2014) that the 2011 census data may have been affected by errors in counting and data management. The 2011 household deaths may have been over-reported for ages 5-9 years and ages were misreported resulting in the implausible mortality pattern displayed. However, as described in Chapter 4, adult mortality results based on the application of demographic methods to orphanhood data in the census were largely plausible, and hence these results were used to estimate mortality over all ages. Issues affecting the quality of census data needed to estimate all-cause mortality are discussed in detail in Chapter 7.2

Table 5.1: Census Household Deaths and ASDRs in PNG (2011)

Age (years)	Population			Deaths			ASDR (per 1,000)		
	All	Male	Female	All	Male	Female	All	Male	Female
0-4	859,988	447,006	412,982	45,947	25,399	20,548	52.8	56.8	49.8
5-9	906,028	471,138	434,890	8,734	4,944	3,790	9.6	10.5	8.7
10-14	810,237	431,595	378,642	5,080	2,918	2,162	6.3	6.8	5.7
15-19	853,794	449,544	404,250	4,303	2,242	2,061	5.0	5.0	5.1
20-24	695,642	359,168	336,474	3,301	1,698	1,603	4.7	4.7	4.8
25-29	632,236	310,521	321,715	2,772	1,432	1,340	4.4	4.6	4.2
30-34	515,033	253,753	261,280	2,133	1,151	982	4.1	4.5	3.8
35-39	507,787	251,624	256,163	1,724	841	883	3.4	3.3	3.4
40-44	385,365	196,740	188,625	1,396	713	683	3.6	3.6	3.6
45-49	343,436	179,410	164,026	1,199	633	566	3.5	3.5	3.5
50-54	241,374	129,156	112,218	1,079	643	436	4.4	5.0	3.9
55-59	173,763	94,184	79,579	841	529	312	4.8	5.6	3.9
60-64	130,664	71,329	59,335	893	569	324	6.8	8.0	5.5
65-69	88,341	49,556	38,785	699	465	234	7.9	9.4	6.0
70-74	49,647	28,255	21,392	569	365	204	11.4	12.9	9.5
75-79	27,274	15,679	11,595	436	283	153	15.9	18.0	13.2
80-84	12,431	6,924	5,507	338	212	126	27.1	30.6	22.9
85-89	5,463	3,119	2,344	250	156	94	45.6	50.0	40.1
90+	2,957	1,698	1,259	365	239	126	121.5	140.8	100.1
<i>PNG</i>	<i>7,254,442</i>	<i>3,757,198</i>	<i>3,497,244</i>	<i>89,982</i>	<i>49,835</i>	<i>40,147</i>	<i>12.4</i>	<i>13.3</i>	<i>11.5</i>

Note: ASDR: age-specific death rate; PNG: Papua New Guinea

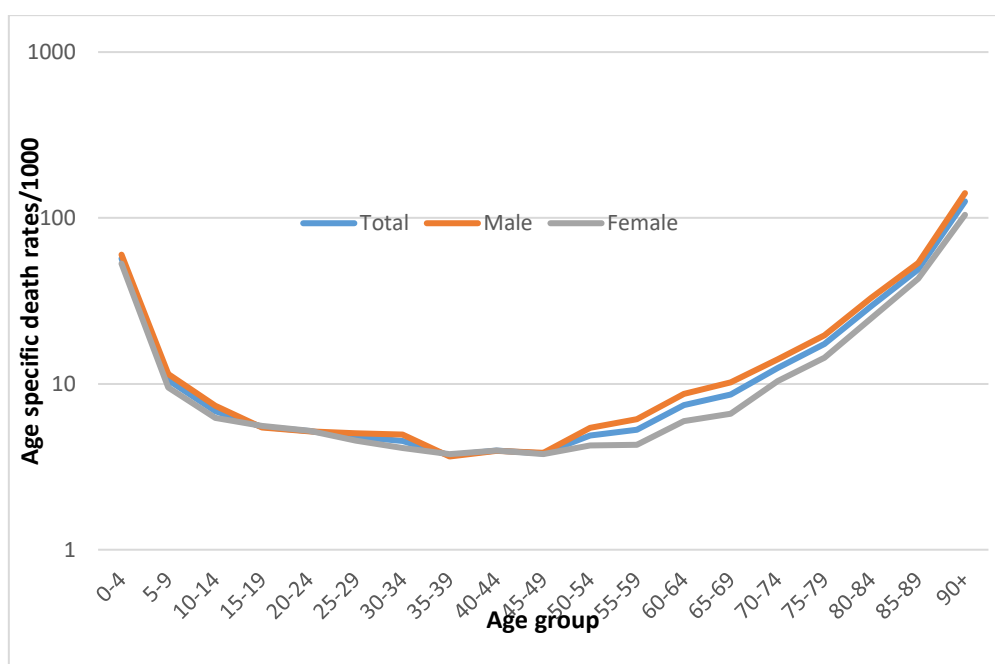


Figure 5.1: Age-Specific Deaths Rate, Log Scale, Papua New Guinea, 2011 (Census Household Deaths)

The published paper reports the completeness estimates for the DHIS and NHIS as 22% and 28% respectively. Based on data collected from health facilities between 2007 and 2013 for the DHIS and 2010 and 2015 for the NHIS, the DHIS has the potential to report between 6,000 and 11,000 deaths annually, while the NHIS is capable of collecting information on a slightly higher number of deaths (8,000–15,000) annually. However, when using the maximum number of deaths occurring annually in each facility to account for the potential coverage of each source, these deaths comprised only 22% (DHIS) and 28% (NHIS) of all provincial deaths annually. Moreover, these data sources are not linked because the NHIS reports an aggregated summary of deaths, while the DHIS collects data on individual deaths. Table 5.2 shows the annual number of deaths in each province from each source for the 2007–2015 period.

Table 5.2: DHIS and NHIS Annual Reported Deaths

Province	DHIS							NHIS					
	2007	2008	2009	2010	2011	2012	2013	2010	2011	2012	2013	2014	2015
<i>Papua New Guinea</i>	3,781	6,833	6,294	6,790	6,498	2,246	5,871	8,230	8,799	8,015	6,003	8,162	6,551
Western	81	168	133	174	140	134	62	268	334	272	166	271	165
Gulf	61	115	33	76	92	60	9	166	116	194	137	136	76
Central	78	105	25	76	99	63	42	96	126	110	102	118	109
National Capital District	34	502	624	504	306	–	672	46	836	108	65	194	51
Milne Bay	250	301	71	358	230	158	40	405	444	378	270	336	372
Oro	279	206	174	193	210	62	107	210	251	204	224	254	209
Southern Highlands	437	347	330	302	323	125	180	557	563	481	218	448	519
Enga	377	253	272	330	288	38	356	398	437	401	235	465	344
Western Highlands	58	1,010	728	682	765	603	914	627	866	1,063	709	995	936
Simbu	166	311	440	415	492	126	486	456	557	551	501	457	484
Eastern Highlands	565	575	779	93	218	69	117	895	856	645	308	691	636
Morobe	540	833	846	1,064	869	153	863	1,408	767	641	411	974	652
Madang	109	297	418	522	611	183	579	529	346	589	820	613	297
East Sepik	205	315	347	415	453	172	354	511	533	604	485	430	363
Sandaun	54	197	93	271	261	181	161	323	315	299	129	285	184
Manus	75	60	74	88	73	7	80	107	98	91	28	83	106
New Ireland	130	227	172	241	169	31	163	293	251	167	156	130	95
East New Britain	90	467	241	305	342	–	367	470	424	490	472	530	373
West New Britain	87	336	328	434	287	–	276	255	383	392	278	457	321
Bougainville	105	208	166	247	270	81	43	210	296	335	289	295	259

Note: DHIS: Discharge Health Information System; NHIS: National Health Information System.

5.2 Use of Model Life Tables to Generate Complete Life Tables

This section elaborates on the methods described in the paper on the use of model life tables. Three model life tables, the UN general life table system (UN, 2013), the modified logit system (Murray et al., 2003) and the log-quadratic system (Wilmoth et al., 2012), were used to generate complete life tables, including ASDRs, across all ages to estimate life expectancy at birth. Each model life table relied on 5q0 and 45q15 as inputs. Life expectancy of males and females for PNG and its provinces was calculated using the average of all three models.

The UN general life tables designed for developing countries (UN, 1982) were revised in 2012 (UN, 2013) to extend life expectancy at birth from 75 years to 92.5 years. Initially, life expectancy generated by UN life tables was only up to 75 years. Murray et al. (2003) proposed a two-parameter system—the modified logit system—which improved on the UN logit system and had the same accuracy as the quadratic logit system (Wilmoth et al., 2012). The quadratic logit system is a flexible two-dimensional model that uses two mortality parameters (5q0 and 45q15) to generate complete life tables. For countries with no data on adult mortality, the model is capable of constructing complete life tables using only one piece of information (child mortality). However, it is advisable to avoid using a single parameter (5q0) because it will be prone to large errors that will substantially add to the uncertainty of mortality estimates (Wilmoth et al., 2012). The log-quadratic method outperforms both the Coale-Demeny model (Coale & Demeny, 1966, 1983), which introduces severe bias in countries in which 5q0 drops below 50–60 per 1,000 live births, and UN model life tables (UN, 1982).

Table 5.3 shows the ASDRs and life expectancy at birth for males and females in PNG generated by each of the three model life tables. The modified logit model produced the highest rates for both males and females, while the log-quadratic and UN models reported similar life expectancy levels for males. Given that there was little difference between the

three models, the average of the three life expectancy estimates was calculated as the final estimate for PNG (Table 5.3) and each of its provinces (Table 5.4).

Table 5.3: ASDRs and Life Expectancy at Birth in PNG (2011) Using Model Life Tables

Data Input and Life Expectancy	UN Model Life Tables		Modified Logit		Log-Quadratic Model Life Tables		Average of the Three Models	
	Male	Female	Male	Female	Male	Female	Male	Female
5q0	0.068	0.058	0.068	0.058	0.068	0.058	0.068	0.058
45q15	0.269	0.237	0.269	0.237	0.269	0.237	0.269	0.237
e0 (years)	61.7	63.4	62.6	65.1	61.8	64.3	62	64.3
Age (years)	ASDRs							
0	0.0481	0.0346	0.0526	0.0390	0.0560	0.0462	0.0522	0.0399
1	0.0054	0.0062	0.0042	0.0051	0.0038	0.0036	0.0045	0.0049
5	0.0015	0.0016	0.0013	0.0015	0.0015	0.0017	0.0014	0.0016
10	0.0010	0.0010	0.0009	0.0011	0.0011	0.0014	0.0010	0.0011
15	0.0015	0.0015	0.0016	0.0020	0.0021	0.0023	0.0017	0.0019
20	0.0022	0.0021	0.0025	0.0027	0.0030	0.0029	0.0026	0.0026
25	0.0026	0.0026	0.0029	0.0030	0.0031	0.0034	0.0028	0.0030
30	0.0032	0.0033	0.0035	0.0035	0.0035	0.0039	0.0034	0.0035
35	0.0042	0.0041	0.0046	0.0044	0.0044	0.0047	0.0044	0.0044
40	0.0060	0.0053	0.0063	0.0057	0.0059	0.0057	0.0061	0.0056
45	0.0088	0.0073	0.0090	0.0076	0.0086	0.0073	0.0088	0.0074
50	0.0134	0.0109	0.0130	0.0105	0.0128	0.0099	0.0131	0.0104
55	0.0205	0.0169	0.0192	0.0147	0.0193	0.0140	0.0197	0.0152
60	0.0324	0.0273	0.0277	0.0211	0.0296	0.0208	0.0299	0.0231
65	0.0509	0.0451	0.0414	0.0315	0.0450	0.0326	0.0458	0.0364
70	0.0775	0.0737	0.0626	0.0493	0.0691	0.0530	0.0697	0.0586
75	0.1135	0.1159	0.0948	0.0770	0.1065	0.0864	0.1049	0.0931
80	0.1606	0.1727	0.1453	0.1225	0.1615	0.1368	0.1558	0.1440
85	0.2304	0.2478	0.2228	0.1950	0.2397	0.2111	0.2310	0.2180
90	0.3205	0.3380	–	–	0.3378	0.3035	0.3291	0.3208
95	0.4502	0.4634	–	–	0.4578	0.4250	0.4540	0.4442
100	0.5284	0.5448	–	–	0.5811	0.5532	0.5548	0.5490
105	0.5848	0.6039	–	–	0.6963	0.6758	0.6406	0.6398
110	0.6471	0.6695	–	–	0.7920	0.7675	0.7196	0.7185

Note: ASDR: Age-specific death rates; PNG: Papua New Guinea.

Table 5.4 shows the derived life expectancy at birth by sex for the three model life tables (UN, modified logit and log-quadratic) using provincial levels of 5q0 and 45q15 (estimated in Chapter 4).

Table 5.4: Estimated Life Expectancy at Birth Derived Using the United Nations (UN) Model, Modified Logit Model and Log-Quadratic Model Life Tables Applied to 5q0 and 45q15

Province	Data Input				Life Expectancy at Birth (Years) Calculated from Different Model Life Tables							
	5q0		45q15		UN Model Life Table		Modified Logit		Log-Quadratic		Estimated	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
<i>Papua New Guinea</i>	68	58	269	237	61.7	63.4	62.6	65.1	61.8	64.3	62.0	64.3
Western	64	57	281	181	61.3	66.9	62.4	67.8	61.7	67.0	61.8	67.2
Gulf	109	97	346	326	56.2	57.2	56.8	58.0	55.8	57.0	56.2	57.4
Central	55	44	283	266	61.7	62.5	63.1	65.0	62.5	64.0	62.4	63.8
National Capital District	34	23	207	171	66.1	67.9	67.9	71.8	67.2	71.1	67.0	70.3
Milne Bay	78	64	266	206	61.4	64.7	62.0	65.3	61.2	64.6	61.5	65.4
Oro	69	64	269	221	61.7	64.1	62.5	65.3	61.7	64.6	62.0	64.6
Southern Highlands	70	59	326	212	59.1	64.8	60.2	66.1	59.4	65.4	59.6	65.4
Enga	69	66	300	272	60.2	61.3	61.3	62.8	60.5	62.0	60.7	62.0
Western Highlands	40	33	223	186	65.1	67.0	66.7	69.9	66.0	69.1	65.9	68.7
Simbu	40	35	197	274	66.6	62.5	67.9	65.6	67.1	64.6	67.2	64.2
Eastern Highlands	53	45	228	253	64.5	63.1	65.4	65.6	64.7	64.7	64.9	64.4
Morobe	84	71	299	287	59.5	60.3	60.3	61.8	59.4	60.8	59.7	61.0
Madang	78	69	298	259	59.9	62.8	60.7	64.0	59.9	63.2	60.2	62.4
East Sepik	100	79	297	240	58.8	62.4	59.2	63.1	58.3	62.4	58.8	62.6
Sandaun	131	119	356	305	54.5	56.9	54.9	57.1	53.8	56.4	54.4	56.8
Manus	83	75	235	211	62.9	64.3	62.9	64.8	62.0	64.1	62.6	64.4
New Ireland	62	48	239	218	63.5	64.8	64.3	66.9	63.5	66.1	63.8	65.9
East New Britain	65	56	269	248	61.9	62.9	62.8	64.8	62.0	63.9	62.2	63.9
West New Britain	54	45	258	236	62.8	63.9	64.1	66.3	63.4	65.5	63.4	65.2
Bougainville	54	43	282	200	61.7	66.0	63.1	68.2	62.4	67.4	62.4	67.2

5.3 Summary of All-Cause Mortality Estimation in PNG

This chapter generated indirect estimates of adult mortality, child mortality and life expectancy at birth for PNG and each of its provinces using established and novel demographic methods applied to available data. While these tools have provided some insight into how mortality levels and patterns vary by province in PNG, this approach is not ideal given the uncertainty of these estimates because of the poor quality and timeliness of mortality data and the rigidity of the methods used to estimate uncertainties. Given these limitations, the priority for PNG is to invest in a routine national surveillance system that will improve reporting of deaths to provide a better understanding of mortality levels and differentials in the country. This is discussed in Chapter 8.

Chapter 6: Estimating the Patterns of Causes of Death in Papua New Guinea

6.1 Introduction

This chapter presents COD estimates and sex patterns across five broad categories for PNG and each of its provinces using statistical methods applied to empirical and modelled GBD data. Specifically, the method uses VA and DHIS data by applying statistical models of expected community versus facility COD patterns to estimate empirical patterns of COD. An expected COD pattern was estimated utilising existing mortality levels in each province derived from the model life tables presented in Chapters 4 and 5, modelling the relationship between all-cause mortality and cause-specific mortality using the GBD data. Given that there is no a priori to choose one over the other, the average of the empirical and expected cause pattern cause-specific mortality fractions (CSMF) was used as the final COD estimate.

As shown earlier in this thesis, there are few published data on the pattern of COD for PNG at the subnational level, which has substantial variations in terms of geography, ethnicity, socioeconomic development and health access. Consequently, there is no clear understanding of the distribution of COD patterns because of the limited data on non-hospital CODs, the routine reporting of deaths from health facilities comprising a fifth or less of all deaths and the failure of the civil registration system to accurately register data on deaths (Duke et al., 2016; Kitur, Adair, & Lopez, 2019a; Montgomery, 2017; Naraqi, Feiling, & Leeder, 2003; Riley, 2009). Further, recent reports have shown the emergence of significant levels of NCD and NCD risk factors in parts of the country (Gouda et al., 2019; Rarau, et al., 2019; Rarau et al., 2017). Estimates from the GBD Study (Naghavi et al., 2017), which is largely based on demographic and statistical modelling that employs little empirical or local data for PNG, suggest that NCDs are a major COD in PNG. Given the great uncertainty and lack of knowledge of COD patterns in

PNG, this chapter aims to address this knowledge gap and provide useful insights into COD in the country by estimating CSMFs by sex for five broad groups of causes—endemic infections, emerging infections (Morens & Fauci, 20113), endemic NCDs, emerging NCDs and injuries—for each of PNG’s provinces (Gouda et al., 2019). Provincial COD estimates are compared with levels of socioeconomic development and health access, as measured by the composite index developed in Chapter 4 (Kitur et al., 2019b), to assess the plausibility of the provincial estimates.

The objectives of this chapter are addressed in the published paper presented below; however, additional data and text not included in the paper are provided to complement and underpin the analysis reported in the paper.

RESEARCH ARTICLE

Open Access

Estimating the pattern of causes of death in Papua New Guinea



Urarang Kitur^{1,2*}, Tim Adair¹, Ian Riley¹ and Alan D. Lopez¹

Abstract

Background: Papua New Guinea (PNG) is a diverse country with high mortality and evidence of increased prevalence of non-communicable diseases (NCDs), but there is no reliable cause of death (COD) data because civil registration is insufficient and routine health data comprise only a small proportion of deaths. This study aims to estimate cause-specific mortality fractions (CSMFs) for five broad groups of causes (endemic infections, emerging infections, endemic NCDs, emerging NCDs and injuries), by sex for each of PNG's provinces.

Methods: CSMFs are calculated as the average of estimates obtained from: (1) Empirical cause method: Utilising available Verbal Autopsy (VA) data and Discharge Health Information System (DHIS) data, and applying statistical models of community versus facility CODs; and (2) Expected cause patterns method: Utilising existing estimates of mortality levels in each province and statistical models of the relationship between all-cause and cause-specific mortality using Global Burden of Disease (GBD) data.

Results: An estimated 41% of male and 49% of female deaths in PNG are due to infectious, maternal (female only), neonatal and nutritional causes. Furthermore, 45% of male and 42% of female deaths arise from NCDs. Infectious diseases, maternal, neonatal and nutritional conditions account for more than half the deaths in a number of provinces, including lower socioeconomic status provinces of Gulf and Sandaun, while provinces with higher CSMFs from emerging NCDs (e.g. ischemic heart disease, stroke) tend to be those where socioeconomic status is comparatively high (e.g. National Capital District, Western Highlands Province, Manus Province, New Ireland Province and East New Britain Province). Provinces with the highest estimated proportion of deaths from emerging infectious diseases are readily accessible by road and have the highest rates of sexually transmitted infections (STIs), while provinces with the highest CSMFs from endemic infectious, maternal, neonatal and nutritional causes are geographically isolated, have high malaria and high all-cause mortality.

Conclusions: Infectious, maternal, neonatal and nutritional causes continue to be an important COD in PNG, and are likely to be higher than what is estimated by the GBD. Nonetheless, there is evidence of the emergence of NCDs in provinces with higher socioeconomic status. The introduction of routine VA for non-facility deaths should improve COD data quality to support health policy and planning to control both infectious and NCDs.

Keywords: Papua New Guinea, Cause of death, Inequalities, Non-communicable disease, Infectious disease, Cause-specific mortality fractions, Emerging diseases

* Correspondence: u.kitur@student.unimelb.edu.au; u.kitur@gmail.com

¹Melbourne School of Population and Global Health, University of Melbourne, Melbourne, Carlton, Victoria, Australia

²National Department of Health, P.O. Box 807, Waigani, National Capital District, Papua New Guinea



© The Author(s). 2019 **Open Access** This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The Creative Commons Public Domain Dedication waiver (<http://creativecommons.org/publicdomain/zero/1.0/>) applies to the data made available in this article, unless otherwise stated.

Background

Accurate and timely cause of death (COD) data is fundamental for health policy, research and development, but this is lacking in most middle and low-income countries [1–5]. In a low resource, geographically, culturally and socioeconomically diverse country like Papua New Guinea (PNG), understanding COD patterns and differentials in terms of age, sex, ethnicity, socioeconomic status and geography is crucial to identify priority areas for targeted interventions to improve health [6–8]. However, little is known about the distribution of CODs in PNG because the civil registration system does not accurately record death data; reported deaths from health facilities comprise only a small proportion of deaths and there is limited data on the causes of non-hospital deaths [9, 10].

COD data in PNG are available from two sources: (1) publications arising from population-based research and (2) routine health facility-based reporting. Population-based research is limited to small-scale studies in a small number of sites [11–16]. Published data from routine sources are limited to selected hospitals [17, 18] with only two studies reporting on the quality of medical certification of deaths [19, 20]. All of these published studies report infectious diseases as the predominant cause of death in PNG; however recent findings by Gouda et al. [16] and Rarau et al. [21], suggest the emergence of significant levels of non-communicable diseases (NCDs) and NCD risk factors in parts of the country, albeit from sites not representative of the entire PNG population. Estimates from the Global Burden of Disease (GBD) study, suggest NCDs are a major COD in PNG, but these are based on demographic and statistical modelling with very little empirical or local data for PNG, and need to be verified based on empirical evidence [22]. A study by Mola and Kirby showed large discrepancies in maternal mortality ratios (MMR) between modelled estimates and empirical estimates, therefore necessitates the verification of published estimates using local data [23].

The GBD Study classifies CODs under three broad groups: Group I (infectious diseases, maternal, child health and conditions of poverty), Group II (Non-communicable diseases), and Group III (Injuries) [24]. In the PNG context, Gouda et al. [16] further categorised CODs into five groups: (1) endemic infections, (2) emerging infections, (3) endemic NCDs, (4) emerging NCDs, and (5) injuries (see Table 1). This classification divides infections into emerging diseases that are recognised for the first time in the PNG population (e.g., HIV and cervical cancer) or have traditionally affected Papua New Guineans but are re-emerging (such as tuberculosis or TB) and endemic diseases like malaria, pneumonia, diarrhoea, maternal and other infections that have affected PNG's population for longer [25]. TB is an introduced disease that was thought to be under control in most

Table 1 Composition of five broad COD groups [16]

Group	Cause (ICD-10 code)	ICD-10 code
1. Endemic Infections	Malaria	[B50-B54]
	Diarrhoea/Dysentery	[A00-A09]
	Pneumonia	[J10-J22, J85]
	Maternal	[O00-O99]
	Other infectious diseases ^a	
2. Emerging Infections	TB	[A15–19]
	HIV	[B20-B24]
	Cervical cancer	[C53]
3. Endemic NCDs	Chronic respiratory diseases	[J40-J46]
	Leukaemia/Lymphoma	[C81-C85; C91-C96]
	Cirrhosis	[K70–76]
	Renal failure	[N17-N19]
	Breast cancer	[C50]
	Stomach cancer	[C16]
	Oesophageal cancer	[C15]
	Colorectal cancer	[C18–21]
	Prostate cancer	[C61]
	Other NCDs ^a	
	Other cancers ^a	
	Other cardiovascular diseases ^a	
4. Emerging NCDs	Diabetes	[E10-E14]
	Stroke	[I60-I69]
	Ischemic heart diseases	[I20-I25]
	Lung cancer	[C34]
5. Injuries	Homicide	[X85-Y09]
	Falls	[W00-W19]
	Road traffic	[V01-V89]
	Drowning	[W65-W74]
	Fires	[X00-X19]
	Bite of venomous animal	[X20–29]
	Poisonings	[X40–49]
	Suicide	[X60-X84]
	Other injuries ^a	

^a Calculated as the difference between total deaths within that sub-category and the total of specific causes within that sub-category

provinces of PNG in the late 1960s, but the devolution of health services, increased prevalence of diabetes, and drug resistance are factors that are responsible for the current epidemic [26]. HIV was unknown in PNG before 1987 but its emergence thereafter, in combination with TB, has resulted in a substantial number of hospital deaths among young adults [27]. Malaria and pneumonia have likely been leading CODs in PNG in the last 50

years; however, deaths from both diseases appear to have declined [28, 13].

Emerging NCDs include diabetes mellitus, stroke, ischaemic heart disease (IHD) and lung cancer, diseases that are largely attributable to individual lifestyle choices, while endemic NCDs comprise chronic respiratory diseases, other cancers, other cardiovascular diseases and all other NCDs. Chronic respiratory diseases among adults are thought to be common in PNG due more to domestic pollution from burning wood in most traditional societies of PNG than from smoking [29, 30]. Diabetes and stroke appear to be increasing in most urban and peri-urban societies of PNG due to life style changes from traditional diets to processed foods, physical inactivity and high rates of cigarette smoking [21]. In this study, we have used Gouda et al's classification to further categorise diseases into these broad categories within GBD Groups I and II since doing so is potentially more informative for public health policy [16].

Given the limited availability of data in PNG, there is enormous uncertainty in COD estimates. This study aims to provide more reliable estimates by generating cause-specific mortality fractions (CSMFs) for five broad groups of causes, by sex, and for each of PNG's provinces utilising a statistical modelling framework that encompasses available verbal autopsy (VA) derived COD data for community (non-facility) deaths from the

Gouda et al. study [16] and National Department of Health (NDoH) Discharge Health Information System (DHIS) routine facility-based data, the GBD database of COD and all-cause mortality estimates, and existing estimates of all-cause mortality by age, sex and province in PNG [10, 31]. This approach thus consolidated empirical evidence on COD and all-cause mortality with expected cause patterns, given the level of all-cause mortality and sociodemographic development in the country to yield COD estimates at national and provincial levels.

Methods

Data sources

Facility deaths

The most comprehensive source of facility deaths in PNG is the NDOH Discharge Health Information System (DHIS). Set up in 1968, the DHIS reports deaths from 20 provincial hospitals, 635 health centres and clinics out of 755 registered health facilities (86% reporting rate) in the country [32]. DHIS deaths are those who died in the facilities, except for those who die on arrival, which are regarded as coroner's cases. Only a very small proportion of deaths are of people residing out of the province, except for the four regional hospitals of Port Moresby in the National Capital District, Mt Hagen in Western Highlands Province (WHP/Jiwaka), Angau in Morobe Province and Nonga in East New Britain Province (ENBP). Deaths in

Table 2 Estimated CSMFs (%) by age and sex, empirical cause method, expected cause pattern method and final estimates, PNG, 2011

Method	Disease Classification	Male (%)					Female (%)				
		< 5	5–44	45–64	65+	All	< 5	5–44	45–64	65+	All
Empirical cause method	Endemic Infections	84	27	25	24	36	85	36	22	24	39
	Emerging Infections	2	20	19	5	12	3	22	19	5	13
	Endemic NCDs	10	18	32	43	28	10	21	34	42	28
	Emerging NCDs	0	12	13	16	11	0	8	14	16	10
	Injuries	4	22	11	12	13	3	12	11	14	10
	Total	100	100	100	100	100	100	100	100	100	100
Expected cause patterns method	Endemic Infections	81	20	12	12	27	80	33	14	12	32
	Emerging Infections	2	13	11	5	8	3	27	17	5	15
	Endemic NCDs	12	24	36	39	30	13	22	35	36	27
	Emerging NCDs	0	8	30	39	22	0	6	30	44	20
	Injuries	5	35	11	5	14	4	13	5	3	7
	Total	100	100	100	100	100	100	100	100	100	100
Final estimates	Endemic Infections	82	24	19	18	31	82	35	18	18	35
	Emerging Infections	2	17	15	5	10	3	25	18	5	14
	Endemic NCDs	11	21	34	41	29	12	22	35	39	27
	Emerging NCDs	0	10	21	27	16	0	7	22	30	15
	Injuries	4	28	11	8	13	3	12	8	8	8
	Total	100	100	100	100	100	100	100	100	100	100

hospitals and health centres are recorded on the standard international medical certificate, with information on age, sex, facility/district/province and COD transferred into the DHIS. Data on deaths in the DHIS are reported using the PNG 3-digit shortlist version of the International Classification of Diseases – Tenth Revision (ICD-10), for over 300 causes, and with age recorded for all deaths. Limitations of the DHIS, detailed elsewhere, are that it is unsuitable for population level mortality because of its exclusion of deaths outside facilities, and that reporting of deaths in some facilities is incomplete in some years. This study uses DHIS data from 2007 to 2013 [32]. The other NDOH data source, the National Health Information System (NHIS), records more deaths than DHIS but only reports deaths based on 26 syndromes. Moreover, 72% of deaths do not have an age recorded, greatly limiting their analytical and policy utility. A new data source, the eNHIS, developed in 2014 records facility deaths using detailed ICD-10 coding but currently operates only in eight provinces, and is still in the early stages of development, with limited numbers of death. Neither NHIS nor eNHIS data were used for analysis in this study given these limitations.

Community deaths

The only source of data on community CODs in PNG are from four sites in the Gouda et al. study [16]. From 2009 to 2014, 1408 community and hospital deaths were recorded from the sites and diagnosed using Smart Verbal Autopsy (the Population Health Metrics Research Consortium (PHMRC) Tariff v.2.0 method). Verbal autopsy is a means of obtaining the probable COD based on signs and symptoms reported in a standardised interview with a family member of the deceased [33]. The Tariff algorithm estimates the most probable COD from a list of 32 specific causes for adults. Three of the study sites (West Hiri in Central Province, Asaro in Eastern Highlands Province and Karkar in Madang Province) are in the top 20 districts in terms of socio-economic development and access to health care as measured by a composite index (described below), while the other site, Hides (Southern Highlands/Hela), is towards the bottom [10, 31, 34].

Global burden of disease study

The GBD Study provides estimates of all-cause mortality and CSMFs by detailed age group and sex for 195 countries and territories for each year 1990–2017 [35]. The GBD uses the statistical modelling framework Cause of Death Ensemble model (CODEm), which combines results from global statistical models of 192 causes of death. For data-scarce countries like PNG, these models are based primarily on covariates. Covariates include the socio-demographic index (SDI), which is the geometric

average of education, economic and fertility indicators and is measured for every country-year, and available risk factor data (e.g. cigarette consumption for lung cancer) [36].

Analytical methods

Given the potential biases and measurement uncertainty associated with extrapolating from the VA samples and also the local imprecision arising from using global models of mortality developed by the GBD to estimate COD patterns in PNG, we had no a priori basis to favour one method over the other and hence the final estimates of COD suggested by this study were calculated as the simple arithmetic average of estimates obtained from two methods:

- 1) Empirical method: Utilising available data (VA data, DHIS) with statistical models of community compared with facility CODs.
- 2) Expected cause patterns method: Utilising existing estimates of mortality levels in each province with statistical models of the relationship between all-cause and cause-specific mortality generated from GBD data.

This approach makes use of the available data, with all their limitations, but also draws on what might be the expected cause patterns given the level of all-cause mortality in each province. CSMFs were estimated for the year 2011, which is close to the mid-point year of the DHIS and VA data and was used for the all-cause mortality estimates applied in this analysis [10].

The basic cause of death measure estimated was the CSMF, defined as the fraction of deaths in the population that is due to each cause. CSMFs were calculated for four broad age groups across which the composition of the leading causes of death was likely to change (0–4, 5–44, 45–64, 65+ years), and for each sex and each province. The four age groups were chosen because leading causes of death commonly vary between each age group; more detailed age groups could not be used because of the limited data available from VA.

Causes of death were first estimated for the five cause categories as defined by Gouda et al.: namely emerging infections, endemic infections, emerging NCDs, endemic NCDs, and injuries [16]. Table 1 lists the main specific causes included under each category. A more precise cause listing was not possible again because of the limited data available from VA.

Empirical cause method

In the empirical cause approach, we estimated CODs separately for facility and community deaths. Facility deaths are defined as those reported by the DHIS and

community deaths are defined as all other deaths. Thirty-eight thousand three hundred three DHIS deaths recorded from 2007 to 13 were used to calculate facility-based CSMFs. Deaths recorded in all these years were used due to the low numbers of deaths in some provinces, especially at older ages, in order to reduce random error. The most recent year of data available is 2013.

Community CSMFs were estimated for each province as follows. For each of the four sites with VA data, the ratio of community CSMFs (from VA) to DHIS-derived CSMFs was calculated, in log space, for each age group and sex. These ratios were then applied to the DHIS CSMFs in each of the provinces to estimate the community CSMFs by age and sex. This method assumes that the ratio of community CSMFs to DHIS CSMFs (within each age and sex group) is constant across provinces. Further detail about the method employed is presented in the Additional file 1.

Once community and DHIS CSMFs were calculated, CSMFs for all deaths by age, sex and province were calculated by weighting them by the proportion of all deaths that occurred within and outside facilities. The proportion of all deaths that occurred within and outside facilities was calculated, for each age, sex and province, as DHIS deaths divided by total deaths, based on the province-specific life tables calculated by Kitur et al. and provincial population data [10]. This method is described in detail in the Additional file 1.

Expected cause patterns method

The expected cause patterns approach uses data from the GBD 2017 study. The GBD data were used to develop linear regressions, for each of the four age groups, with outcome variable of the natural log of the ratio of each specific cause to a base cause (endemic NCDs) and covariates of the natural log of the probability of dying in that age group (using the all-cause mortality estimates of Kitur et al), calendar year and SDI [10]. This regression was developed for each sex and cause and these were used to predict CSMFs at the national level for PNG. Provincial-specific estimates were made based on regressions as above but excluding the SDI measure because there is no equivalent available for PNG's provinces. These CSMFs were then predicted for each province, age, sex and then scaled to the national level CSMFs in PNG. More details about this method can be found in the Additional file 1.

Ethics and data permission

We used aggregated cause of death (COD) data from a published PNGIMR study [16], publicly available Global Burden of Disease data and from the National Department of Health where the lead author works. Since these data sources contained aggregated data with no personal

identifiers and no risk to any individual, this was considered a low risk research that required no ethical approval. Verbal approval was granted from NDoH in 2016 to use the DHIS data.

Presentation of findings

The findings are presented in the main body of the text and the Additional file 1 for each broad age group, sex and province. The plausibility of CSMF estimates and patterns of geographical distribution were assessed by comparing provincial CSMFs to a composite index developed by Kitur et al. [10, 31] which measures provincial differences in socioeconomic development and health access. The composite index is derived from the arithmetic mean of education, economic, and health access indicators, with each indicator adjusted to be a normally distributed percentage with a mean of 50%. The education indicator measures net admission rate (percentage of children aged 6 years who are admitted into elementary prep school) and female literacy rate while the economic indicator is an average of poverty levels as assessed by the World Bank based on food and non-food expenditure and the proportion of people engaged in paid work activities from the 2011 census. The health access index was computed based on information about number of health workers per population and immunization rates from the 2011 Health Sector Performance Annual Review [34, 37, 38].

Results

National level cause specific mortality fractions (CSMFs)

In Table 2, the empirical cause method suggests a higher proportion of deaths from infectious diseases, maternal (females only), child health and conditions of poverty and a lower proportion from NCDs, compared with the expected cause patterns method, at all ages and in both males and females. Injury cause-fractions are higher in the empirical cause method at all ages except 5–44 years. More detailed information is provided in the Additional file 1: Table S1. These data show that there are more facility deaths from infections in children under 5 years than in the community and consistently higher injury deaths in the community.

Nationally, at all ages, more females (49%) die from infectious, maternal, neonatal and nutritional conditions (Groups 1 & 2) than males (41%). Conversely, slightly more males (45%) than females (42%) die from NCDs (Groups 3 & 4). Groups 1 & 2 CSMFs decline with age, and at ages 5–44 are 60% of female deaths, with emerging infections (Group 2) comprising 25%. NCDs, particularly emerging NCDs (Group 4), increase with age and account for 27% of male deaths and 30% of female deaths at ages 65+ years. Overall, endemic diseases (Groups 1 & 3) comprise over half of all deaths and

emerging diseases (Groups 2 & 4) just over one-quarter. At ages 45–64 years, emerging diseases comprise 36% of deaths in males (15% emerging infections, 21% emerging NCDs) and 40% of deaths in females (18% emerging infections, 22% emerging NCDs). Injury CSMFs at ages 5–44 years in males (28%) are more than double than in females (12%).

Provincial estimated cause fractions by sex

CSMF estimates for the different disease groups vary considerably by province (Table 3). We present results primarily for both sexes, but identify sex-specific differences of note. Additional file 1: Table S2 presents detail information on sex-specific mortality differences.

1. Endemic infections (malaria, pneumonia, diarrhoea), neonatal, nutritional and maternal

The proportion of deaths from endemic infectious, neonatal, nutritional and maternal causes (females only) are highest in Sandaun Province (43%), Gulf Province (41%), Milne Bay Province (MBP) (40%), East Sepik Province (ESP) (38%) and Morobe Province (37%). All these provinces have high levels of all-cause mortality as shown Additional file 1: Figure S1–S3.

2. Emerging infections (TB, HIV, cervical cancer)

CSMFs from emerging infections are highest in the highlands of Simbu Province (15%), Enga Province (14%), Southern Highlands Province (SHP/Hela 12%) and Eastern Highlands Province (EHP) (12%), in Morobe Province (14%) and Madang Province (13%) and the National Capital District (NCD). Apart from the National Capital District, all these provinces are linked by the Highlands highway and report the highest rates of sexually transmitted infections (STIs) in the country [39].

Table 3 Estimated CSMFs for both sexes (%), under-five mortality (per 1000 live births) by sex, life expectancy (years) by sex and composite index (%) by province and sex, PNG, 2011^a

Province	Endemic Infections	Emerging Infections	Endemic NCDs	Emerging NCDs	Injuries	Under 5 mortality per 1000		Life expectancy in years		Composite index (%)
						Male	Female	Male	Female	
Both sexes (%)										
PNG	32.7	11.7	28.1	15.6	10.8	68	58	62.0	64.3	50
National Capital District	25.2	12.8	30.0	23.0	9.4	34	23	67.0	70.3	95
East New Britain	34.9	10.4	27.6	16.9	9.6	65	56	62.2	63.9	75
New Ireland	33.9	8.7	31.1	16.0	9.3	62	48	63.8	65.9	60
Bougainville	35.8	9.8	27.4	14.4	11.5	54	43	62.4	67.2	60
Eastern Highlands	28.4	11.9	30.6	15.6	14.1	53	45	64.9	64.4	59
Morobe	36.9	13.9	26.6	13.0	10.1	84	71	59.7	61.0	59
Western Highlands/ Jiwaka ^b	23.6	10.6	35.2	18.6	12.4	40	33	65.9	68.7	58
Simbu	25.0	15.4	31.0	17.0	11.0	40	35	67.2	64.2	57
West New Britain	37.3	12.3	22.6	14.0	13.3	54	45	63.4	65.2	56
Milne Bay	40.4	8.8	28.0	14.0	8.7	78	64	61.5	65.4	51
Manus	35.5	6.8	31.5	17.5	8.1	83	75	62.6	64.4	50
East Sepik	38.3	9.8	25.4	13.0	13.9	100	79	58.8	62.6	49
Madang	37.2	13.3	25.6	12.7	10.8	78	69	60.2	62.4	48
Central	28.8	8.3	29.0	17.1	16.8	55	44	62.4	63.8	45
Oro	35.7	11.9	29.7	14.6	8.7	69	64	62.0	64.6	43
Western	36.2	9.4	29.4	13.6	11.3	64	57	61.8	67.2	41
Sandaun ^c	43.4	12.4	23.5	10.1	10.7	131	119	54.4	56.8	29
Southern Highlands /Hela ^b	34.8	12.4	28.6	13.0	10.9	70	59	59.6	65.4	28
Gulf	41.4	13.5	22.5	10.0	12.1	109	97	56.2	57.4	27
Enqa	25.0	13.6	29.1	14.8	17.4	69	66	60.7	62.0	25

^aThis table has been sorted by the composite index ranking (%), from the highest rank in level of socioeconomic development and health access (National Capital District) to the lowest rank (Enga Province). ^b These provinces were still united at the time of data collection. ^c Sandaun Province is also known as West Sepik Province

3. Endemic NCDs (chronic respiratory diseases, cancers, renal failure, liver cirrhosis)

A large proportion of deaths from endemic NCDs are from the central highlands provinces of WHP/Jiwaka (35%), Simbu Province (31%), and EHP (31%); Manus Province (32%) and New Ireland Province (NIP) (31%) and National Capital District (30%). The lowest proportions of deaths from endemic NCDs are found in Gulf Province and Sandaun Province, although there is relatively little variation amongst provinces in this cause.

4. Emerging NCDs (diabetes, stroke, ischaemic heart diseases, lung cancer)

Provinces with the highest cause fractions for emerging NCDs include National Capital District (23%) and Central Province (17%), WHP/Jiwaka (19%), Simbu Province (17%), and EHP (16%) and Manus Province (18%), ENBP (17%) and NIP (16%). The lowest CSMFs are found in Gulf Province and Sandaun Province, at approximately 10%. The proportion of deaths from emerging NCDs is positively related with a province's level of life expectancy. WHP/Jiwaka, Simbu Province, National Capital District, Manus Province and NIP report the highest rates of deaths from NCDs among males and females, at about 50% of deaths for males and slightly lower for females.

5. Injuries (homicide, falls, road traffic accidents, bites of venomous animals, fires, poisoning, suicide)

CSMFs for injury deaths are highest in Enga Province (17%), Central Province (17%), EHP (14%), ESP (14%) and West New Britain Province (WNBP) (13%). These provinces have also been found to have the highest rates of violence, road traffic accidents and falls [16, 43, 44].

Relationship of cause fractions with under five mortality and life expectancy

NCDs, especially emerging are higher in low mortality provinces and infections are higher in high mortality provinces. Table 3 shows great variation in mortality between provinces with the lowest (National Capital District, male 34/1000, female 23/1000) and highest (Sandaun Province male 131/1000, female 119/1000) level of child mortality estimates. In both sexes, there is a life expectancy gap of about 13 years between the province with the lowest levels (Sandaun Province; male 54.4 years, female 56.8 years) and the National Capital District (male 67.0 years, female 70.3 years), the province with the highest life expectancy in PNG.

Composite index

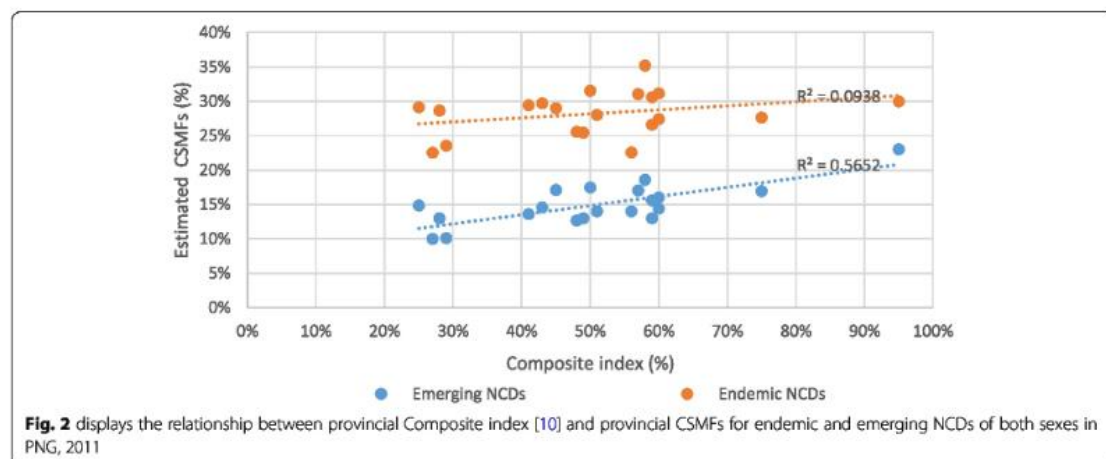
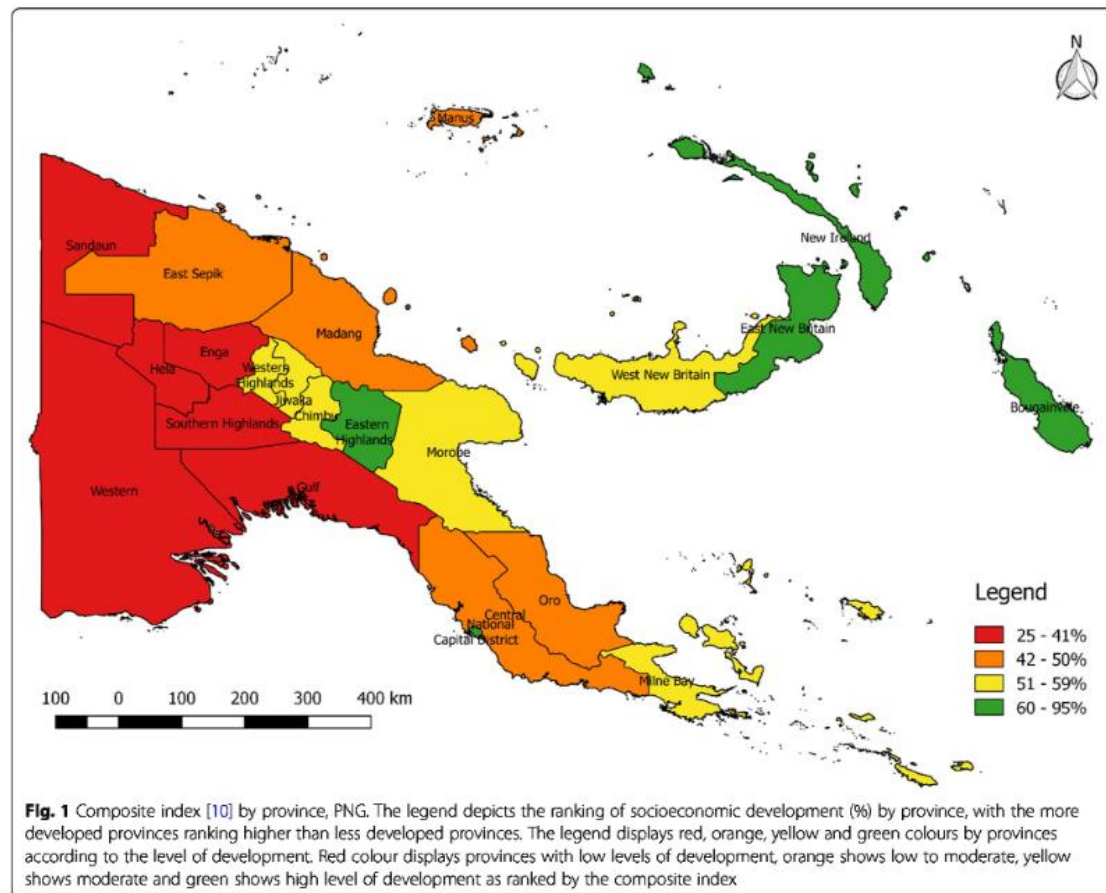
The level of socioeconomic development and health access varies significantly across PNG as shown in Table 3 and Fig. 1. Development is low in the western (Sandaun Province, Enga Province and Western Province) and southern (SHP/Hela, Gulf Province, Central Province and Oro Province) and comparatively high in the National Capital District and in East and West New Britain, NIP and Bougainville. It is moderate to high in the central highlands provinces of WHP/Jiwaka, Simbu Province and EHP, while in the north (Morobe Province, Madang Province and ESP) the composite index is low to moderate. More information is available in the Additional file 1: Table S3.

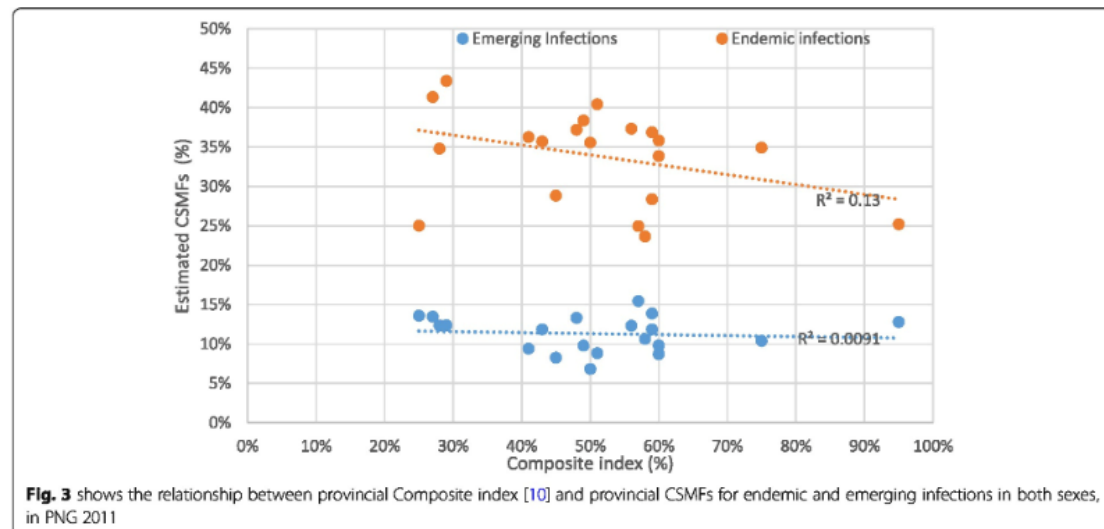
The provincial composite index correlates strongly with CSMFs for both sexes from emerging NCDs (Fig. 2), but less so with other causes (Figs. 2 and 3). There are no clear outliers among any provinces in the relationship between the composite index and emerging NCDs, with a reasonably strong r -squared of 0.57. The weakness of the relationship between the composite index and endemic NCDs ($r^2 = 0.09$), emerging infectious diseases ($r^2 = 0.01$), and endemic infectious diseases ($r^2 = 0.13$) is confirmed by their low r -squared.

Discussion

Our findings demonstrate that infectious, maternal (females only), neonatal and nutritional causes (Groups 1 & 2) are still an important cause of death in PNG, accounting for more than 50% of all deaths in some provinces. However, NCDs (Groups 3 & 4), especially emerging NCDs (Group 4), are particularly high in provinces with higher levels of socioeconomic development. These results demonstrate the challenge for public health policymakers in PNG in addressing the dual burden of infectious diseases and NCDs, particularly with significant mortality occurring due to emerging forms of each.

Our findings from this study show Groups 1 & 2, both in children and also adults and are much more important as a cause of death accounting for 41% of deaths in males and 49% of deaths in females. This is almost double what is reported by the GBD [35] (23% for males and 29% for females) and for other Melanesian countries [40, 41]. The GBD Study estimates lower infectious disease mortality for PNG due to the greater reliance on data from neighbouring countries such as Fiji, Tonga and Samoa, all Pacific countries with higher NCD mortality [35]. Our findings also show that more boys than girls under the age of five years die at health facilities which is not uncommon. This is well documented in the literature and is due both to boys' biological frailty and their higher accident mortality. For example, the UN (UNIGME, 2013) have estimated that for every 1000 live





births in 2012, there were 50 male deaths compared to 46 female deaths in children under 5 years globally [42]. According to the same report, there were 68 male deaths compared to only 58 female deaths per 1000 live births under the age of five in PNG, and is consistent with estimates published in an earlier article [10].

Endemic and emerging infectious diseases, maternal, neonatal & nutritional causes (groups 1 & 2)

Groups 1 & 2 still account for more deaths than deaths from NCDs in most provinces of PNG. Mortality from this broad group of causes are affected by geography and interprovincial movement and does not depend so much on socioeconomic development, as our findings show. The largest proportion of deaths from endemic infectious diseases and maternal causes (in females) occur in Sandaun Province, Gulf Province, ESP and Milne Bay Province; provinces that are relatively remote, report high malaria cases and have the highest all-cause mortality in PNG [10, 28]. Deaths from emerging infectious diseases are highest in Simbu Province, Enga Province, EHP, Morobe Province and Madang Province; provinces that are accessible by the Highlands highway and National Capital District. These provinces report the highest rates of sexually transmitted infections, including HIV and human papilloma virus (HPV) which are responsible for deaths from AIDS and cervical cancer in PNG [39]. High mortality from emerging infections can be directly linked to the epidemic of HIV, to synergism between TB and HIV, and cervical cancer to Human Papilloma Virus.

Endemic and emerging NCDs (groups 3 & 4)

Non-communicable diseases are becoming more prominent than infectious diseases, maternal and conditions of poverty globally [35], regionally [40, 41], and in some sections of the PNG population [16, 21]. Our findings demonstrate that evidence of more advanced epidemiological transition in PNG, measured both as the % of all deaths from but also in comparison to the level of infectious disease mortality, is related to higher socioeconomic status [23]. National Capital District, WHP/Jiwaka, Simbu Province, EHP, Manus Province and NIP have relatively higher life expectancy. Emerging NCDs, such as IHD, stroke and diabetes, are becoming particularly prominent in these provinces with higher socioeconomic development, demonstrating progress through the epidemiological transition and further supporting the claims by Gouda et al. [16] that the transition is not uniformly distributed across PNG. The three central Highlands provinces of WHP/Jiwaka, Simbu and EHP have experienced modernisation through small-scale commercial enterprise, fresh food and cash cropping, and through access to goods and services in Mt Hagen, Kundiawa and Goroka [43]. Port Moresby is a relatively developed city that is accessible by the majority of the population of Central Province (which also has high emerging NCD) who live in peri urban areas of the capital city. Furthermore, changes in lifestyle in Manus Province, NIP, ENBP, National Capital District and Central Province (particularly western parts) including high rates of cigarette smoking, inactivity and unhealthy diets are responsible for high rates of diabetes and coronary heart diseases in these provinces [21].

Males account for twice the burden of injuries as females, similar to what has been reported in Vanuatu [40]. Provinces with the highest burden of injuries are believed to have the highest rates of violence and road traffic accidents. Enga province, ESP and WNB have the highest rates of violence-related deaths in PNG [44], while EHP and Central Province record more deaths resulting from road traffic accidents [45]. Gouda et al. reported homicide as the major cause of injuries in the highlands (Asaro and Hides), while falls from buildings was largely responsible for the majority of deaths from injuries in the coastal areas (Hiri and Karkar) [16].

Limitations

There are a number of limitations in our study. Firstly, the empirical cause model was developed using VA and DHIS data from only four sites and applied to DHIS data throughout the country; the use of community cause data from only four sites was necessary due to the unavailability of other data. Hence, we also used the expected cause pattern model, to offset any implausible provincial level results. Secondly, the diagnostic accuracy of the DHIS data has yet to be established, however the use of five broad cause groups reduces any potential error from this issue. Thirdly, Port Moresby General Hospital could have included deaths from people travelling in from other provinces including Central and Gulf. Hence, deaths recorded under Port Moresby General Hospital could not exclude those residing outside of Port Moresby. The same could be said of other regional hospitals including Mt Hagen in WHP/Jiwaka and Angau in Morobe Province. Fourthly, our estimated cause fractions are not as specific as those produced by GBD and hence potentially less useful for policy. However, we were unable to reliably conclude what might have been the cause of death distribution at a more granular level from the available data. Nonetheless, understanding where various provinces might be on the path of epidemiological transition, and particularly the likely extent of emerging diseases as causes of death has, we believe, intrinsic policy value. Finally, we were also unable to estimate the level of uncertainty around our CSMF estimates in this study due to the unavailability of data. Based on a comparison with the GBD modelled estimates for PNG, our estimated CSMFs generally fell within 20% of these predicted estimates, which are themselves subject to significant uncertainty because of a lack of data in the country.

Conclusion

Our estimated cause-specific mortality fractions are the first such estimates to be based on empirical data for PNG and its provinces. While infectious diseases, maternal, neonatal and nutritional causes remain an important

cause of death in PNG; there is evidence of the emergence of NCDs as leading cause of death in the highlands provinces of WHP/Jiwaka and Simbu, islands provinces of NIP, ENBP and Manus and in National Capital District, consistent with their higher level of socioeconomic status. CSMFs from emerging infections are influenced by high rates of STIs in provinces that are linked by road while CSMFs from endemic infections are related to malaria endemicity in geographically isolated provinces. While socioeconomic development has been shown to explain epidemiological transition (emerging NCDs), geographical and cultural factors are also responsible contributors to CSMFs of the five broad disease categories in PNG. In a country where most deaths occur outside of health facilities, verbal autopsy appears to be the only option to reduce ignorance about the causes of home deaths. The introduction of VA into selected districts in PNG as part of a broader effort by the Bloomberg Data for Health Initiative to improve cause of death data offers some optimism that this critical data gap can be addressed cost-effectively over the next few years [46]. The estimated cause specific mortality fractions by disease group and by province in this study should provide valuable health intelligence and reduce persistent knowledge gaps about causes of death in PNG.

Supplementary information

Supplementary Information accompanies this paper at <https://doi.org/10.1186/s12889-019-7620-5>.

Additional file 1: Table S1. Estimated CSMFs (%) by age and sex, DHIS and community, PNG, 2011. **Table S2.** Estimated CSMFs (%) by province and sex, PNG, 2011. **Table S3.** Composite Index components by province, PNG. **Table S4.** Facility deaths as a percentage of all deaths, by province and sex, PNG, 2011. **Table S5.** Coefficients in the expected cause patterns method. **Figure S1.** Under-five mortality rate (per 1000 live births) by province, PNG, 2011 [10]. **Figure S2.** Male life expectancy by province, PNG, 2011 [10]. **Figure S3.** Female life expectancy by province, PNG, 2011 [10].

Abbreviations

COD: Cause of Death; CSMFs: Cause Specific Mortality Fraction; DHIS: Discharge Health Information System; eNHIS: Electronic National Health Information System; GBD: Global Burden of Disease Study; NCDs: Non-communicable diseases; NDoH: National Department of Health; NHIS: National Health Information System; PIHP: Partnership in Health Project; PNG: Papua New Guinea; VA: Verbal Autopsy

Acknowledgements

The authors wish to thank Hebe Gouda and PNGIMR for providing the verbal autopsy data and the National Department of Health for providing the DHIS data used in the analysis for this study.

Declarations

We declare that the content of this manuscript has not been published or submitted for publication elsewhere.

Authors' contributions

UK, TA, IR and ADL conceptualised the research theme and analytical framework. UK conducted the data analysis with advice from TA and UK was

responsible for drafting the manuscript. TA, IR and ADL critically revised the manuscript. All authors approved the final draft.

Funding

This research was conducted as part of Urarang Kitur's PhD, funded by the Australia Award Scholarship. The funder had no influence on the results.

Availability of data and materials

Request for data access should be directed to the corresponding author and will be granted subject to approval by the National Department of Health and Papua New Guinea Institute of Medical Research.

Ethics approval and consent to participate

Only secondary data were used so ethics considerations are not applicable. Data was sourced from a PNG Medical Research approved research project (MRAC # 11.41).

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Received: 11 May 2019 Accepted: 13 September 2019

Published online: 22 October 2019

References

- Naghavi M, Wang H, Lozano R, et al. Global, regional, and national age-sex specific all-cause and cause-specific mortality for 240 causes of death, 1990–2013: a systematic analysis for the global burden of disease study 2013. *Lancet*. 2014;385(9963):117–71.
- Wang H, Dwyer-Lindgren L, Lofgren KT, et al. Age-specific and sex-specific mortality in 187 countries, 1970–2010: a systematic analysis for the global burden of disease study 2010. *Lancet*. 2012;380(9859):2071–94.
- Mahapatra P, Shibuya K, Lopez A, et al. Civil registration systems and vital statistics: successes and missed opportunities. *Lancet*. 2007;370:1653–63.
- Abou Zhar C, de Savigny D, Mikkelsen L, et al. CRVS progress in data revolution for counting and accountability. *Lancet*. 2015;386:1373–85.
- Mikkelsen L, Phillips DE, Abou Zahr C, et al. Counting births and deaths 3: a global assessment of civil registration and vital statistics systems: monitoring data quality and progress. *Lancet*. 2015;386:1395–406.
- GBD 2015 SDG Collaborators. Measuring the health-related Sustainable Development Goals in 188 countries: a baseline analysis from the Global Burden of Disease Study 2015. *Lancet*. 2016;388:1813–50. Published Online September 21, 2016. [https://doi.org/10.1016/S0140-6736\(16\)31467-2](https://doi.org/10.1016/S0140-6736(16)31467-2).
- National Statistics Office (NSO). The National Population and Housing Census for Papua New Guinea for 2011. Port Moresby: NSO; 2011.
- McGehee M. Mortality. In: Siegel JS, Swanson DA, editors. *The Methods and Materials of Demography*. 2nd ed. San Diego: Elsevier Academic Press; 2004. p. 265–300.
- Montgomery J. Foundations for a successful CRVS eco-system in Papua New Guinea. Port Moresby: National Department of Health; 2017.
- Kitur U, Adair T, Lopez AD. Patterns of all-cause mortality in Papua New Guinea. *Asia Pac J Public Health*. <https://doi.org/10.1177/1010539519841492>.
- Scragg R. Depopulation in New Ireland. A Study of Demography and Fertility. MD Thesis. Port Moresby: University of Adelaide, Administration of Papua New Guinea; 1954.
- Riley ID. Demography and epidemiology of disease in Papua New Guinea. *PNG Med J*. 2009;52(3–4):83–95.
- Riley ID. Pneumonia research in Papua New Guinea: 1967–1986. *PNG Med J*. 2010;53(3–4):106–18.
- Gouda H, Lehmann D, Riley I. Measurement of cause of death in Papua New Guinea populations using locally developed verbal autopsy instrument: 1970–2001. Working Paper. 2013;36:1–45.
- PNGIMR. Papua New Guinea Institute of Medical Research Progress Report, Partnership in Health Project. https://www.researchgate.net/publication/269168896_PNG_Institute_of_Medical_Research_Partnership_in_Health_Project_Report_September_2014. Accessed March 12, 2019.
- Gouda H, Maraga S, Flaxman A, et al. The epidemiological transition in Papua New Guinea: new evidence from verbal autopsy studies. *Int J Epidemiol*. 2019;1:12. <https://doi.org/10.1093/ije/dyz018>.
- Naraqi S, Felling B, Leeder SR. Disease and death in Papua New Guinea. *Med J Aust*. 2003;178(1):7–8. <https://doi.org/10.5694/j.1326-5377.2003.tb05030.x>.
- Duke T, Edilson Y, Hutchinson A, et al. Large-scale data reporting of paediatric morbidity and mortality in developing countries: it can be done. *Arch Dis Child*. 2016;101:392–7.
- Beracochea E. Audit of death certificates. *PNG Med J*. 1995;38(3):191–7.
- CRVS country perspectives. Applying country experiences and knowledge November 2018 Fellowship report: An analysis of cause of death data from Papua New Guinea Fellowship Report. December 2017. University of Melbourne. <https://crvs.gatewayinfo/file/9785/2376>. Accessed February 23, 2019.
- Rarau P, Vengiau G, Gouda H, et al. Prevalence of non-communicable disease risk factors in three sites across Papua New Guinea: a cross-sectional study. *BMJ Global Health*. 2017:e00021. <https://doi.org/10.1136/bmjgh-2016-000221>.
- Global Burden of Disease Study (GBD). Global collaborators. Global, regional, and national age-sex specific mortality for 264 causes of death, 1980–2016: a systematic analysis for the global burden of disease study 2016. *Lancet*. 2016;390:1151–210.
- Mola G, Kirby B. Discrepancies between national maternal mortality data and international estimates: the experience of Papua New Guinea. *Reproductive Health Matters*. 2013;21:191–202. [https://doi.org/10.1016/S0968-8080\(13\)42725-8](https://doi.org/10.1016/S0968-8080(13)42725-8).
- Murray CJL, Lopez AD. World Health Organization, World Bank & Harvard School of Public Health. In: Murray CJL, Lopez AD, editors. *The Global burden of disease: a comprehensive assessment of mortality and disability from diseases, injuries, and risk factors in 1990 and projected to 2020: summary*. Geneva: World Health Organization; 1996. <http://www.who.int/iris/handle/10665/41864>.
- Morens DM, Fauci AS. Emerging infectious diseases: threats to human health and global stability. *PLoS Pathog*. 2013;9(7):e1003467. <https://doi.org/10.1371/journal.ppat.1003467>.
- Ley SD, Riley I, Beck HP. Tuberculosis in Papua New Guinea: from yesterday until today. *Microbes Infect*. 2014;16(8):607–14.
- Coghlan B, Milan J, Malau C, Kaldor J, Toole M. The HIV epidemic in Papua New Guinea. *J Acquir Immune Defic Syndr*. 2011;58(2):e48–51.
- Hetzel MW, Pulford J, Ura Y, et al. Insecticide-treated nets and malaria prevalence, Papua New Guinea, 2008–2014. *Bull World Health Organ*. 2017; 95:695–705.
- Anderson HR. Chronic lung disease in the Papua New Guinea highlands. *Thorax*. 1979;34:647–53. Retrieved from <https://thorax.bmj.com/content/thoraxjnl/34/5/647.full.pdf>.
- Martin W, Sengupta S, Murthy D, Barua D. The spectrum of cancer in Papua New Guinea: an analysis based on the cancer registry 1979–1988. *Cancer*. 1992;70(12):2942–50.
- Kitur U, Adair T, Lopez A. Estimating adult mortality in Papua New Guinea, 2011. *Popul Health Metr*. 2019;17:4. <https://doi.org/10.1186/s12963-019-0184-x>.
- National Department of Health. National Health Information System (NHIS) and Discharge Health Information System (DHIS). Port Moresby: National Department of Health; 2017.
- James SL, Flaxman AD, Murray CJL. Performance of the tariff method: validation of a simple additive algorithm for analysis of verbal autopsies. *Popul Health Metrics*. 2011;9:31. <http://www.pophealthmetrics.com/content/9/1/31>.
- National Research Institute. Papua New Guinea District and Provincial profiles. Port Moresby: National Research Institute; 2010.
- GBD 2017 Causes of Death Collaborators. Global, regional, and national age-sex-specific mortality for 282 causes of death in 195 countries and territories, 1980–2017: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet*. 2018;392:1736–88.
- GBD 2016. Risk Factors Collaborators. Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016. *Lancet*. 2017;390:1345–422.
- World Bank. Papua New Guinea: poverty assessment (English). Washington, DC: World Bank. Retrieved from <http://documents.worldbank.org/curated/en/500511468082129284/Papua-New-Guinea-poverty-assessment>. Accessed July 25, 2018.

38. National Department of Health (NDOH). Sector Performance Annual Review 2007-2011. Port Moresby: NDOH; 2011.
39. National Department of Health (NDOH). 2018 STI/HIV & AIDS program annual report. Port Moresby: National Department of Health; 2019.
40. Carter KL, Tovu V, Langati JT, et al. Causes of death in Vanuatu. *Popul Health Metrics*. 2016;14(7):1–9.
41. Carter KL, Cornelius M, Taylor R, et al. Mortality trends in Fiji. *Aust N Z J Public Health*. 2011;35(5):412–20.
42. United Nations Inter-agency Group for Child Mortality Estimation. Levels and Trends in Child Mortality, Report 2013. <https://childmortality.org/reports>. Accessed August 06, 2019.
43. Chang HSC, Mullen B, Anjen J, Be'Soer L. Assessing the socioeconomic impact of a rural market: The case of Mt Hagen Market in the Papua New Guinea Highlands. *Australasian Agribusiness Perspectives*, Paper 98, ISSN 1442-6951, 13th August 2014. Pp 1-20
44. The World Bank Group. The socioeconomic cost of crime and violence in Papua New Guinea. Trends in Crime and Violence in Papua New Guinea, 2014 www.worldbank/socialdevelopment. Accessed March 12, 2019.
45. Herman J, Ameratunga S, Jackson R. Burden of road traffic injuries and related risk factors in low and middle-income Pacific Island countries and territories: a systematic review of the scientific literature (TRIP 5). *BMC Public Health*. 2012;12:479. <https://doi.org/10.1186/1471-2458-12-479>.
46. Lopez AD, Setel PW. Better health intelligence: a new era for civil registration and vital statistics? *BMC Medicine*. 2015;13:73. <https://doi.org/10.1186/s12916-015-0333-4>.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Ready to submit your research? Choose BMC and benefit from:

- fast, convenient online submission
- thorough peer review by experienced researchers in your field
- rapid publication on acceptance
- support for research data, including large and complex data types
- gold Open Access which fosters wider collaboration and increased citations
- maximum visibility for your research: over 100M website views per year

At BMC, research is always in progress.

Learn more blomedcentral.com/submissions



Table 6.1 presents details of the ratios of VA to DHIS deaths by age, sex and cause from the VA sites used in the empirical cause method.

Table 6.1: Cause Ratios of VA and DHIS Mortality Data from VA Sites

Age Group (years)	VA		DHIS		Ratio	
	Female (%)	Male (%)	Female (%)	Male (%)	Female (%)	Male (%)
< 5						
Endemic and emerging infections	81	70	94	94	-1.332	-1.829
Endemic and emerging NCDs + injuries	19	30	6	6	Base cause	Base cause
5–44						
Endemic infections	25	18	44	35	-1.792	-1.533
Emerging infections	24	18	32	33	-1.525	-1.467
Endemic NCDs	27	19	19	20	-0.864	-0.914
Emerging NCDs	13	22	2	3	0.690	1.103
Injuries	12	23	4	10	Base cause	Base cause
45–64						
Endemic infections	16	18	27	26	-2.387	-1.707
Emerging infections	17	17	20	25	-2.060	-1.687
Endemic NCDs	36	31	40	33	-1.980	-1.428
Emerging NCDs	22	22	12	13	-1.264	-0.846
Injuries	9	12	1	3	Base cause	Base cause
65+						
Endemic infections	17	17	24	23	-2.147	-1.966
Emerging infections	5	5	13	19	-2.845	-3.081
Endemic NCDs	43	41	45	38	-1.844	-1.595
Emerging NCDs	26	26	18	17	-1.464	-1.263
Injuries	10	12	1	2	Base cause	Base cause

Note: VA: verbal autopsy; DHIS: Discharge Health Information System; NCD: non-communicable disease.

Table 6.2 shows the estimated percentage of deaths in facilities and the community by age, sex and province derived from the maximum deaths from facilities and estimated total deaths from ASDRs (Chapter 5) multiplied by the population. These were used in the empirical cause method.

Table 6.2: Estimated Annual Deaths and Maximum Annual DHIS Deaths with Proportion Of Facility And Community Deaths By Age, Sex And Province (2011)

Province	Age (Years)	Estimated Annual Deaths		Max. Annual DHIS (Facility) Deaths		% Facility Deaths		% Community Deaths	
		Female	Male	Female	Male	Female	Male	Female	Male
Western	< 5	184	152	40	46	22	30	78	70
	5–44	190	126	86	63	45	50	55	50
	45–64	160	88	25	48	16	54	84	46
	65+	163	126	12	11	7	9	93	91
Gulf	< 5	237	197	32	38	13	19	87	81
	5–44	213	236	41	39	19	17	81	83
	45–64	158	112	18	27	11	24	89	76
	65+	131	113	3	6	2	5	98	95
Central	< 5	194	145	32	45	16	31	84	69
	5–44	248	260	50	57	20	22	80	78
	45–64	271	205	24	31	9	15	91	85
	65+	373	290	7	9	2	3	98	97
National Capital District	< 5	126	76	62	60	49	80	51	20
	5–44	248	201	163	118	66	59	34	41
	45–64	286	154	85	111	30	72	70	28
	65+	220	143	22	32	10	22	90	78
Milne Bay	< 5	304	215	77	90	25	42	75	58
	5–44	254	207	98	95	39	46	61	54
	45–64	268	169	70	82	26	48	74	52
	65+	330	246	35	46	11	19	89	81
Oro	< 5	189	166	70	73	37	44	63	56
	5–44	171	151	70	73	41	48	59	52
	45–64	175	108	32	41	18	38	82	62
	65+	220	145	11	16	5	11	95	89
Southern Highlands	< 5	230	198	161	159	70	80	30	20
	5–44	949	669	127	115	13	17	87	83
	45–64	1,055	512	49	72	5	14	95	86
	65+	992	432	8	23	1	5	99	95
Enga	< 5	124	125	87	100	70	80	30	20
	5–44	490	537	118	95	24	18	76	82
	45–64	538	359	56	73	10	20	90	80
	65+	564	283	9	24	2%	8	98	92
Western Highlands	< 5	144	122	101	98	70	80	30	20
	5–44	501	486	351	208	70	43	30	57
	45–64	702	453	91	126	13	28	87	72
	65+	872	486	27	28	3	6	97	94
Simbu	< 5	67	64	47	51	70	80	30	20
	5–44	232	419	97	130	42	31	58	69
	45–64	375	362	71	94	19	26	81	74
	65+	498	301	12	27	2%	9	98	91
Eastern Highlands	< 5	197	170	143	191	70	80	30	20
	5–44	432	583	197	181	46	31	54	69
	45–64	551	467	87	107	16	23	84	77

Province	Age (Years)	Estimated Annual Deaths		Max. Annual DHIS (Facility) Deaths		% Facility Deaths		% Community Deaths	
		Female	Male	Female	Male	Female	Male	Female	Male
	65+	660	449	22	28	3	6	97	94
Morobe	< 5	572	470	188	248	33	53	67	47
	5–44	759	825	272	318	36	39	64	61
	45–64	707	543	126	180	18	33	82	67
	65+	731	562	23	36	3	6	97	94
Madang	< 5	459	386	165	176	36	46	64	54
	5–44	528	509	151	176	29	35	71	65
	45–64	457	300	91	117	20	39	80	61
	65+	472	311	28	39	6	13	94	87
East Sepik	< 5	525	400	123	151	23	38	77	62
	5–44	476	439	148	128	31	29	69	71
	45–64	412	307	86	85	21	28	79	72
	65+	554	453	25	27	5	6	95	94
Sandaun	< 5	485	402	64	92	13	23	87	77
	5–44	360	350	92	80	26	23	74	77
	45–64	279	206	50	58	18	28	82	72
	65+	244	192	12	12	5	6	95	94
Manus	< 5	66	52	18	24	27	46	73	54
	5–44	47	47	18	16	38	34	62	66
	45–64	50	41	20	25	40	61	60	39
	65+	69	57	8	12	12	21	88	79
New Ireland	< 5	150	103	64	57	43	55	57	45
	5–44	150	143	68	58	45	40	55	60
	45–64	159	108	46	68	29	63	71	37
	65+	208	143	25	35	12	24	88	76
East New Britain	< 5	275	223	97	119	35	53	65	47
	5–44	281	307	106	120	38	39	62	61
	45–64	303	224	66	114	22	51	78	49
	65+	342	281	25	36	7	13	93	87
West New Britain	< 5	200	151	104	113	52	75	48	25
	5–44	228	227	107	136	47	60	53	40
	45–64	220	150	51	71	23	47	77	53
	65+	265	182	14	27	5	15	95	85
Bougainville	< 5	176	134	68	77	39	58	61	42
	5–44	222	172	79	69	36	40	64	60
	45–64	242	145	44	53	18	37	82	63
	65+	280	188	12	15	4	8	96	92
Papua New Guinea	< 5	4,906	3,951	2,023	2,357	41	60	59	40
	5–44	6,977	6,894	2,467	2,275	35	33	65	67
	45–64	7,369	5,013	1,188	1,583	16	32	84	68
	65+	8,187	5,383	340	489	4	9	96	91

Note: DHIS = Discharge Health Information System

Table 6.3 shows CSMFs of facility and community deaths by age, sex and province, which were used in the empirical cause method.

The final CSMFs by age, sex and cause estimated by the empirical cause method are shown in Table 6.4. These were derived from the percentage of deaths estimated to occur in facilities and the community (Table 6.2) and facility and community CSMFs (Table 6.3).

Table 6.5. presents the CSMF estimates by age, sex and province according to the expected cause patterns method.

Table 6.6 shows the final CSMFs for PNG by age, sex and province calculated using the empirical cause and expected cause pattern methods.

Table 6.7 presents how undetermined VA deaths were redistributed to specific causes, based on the methods and assumptions reported in the paper.

Table 6.3: CSMFs of Facility and Community Deaths by Age, Sex and Province

Province	Age	Female										Male									
		DHIS (Facility) CSMFs (%)					Estimated Community CSMFs (%)					DHIS (Facility) CSMFs (%)					Estimated Community CSMFs (%)				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Western	< 5	91	–	6	–	3	73	–	24	–	3	90	–	8	–	2	60	–	30	–	10
	5–44	42	24	26	1	8	21	16	34	5	23	33	25	30	3	9	17	13	28	20	21
	45–64	24	27	38	9	2	15	23	35	17	10	34	19	35	8	5	24	14	32	13	18
	65+	32	12	43	11	2	23	4	42	16	14	31	14	41	11	3	23	4	44	16	13
Gulf	< 5	93	–	5	–	2	77	–	21	–	3	93	–	5	–	2	70	–	23	–	8
	5–44	58	18	17	1	7	33	13	24	8	23	34	39	12	1	14	19	24	12	8	36
	45–64	32	26	36	3	4	18	21	31	5	25	32	26	36	3	4	24	20	35	5	16
	65+	32	12	43	11	2	23	4	42	16	14	31	14	41	11	3	23	4	44	16	13
Central	< 5	87	–	9	–	4	64	–	32	–	4	93	–	6	–	2	67	–	24	–	9
	5–44	48	19	17	1	14	23	12	20	6	40	34	15	14	3	34	12	6	9	17	56
	45–64	47	19	25	6	3	29	16	23	12	21	32	14	29	11	14	17	8	21	14	41
	65+	32	12	43	11	2	23	4	42	16	14	31	14	41	11	3	23	4	44	16	13
National Capital District	< 5	91	–	6	–	3	73	–	24	–	3	90	–	8	–	2	60	–	30	–	10
	5–44	38	36	20	3	4	20	25	27	17	11	31	38	19	5	8	14	19	16	35	16
	45–64	25	16	35	24	1	14	12	29	41	4	20	25	31	23	2	13	17	28	36	6
	65+	20	11	35	32	1	14	4	33	43	7	16	16	39	28	1	11	4	39	40	6
Milne Bay	< 5	91	–	6	–	3	73	–	24	–	3	95	–	4	–	1	75	–	19	–	7
	5–44	60	19	15	1	4	37	15	24	9	15	55	17	17	1	11	33	11	19	7	30
	45–64	41	20	32	4	2	27	18	31	9	15	32	23	36	8	2	25	18	36	14	7
	65+	43	8	38	10	1	34	3	40	15	8	43	8	38	10	1	33	2	43	15	7
Oro	< 5	90	–	7	–	3	70	–	27	–	4	92	–	6	–	2	65	–	26	–	9
	5–44	44	29	19	3	5	23	20	25	16	15	35	30	27	2	6	21	19	29	14	17

Province	Age	Female										Male									
		DHIS (Facility) CSMFs (%)					Estimated Community CSMFs (%)					DHIS (Facility) CSMFs (%)					Estimated Community CSMFs (%)				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
	45–64	26	27	36	9	2	16	22	33	17	12	24	32	34	9	1	19	26	35	17	3
	65+	26	17	45	10	1	20	7	49	16	8	26	17	45	10	1	20	4	52	17	7
Southern Highlands	< 5	97	–	2	–	1	88	–	10	–	1	97	–	3	–	1	82	–	13	–	5
	5–44	70	16	10	1	3	48	14	18	7	1	57	22	14	0	6	41	16	19	3	21
	45–64	50	16	32	1	1	37	17	36	2	8	45	18	32	3	1	37	15	35	7	6
	65+	49	15	33	2	2	41	6	37	3	13	49	15	33	2	2	42	4	40	3	11
Enga	< 5	96	–	3	–	1	87	–	12	–	3	96	–	3	–	1	79	–	16	–	5
	5–44	46	34	13	2	5	26	25	19	11	18	36	29	18	1	15	19	16	18	10	37
	45–64	32	13	51	1	3	19	11	47	2	21	25	23	40	6	6	17	16	36	10	22
	65+	10	14	62	5	10	5	4	44	5	43	27	12	41	12	7	16	2	36	15	31
Western Highlands	< 5	96	–	3	–	1	87	–	11	–	2	96	–	3	–	1	80	–	15	–	5
	5–44	48	27	16	1	6	27	20	23	9	22	35	30	21	3	11	18	16	20	20	25
	45–64	30	17	42	9	2	18	14	38	17	13	27	22	39	8	5	19	15	36	13	17
	65+	24	7	56	10	3	16	2	51	14	17	29	15	45	8	2	22	4	50	13	11
Simbu	< 5	96	–	3	–	1	86	–	12	–	2	95	–	4	–	1	77	–	17	–	6
	5–44	43	38	17	1	2	27	31	27	8	6	37	39	16	2	7	23	26	18	13	20
	45–64	33	33	30	4	0	24	33	32	8	3	30	27	35	5	2	23	21	35	9	10
	65+	35	12	41	8	4	24	4	37	10	25	35	12	41	8	4	24	3	41	11	22
Eastern Highlands	< 5	96	–	3	–	1	87	–	12	–	2	93	–	5	–	1	69	–	23	–	8
	5–44	52	24	20	1	3	31	19	30	10	11	40	29	19	2	11	22	17	19	14	27
	45–64	32	19	42	3	4	18	15	36	5	25	33	20	35	5	7	22	14	31	8	25
	65+	33	16	41	5	4	23	5	38	7	26	33	16	41	5	4	24	4	42	8	23
Morobe	< 5	97	–	2	–	1	88	–	10	–	1	97	–	2	–	1	83	–	13	–	4
	5–44	52	28	15	2	4	30	21	21	15	13	42	30	16	1	11	25	19	18	8	30
	45–64	33	24	35	6	2	21	22	34	12	11	34	23	32	7	4	25	17	31	12	14

Province	Age	Female										Male									
		DHIS (Facility) CSMFs (%)					Estimated Community CSMFs (%)					DHIS (Facility) CSMFs (%)					Estimated Community CSMFs (%)				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
	65+	36	17	40	5	2	29	7	43	8	12	29	18	47	5	1	24	5	57	9	5
Madang	< 5	95	–	4	–	1	83	–	15	–	2	95	–	4	–	1	74	–	19	–	7
	5–44	47	33	14	1	4	28	25	22	10	15	37	31	19	2	11	20	18	19	16	27
	45–64	30	25	40	4	2	19	22	39	8	11	31	28	30	8	3	23	22	30	14	12
	65+	37	13	42	6	2	28	5	45	9	13	24	25	37	13	2	19	6	42	21	12
East Sepik	< 5	95	–	4	–	1	83	–	15	–	2	95	–	4	–	1	75	–	18	–	7
	5–44	58	19	15	0	8	34	15	22	2	27	43	17	16	2	23	19	8	13	13	47
	45–64	35	21	38	5	1	24	20	40	10	7	33	20	33	6	7	22	14	29	10	25
	65+	35	11	39	10	5	22	4	34	13	27	35	11	39	10	5	23	2	37	13	24
Sandaun	< 5	94	–	4	–	2	80	–	18	–	2	93	–	6	–	2	67	–	25	–	9
	5–44	51	24	20	1	4	30	18	29	7	15	47	19	18	2	13	24	11	17	17	31
	45–64	27	28	36	4	5	14	21	29	7	29	30	29	31	5	5	22	21	30	8	19
	65+	32	9	49	9	2	23	3	48	12	13	32	9	49	9	2	23	2	51	12	11
Manus	< 5	89	–	8	–	3	67	–	29	–	4	92	–	6	–	2	65	–	26	–	9
	5–44	50	24	18	6	2	24	15	21	34	7	41	9	43	5	2	19	4	37	35	4
	45–64	19	11	53	15	1	11	9	45	27	9	33	11	40	13	3	23	8	37	22	10
	65+	27	4	53	13	3	18	1	47	17	16	27	4	53	13	3	18	1	51	17	13
New Ireland	< 5	92	–	5	–	2	76	–	21	–	3	95	–	4	–	1	75	–	19	–	7
	5–44	56	18	18	2	5	31	13	26	12	18	42	16	25	2	16	20	8	22	16	34
	45–64	26	19	40	14	2	15	15	34	24	13	24	18	43	12	3	16	13	39	19	12
	65+	28	12	49	10	1	22	5	53	15	5	28	12	49	10	1	22	3	56	15	4
East New Britain	< 5	89	–	8	–	3	67	–	29	–	4	85	–	11	–	3	48	–	39	–	14
	5–44	52	21	18	6	2	25	13	22	33	7	42	26	23	3	6	23	15	23	25	15
	45–64	35	20	30	12	4	19	15	24	20	21	36	21	29	11	4	25	15	27	18	15
	65+	38	10	39	11	2	28	4	40	17	12	38	10	39	11	2	28	2	42	17	10

Province	Age	Female										Male									
		DHIS (Facility) CSMFs (%)					Estimated Community CSMFs (%)					DHIS (Facility) CSMFs (%)					Estimated Community CSMFs (%)				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
West New Britain	< 5	98	–	2	–	1	91	–	8	–	1	94	–	5	–	1	72	–	21	–	7
	5–44	55	25	13	2	5	31	19	18	14	18	45	32	9	4	11	23	17	9	26	25
	45–64	40	26	24	9	2	25	22	23	16	14	40	28	21	5	5	29	21	20	9	21
	65+	38	21	25	8	7	24	7	21	10	38	38	21	25	8	7	26	5	24	11	34
Bougainville	< 5	90	–	7	–	3	71	–	25	–	3	92	–	6	–	2	66	–	25	–	9
	5–44	56	21	18	2	3	33	16	27	13	11	45	21	16	1	17	24	12	16	7	41
	45–64	49	18	21	9	2	31	16	20	18	15	45	19	23	9	4	33	14	22	16	15
	65+	43	13	37	6	2	34	5	40	9	13	43	13	37	6	2	34	3	43	9	11
PNG	< 5	95	–	4	–	1	83	–	15	–	2	95	–	4	–	1	73	–	20	–	7
	5–44	50	27	17	2	5	29	20	24	12	16	40	28	18	2	11	21	16	18	17	28
	45–64	32	21	37	8	2	20	18	34	15	13	31	23	33	9	4	22	17	31	15	15
	65+	32	12	43	11	2	23	4	42	16	14	31	14	41	11	3	23	4	44	16	13

Note: DHIS: Discharge Health Information System; CSMF: cause-specific mortality fractions; 1 = endemic infectious diseases and maternal, neonatal, nutritional and poverty-related conditions; 2 = emerging infectious diseases; 3 = endemic non-communicable diseases (NCDs); 4 = emerging NCDs; 5 = injuries. For the age group < 5 years, all infections and NCDs were combined. These were calculated from the cause ratio for this age group of all infections versus all other causes. The resultant CSMFs for NCDs and injuries were split into these two categories using Global Burden of Disease expected cause pattern CSMFs for this age group (e.g. NCDs/(injuries + NCDs)).

Table 6.4: Final Empirical Cause-Specific Mortality Fractions by Age, Sex and Province

Province	Age	Male					Female					Province	Age	Male					Female				
		1	2	3	4	5	1	2	3	4	5			1	2	3	4	5	1	2	3	4	5
Papua New Guinea	< 5	86	–	10	–	4	88	–	11	–	2	Eastern Highlands	< 5	88	–	9	–	3	93	–	5	–	1
	5–44	27	20	18	12	22	36	22	21	8	12		5–44	28	21	19	10	22	41	21	25	6	7
	45–64	25	13	19	32	11	22	19	34	14	11		45–64	24	8	15	32	21	20	16	37	5	22
	65+	24	5	43	16	12	24	5	42	16	14		65+	24	5	42	8	22	23	6	38	7	26
Western	< 5	69	–	23	–	8	77	–	20	–	3	Morobe	< 5	90	–	7	–	2	91	–	8	–	1
	5–44	25	19	29	12	15	31	20	30	3	16		5–44	31	23	17	6	23	38	24	19	10	9
	45–64	29	10	16	34	11	16	24	35	16	9		45–64	28	11	19	31	11	23	22	34	11	9
	65+	24	4	43	16	12	24	5	42	16	13		65+	25	6	56	9	5	30	7	43	8	12
Gulf	< 5	74	–	19	–	4	79	–	19	–	3	Madang	< 5	83	–	12	–	4	87	–	11	–	2
	5–44	22	26	12	7	21	38	14	22	6	20		5–44	26	23	19	11	22	33	27	20	7	12
	45–64	26	5	21	35	4	20	21	31	5	23		45–64	26	11	24	30	8	21	23	39	7	9
	65+	24	4	43	16	6	23	5	42	16	14		65+	19	9	41	20	11	29	6	44	9	12
Central	< 5	75	–	19	–	6	68	–	28	–	4	East Sepik	< 5	83	–	13	–	4	86	–	12	–	2
	5–44	17	8	10	14	51	28	13	20	5	35		5–44	26	11	14	10	40	38	24	19	10	9
	45–64	20	13	9	22	37	30	16	23	11	19		45–64	25	9	16	31	20	26	20	39	9	5
	65+	24	4	43	16	13	23	5	42	16	14		65+	24	3	38	13	23	23	4	34	13	26
National Capital District	< 5	84	–	12	–	4	82	–	15	–	3	Sandaun	< 5	73	–	20	–	7	82	–	16	–	2
	5–44	24	30	18	18	11	32	32	22	8	6		5–44	29	13	17	14	27	35	20	27	6	12
	45–64	18	26	23	30	3	17	13	31	36	3		45–64	24	7	23	30	15	17	22	30	6	25
	65+	12	6	39	37	5	14	5	33	42	6		65+	24	2	51	12	10	24	3	48	12	13
Milne Bay	< 5	83	–	13	–	4	78	–	19	–	3	Manus	< 5	78	–	17	–	6	73	–	23	–	4
	5–44	43	14	18	4	21	46	17	20	6	11		5–44	27	6	39	25	3	34	18	20	23	5
	45–64	29	11	20	36	4	31	19	32	7	12		45–64	29	17	9	39	6	14	10	48	22	6
	65+	35	3	42	14	6	35	4	40	14	7		65+	20	2	51	16	11	19	2	48	16	15

Province	Age	Male					Female					Province	Age	Male					Female				
		1	2	3	4	5	1	2	3	4	5			1	2	3	4	5	1	2	3	4	5
Oro	< 5	77	–	17	–	6	77	–	19	–	3	New Ireland	< 5	86	–	11	–	4	83	–	14	–	3
	5–44	28	24	28	8	12	32	24	23	11	11		5–44	29	11	23	10	27	43	16	22	7	12
	45–64	21	14	28	35	2	17	23	33	16	10		45–64	21	14	16	42	7	18	16	36	21	10
	65+	21	6	51	16	6	21	7	48	16	8		65+	24	5	54	14	3	23	6	52	15	5
Southern Highlands	< 5	94	–	5	–	1	94	–	5	–	1	East New Britain	< 5	68	–	24	–	8	75	–	21	–	4
	5–44	44	17	18	3	19	51	14	17	6	12		5–44	30	19	23	16	11	35	16	21	23	5
	45–64	38	6	15	35	5	38	17	36	2	8		45–64	31	14	18	28	9	23	16	25	18	18
	65+	42	5	40	3	11	41	6	37	3	13		65+	29	3	42	16	9	29	4	40	16	11
Enga	< 5	93	–	6	–	2	93	–	5	–	2	West New Britain	< 5	88	–	9	–	3	94	–	5	–	1
	5–44	22	18	18	9	33	31	27	18	9	15		5–44	36	26	9	13	16	42	22	16	9	12
	45–64	19	9	17	37	18	21	11	47	2	19		45–64	34	7	24	21	14	28	23	23	14	12
	65+	17	3	36	14	29	5	4	44	5	42%		65+	27	7	24	11	30	25	7	21	10	37
Western Highlands	< 5	93	–	5	–	2	93	–	5	–	1	Bougainville	< 5	81	–	14	–	5	78	–	18	–	3
	5–44	25	22	21	13	19	42	25	18	3	11		5–44	33	16	16	5	31	41	18	24	9	9
	45–64	21	11	17	37	14	20	14	39	16	11		45–64	37	14	16	22	11	35	16	20	17	1
	65+	22	5	50	12	11	16	3	51	14	17		65+	35	4	42	9	10	34	5	40	9	12
Simbu	< 5	92	–	6	–	2	93	–	6	–	1		< 5	92	–	6	–	2	93	–	6	–	1
	5–44	27	30	18	9	16	33%	34	23	5	4		5–44	27	30	18	9	16	33%	34	23	5	4
	45–64	25	8	23	35	8	25	33	32	7	3		45–64	25	8	23	35	8	25	33	32	7	3
	65+	25	4	41	10	20	24	4	37	10	25		65+	25	4	41	10	20	24	4	37	10	25

Note: 1 = endemic infectious diseases and maternal, neonatal, nutritional and poverty-related conditions; 2 = emerging infectious diseases; 3 = endemic non-communicable diseases (NCDs); 4 = emerging NCDs; 5 = injuries. Within each age group, rows add to 100%.

Table 6.5: Expected Cause Pattern Cause-Specific Mortality Fractions Estimates by Age, Sex and Province

Province	Age	Male (%)					Female (%)					Province	Age	Male (%)					Female (%)				
		1	2	3	4	5	1	2	3	4	5			1	2	3	4	5	1	2	3	4	5
Papua New Guinea	< 5	81	2	12	0	5	80	3	13	0	4	Eastern Highlands	< 5	79	2	14	0	5	78	2	15	0	5
	5–44	20	13	24	8	35	33	27	22	6	13		5–44	16	9	27	9	38	34	28	21	6	12
	45–64	12	11	36	30	11	14	17	35	30	5		45–64	11	8	38	32	11	15	18	33	29	5
	65+	12	5	39	39	5	12	5	36	44	3		65+	12	4	40	39	5	12	5	36	44	3
Western	< 5	80	2	12	0	5	80	3	13	0	4	Morobe	< 5	82	3	11	0	4	81	3	11	0	4
	5–44	20	13	24	8	35	27	21	28	8	16		5–44	23	16	22	7	32	37	31	17	5	10
	45–64	13	12	35	29	11	10	13	40	31	5		45–64	13	13	34	29	11	16	20	31	28	5
	65+	12	5	39	39	5	11	4	37	44	3		65+	12	5	39	39	5	12	6	35	44	3
Gulf	< 5	84	3	9	0	4	83	4	9	0	3	Madang	< 5	82	3	11	0	4	81	3	12	0	4
	5–44	26	22	19	6	28	39	34	14	4	8		5–44	22	16	22	7	32	33	27	21	6	12
	45–64	15	16	32	27	10	17	22	29	27	4		45–64	13	13	34	29	10	14	17	35	30	5
	65+	13	6	38	38	5	13	6	35	44	3		65+	12	5	39	39	5	12	5	36	44	3
Central	< 5	81	2	11	0	5	80	3	12	0	4	East Sepik	< 5	83	3	9	0	4	82	3	11	0	4
	5–44	19	12	25	8	35	33	27	22	6	13		5–44	23	17	22	7	31	34	28	21	6	12
	45–64	12	11	35	30	11	16	19	32	28	5		45–64	13	13	35	29	11	14	17	35	30	5
	65+	8	1	46	40	4	9	3	41	44	3		65+	12	5	39	39	5	12	5	36	44	3
National Capital District	< 5	75	1	18	0	6	71	1	21	0	6	Sandaun	< 5	84	4	8	0	4	84	5	8	0	3
	5–44	14	7	29	10	40	24	18	32	9	18		5–44	27	23	18	5	26	39	34	15	4	9
	45–64	10	7	39	33	11	10	13	40	31	5		45–64	15	17	32	27	10	16	20	31	28	5
	65+	12	4	40	39	5	11	4	38	44	3		65+	13	6	39	38	5	12	6	35	44	3
Milne Bay	< 5	82	3	11	0	4	81	3	11	0	4	Manus	< 5	82	3	11	0	4	82	3	11	0	4
	5–44	20	13	24	8	34	30	24	25	7	14		5–44	18	11	26	9	37	31	25	24	7	14
	45–64	12	11	36	30	11	12	14	38	31	5		45–64	11	8	38	32	11	12	15	38	30	5
	65+	12	5	40	39	5	11	5	37	44	3		65+	12	4	41	39	5	11	5	37	44	3

Province	Age	Male (%)					Female (%)					Province	Age	Male (%)					Female (%)				
		1	2	3	4	5	1	2	3	4	5			1	2	3	4	5	1	2	3	4	5
Oro	< 5	81	2	12	0	5	81	3	12	0	4	New Ireland	< 5	80	2	13	0	5	79	2	14	0	5
	5–44	20	13	24	8	35	31	26	23	7	13		5–44	18	11	26	9	37	31	25	24	7	14
	45–64	1	11	36	30	11	13	16	37	30	5		45–64	11	9	37	32	11	13	16	37	30	5
	65+	12	5	39	39	5	12	5	36	44	3		65+	12	4	40	39	5	12	5	36	44	3
Southern Highlands	< 5	81	2	12	0	5	80	3	13	0	4	East New Britain	< 5	81	2	12	0	5	80	3	13	0	4
	5–44	24	18	21	6	3	30	25	24	7	14		5–44	20	13	24	8	35	34	28	21	6	12
	45–64	15	16	32	27	10	12	15	37	30	5		45–64	12	11	36	30	11	14	18	34	29	5
	65+	13	6	38	38	5	11	5	37	44	3		65+	12	5	39	39	5	12	5	36	44	3
Enga	< 5	81	2	12	0	5	81	3	12	0	4	West New Britain	< 5	79	2	14	0	5	78	2	15	0	5
	5–44	22	16	22	7	32	36	30	18	5	11		5–44	19	12	25	8	36	32	26	22	6	13
	45–64	14	14	34	28	10	15	19	32	28	5		45–64	12	11	36	30	11	14	17	35	29	5
	65+	13	6	39	38	5	12	5	35	44	3		65+	12	5	39	39	5	12	5	36	44	3
Western Highlands	< 5	76	2	16	0	6	75	2	18	0	5	Bougainville	< 5	79	2	14	0	5	78	2	15	0	5
	5–44	15	8	28	10	39	26	21	29	8	16		5–44	20	14	24	8	34	29	23	26	7	15
	45–64	11	8	38	32	11	11	13	39	31	5		45–64	13	13	34	29	11	12	14	38	31	5
	65+	12	5	40	39	5	11	5	37	44	3		65+	13	5	39	39	5	11	5	37	44	3
Simbu	< 5	76	2	16	0	6	76	2	17	0	5		< 5	76	2	16	0	6	76	2	17	0	5
	5–44	13	7	29	10	41	35	29	19	6	11		5–44	13	7	29	10	41	35	29	19	6	11
	45–64	9	6	39	33	11	16	20	31	28	5		45–64	9	6	39	33	11	16	20	31	28	5
	65+	12	4	41	39	5	12	5	36	44	3		65+	12	4	41	39	5	12	5	36	44	3

Note: 1 = endemic infectious diseases and maternal, neonatal, nutritional and poverty-related conditions; 2 = emerging infectious diseases; 3 = endemic non-communicable diseases (NCDs); 4 = emerging NCDs; 5 = injuries. Within each age group, rows add to 100%.

Table 6.6: Final CSMFs (%) Based on Average Empirical and Expected Cause Patterns by Age, Sex and Province, 2011

Province	Male																			
	< 5 years					5–44 years					45–64 years					65+ years				
	Endemic infections	Emerging infections	Endemic NCDs	Emerging NCDs	Injuries	Endemic infections	Emerging infections	Endemic NCDs	Emerging NCDs	Injuries	Endemic infections	Emerging infections	Endemic NCDs	Emerging NCDs	Injuries	Endemic infections	Emerging infections	Endemic NCDs	Emerging NCDs	Injuries
<i>Papua New Guinea</i>	82	2	11	0	4	24	17	21	10	28	19	15	34	21	11	18	5	41	27	8
Western	74	2	18	0	6	23	16	27	10	25	21	14	34	20	11	18	5	41	27	8
Gulf	77	3	14	0	5	24	24	16	6	30	20	19	34	16	12	18	5	41	27	9
Central	77	2	15	0	5	18	10	17	11	43	16	10	29	22	24	16	3	45	28	9
National Capital District	79	1	15	0	5	19	18	23	14	26	14	15	34	29	7	12	5	40	38	5
Milne Bay	81	3	12	0	4	32	13	21	6	28	20	15	36	21	8	24	4	41	26	5
Oro	78	2	14	0	5	24	19	26	8	23	17	20	35	22	6	17	5	45	27	5
Southern Highlands	86	3	8	0	3	34	18	19	5	25	26	16	34	17	8	27	5	39	21	8
Enga	85	3	9	0	3	22	17	20	8	33	16	15	35	19	14	15	4	38	26	17
Western Highlands	84	2	11	0	4	20	15	24	11	29	16	13	37	22	12	17	5	45	26	8
Simbu	83	2	11	0	4	20	18	23	10	28	17	15	37	21	10	18	4	41	25	12
Eastern Highlands	83	2	11	0	4	22	15	23	10	30	18	12	35	20	16	18	4	41	23	13
Morobe	85	3	9	0	3	27	20	20	6	27	21	16	33	20	11	19	5	48	24	5
Madang	81	3	12	0	4	24	19	21	9	27	20	19	32	20	9	16	7	40	29	8
East Sepik	81	3	11	0	4	24	14	18	8	36	19	14	33	19	15	18	4	38	26	14
Sandaun	77	4	14	0	5	28	18	18	10	27	20	20	31	17	13	18	4	45	25	8
Manus	79	3	13	0	5	22	8	33	17	20	20	9	38	24	8	16	3	46	28	8
New Ireland	82	2	12	0	4	23	11	25	10	32	16	13	39	23	9	18	5	47	26	4

Province	Male																			
	< 5 years					5–44 years					45–64 years					65+ years				
	Endemic infections	Emerging infections	Endemic NCDs	Emerging NCDs	Injuries	Endemic infections	Emerging infections	Endemic NCDs	Emerging NCDs	Injuries	Endemic infections	Emerging infections	Endemic NCDs	Emerging NCDs	Injuries	Endemic infections	Emerging infections	Endemic NCDs	Emerging NCDs	Injuries
East New Britain	73	2	18	0	6	25	16	24	12	23	22	15	32	22	10	21	4	41	28	7
West New Britain	83	2	11	0	4	27	19	17	10	26	23	17	28	19	12	20	6	32	25	17
Bougainville	79	2	14	0	5	26	15	20	6	33	25	14	28	21	11	24	5	41	24	7
Province	Female																			
	< 5 years					5–44 years					45–64 years					65+ years				
	Endemic infections	Emerging infections	Endemic NCDs	Emerging NCDs	Injuries	Endemic infections	Emerging infections	Endemic NCDs	Emerging NCDs	Injuries	Endemic infections	Emerging infections	Endemic NCDs	Emerging NCDs	Injuries	Endemic infections	Emerging infections	Endemic NCDs	Emerging NCDs	Injuries
<i>Papua New Guinea</i>	82	3	12	0	3	35	25	22	7	12	18	18	35	22	8	18	5	39	30	8
Western	77	3	16	0	4	29	20	29	6	16	13	18	38	24	7	17	5	40	30	8
Gulf	79	4	14	0	3	38	24	18	5	14	19	22	30	16	13	18	5	38	30	8
Central	73	3	20	0	4	30	20	21	5	24	23	18	28	20	12	16	4	41	30	8
National Capital District	76	1	18	0	4	28	25	27	8	12	14	13	36	33	4	13	4	35	43	4
Milne Bay	78	3	15	0	3	38	20	22	6	12	21	16	35	19	8	23	4	39	29	5
Oro	78	3	16	0	4	32	25	23	9	12	15	19	35	23	8	16	6	42	30	5
Southern Highlands	86	3	9	0	3	40	19	21	7	13	25	16	37	16	6	26	5	37	24	8

Province	Male																			
	< 5 years					5–44 years					45–64 years					65+ years				
	Endemic infections	Emerging infections	Endemic NCDs	Emerging NCDs	Injuries	Endemic infections	Emerging infections	Endemic NCDs	Emerging NCDs	Injuries	Endemic infections	Emerging infections	Endemic NCDs	Emerging NCDs	Injuries	Endemic infections	Emerging infections	Endemic NCDs	Emerging NCDs	Injuries
Enga	85	3	9	0	3	33	29	18	7	13	18	15	40	15	12	9	5	40	25	22
Western Highlands	83	2	11	0	3	34	23	24	6	14	15	14	39	24	8	14	4	44	29	10
Simbu	83	2	11	0	3	34	31	21	5	8	21	27	31	17	4	18	5	36	27	14
Eastern Highlands	84	2	10	0	3	37	24	23	6	10	17	17	35	17	13	17	6	37	26	14
Morobe	84	3	9	0	3	37	28	18	8	10	20	21	33	19	7	21	6	39	26	7
Madang	83	3	11	0	3	33	27	20	7	12	18	20	37	18	7	20	5	40	27	7
East Sepik	82	4	11	0	3	37	22	20	4	17	20	18	37	19	5	17	4	35	28	15
Sandaun	81	5	12	0	3	37	27	21	5	11	17	21	31	17	15	18	4	42	28	8
Manus	76	3	17	0	4	32	21	22	15	9	13	12	43	26	5	15	3	42	30	9
New Ireland	80	2	14	0	4	37	20	23	7	13	15	16	36	25	8	17	5	44	29	4
East New Britain	76	3	17	0	4	34	22	21	14	9	18	17	30	24	11	20	5	38	30	7
West New Britain	85	2	10	0	3	37	24	19	7	12	21	20	29	22	8	18	6	29	27	20
Bougainville	77	2	17	0	4	35	20	25	8	12	23	15	29	24	9	23	5	38	26	7

Note: CSMF: cause-specific mortality fraction; NCD: non-communicable disease. The < 5 years group caused categories to split using the proportions of the five cause categories within each broader cause group from the expected cause patterns method. Within each age group, rows add to 100%.

Table 6.7: Undetermined Redistribution of Verbal Autopsy Deaths

Adult			Child			Neonate		
Undetermined redistribution			Undetermined redistribution			Undetermined redistribution		
Cause	Male	Female	Cause	Male	Female	Cause	Male	Female
AIDS	0.02	0.015	AIDS	0.014	0.017	Birth asphyxia	0.184	0.184
Bite of venomous animal	0.002	0.003	Bite of venomous animal	0.005	0.006	Congenital malformation	0.12	0.114
Breast cancer	0.006	0.01	Childhood cancer	0.029	0.028	Neonatal meningitis/sepsis	0.116	0.118
Cervical cancer	0.006	0.006	Childhood cardiovascular disease	0.071	0.071	Neonatal pneumonia	0.265	0.266
Chronic renal failure	0.026	0.029	Diarrhoea/dysentery	0.071	0.07	Preterm delivery	0.314	0.316
Chronic respiratory	0.123	0.118	Digestive disease	0.026	0.026	Stillbirth	0.009	0.002
Cirrhosis	0.025	0.028	Drowning	0.044	0.045	AIDS	0.000	0.000
Colorectal cancer	0.006	0.007	Encephalitis	0.017	0.019	Bite of venomous animal	0.000	0.000
Diabetes	0.058	0.057	Falls	0.004	0.006	Childhood cancer	0.000	0.000
Diarrhoea/dysentery	0.032	0.032	Fires	0.009	0.006	Childhood cardiovascular disease	0.000	0.000
Drowning	0.025	0.024	Haemorrhagic fever	0.012	0.01	Diarrhoea/dysentery	0.000	0.000
Oesophageal cancer	0.001	0.001	Homicide	0.005	0.006	Digestive diseases	0.000	0.000
Falls	0.002	0.006	Malaria	0.063	0.061	Drowning	0.000	0.000
Fires	0.001	0.004	Measles	0.088	0.086	Encephalitis	0.000	0.000
Homicide	0.017	0.016	Meningitis	0.041	0.041	Falls	0.000	0.000
Ischaemic heart disease	0.109	0.11	Other defined causes	0.2	0.199	Fires	0.000	0.000
Leukaemia/lymphomas	0.008	0.011	Other infectious diseases	0.09	0.089	Haemorrhagic fever	0.000	0.000
Lung cancer	0.012	0.009	Pneumonia	0.155	0.156	Homicide	0.000	0.000
Malaria	0.033	0.033	Poisonings	0.02	0.016	Malaria	0.000	0.000
Maternal	0.029	0.028	Road traffic accident	0.023	0.023	Measles	0.000	0.000
Other cancers	0.024	0.026	Breast cancer	0.000	0.000	Meningitis	0.000	0.000
Other cardiovascular disease	0.052	0.054	Cervical cancer	0.000	0.000	Other defined causes	0.000	0.000
Other infectious disease	0.017	0.02	Chronic renal failure	0.000	0.000	Other infectious diseases	0.000	0.000

Other injuries	0.031	0.027	Chronic respiratory disease	0.000	0.000	Pneumonia	0.000	0.000
Other non-communicable disease	0.073	0.072	Cirrhosis	0.000	0.000	Poisonings	0.000	0.000
Pneumonia	0.057	0.061	Colorectal cancer	0.000	0.000	Road traffic accidents	0.000	0.000
Poisoning	0.006	0.004	Diabetes	0.000	0.000			
Prostate cancer	0.001	0.006	Oesophageal cancer	0.000	0.000			
Road traffic accident	0.043	0.048	Ischaemic heart disease	0.000	0.000			
Stomach cancer	0.006	0.008	Leukaemia/lymphomas	0.000	0.000			
Stroke	0.093	0.095	Lung cancer	0.000	0.000			
Suicide	0.029	0.033	Maternal	0.000	0.000			
Tuberculosis	0.01	0.011	Other cancers	0.000	0.000			
Childhood cancer	0.000	0.000	Other cardiovascular diseases	0.000	0.000			
Childhood cardiovascular disease	0.000	0.000	Other injuries	0.000	0.000			
Digestive disease	0.000	0.000	Prostate cancer	0.000	0.000			
Encephalitis	0.000	0.000	Stomach cancer	0.000	0.000			
Haemorrhagic fever	0.000	0.000	Stroke	0.000	0.000			
Measles	0.000	0.000	Suicide	0.000	0.000			
Meningitis	0.000	0.000	Tuberculosis	0.000	0.000			
Other defined causes	0.000	0.000	Birth asphyxia	0.000	0.000			
			Congenital malformation	0.000	0.000			
			Neonatal meningitis/sepsis	0.000	0.000			
			Neonatal pneumonia	0.000	0.000			
			Preterm delivery	0.000	0.000			
			Stillbirth	0.000	0.000			

Note: Each column adds to 1.000.

6.2 Summary of Estimating the Pattern of Causes of Death in PNG

The CSMFs presented in this chapter are the first such estimates based on empirical data for PNG and its provinces. Multiple data sources reporting deaths in PNG were used with statistical modelling because there is no single high-quality mortality data source. The results indicate that infectious, maternal, neonatal and nutritional diseases are still an important COD in PNG, despite evidence of the emergence of NCDs as a leading COD in the central highland provinces of Western Highlands and Simbu, the island provinces of New Ireland, East New Britain and Manus and the National Capital District, consistent with their higher socioeconomic status levels. While socioeconomic development has been shown to be closely linked to epidemiological transition, especially for emerging NCDs, geographical and cultural factors are also likely to contribute substantially to the CSMFs of the five broad disease categories in PNG. For example, CSMFs from emerging infections are influenced by high rates of sexually transmitted infections in provinces that are linked by road, while CSMFs from endemic infections are related to malaria endemicity in geographically isolated provinces.

Given that most deaths in PNG occur outside of health facilities, VAs appear to be the only option to reduce ignorance about the causes of household deaths. The introduction of VAs in selected districts in PNG as part of a broader effort by the Bloomberg Data for Health Initiative to improve COD data offers some optimism that this critical data gap can be addressed in a cost-effective manner over the next few years. The specific strategies of this initiative are discussed in more detail in Chapter 8 as part of the key recommendations to improve mortality surveillance in PNG. In Chapter 7, the estimated CSMFs by disease group and province generated in this chapter are discussed collectively with the major findings on adult and all-cause mortality estimated in Chapters 4 and 5. The new evidence generated in this thesis on all-cause and COD patterns in PNG provides critical health intelligence to address the

persistent knowledge gaps about levels, patterns, distributions and CODs in PNG, thus supporting policymaking in the country.

Chapter 7: Discussion: Mortality and Cause of Death Estimates

7.1 Introduction

PNG is a highly diverse country of 9 million people with substantial geographic and socioeconomic differences and high rates of mortality (NSO, 2015b). In a poor country with great diversity, knowledge about the mortality of the population is important for directing public health policy to improve population health. However, despite the availability of multiple disparate data sources, there is limited evidence on the levels and differentials of adult mortality, all-cause mortality and cause-specific mortality in PNG and its provinces (Kitur, Adair, & Lopez, 2019a). Previous research into mortality in PNG has primarily focused on infectious diseases, including malaria, pneumonia and TB (Douglas, 2010; Riley, 2009; Ley et al., 2014; Hetzel et al., 2017), and childhood (Bauze et al., 2012; Duke et al., 2016; Lagani et al., 2010; Tran et al., 2011) and maternal mortality (Mola & Kirby, 2013), despite the importance of adult mortality and its causes of premature deaths in countries such as PNG (Naghavi et al., 2017). To date, there are only two studies conducted on the quality of medical certification of COD in the country (Beracochea, 1995; Rouka & Mathias, 2019). In addition, population-based studies have been limited to few sites with small population sizes that may not be representative of mortality rates in PNG (Gouda et al., 2019; Gouda et al., 2013). Despite recent evidence of increasing levels of NCDs and NCD risk factors in some communities (Gouda et al., 2019; Rarau et al., 2017), there is no comprehensive understanding of mortality and the epidemiological transition occurring in PNG at the national and subnational levels. Further, previous mortality estimates for PNG have relied on indirect demographic methods and statistical models necessitated by the lack of high-quality mortality data (Naghavi et al., 2017; United Nations Department of Economic and Social Affairs, Population Division, 2017), which may fail to reliably measure the true epidemiology and diversity in the country.

Given the gaps in the academic literature, more needs to be known about the complexities of mortality in PNG, its progress in the epidemiologic transition and how these differ between provinces. This thesis aims to better understand the complex picture of mortality and COD levels and differentials in PNG and its provinces by using available data with appropriate demographic and statistical methods to estimate mortality and COD to provide a better understanding of mortality patterns in the country. Specifically, this thesis has estimated the under-five mortality rate (5q0), adult mortality rate (45q15), life expectancy at birth and CSMFs by province and sex. Because of the lack of a high-quality and comprehensive routine source of mortality data, this thesis used indirect demographic methods to generate a range of mortality measures to describe the mortality and COD levels and patterns in PNG, nationally and subnationally. Despite the inseparable coexistence of mortality and morbidity experienced in populations, morbidity was outside of the scope of this study, which focused on mortality only.

Using the best available local data presented in Chapter 3, estimates of adult mortality for PNG and each of its provinces were presented in Chapter 4, estimates of all-cause mortality and life expectancy were presented in Chapter 5 and estimates of COD patterns measured by CSMFs were presented in Chapter 6. This chapter summarises the major findings from Chapters 2–6, discusses, and contextualises key mortality and COD estimates for PNG and its provinces.

In summary, the major findings of this thesis are as follows:

- (1) The first estimates of provincial adult mortality, life expectancy at birth and CSMFs derived using empirical data for PNG and each of its provinces in the academic literature were generated;
- (2) Estimates of adult mortality, life expectancy at birth and CSMFs were correlated with the level of development as measured by the composite index;
- (3) Substantial subnational (provincial) differences in levels of adult mortality, life expectancy at birth and CSMFs exist;

- (4) PNG's mortality surveillance system does not provide adequate data to directly estimate mortality statistics in a timely manner; hence, strengthening of this system is of immediate importance for the further development of the country.

This chapter expands on the major findings of this thesis, first discussing and providing a rationale for the major mortality data sources used to generate the estimates, followed by a discussion of the estimates of all-cause mortality (adult mortality, under-five mortality and life expectancy at birth). Next, provincial variations in COD estimates of CSMFs for PNG and its provinces are discussed to account for the level of epidemiologic transition in PNG's provinces. The major limitations encountered in this thesis in terms of generating mortality and COD estimates conclude this chapter and lead into the recommendations subsequently proposed and discussed in Chapter 8.

7.2 Mortality Data Sources Used to Estimate Adult Mortality, Under-Five Mortality, Life Expectancy at Birth and Cause-Specific Mortality Fractions

The gold standard data source for measuring mortality and COD is an accurate and timely civil registration system (Mikkelsen et al., 2015; Roth et al., 2018), which does not yet exist in PNG because the civil registration system is non-functional (Montgomery, 2017) and deaths collected from routine health data represent only a small proportion of deaths in provinces (Kitur et al., 2019b). To meet the demand for mortality statistics in PNG, where the CRVS is weak, WHO (2014) recommends a range of alternative data sources, including VAs with deaths identified in household surveys or censuses to ascertain COD, healthcare facility data, community-based reporting, longitudinal HDSS in selected sentinel sites and vital events enumeration coupled with VA to determine probable CODs.

As presented in Chapter 3, the potential sources of mortality and COD data in PNG include population- and health facility-based sources and sources suggested by WHO. PNG's population-based sources include the CRVS system, population censuses, DHSs, VAs from the

PNGIMR HDSS, health facility data collected from the NHIS, eNHIS, DHIS and perinatal and maternal mortality registers and the public health report. However, despite this wide array of sources, there was no single credible source found; hence, estimation of mortality and COD for PNG and its provinces was based on a combination of some of these sources. Despite the strengths of different mortality data sources in PNG, all sources were found to have considerable weaknesses. This thesis has sought to utilise the strengths of the various data sources to build empirical evidence on mortality and COD in PNG and its provinces. The lack of evidence on mortality and COD in PNG does not necessarily mean that PNG lacks data on deaths. The country has multiple data sources on mortality, but there is no single dataset that provides comprehensive, accurate and timely data on mortality and COD. In fact, data on births and deaths are being collected by various organisations but are not being shared for national use (Montgomery, 2017).

Given the paucity of high-quality data on deaths from any source to directly measure mortality, this thesis applied indirect demographic methods based on the best available data to measure mortality and COD patterns in PNG. Specifically, parental survival data collected from the 2011 and 2000 censuses were used with the orphanhood method to estimate adult mortality, while summary birth histories from the 2000 and 2011 censuses were used to estimate under-five mortality. Estimated 45q15 and 5q0 were inputted into three model life tables to generate complete life tables and estimate all-cause mortality and life expectancy at birth for PNG and its provinces. Routine health data from the DHIS and VA data from the PNGIMR HDSS sites were key inputs used to estimate CSMFs by five categories for PNG and its provinces.

A major advantage of the national population census is that it theoretically counts the whole population, thus is potentially valuable for subnational mortality analysis. The population census is a potential source of data required for the indirect estimation of 5q0, 45q15 and

ASDRs. The 2000 and 2011 population censuses could be used to estimate 45q15 for males (2011 only) and females (2000 and 2011) and 5q0, while ASDR data were implausible for use. Despite providing such data, population censuses suffer a major limitation in that they do not provide timely data on deaths for mortality statistics. In PNG, censuses are conducted every 10 years, and such long delays are not beneficial for policymakers who require timely mortality information to make decisions on policy development and program monitoring. In line with WHO's (2014) recommendation, PNG could benefit from the census by conducting a follow-on study on recent deaths identified in the census using VA to ascertain the CODs. However, improvement in the notification of deaths (see 8.2.1) and improving CRVS systems (see 8.2.4) are key priorities for improving population data on mortality in PNG.

DHSs are a potential source of orphanhood data and summary birth histories to estimate 45q15 and 5q0. Despite including the paternal and maternal orphanhood question, these data have never been published in official survey reports (NSO, 2011a). It was noted that questions of paternal survival were not correctly answered. In an attempt to shorten the interview process, the interviewers conveniently selected responses that would truncate a series of questions on summary birth histories (NSO, 2011a).

Approaches to the collection of information regarding deaths (and births) from a DHS is costly, time-consuming and often problematic because the methodology used for estimating demographic parameters from these kinds of data is far from straightforward (NSO, 2011a). The reliability of data collected on mortality is influenced by the sample size, the operational efficiency of the enumerator and investigator, the adequacy of supervision and the effort put into monitoring of results. While it may be expected that the quality of mortality data collected in a specialised (sample) survey such as a DHS in PNG will almost certainly be superior to the quality of data collected in a census, in reality this has turned out to be completely contrary to what is expected, with the 2000 and 2011 censuses providing better-quality data than the

1996 and 2006 DHSs. Because of inadequate supervision, the majority of probing questions pertaining to mortality were truncated by field enumerators to reduce their workload and quicken the completion of questionnaires at the expense of obtaining high-quality mortality data. Further, subnational analysis of mortality data collected through this source is impossible because the sample surveyed does not represent the whole population, further limiting the utility of this source at subnational levels.

Integrated sample surveys are a possible source of COD data. COD data in PNG are scarce, with the latest publication on VA deaths obtained from only four sites in the country. However, the estimate crude death rate is comparable to GBD estimates (Naghavi et al., 2017), which were used together with DHIS data and GBD-modelled data to estimate CSMFs for five broad CODs by sex for each of PNG's provinces using a range of different methods (Gouda et al., 2019; Kitur, Adair, Riley, & Lopez, 2019).

Routine health facility sources that include mortality data have been the cornerstone for estimating mortality and COD indicators in well-functioning NHISs in neighbouring Pacific Island countries (Carter et al., 2016). Unfortunately, data on deaths collected through the NHIS and DHIS have only reported on an estimated 28% and 22% of all deaths, respectively, each year, with age not reported in 72% of deaths annually in the NHIS. Further, the quality of DHIS data is affected by the fact that not all health facilities in the country report deaths and CODs annually, and the COD is based on death certificates the quality of which is yet to be verified. An initiative by the NDoH and its partners to improve the quality and timeliness of electronically recorded data through the eNHIS by basing them on the rules and procedures of the ICD-10 is promising. However, the eNHIS is available in only eight of 22 provinces in PNG, and the number of deaths recorded is still very low (Kitur et al., 2019a; Matterson et al., 2017). This approach should be rolled out quickly to other provinces because it will be less costly in the long term and has the potential to generate high-quality mortality and COD data from

health facilities and the community. The Data for Health (D4H) initiative has invested heavily in trialling the use of VAs in three of these districts in PNG to ascertain the CODs in health facilities and surrounding communities as part of a broader civil registration strengthening initiative in selected countries (Lopez & Setel, 2015).

The civil registration system remains the gold standard data source for mortality and COD data. However, in PNG the civil registration system is non-functional, largely because of a lack of central coordination between the PNGCIR, the Department of National Planning and Monitoring, the NDoH, the NSO and the Department of Provincial and Local Level Government Authorities (Montgomery, 2017). A joint project by the PNGCIR, the PNG Electoral Commission and the NSO to develop a national identity system was planned to include information on births and deaths. More than 80% of registered births are adults with the primary objective of obtaining a national identity card (Montgomery, 2019). This was a missed opportunity to make important changes to a crucial data source for mortality as well as other registration purposes.

7.2.1 Conclusion on data sources

Despite being the gold standard data source for mortality and COD data, civil registration is non-functional and routine reporting of health facility data comprises only a small percentage of deaths. VA data are limited to a few sites that are not necessarily representative of the mortality experience of PNG. National population censuses provide minimal population-based mortality data that can be used for subnational analysis. Given the inherent weaknesses in all mortality data sources, a combination of demographic and statistical methods was used in this thesis to address these shortcomings and derive estimates of adult mortality, under-five mortality, life expectancy at birth and COD for PNG and each of its provinces.

7.3 Adult Mortality (45q15) Estimates

Derived estimates of adult mortality, under-five mortality and CSMFs represent essential knowledge about a country's demographic and epidemiological situation and are discussed here in this order. Understanding mortality levels and differentials enables governments and partners to better understand key priorities for targeted interventions to improve population health and monitor changes in the health of the population over time.

Adult mortality measures the total impact of premature deaths in the population resulting from infections, maternal mortality, NCDs and injuries. Adult mortality has been the focus of attention because it occurs in the most economically productive age group in which all mortality could be referred to as premature deaths. In addition, most violent deaths occurring in PNG are reported in this age group (World Bank, 2014). Estimates of adult mortality levels for PNG are some of the highest in the world (Naghavi et al., 2017; United Nations Department of Economic and Social Affairs, Population Division, 2017). This thesis has confirmed these claims by presenting the first empirically based estimates of adult mortality for PNG and its provinces in 2011 (national male 45q15 at 269 per 1,000, while national female 45q15 was approximately 12% lower at 237 per 1,000). Sex differences in adult mortality are generally low in PNG, as expected in a country early in an epidemiologic transition (Lopez, 1983). The low sex difference is attributable to a high female 45q15, resulting from infectious disease, conditions of poverty and malnutrition and high rates of maternal death (Mola & Kirby, 2013; NSO, 2006). PNG ranks second only to Afghanistan in the Asia-Pacific region in terms of maternal mortality ratio, with figures reported to be as high as 733 per 1,000 live births according to the 2006 DHS (NSO, 2009). Although this figure is highly uncertain, maternal mortality is high in PNG (Mola & Kirby, 2013). PNG is in the early stage of an epidemiologic transition as evidenced by the low sex differences in adult mortality. Major sex differences will likely become more evident when there is an increase in deaths from NCDs from higher rates

of smoking and other risky behaviours among men (Beltran-Sanchez, Finch, & Crimmins, 2015; Oksuzyan, Juel, Vaupel, & Christensen, 2008).

These estimates can be compared with modelled estimates from the GBD Study (Naghavi et al., 2017) and the United Nations Department of Economic and Social Affairs, Population Division (2017), given the limited published literature on adult mortality estimates for PNG and none for its provinces. The estimates derived in this thesis from empirical data were slightly higher than the UN estimates of 266 per 1,000 for males and 202 per 1,000 for females (United Nations Department of Economic and Social Affairs, Population Division, 2017); however, they were significantly lower than the GBD-modelled estimates of 392 per 1,000 for males and 338 per 1,000 for females (Naghavi et al., 2017). The GBD estimates are higher because they incorporated little local data and were derived using model life tables that relied heavily on the mortality experiences of nearby Pacific Island countries with high rates of NCDs. The use of modifiers for HIV is likely to be the reason for reporting higher levels of adult mortality for PNG in 2010 (Rajaratnam, Marcus, et al., 2010). Conversely, the use of local data from PNG by the United Nations Department of Economic and Social Affairs, Population Division (2017), including parental survival data from the 2000 census, child mortality data from the 2006 DHS and modelled life tables, is the primary reason for their estimates being closer to those derived in this thesis. Therefore, this thesis has established that current empirical estimates are lower and likely more accurate than the GBD estimates of more than 300 per 1,000 for males and females (Naghavi et al., 2017), largely because of the incorporation of local data sources that were appropriately adjusted.

These first subnational adult mortality estimates that were derived directly from empirical data show substantial variations between provinces, correlating with the level of socioeconomic development and health access as measured by the composite index. The western and southern provinces of Sandaun, Enga, Southern Highlands/Hela and Gulf reported

the highest rates of 45q15, corresponding with their low levels of development. These provinces contain some of the most remote communities in the country (NSO, 2015b), with poor health access and low socioeconomic development (Kitur et al., 2019a; NDoH, 2011; NRI, 2010). Conversely, provinces with high levels of development such as National Capital District, New Ireland, Bougainville, Eastern Highlands and Simbu (males only) reported the lowest levels of adult mortality. These provinces have the best health access and socioeconomic levels in terms of education and economic development (NRI, 2010).

Although the orphanhood method has proven useful for estimating adult mortality for PNG and each of its provinces, a high-quality routine mortality data collection system is preferable. A routine data collection system that generates high-quality mortality data will enable a direct estimation of adult mortality and provide timely information for policy development and monitoring of health interventions.

7.4 All-Cause Mortality and Life Expectancy

Existing estimates of mortality for PNG have primarily been based on models with little empirical data. Further, there has been no estimation of life expectancy at the subnational level, despite the obvious benefits for targeting interventions to communities with different mortality levels to improve survival rates. Data on deaths from the 2000 and 2011 censuses and indirect demographic methods were used to estimate under-five mortality (5q0), adult mortality (45q15) and life expectancy by province and sex. In addition, a composite index to measure socioeconomic status and health access of provinces was constructed to assess the plausibility of these mortality estimates (Kitur et al, 2019a, 2019b).

Both infant and childhood mortality have gradually declined in PNG since the 1950s (Duke, 1999; van de Kaa, 1971) and have also been studied more extensively than any other mortality indicators down to the district level (Bakker, 1986; Bauze et al., 2012; Duke et al., 2016; NSO,

2011; Tran et al., 2011). This thesis estimated a lower 5q0 in 2011 than that reported by Bauze et al. (2012). Bauze et al. (2012) estimated the 5q0 for 2000 at 78 per 1,000 live births using summary birth histories collected in the 2000 census and the 5q0 for 2011 at 63 per 1,000 live births for both sexes using the 2011 population census.

It is debatable whether infant and under-five mortality rates are declining; for example, the NSO (2011) has estimated that since 1966, there has been a 20% decline in under-five mortality in both sexes overall, despite suggestions otherwise and the performance of the PNG public health system, which has deteriorated in the last 50 years (NDoH, 2015a, 2015b). The rate of immunization is a major factor in reducing infant and child mortality. Despite donor support, immunization rates have been declining in PNG. For example, there has been a drop in rates for measles from 50% in 2000 to 40% in 2015 (NDoH, 2015a). The declining rates of immunization is likely to result in higher infant and child mortality. There was a fourfold difference in estimated 5q0 between the province with the lowest 5q0 (National Capital District at 24 per 1,000 live births) and that with the highest (Sandaun at 126 per 1,000 live births) (Kitur et al., 2019b). Comparable rates of 5q0 have been reported from Kiribati at 60–70 deaths per 1,000 live births (Linhart, Carter, Taylor, Rao & Lopez, 2014). Apart from Kiribati, rates in other Pacific Island countries range from 40 per 1,000 in Solomon Islands to less than 5 per 1,000 in Guam and New Caledonia (Linhart, et al., 2014). However, it may be difficult to compare PNG with other Pacific Island countries with lower populations and land masses that face different challenges.

Life expectancy in PNG is reported to be in the high 50s for males and low 60s for females and appears to have remained stagnant for the last 40 years (Linhart, et al., 2014; Naghavi et al., 2017; NSO, 2011). A population's life expectancy rate is largely determined by the probability of dying between the ages of 0 and 5 years (5q0) and 15 and 60 years (45q15). For PNG, life expectancy at birth for 2011 was estimated at 62.0 years for males and 64.3 years for females,

with a difference of 13 years (for both sexes combined) between the lowest and highest provinces. Given the estimated levels of adult mortality and child mortality reported above, these estimates are substantially higher than those derived in the GBD Study, which estimated 57.8 years for males and 60.3 years for females (Naghavi et al., 2017), but lower than the United Nations Department of Economic and Social Affairs, Population Division (2017) estimates of 67.2 years for females and similar to the UN-estimated male life expectancy.

These estimates are substantially different from those by the NSO (2011), which estimated life expectancy at birth as 56 years for males and 57 years for females, revealing a low sex difference. Differences in mortality between the sexes is expected to widen as the epidemiologic transition in PNG takes place because NCDs will overtake infectious, maternal, neonatal and nutritional diseases as the leading CODs (Beltran-Sanchez et al., 2015). The low sex difference in life expectancy implies that in PNG, infectious diseases are still the leading COD, and epidemiological transition has not fully taken place in all communities.

The Pacific mortality report estimated the life expectancy at birth for both males and females in 2010 as less than 55 years in both males and females and plateauing (Linhart, et al., 2014). PNG has been grouped in the same category as Nauru, while females in American Samoa and Niue have life expectancy levels comparable to those in Australia and New Zealand. Fiji's life expectancy, which has been stagnant for 13 years (Taylor, et al., 2013), is reported to be in the low 60s for males and high 60s for females because of high mortality rates from NCDs. In PNG, life expectancy rates in the National Capital District and provinces with higher socioeconomic levels would be comparable to those in most Pacific Island countries.

There is a 13-year gap between the provinces with the lowest (Sandaun) and the highest (National Capital District) levels of life expectancy at birth for both males and females. Given the substantial provincial variations observed in under-five mortality and adult mortality estimates reported in this thesis, this is to be expected.

Chapter 5 showed that life expectancy at birth in PNG and its provinces is linearly related to socioeconomic development and health access. Life expectancy is highest in the National Capital District (67.0 years for males, 70.3 years for females), Western Highlands/Jiwaka (65.9 years for males, 68.7 years for females), Simbu (67.2 years for males) and Bougainville (67.2 years for females), all socioeconomically developed provinces. As discussed in Chapter 5, the low female life expectancy in Simbu Province was caused by an error in the data. Conversely, lower-ranking provinces such as Sandaun and Gulf have recorded lower levels of life expectancy at birth for both sexes.

7.5 Cause of Death Estimates by Province

7.5.1 Cause-specific mortality fractions

Epidemiological transition refers to a shift away from infectious disease as the major cause of degenerative and man-made disease (McKeown, 2009; Omran, 1971). The GBD Study estimated that 72.3% of deaths worldwide are caused by NCDs, while infectious, maternal, neonatal and nutritional diseases account for 19.3% of deaths (Naghavi et al., 2017). In PNG, infectious, maternal, neonatal and nutritional causes have been largely responsible for the majority of premature deaths for many years (Riley, 2009). Studies have shown the existence of high all-cause mortality (Kitur, Adair, Riley, & Lopez, 2019; Naghavi et al., 2017; United Nations Department of Economic and Social Affairs, Population Division, 2017) but also the emergence of NCDs in PNG (Gouda et al., 2019). However, there are still no reliable COD data because civil registration is non-functional and routine health data comprise only a small proportion of deaths, which fails to represent the mortality patterns of PNG and each of its provinces (Kitur et al., 2019b). Given the lack of reliable COD data in PNG, this thesis applied a combination of empirical and expected cause patterns to estimate CSMFs by sex for five broad groups of causes (endemic infections, emerging infections, endemic NCDs, emerging NCDs and injuries) for each of PNG's provinces. This process built on the complete life tables presented and

discussed in Chapter 5 to estimate the ASDRs in each province using the maximum number of deaths reported at each health facility.

Findings from this thesis demonstrate that infectious, maternal, neonatal and nutritional diseases are still important CODs in PNG, being responsible for over 50% of deaths in some provinces. Despite the importance of infectious disease as a leading COD, emerging NCDs have been shown to be particularly high in provinces with higher levels of socioeconomic development, confirming earlier reports by Gouda et al. (2019) and Rarau et al. (2017;2019) that NCDs and NCD risk factors are emerging in some communities of PNG. These results reveal the challenge for public health policymakers in PNG in addressing the dual burden of infectious disease and NCDs and also demonstrate the policy utility of disaggregated COD data for different provincial populations.

An estimated 41% of male and 49% of female deaths in PNG are attributable to infectious, maternal, neonatal and nutritional diseases, while an estimated 45% of male and 42% of female deaths arise from NCDs. The CSMFs for infectious, maternal, neonatal and nutritional causes were almost double the GBD estimates (Naghavi et al., 2017) of 23% for males and 29% for females. This highlights that these causes, in both children and adults, are much more important CODs than reported by the GBD and in other Melanesian countries (Carter et al., 2011; Carter et al., 2016). The GBD Study estimated lower infectious disease mortality for PNG because of its reliance on data from neighbouring countries such as Fiji, Tonga and Samoa, all Pacific countries with higher NCD mortality (Naghavi et al., 2017). Hence, the lack of reliable data necessitated the use of and reliance on models for other Pacific Island countries that have high rates of NCDs, particularly diabetes and cardiovascular disease (Carter et al., 2016; Taylor, et al., 2013).

Infectious disease and maternal and neonatal conditions accounted for more than half the deaths in Gulf and Sandaun provinces. Provinces with higher CSMFs from emerging NCDs such

as ischaemic heart disease, stroke and diabetes tended to be those in which socioeconomic status is comparatively high (e.g. National Capital District, Western Highlands, Manus, New Ireland and East New Britain). Provinces with the highest estimated proportion of deaths from emerging infectious diseases are readily accessible by road and have the highest rates of sexually transmitted infections (NDoH, 2019), while provinces with the highest CSMFs from endemic infectious diseases are geographically isolated, have a high prevalence of malaria and high all-cause mortality (Hetzel et al., 2017; Kitur et al., 2019b).

7.5.2 Endemic and emerging infectious diseases

Infectious diseases, maternal causes and conditions of poverty still account for more deaths than do NCDs in most provinces of PNG. Mortality from infectious, maternal, neonatal and nutritional causes results more from geography and interprovincial movement and less from socioeconomic development, as demonstrated in this thesis. The largest proportion of deaths from endemic infectious, maternal, neonatal and nutritional causes occurred in Sandaun, Gulf, East Sepik and Milne Bay, relatively remote provinces that report a high number of malaria cases and have among the highest all-cause mortality in PNG (Hetzel et al., 2017; Kitur et al.; 2019b). These provinces are surrounded by swampy lands that are ideal breeding environments for mosquitoes.

Deaths from emerging infectious diseases were highest in Simbu, Enga, Eastern Highlands, Morobe and Madang, provinces connected by the Highlands (Okuk) Highway, as well as the National Capital District and Gulf Province, which are connected by the Hiritano Highway. Apart from Gulf Province, these provinces reported the highest rates of sexually transmitted diseases in PNG, including HIV (NDoH, 2019; Coghlan, Millan, Malau, Kaldor & Toole, 2011), a disease spread by frequent movement of people between provinces and from rural to urban areas. HIV is spread between major towns and from towns to villages by commuters who live in villages or rural communities but travel into towns for work or to access services, similar to

the Sub-Saharan African experience (Tanser, Lesueur, Solarsh, & Wilkinson, 2000). In addition, the betel nut trade involves people from highland towns and rural communities frequenting the highway between Madang and Lae and highland communities using the Highlands Highway.

While Gouda et al. (2019) reported HIV and TB as the leading CODs at their study sites, pneumonia, diarrhoea/dysentery and maternal deaths are also important CODs in PNG. Our data did not allow us to determine disease-specific causes.

7.5.3 Endemic and emerging non-communicable diseases

Findings from this thesis provide evidence that a more advanced epidemiological transition in PNG, measured as the percentage of all deaths from NCDs as well as a comparison of deaths from NCDs with deaths from infectious causes, is related to higher socioeconomic status (Kitur, Adair, Riley, & Lopez, 2019). National Capital District, the central highland provinces of Western Highlands, Simbu and Eastern Highlands and the New Guinea Island provinces of Manus and New Ireland have relatively higher life expectancies. This thesis found that emerging NCDs such as ischaemic heart disease, stroke and diabetes are becoming particularly prominent in provinces with higher socioeconomic development, demonstrating progress through the epidemiological transition and further supporting claims by Gouda et al. (2019) that the transition is not uniformly distributed across PNG. The three central highland provinces of Western Highlands, Simbu and Eastern Highlands have experienced modernisation from small-scale commercial enterprises, fresh food and cash cropping and by having access to goods and services in Mt Hagen, Kundiawa and Goroka (Chang, Mullen, Anjen, & Be'Soer, 2014). This epidemiological transition has progressed over a relative short period. The first European contact with the highland provinces was with the Leahy brothers in the early 1930s (Connolly & Anderson, 1987), and the opening of the Highlands Highway occurred after 1965 (Romaine, 1992). Thus, it has taken less than 100 years for much of the

epidemiological transition to take place, in contrast with the Western world in which a similar transition in disease patterns took more than 200 years (Omran, 1971).

The National Capital District is a relatively developed area accessible by the majority of the population of Central Province (which also has high emerging NCD levels), most of whom live in peri-urban areas of the capital city. Further, changes in lifestyle in Manus, New Ireland, East New Britain, National Capital District and Central (particularly the western parts), including high rates of cigarette smoking, inactivity and unhealthy diets, have contributed to the high rates of diabetes and coronary heart disease in these provinces (Rarau et al., 2017). The *2016 Global Youth Tobacco Survey* (WHO, 2018) found that one in every three youths between the ages of 13 and 15 years in PNG are current smokers of any tobacco product, with 21% being current smokers of cigarettes. An alarming 73% of respondents claimed that they were being exposed to smoking in public places. Despite regulations prohibiting smoking in public places, tobacco products are sold and consumed everywhere. Concurrently, the chewing of betel nut, which was once a traditional social event, is now an everyday occurrence. Reports from Port Moresby General Hospital in the National Capital District indicate that coronary artery disease from betel nut chewing is the leading cause of admission to the medical ward (Auka-Salmang, 2019). For heart attacks alone, the number of admissions has increased tenfold since the 1980s. Between 1985 and 1988, there were 20 cases admitted to the medical ward, increasing to 200 cases from 2016 to 2018 (Auka-Salmang, 2019).

Compared with other provinces in the country, the New Guinea Island provinces of Manus, New Ireland and East New Britain have the highest levels of education in the country (NRI, 2010) and better health care access (NDoH, 2011, 2015a, 2015b). The Kairuku-Hiri district of Central Province lies in the peri-urban area of the National Capital District and has had a longer exposure to modernisation and changes in lifestyle. Rarau et al. (2019) also noted high rates of

alcohol consumption (43%) and stress (46%), particularly in the West Hiri population, among 15–65-year-olds, associated with employment.

PNG is reported to have one of the highest rates of violence in the world (World Bank, 2014), including domestic violence, election-related violence, sorcery-related violence and violence in general, which is high in both sexes. This thesis confirms that males accounted for twice the burden of injuries as females, similar to what has been reported in Vanuatu and other developing countries (Carter et al., 2016). Enga, East Sepik and West New Britain had the highest rates of violence-related deaths in PNG. These findings are consistent with World Bank (2014) reports, while deaths from road traffic accidents are common in Eastern Highlands and Central Province (Herman et al., 2012). Recent findings by Gouda et al. (2019) showed homicide as the major cause of injury in the highlands (Asaro and Hides), while falls from buildings were responsible for most deaths from injuries in coastal areas (Hiri and Karkar).

These findings suggest that while COD patterns in PNG relate to the level of socioeconomic development, this does not explain COD differentials and patterns between provinces in PNG for emerging and endemic infectious diseases and maternal, neonatal and nutritional causes. A major limiting factor relates to the uncertainty of the CSMF estimates derived given the poor quality of data used. For example, the empirical cause model was developed using VA and DHIS data from only four sites and applied to DHIS data (without adjustment for diagnostic accuracy) throughout the country. Moreover, the CSMFs were derived for five broad categories, limiting their usefulness in identifying disease specificity because of poor-quality data.

7.6 Use of Composite Index for Socioeconomic Development and Health Access

Given the lack of published estimates with which to compare the findings of this thesis, an index measuring the level of socioeconomic development and health access was constructed

and used to verify the plausibility of derived estimates. The use of an index based on the level of development to rank provinces in PNG was more informative than categorising communities as urban/rural or highland/coastal (Lim et al., 2016).

Variations in mortality and COD are likely to be associated with social, economic and health system characteristics, including income, socioeconomic class, education and access to health services (Alijanzadeh et al., 2016; McGehee, 2004; Moradi-Lakeh et al., 2017; Naghavi et al., 2017). Previous studies have employed various socioeconomic indicators to rank regions, countries and provinces in terms of level of development rather than classifying them as developing or developed, rural or urban (Lim et al., 2016; Moradi-Lakeh et al., 2017). For example, Naghavi et al. (2017) used a sociodemographic index to quantify the relationship between level of development and mortality in 285 countries; Moradi-Lakeh et al. (2017) used a similar index to compare mortality in Iran with development; and Alijanzadeh et al. (2016) compared infant mortality with the human development index.

The use of a composite index to rank each province in PNG by socioeconomic development status was more informative for guiding policies aimed at reducing mortality differentials than by simply using a rural or urban classification (Gibson & Rozelle, 2002; Gibson et al., 2014; Hanson, 2001; National Economic and Fiscal Commission, 2004; NRI, 2010). Using electoral boundaries to identify urban and rural populations would not have been useful because they have not been reviewed since the 1980s (Montgomery, 2019; NSO, 2011). Hence, areas previously demarcated as rural may well become urban because of the expansion of urban areas, especially in National Capital District/Central Province, Lae, Mt Hagen and Rabaul/Kokopo.

The composite index can serve as a benchmark against which implausible mortality estimates can be interrogated further. As depicted by the composite index, provinces with higher levels of socioeconomic development (e.g. National Capital District, Autonomous Region of

Bougainville, Western Highlands/Jiwaka and Simbu) had low levels of under-five mortality and adult mortality and higher life expectancies for both males and females. Conversely, Sandaun, Gulf and Enga provinces, which had high all-cause mortality and low life expectancy at birth, had the lowest levels of development as measured by the composite index.

In this thesis, the composite index could not accurately predict mortality rates but was useful in assessing the plausibility of adult mortality, child mortality, life expectancy and CSMF estimates for each province. In Chapter 4, adult mortality was shown to be strongly and negatively correlated with socioeconomic development in adult males ($R^2 = 0.5363$) but only moderately negatively correlated with socioeconomic development in females ($R^2 = 0.2163$). Hence, National Capital District, Eastern Highlands Province, Simbu Province and New Ireland Province reported low 45q15 and higher CSMFs from emerging NCDs, corresponding with their higher levels of development as measured by the composite index. Conversely, the geographically isolated southern and western provinces of Sandaun, Southern Highlands/Hela and Gulf had high rates of all-cause mortality and high CSMFs from endemic infections and maternal, neonatal and nutritional causes, showing that the epidemiological transition is not uniform across provinces in PNG. The use of the composite index developed in this thesis was helpful in identifying highly implausible estimates that could not be validated against previous studies.

This thesis provides the first comprehensive evidence about probable levels and patterns of mortality and COD for PNG and each of its provinces using direct empirical evidence applied to demographic and statistical methods. These findings are inherently uncertain given the poor quality of mortality surveillance in PNG. The problem of uncertainty and other limitations of this study are discussed next, with each area addressed in the concluding chapter.

7.7 Limitations of the Thesis

This study reveals a number of important limitations encountered during the estimation process that were also inherent in PNG's mortality surveillance systems. These included limitations of data sources used, methods applied and resulting levels and patterns of mortality and COD estimates. Specifically, these limitations included data availability, which dictated the methods employed for estimating mortality in PNG. Mortality estimates were and will continue to be derived using indirect methods because of the currently available data, and the use of data on parental survival is undesirable in the long term because censuses are held every 10 years. In addition, the methods used did not permit measurement of uncertainty of mortality estimates, and the small number of deaths at the district level did not allow an estimation at this level. Further, the small amount of community COD data from only four sites made it impossible to estimate CSMFs at the district level because of the low numbers of deaths, limiting the estimation of CSMFs for specific or even five-year age groups to provinces and to only four broad age groups.

The 2011 and 2000 censuses were the major sources of data for estimating all-cause mortality in this thesis. However, these data sources were less reliable or useful because they provide estimates infrequently. Population censuses in PNG are conducted every 10 years (NSO, 2011a); hence, reliance on censuses is less helpful because they do not provide timely data required by policymakers. Despite being less than ideal, the orphanhood method was the only method available to apply to the minimal parental survival (orphanhood) data. To overcome the shortcomings of such data, a modified version of the orphanhood method using the two-census method was adopted to estimate the adult mortality for women. Male adult mortality estimates were based on the orphanhood method using data from one census, adjusted using the empirical completeness method developed by Adair and Lopez (2018). Further, the lack of timely data required either a forward projection to 2011 for male adult mortality or the scaling

of childhood mortality to 2011 estimates, both unavoidable procedures given the poor quality of data sources (Kitur et al, 2019a). Some provinces (e.g. Simbu) had a high female adult mortality rate, which was highly implausible given the province's high level of socioeconomic development and health access. This thesis relied heavily on the use of model life tables to ascertain the all-cause mortality levels for each province, a common practice in demography and epidemiology.

While this thesis does not require the estimation of population size, it is possible that reporting of deaths at the household level in 2011 was neither complete nor accurate as other aspects of the census. Inconsistencies and errors within and between census, are well recognized as reported by Allen in 2014. Allen (2014) found local level government areas (LLGAs) with relatively large increases or decreases in population between 2000 and 2011, but without any obvious explanations for them. Therefore, any errors in counting and management of the census data at the LLGAs would inevitably affect the reporting of deaths at the household level, resulting in the implausible mortality pattern displayed by ASDRs reported in Chapter 5. Possible errors for the implausible ASDRs could have resulted from over-reporting of deaths and age misreporting. However, there was no document available on the counting and management of household deaths. To understand possible errors in the census data, Allen (2014) suggested that NSO release census village units results and a description of how the field data was collected and managed. Despite these potential issues, the mortality results in Chapters 4 and 5 based on the application of demographic methods to the orphanhood data in the Census showed plausible results at the provincial level when compared with a composite index of socioeconomic and health access, and also compared with the national adult mortality rank against health and development measures for PNG.

Additionally, the poor quality of DHIS data may have affected the estimates. To overcome this limitation, CSMFs were estimated across four broad age groups for five broad disease group

classifications, generating results that were highly plausible against the composite index.

Further, the mortality experience of a province is inherent with problems arising from people bypassing their local health facilities for convenience or in search of better-quality services. For example, hospitals such as Port Moresby General Hospital may record deaths of individuals from Central and Gulf provinces who have accessed its services. Similarly, people dying at Mt Hagen hospital may be from any of the western and southern highland provinces of Enga, Southern Highlands/Hela or from the neighbouring Simbu province. Deaths in Angau may include those of people from the Momase Region, while deaths at the Nonga Baese Hospital may easily be from individuals coming from other neighbouring New Guinea Island provinces.

Given the poor quality of PNG's mortality surveillance system, uncertainty about levels and differentials is inherent in the estimates. The type of data available dictated the methods used, which did not permit the measurement of uncertainty. Uncertainty is likely to be substantial given the poor quality of data sources used and the reliance on GBD models and data for all-cause mortality and COD estimations. While communicating this level of uncertainty to policymakers is necessary, greater emphasis should be placed on measures to strengthen and develop better data systems for PNG, as discussed in Chapter 8.

Given that PNG does not have high-quality sources of mortality data or a functioning civil registration system, current data sources and methods will continue to be used in the near future. The overall plausibility of the final estimates of this thesis with the composite index supports the use of these methods as an interim measure while routine systems are being strengthened.

In a country with such cultural, geographic and developmental diversity, the estimation of mortality and COD levels and patterns would be more useful if they were prepared at the district level. However, as mentioned, the small number of deaths reported at the district level did not allow for the estimation of all-cause mortality or CSMFs by district. In fact, the

estimation of summary mortality estimates at this level would have introduced even more uncertainty.

7.8 Summary of Mortality and COD Estimates in PNG

This thesis has attempted to address the major knowledge gaps about mortality in PNG, including the absence of adult mortality data for PNG's provinces, life expectancy at birth estimates for provinces in PNG and reliable data on COD for facility and community deaths. This study provides the first comprehensive estimates of adult mortality (45q15), under-five mortality and life expectancy at birth and CSMFs by sex for PNG and its provinces by applying available data to established and novel demographic and statistical methods. These estimates show substantial geographical inequalities and sex differentials in mortality levels and COD patterns that are consistent with provincial differences in socioeconomic development. Provinces with higher levels of development, as shown by a high composite index ranking, had low levels of all-cause mortality and high life expectancies at birth. Provinces with high levels of all-cause mortality and low life expectancies had low levels of development. Similarly, high levels of development in provinces was consistent with high CSMFs from emerging NCDs. However, the level of development is not the only contributing factor to the CODs in PNG. CSMFs from emerging infections were seen mostly in provinces with high rates of sexually transmitted infections and linked by roads, while those from endemic infections were high in geographically isolated provinces situated in swampy areas with a high incidence of malaria and high all-cause mortality.

The mortality and COD estimates for PNG and each of its provinces in this thesis were derived using indirect methods on multiple data sources because the individual data sources had limitations. While using the available data and applying established and novel statistical and demographic methods provided insights into how mortality and COD levels and patterns vary in PNG, the results are uncertain because of the lack of high-quality mortality statistics for the

country. Hence, a reliable and continuous national mortality surveillance is a development priority for PNG to accurately measure progress with national and global goals. This recommendation and future policy and research activities to improve mortality surveillance in PNG are outlined in the following chapter.

Chapter 8: Conclusions and Recommendations

This final chapter reiterates the main findings from the results chapters (chapters 1-6) of my thesis and makes relevant recommendations. In summary, this chapter presents recommendations to improve mortality surveillance, develop policies to reduce high adult and under-five mortality risk and conduct further research into mortality and COD in PNG.

8.1 Conclusions

8.1.1 Chapter 1 Introduction and profile of PNG and its provinces

PNG is one of the diverse countries in the world in terms of geography, ethnicity and culture, socioeconomic development and health access. By reviewing the profile of provinces, I found that the substantial provincial variations in terms of geography, level of development and health access affect mortality and COD patterns in PNG as illustrated in chapters 4-6. This review confirms that PNG is a low- to middle-income country with great diversity in terms of geography, ethnicity and socioeconomic development. A good understanding of the local context helps to explain the provincial mortality and COD differentials in the absence of published data.

8.1.2 Chapter 2 Literature Review on mortality and COD in PNG

The results of my literature review revealed that there is not much published data on mortality and COD in PNG. There is no publication on adult mortality for PNG and its provinces in the academic literature, while there are very few publications on under-five mortality, with only one study showing geographical variations. Estimates on COD is limited to one study that was conducted in four sites from which I used the verbal autopsy data to estimate COD for PNG and its provinces.

8.1.3 Chapter 3 Sources of mortality and COD in PNG

My review of the different data sources on mortality and COD in chapter 3 revealed that there is no single data set that comprehensively describes mortality and COD patterns in PNG. Each data source had its limitations; thus, it was not possible to estimate mortality and COD directly using these sources. Mortality and COD data are fundamental in informing health policy and improving the health of the population. However, as detailed in this thesis, there is no clear understanding of mortality and COD patterns in PNG because, despite the availability of multiple disparate data sources, there is no single data source that describes mortality and COD patterns.

The civil registration system has failed to provide accurate mortality and COD data, while routine health facility data comprise a small proportion of deaths that are not representative of population-wide mortality (Kitur et al., 2019b; Montgomery, 2019). Census data only provide information on mortality every 10 years, but policymakers need timely data to make informed decisions. In addition, mortality and COD data are only available at the provincial level, despite substantial variations in mortality and COD at the district level.

8.1.4 Estimating adult mortality in PNG

My estimates of adult mortality for PNG and its provinces presented in chapter 4 are the first estimates in the academic literature. They have been derived using novel demographic and statistical methods applied to empirical data. These estimates will improve our understanding of adult mortality in PNG.

8.1.5 Estimating the pattern of all-cause mortality in PNG

In chapter 5, I present the first estimates of life expectancy at birth by province. The level of life expectancy at birth is negatively correlated to the level of adult and under-five mortality risk.

8.1.6 Estimating the pattern of causes of death in PNG.

Publications on mortality and COD are scarce, and there has been no previous attempt to assemble the available sources to present a complete picture of mortality and COD patterns for PNG. Using the empirical method and expected cause method, I was able to estimate the cause-specific mortality fractions (CSMFs) of the five broad disease groups for four broad age groups in each province. The COD estimates are the first published estimates of facility and community CSMFs for provinces.

8.1.7 Limitations

Although this thesis was able to estimate mortality and COD patterns by province, the lack of high-quality data has resulted in a number of limitations, including untimely data, uncertainty of estimates, estimates only available at the provincial level and the lack of detailed CODs. Further, limited VA data from only a few sites has resulted in the lack of specific CODs (Gouda et al., 2019). Adding to these limitations is the uncertainty about the estimates derived in this thesis, which are likely to be no less than the GBD estimates of $\pm 20\%$ (Naghavi et al., 2017). Given these limitations, the priority for PNG is to develop and maintain an ongoing mortality surveillance system that will enable the country to reliably measure progress in its national and global development goals. This is the focus of this chapter and is discussed here in a systematic approach, starting with the most practical recommendations.

8.2 Policy Recommendations

8.2.1 Improve notification of deaths linked to the electronic National Health Information System

Deaths reported through the DHIS and NHIS represent only 22% and 28% of national deaths, respectively, despite them recording the maximum number of deaths annually over seven years from 2007 to 2013 (Kitur et al., 2019b). Both the DHIS and NHIS have collected mortality data, but there was no way of comparing these data because 72% of deaths reported by the NHIS were an aggregated number with no age recorded, while the DHIS has collected data on individual deaths but has a four-year backlog of data that has not yet been entered or analysed. It is simpler to strengthen the existing system rather than introduce a completely new system. In addition to the collection of data by the NHIS and DHIS in all 22 provinces, mortality data are currently being collected via the eNHIS in eight provinces. The eNHIS is the recommended system for the health sector to use in the long term because it provides timely and high-quality data on mortality and COD (Matterson et al., 2017). It is recommended that the NDoH use a single source to record death data. The eNHIS database appears to be more functional than the DHIS and NHIS because it records all essential details of deaths in line with the ICD-10 and provides data on deaths and COD in a timely manner, as reported in the three districts using VAs. Strengthening the routine notification of deaths through the eNHIS will improve the quality and timeliness of mortality reporting from health facilities. However, in PNG the majority of deaths occur in communities and are not reported through any of the mortality data sources. Improving the reporting of community deaths using VA is discussed in the next recommendation.

8.2.2 Introduce verbal autopsies linked to notifications in the electronic National Health Information System

The introduction of VAs linked to the eNHIS notification in selected districts will enable PNG to collect high-quality data on community deaths in a timely manner. Given that the majority of deaths occur outside of health facilities, VAs are the most feasible means of generating mortality and COD data in the absence of medical certification of deaths. VAs have been used in PNG since the early 1970s and have proven to be useful in generating mortality and COD data from communities. Current practices utilise technology, which is beneficial for places in which technology is effective and a challenge in places in which infrastructure is lacking (Gouda et al., 2019). However, where infrastructure allows, VAs should be encouraged as a tool to generate mortality and COD data. VA is being trialled in three districts in provinces using the eNHIS and have successfully collected data on over 1,000 deaths.

The rollout of VAs in districts across PNG poses a challenge in terms of resources (financial, labour and time). Hence, there should initially be a systematic rollout in selected districts in provinces that have implemented the eNHIS and the *Provincial Health Authority (PHA) Act 2007*, because these have sufficient infrastructure for implementation and supervision. Given that the primary objective of VAs should be to produce high-quality nationally representative mortality statistics disaggregated by age and sex, adequate regional representation by selected districts is recommended. In addition, the selection of accessible cluster units for an appropriately large sample of deaths is critical. VA interviewers should be able to reach their catchment populations (2,000–20,000) on foot without having to face expensive transport costs and be able to conduct 2–4 VAs per month. As many clusters as feasible and affordable should be used, with the smallest operational clusters and more constant clusters as possible, and these should be spread across the country to produce nationally representative statistics. Successes and lessons learnt from the experiences of the D4H Bloomberg Initiative should be replicated in other districts or communities with the guidance of implementation research that

has documented the processes followed and challenges encountered. The introduction of VAs linked to eNHIS notification will enable PNG to obtain a clearer picture of the mortality and COD levels and patterns in communities, where most deaths occur.

8.2.3 Strengthen medical certification of causes of death

It is important to concurrently strengthen medical certification of CODs while improving the notification of deaths through routine health facility reporting and implementing VAs in selected districts of PNG. To further improve the quality of COD data collected through the eNHIS, proper training on the medical certification of CODs is required for medical officers at different stages of their professional careers and according to need. Medical certification of CODs should be introduced in medical school (pre-service) and as a refresher course for physicians (post-service) as and when required by each hospital. The D4H Initiative has supported the NDoH by training over 300 doctors and over 100 health extension officers in the medical certification of CODs (D4H, 2019). Although the capacity for coding exists at the NDoH, there is room for additional staff to be trained, including staff in major hospitals. Eventually, the medical certification of CODs and death and VA data will need to be integrated.

8.2.4 Improve civil registration legislation to enable verbal autopsies and notifications to feed into registration, improving routine surveillance of mortality and causes of death

The lack of high-quality data on mortality and COD is mainly attributable to the dysfunctional civil registration system, the multiple disparate data sources and the small number of deaths routinely reported. Improving mortality surveillance will require strengthening of the civil registration system; however, having different departments work together at the central level will take time and require amendments to sections of the *Civil Registration Act 1963* to ensure that each department and office understands its role and takes a whole-of-government approach. The NDoH should create a pathway through which it can share birth and death data with the PNGCIR and NSO. However, before this can take place, the NDoH must ensure the

collection of reliable and timely mortality and COD data. Improving mortality surveillance by the NDoH through VAs and the strengthening of existing NDoH mortality data sources is a priority.

8.2.5 Use mortality surveillance data for health planning and policy

Mortality surveillance in PNG should be regarded as a priority area in assessing the health sector performance. A position for an epidemiologist should be created at the NDoH, and the Technical Committee on Mortality Surveillance (Burden of Disease) should be strengthened. The epidemiologist's primary responsibility would be to coordinate the mortality surveillance activities of the NDoH, but coordination of the Burden of Disease Committee quarterly meetings may be a secondary role. In addition, an annual report on mortality and COD should be produced, either as a standalone report or as part of the Sector Performance Annual Review. Further, a slot at PNG's annual medical symposium on mortality and COD is another way of advocating for mortality surveillance in PNG. This should continue as an annual event to promote mortality surveillance in PNG.

8.2.6 Address the emergence of non-communicable disease in a country struggling with infectious, maternal, childhood and poverty-related diseases

PNG is faced with a dual burden of disease, both infectious, maternal, neonatal and nutritional diseases as well as the emergence of NCDs in socioeconomically developed provinces.

Traditionally, the emphasis of the health sector in PNG has been on infectious disease, but with the current evidence of emerging NCDs, there should be a paradigm shift in disease priority. There should be a concerted effort for both diseases of infectious, maternal, neonatal and nutritional origin as well as NCDs to ensure both are appropriately addressed.

It would be desirable to address both groups simultaneously using a holistic approach, which will require strengthening of the health system to ensure the greatest benefits and sustainability in the long term. Despite the epidemiologic transition not being uniform across

provinces in PNG, preventative measures to address risk factors must be implemented for future success. More information on NCD risk factors should be generated from provinces to assist with strategies to address NCDs now and in the future.

8.3 Recommendations for Ongoing and Future Mortality Research Activities

8.3.1 Expand notification of deaths and verbal autopsies for cause of death data

The estimates on mortality and COD derived in this study have their limitations. VAs introduced into selected districts will provide more accurate information on mortality patterns in PNG. A single-pronged strategy for conducting VAs will be ineffective in a country that is geographically, ethnically and socioeconomically diverse. Implementation research is required in districts implementing VA to meticulously and systematically document each step taken, the challenges faced and how challenges are overcome to provide key lessons for the successful implementation of VA in other districts of PNG.

8.3.2 Introduce STEPS surveys to ascertain non-communicable disease risk factors

WHO continues to advocate for the monitoring of NCD and NCD risk factors in countries using its STEP wise approach manual (WHO, 2017). This is a standardized way of collecting, analysing and disseminating information on NCD and NCD risk factors, beneficial for PNG and its provinces. Despite the rapid socioeconomic changes in PNG, little is known about NCD risk factors in communities. Research should focus on identifying NCD risk factors in provinces or districts and will be useful for developing NCD strategies.

8.4 Limitations of Policy Recommendations

This study has revealed several weaknesses with the current sources of mortality and COD data in PNG, all of which require intervention. However, only recommendations deemed practical have been suggested here, with the overall aim of improving mortality surveillance and advising government on mortality patterns for PNG.

References

- AbouZahr, C., & Boerna, T. (2005). Health information systems: The foundations of public health. *Bulletin of the World Health Organization* 2005; 83:578-583.
- AbouZahr, C., Cleland, J., Coullare, F., Macfarlane, S. B., Notzon, F.C., Setel, P., Szreter, S. (2007). Who Counts? 4: The Way Forward. *The Lancet*, 370(9601), 1791-1799.
DOI:[https://doi.org/10.1016/S0140-6736\(07\)61310-5](https://doi.org/10.1016/S0140-6736(07)61310-5)
- AbouZahr, C., de Savigny, D., Mikkelsen, L., Setel, P. W., Lozano, R., Nichols, E., . . . Lopez, A. D. (2015). Civil registration and vital statistics: Progress in the data revolution for counting and accountability. *The Lancet*, 386(10001), 1373–1385.
- Adair, T., & Lopez, A. D. (2018). Estimating the completeness of death registration: An empirical method. *PLoS ONE*, 13(5), e0197047.
<https://doi.org/10.1371/journal.pone.0197047>
- Allen, B. (2014). *Papua New Guinea National Census 2011: Rates of Population Change in Local Level Government Areas*. Canberra. The Australian University. Available at
(http://bellschool.anu.edu.au/sites/default/files/publications/attachments/2015-12/IB-2014-44-Allen-ONLINE_0.pdf)
- Allen, L., Cobiac, L., & Townsend, N. (2017). Quantifying the global distribution of premature mortality from non-communicable diseases. *Journal of Public Health*, 39 (4), 698–703.
Available at <https://doi.org/10.1093/pubmed/fox008>
- Alijanzadeh, M., Asefzadeh, S., & Zare, S. A. M. (2016). Correlation between human development index and infant mortality rate worldwide. *Biotechnology and Health Sciences*, 3(1), 1–5. <https://doi.org/10.17795/bhs-35330>
- Ashwell, H., & Barclay, L. (2010). Problems measuring community health status at a local level. Papua New Guinea's health information system. *Rural and Remote Health*, 1-6.
Available at <https://www.rrh.org.au>

- Asian Development Bank. (2015). *Sector assessment (summary): Transport*. Manila, Philippines: Author. Retrieved from <https://www.adb.org/documents/papua-new-guinea-country-partnership-strategy-2016-2020>
- Auka-Salmang, G. (2019), Heart disease ranked top cause of admissions in medical wards. *Post Courier*, Retrieved from <https://postcourier.com.pg/heart-disease-ranked-top-cause-admissions-medical-wards/>
- Bakker, M. L. (1983). *Spatial differentiation of mortality in Papua New Guinea: A classification based on the results of the 1980 census* (Working Paper No. 4). Port Moresby, Papua New Guinea: National Statistical Office.
- Bakker, M. L. (1986). *The mortality situation in Papua New Guinea: Levels, differentials, patterns, and trends*. Port Moresby, Papua New Guinea: National Statistical Office.
- Bauze, A. E., Tran, L. N., Nguyen, K.-H., Firth, S., Jimenez-Soto, E., Dwyer-Lingren, L., . . . Lopez, A. D. (2012). Equity and geography: The case of child mortality in Papua New Guinea. *PLoS ONE*, 7(5), e37861. <https://doi.org/10.1371/journal.pone.0037861>
- Bell, C. (1973). Mortality. In C. Bell (Eds.), *The Diseases and Health Services of Papua New Guinea*, (pp 142-150). Port Moresby: Department of Public Health.
- Beltran-Sanchez, H., Finch, C., & Crimmins, E. (2015). Twentieth century surge of excess adult male mortality. *Proceedings of the National Academy of Sciences of the United States of America*, 112(29), 8993–8998.
- Bennett, N.G., & Horiuchi, S. (1984). Mortality estimation from registered deaths in less developed countries. *Demography*, 21, 217–233. pmid:6734860
- Beracochea, E. (1995). Audit of death certificates. *Papua New Guinea Medical Journal*, 38(3), 191–197.
- Brass W. (1975). *Methods for estimating fertility and mortality from limited and defective data*. University of North Carolina. Chapel Hill.

- Breiman, R.F., Streatfield, P.K., Phelan, M., Shifa, N., Rashid, M., & Yunus, M. (2004). Effect of Infant Immunisation on Childhood Mortality in Rural Bangladesh: Analysis of Health and Demographic Surveillance Data. *Lancet*, 364(9452), 2204-11.
- Burd, E.M. (2003). Human Papillomavirus and Cervical Cancer. *American Society for Microbiology*, 16(1), 1-17. Available at DOI: 10.1128/CMR.16.1.1-17.2003
- Caldwell, J., & Caldwell, P. (1993). Women's positions and child mortality and morbidity in less developed countries. In N. Mason, & S. Sogner (Eds.) *Women's Positions and Demographic Change* (pp. 122-13). Oxford, Great Britain: Clarendon Press.
- Caldwell, J.C. (1979). Education as a factor in mortality decline: An examination of Nigerian data. *Population Studies*, 33, 395–413
- Carter, K. L., Cornelius, M., Taylor, R., Ali, S. S., Rao, C., Lopez, A. D., . . . Mowry, C. (2011). Mortality trends in Fiji. *Australian and New Zealand Journal of Public Health*, 35(5), 412–420.
- Carter, K. L., Tovu, V., Langati, J. T., Buttsworth, M., Dingley, L., Calo, A., . . . Taylor, R. (2016). Causes of death in Vanuatu. *Population Health Metrics*, 14(7), 1–9.
- Chang, H. S. C., Mullen, B., Anjen, J., & Be'Soer, L. (2014). *Assessing the socioeconomic impact of a rural market: The case of Mt Hagen Market in the Papua New Guinea Highlands* (Australasian Agribusiness Perspectives Paper No. 98).
<https://doi.org/10.22004/ag.econ.234409>
- Chowdhury, R.H., Flaxman, A.D., Joseph, J.C., Riley, H.H., Alam, N., Riley, I.D., & Lopez, A.D. (2019). Robustness of the Tarrif method for diagnosing verbal autopsies: Impact of additional site data on the relationship between symptom and cause. *BMC Medical Research Methodology*, 19, 232 Available at <https://doi.org/10.1186/s12874-019-0877-7>
- Cibulski, C., & Hiawalyer, G. (2002). Information systems for health sector monitoring in Papua New Guinea. *Bulletin of the World Health Organization*, 80(9), 752–758

- Coale, A.J., & Demeny, P. (1966). *Regional Model Life Tables and Stable Population*. Princeton, New Jersey: Princeton University Press.
- Coghlan, B., Millan, J., Malau, C., Kaldor, J., & Toole, M. (2011). The HIV epidemic in Papua New Guinea. *Journal of Acquired Immune Deficiency Syndromes*, 58(2), e48–51.
- Connolly, B., & Anderson, R. (1987). *First contact*. New York, NY: Viking Press.
- Day, B. (2009). The primacy of politics: Charting the governance of the Papua New Guinea health system since Independence, *PNG Medical Journal*, 52, 3-4
- Department of National Planning and Monitoring. (2015). *Summary Report for Papua New Guinea. Millennium Development Goals 2015*. Port Moresby, Papua New Guinea: DNPM.
- Department of Public Health. (1973). *Hospital and health centre disease statistics 1968-1972*. Port Moresby. Department of Health. p. 59
- Department of Public Health. (1974). *Papua New Guinea National Health Plan 1974-1978*. Konedobu. Kristen Press Incorporation. p. 23-26
- Desai, S., & Alva, S. (1998). Maternal education and child health: Is there a strong causal relationship? *Demography*, 35(1), 71-81.
- Doll, R., & Hill, A.B. (1950). Smoking and carcinoma of the lung; Preliminary report. *British Medical Journal*, 2(4682), 739-48.
- Dorrington, R. (2013a). The Brass Growth Balance method. In T. Moultrie T, R. Dorrington, A. Hill, K. Hill, I. Timaeus & B. Zaba (Eds.), *Tools for demographic estimation* (pp 196-208). Paris, France: International Union for the Scientific Study of Population. Available from <http://demographicestimation.iussp.org>.
- Dorrington, R. (2013b). The Generalized Growth Balance method. In T. Moultrie, R. Dorrington, A. Hill, K. Hill, L. Timaeus & B. Zaba (Eds.), *Tools for demographic estimation* (pp. 258–274). Paris, France: International Union for the Scientific Study of Population. Available from <http://demographicestimation.iussp.org>.

- Dorrington, R. (2013c). The Generalized Growth Balance method. In T. Moultrie, R. Dorrington, A. Hill, K. Hill, L. Timaeus & B. Zaba (Eds.), *Tools for demographic estimation* (pp. 275–292). Paris, France: International Union for the Scientific Study of Population. Available from <http://demographicestimation.iussp.org>.
- Douglas, R. M. (2010). Pneumonia in Papua New Guinea, from the past to the future. *Papua New Guinea Medical Journal*, 53(3–4), 99–105.
- Duke, T. (1999). Decline in child health in rural Papua New Guinea. *The Lancet*, 354(9186), 1291–1294. [https://doi.org/10.1016/S0140-6736\(99\)00335-9](https://doi.org/10.1016/S0140-6736(99)00335-9)
- Duke, T., Yano, E., Hutchinson, A., Hwaihwanje, I., Aipit, J., Tovilu, M., . . . Amini, J. (2016). Large-scale data reporting of paediatric morbidity and mortality in developing countries: It can be done. *Archives of Disease in Childhood*, 101(4), 392–397.
- Fearon, J.D. (2003). Ethnic and Cultural Diversity by Country. *Journal of Economic Growth*, 8, 195–222.
- Flaxman, A.D., Vahdatpour, A., Xiao, D., James, S.L., & Murray, C.J.L. (2011). Random forests of verbal autopsy analysis: Multisite validation study using clinical diagnostic gold standards. *Population Health Metrics*, 9(1), 29. Available at DOI: 10.1186/1478-79954-9-29.
- Garner, P., Heywood, P., Baea, M., Lai, D., & Smith, T. (1996). Infant mortality in a deprived area of Papua New Guinea: Priorities for antenatal services and health education. *Papua New Guinea Medical Journal*, 39(1), 6–11.
- Gibson, J., Datt, G., Allen, B., Hwang, V., Bourke, M. R., & Parajuli, D. (2005). Mapping poverty in rural Papua New Guinea. *Pacific Economic Bulletin*, 21(1), 1–26.
- Gibson, J., & Rozelle, S. (2002). *Poverty and access to infrastructure in Papua New Guinea* (UC Davis Working Paper No. 02-008). Davis, CA: California Agricultural Experiment Station.
- Gouda, H., Hazard, R. H., Maraga, S., Flaxman, A. D., Stewart, A., Joseph, J. C., . . . Riley, I. D. (2019). The epidemiological transition in Papua New Guinea: New evidence from

- verbal autopsy studies. *International Journal of Epidemiology*, 48(3), 966–977.
<https://doi.org/10.1093/ije/dyz018>
- Gouda, H., Lehmann, D., & Riley, I. D. (2013). *Measurement of cause of death in Papua New Guinea populations using a locally developed verbal autopsy instrument: 1970-2001* (Working Paper No. 36). Brisbane: Health Information Systems Knowledge Hub, University of Queensland.
- Greenberg, S.J. (1997). The “Dreadful Visitation”: Public health and public awareness in the seventeenth century. *Bulletin of Medical Library Association*, 85(4), 391-401.
- Hanson, L. W. (2001). *Papua New Guinea rural development handbook*. Canberra, ACT: Land Management Group, Department of Human Geography, Research School of Pacific and Asian Studies, Australian National University.
- Herman, J., Ameratunga, S., & Jackson, R. (2012). Burden of road traffic injuries and related risk factors in low and middle-income Pacific Island countries and territories: A systematic review of the literature (TRIP 5). *BMC Public Health*, 12(1), 111.
<https://doi.org/10.1186/1471-2458-12-479>
- Hetzel, M. W., Pulford, J., Ura, Y., Jamea-Maiasa, S., Tandrapah, A., Tarongka, N., . . . Mueller, I. (2017). Insecticide-treated nets and malaria prevalence, Papua New Guinea, 2008–2014. *Bulletin of the World Health Organization*, 95(10), 695–705B.
- Hill, K. (1987). Estimating census and death registration completeness. *Asian and Pacific Census Forum*, 1, 8–13.
- Hill, K., You, D., Choi, Y. (2009). Death distribution methods for estimating adult mortality: sensitivity analysis with simulated data error. *Demographic Research*, 21, 235–254.
- Howes, S., Mako, A.A., Swan, A., Walton, G., Webster, T., & Wiltshire, C. (2014). *A lost decade? Service delivery and reforms in Papua New Guinea 2002 – 2012*, The National Research Institute and the Development Policy Centre, Canberra.

- Kakazo, M., Lehmann, D., Coakley, K., Gratten, H., Saleu, H., Taime, J., . . . Alpers, M. (1999). Mortality rates and the utilization of health services during terminal illness in the Asaro Valley, Eastern Highlands Province, Papua New Guinea. *Papua New Guinea Medical Journal*, 42(1-2), 13-26
- Kitur, U. (2012). Health information challenges for Papua New Guinea. *Pacific Health Dialog*, 18(1), 29–31.
- Kitur, U., Adair, T., & Lopez, A. D. (2019a). Estimating adult mortality in Papua New Guinea, 2011. *Population Health Metrics*, 17(1), 1–14. <https://doi.org/10.1186/s12963-019-0184-x>
- Kitur, U., Adair, T., & Lopez, A. D. (2019b). Patterns of all-cause mortality in Papua New Guinea, 2011. *Asia Pacific Journal of Public Health*, 31(4), 315–324. <https://doi.org/10.1177%2F1010539519841492>
- Kitur, U., Adair, T., Riley, I., & Lopez, A. D. (2019). Estimating the pattern of causes of death in Papua New Guinea. *BMC Public Health*, 19(1), 1322. <https://doi.org/10.1186/s12889-019-7620-5>
- Lagani, W., Mokela, D., Saweri, W., Kiromat, M., Ripa, P., Vince, J., . . . Duke, T. (2010). Papua New Guinea: Real progress towards MDG 4 and real challenges. *International Health*, 2(3), 186–196.
- Lawrence, C. (2004). 'Cholera, chloroform and the science of medicine: a life of John Snow', *Medical History*, 48(4), pp 531-532.
- Lehmann, D. (1991). Mortality and morbidity from acute lower respiratory tract infections in Tari, Southern Highlands Province 1977-1983. *Papua New Guinea Medical Journal*, 34, 174-184.
- Ley, S. D., Riley, I., & Beck, H. P. (2014). Tuberculosis in Papua New Guinea: From yesterday until today. *Microbes and Infection*, 16(8), 607–614.

- Lim, S. S., Allen, K., Bhutta, Z. A., Dandona, L., Forouzanfar, M. H., Fullman, N., . . . Murray, C. J. L. (2016). Measuring the health-related sustainable development goals in 188 countries: A baseline analysis from the Global Burden of Disease Study 2015. *The Lancet*, 388(10053), 1813–1850.
- Lopez, A. D., & Setel, P. W. (2015). Better health intelligence: A new era for civil registration and vital statistics? *BMC Medicine*, 13(1), 73 <https://doi.org/10.1186/s12916-015-0333-4>
- Lopez, A.D. (1983). “The sex mortality differential in developed countries”, in A. D. Lopez and L. T. Ruzicka (eds.), *Sex Differentials in Mortality*. Canberra: Australian National University Press.
- Maddocks, I. (1973). History of Disease in Papua New Guinea. In C. Bell (Eds.), *The Diseases and Health Services of Papua New Guinea* (pp 70-74). Port Moresby: Department of Public Health.
- Mahapatra, P., Shibuya, K., Lopez, A. D., Coullare, F., Notzon, F. C., Rao, C., & Szreter, S. (2007). Civil registration systems and vital statistics: Successes and missed opportunities. *The Lancet*. 370(9599), 1653–1663.
- Matai, S., Peel, D., Wandi, F., Jonathan, M., Subhi, R., & Duke, T. (2008). Implementing an oxygen programme in Papua New Guinea. *Annals of Tropical Paediatrics*, 28, 71-78.
- Mathers, C.D., Ma Fat, D., Inoue, M., Rao, C., & Lopez, A.D. (2005) . Counting the dead and what they died from: An assessment of the global status of cause of death data / Colin D. Mathers [et al.]. *Bulletin of the World Health Organization: The International Journal of Public Health* 2005; 83(3) : 171-177 <https://apps.who.int/iris/handle/10665/72966>
- Matterson, D., Douglas, M., & Bhattacharya, S. (2017). *Independent review of the PNG NHIS for rural primary health services delivery*. Port Moresby, Papua New Guinea: National Department of Health.

- McGehee, M. (2004). Mortality. In J. S. Siegel & D. A. Swanson (Eds.), *The methods and materials of demography* (pp. 265–300). San Diego, CA: Elsevier Academic Press.
- McGovern, M.E., & Canning, D. (2015). Vaccination and All-Cause Child Mortality from 1985 to 2011: Global Evidence from the Demographic and Health Surveys. *American Journal of Epidemiology*, 182(9), 791-8.
- McKeown, R.E. (2009). The Epidemiologic Transition: Changing Patterns of Mortality and Population Dynamics. *American Journal of Lifestyle Medicine*, 3(1), 19S–26S. Available from doi: 10.1177/1559827609335350.
- Mikkelsen, L., Phillips, D. E., AbouZhar, C., Setel, W., de Savigny, D., Lozano, R., & Lopez, A. D. (2015). A global assessment of civil registration and vital statistics systems: Monitoring data quality and progress. *The Lancet*, 386(10001), 1395–1406.
- Mola, G., & Kirby, B. (2013). Discrepancies between national maternal mortality data and international estimates: The experience of Papua New Guinea. *Reproductive Health Matters*, 21(42), 191–202. [https://doi.org/10.1016/S0968-8080\(13\)42725-8](https://doi.org/10.1016/S0968-8080(13)42725-8)
- Montgomery, J. (2017). *Foundations for a successful CRVS eco-system in Papua New Guinea*. Port Moresby, Papua New Guinea: National Department of Health.
- Montgomery, J. (2019). *Papua New Guinea CRVS system assessment: 2019*. Noumea, New Caledonia: PNG CRVS Committee and the Pacific Community. 34 p. Retrieved from <https://sdd.spc.int/media/812>
- Moradi-Lakeh, M., Sepanlou, S. G., Karimi, S. M., Khalili, N., Djalalinia, S., Karimkhani, C., . . . Naghavi, M. (2017). Trend of socio-demographic index and mortality estimates in Iran and its neighbors, 1990–2015; findings of the Global Burden of Diseases 2015 Study. *Archives of Iranian Medicine*, 20(7), 419–425.
- Morens, D. M., & Fauci, A. S. (2013). Emerging infectious diseases: Threats to human health and global stability. *PLoS Pathogens*, 9(7): e1003467. <https://doi.org/10.1371/journal.ppat.1003467>

- Moultrie, T. A., & Timaeus, I. A. (2013). Introduction to model life tables. In T. Moultrie, R. Dorrington, A. Hill, K. Hill, L. Timaeus & B. Zaba (Eds.), *Tools for demographic estimation* (pp. 341–347). Paris, France: International Union for the Scientific Study of Population.
- Murray, C. J. L., Ferguson, B. D., Lopez, A. D., Guillot, M., Salomon, J. A., & Ahmad, O. (2003). Modified logit life table system: Principles, empirical validation, and application. *Population Studies*, 57(2), 165–182.
- Murray, C. J. L., & Lopez, A. D. (Eds.). (1996). The global burden of disease: A comprehensive assessment of mortality and disability from diseases, injuries, and risk factors in 1990 and projected to 2020: Summary. Geneva, Switzerland: World Health Organization. <http://www.who.int/iris/handle/10665/41864>.
- Murray, C.J.L., & Lopez, A. (1997). Mortality by cause for eight regions of the world: Global Burden of Disease Study. *Lancet*, 349, 1269-1276.
- Murray, C.J.L., Rajaratnam, J.K., Marcus, J., Laakso, T., & Lopez, A.D. (2010). What can we conclude from death registration? Improved methods for evaluating completeness. *PLoS Medicine*, 7: e1000262. Available from: <http://journals.plos.org/plosmedicine/article?id=10.1371/journal.pmed.1000262>. [pmid:20405002](https://pubmed.ncbi.nlm.nih.gov/20405002/)
- Murray, C.J.L., Lopez, A.D., Black, R., Ahuja, R., Ali, S.M., Baqui, A., . . . Tallo, V. (2011). Population Health Metrics Research Consortium gold standard verbal autopsy validation study: design, implementation, and development of analysis datasets. *Population Health Metrics* 9, 27. Available at <https://doi.org/10.1186/1478-7954-9-27>
- Naghavi, M., Abajobir, A. A., Abbafati, C., Abbas, K. M., Abd-Allah, F., Abera, S. F., . . . Murray, C. J. L. (2017). Global, regional, and national age-sex specific mortality for 264 causes of death, 1980–2016: A systematic analysis for the Global Burden of Disease Study 2016. *The Lancet*, 390(10100), 1151–1210.

Naraqi, S., Feiling, B., & Leeder, S. R. (2003). Disease and death in Papua New Guinea. *Medical Journal of Australia*, 178(1), 7–8. <https://doi.org/10.5694/j.1326-5377.2003.tb05030.x>

National Department of Health. (2011a). *National Health Service Standards for Papua New Guinea 2011-2020*. Port Moresby, Papua New Guinea: National Department of Health. Available at https://hwfsm.png.net/publications/NHSS_PNG_2011-2020_Vol1&2/national_health_service_standards_for_png_2011-2020_Vol1.pdf

National Department of Health. (2011b). *Sector performance annual review 2007–2011*. Port Moresby, Papua New Guinea: National Department of Health.

National Department of Health. (2015a). *Sector performance annual review 2011–2015*. Port Moresby, Papua New Guinea: National Department of Health.

National Department of Health. (2015b). *Independent Annual Mid-Sector Review of the National Health Plan, 2015*. Port Moresby, Papua New Guinea: National Department of Health.

National Department of Health. (1986). *Papua New Guinea National Health Plan 1986-1990*. Port Moresby, Papua New Guinea: National Department of Health.

National Department of Health. (2016). *National Health Information System (NHIS) and Discharge Health Information System (DHIS)*. Port Moresby, Papua New Guinea: National Department of Health.

National Department of Health. (2019). *2018 STI/HIV & AIDS program annual report*. Port Moresby, Papua New Guinea: National Department of Health.

National Economic and Fiscal Commission. (2004). *Review of intergovernmental financing arrangements (RIGFA): NEFC Less Developed District Index*. Port Moresby, Papua New Guinea: NEFC.

National Research Institute. (2001). *Review of NEFC's less developed provinces and districts*. Port Moresby, Papua New Guinea: Author.

- National Research Institute. (2010). *Papua New Guinea district and provincial profiles*. Port Moresby, Papua New Guinea: National Research Institute.
- National Statistical Office. (1995). *Report on the 1991 demographic and health survey*. Port Moresby, Papua New Guinea: National Statistical Office.
- National Statistical Office. (1997). *Papua New Guinea demographic and health survey 1996: National Report*. Port Moresby, Papua New Guinea: National Statistical Office.
- National Statistical Office. (2009). *Papua New Guinea Demographic and Health Survey: 2006 National Report*. Port Moresby, National Statistical Office.
- National Statistical Office (2000). *The national population and housing census for Papua New Guinea for 2000*. Port Moresby, Papua New Guinea: National Statistical Office.
- National Statistical Office. (2011a). *Mortality situation, trend and differentials in Papua New Guinea based on the analysis of data from censuses and demographic and health surveys* (2011 Census Research Monograph No. 1). Port Moresby, Papua New Guinea: National Statistical Office (2011b). *The national population and housing census for Papua New Guinea for 2011*. Port Moresby, Papua New Guinea: National Statistical Office.
- National Statistical Office. (2015a). *The national population and housing census for Papua New Guinea for 2011: Count me in*. Port Moresby, Papua New Guinea: NSO.
- National Statistical Office (2015b). *Papua New Guinea 2011 national report*. Port Moresby, Papua New Guinea: NSO.
- O'Connor, S.M., Taylor, C.E., & Hughes, J.M., (2006). Emerging Infectious Determinants of Chronic Diseases. *Emerging Infectious Diseases*, 12(7), 1051–1057.
- Oksuzyan, A., Juel, K., Vaupel, J. W., & Christensen, K. (2008). Men: Good health and high mortality. Sex differences in health and aging. *Aging Clinical and Experimental Research*, 20(2), 91–102.

- Omran, A.R. (1971). The Epidemiologic Transition: A theory of the Epidemiology of Population Change. *The Milbank Memorial Fund Quarterly*, 83(4), 731-757.
- Pery, J., & Elapa, J. (2012), Hela, Jiwaka declared. *The National*, Retrieved from <https://www.thenational.com.pg/hela-jiwaka-declared/>
- Pham, B.N., Maraga, S., Kunai, J., Emori, R., Boli, R., Aga, T., . . . Siba, P. (2015). Papua New Guinea Institute of Medical Research Progress Report, Partnership in Health Project, July 2014 – December 2014. Goroka, Eastern Highlands Province: PNGIMR.
- Preston, S.H., Coale, A.J., Trussell, J., Weinstein, M. (1980). Estimating the completeness of reporting of adult deaths in populations that are approximately stable. *Population Index*, 46, 179–202. pmid:12310104
- Preston, S.H., Heveline, P., & Guillot, M. (2001). *Demography: Measuring and Modeling Population Processes*. Willey-Blackwell.
- Rajaratnam, J. K., Marcus, J. R., Levin-Rector, A., Chalupka, A. N., Wang, H., Dwyer, L., . . . Murray, C. J. K. (2010). Worldwide mortality in men and women aged 15–59 years from 1970 to 2010: A systematic analysis. *The Lancet*, 375(9727), 1704–1720.
- Rajaratnam, J. K., Tran, L. N., Lopez, A. D., & Murray, C. M. L. (2010). Measuring under-five mortality: Validation of new low-cost methods. *PLoS Medicine*, 7(4), e1000253. <https://doi.org/10.1371/journal.pmed.1000253>
- Rao, C., Soemantri, S., Djaja, S., Suhardi, S., Adair, T., Wiryawan, Y., . . . Lopez, A.D. (2010). Mortality in central Java: Results from the Indonesian Mortality Registration System Strengthening Project. *BMC Research Notes*, 3, 325, 1-8. Available from: <https://bmcresearchnotes.biomedcentral.com/articles/10.1186/1756-0500-3-325>. pmid:21122155
- Rarau, P., Vengiau, G., Gouda, H., Phuanukoonon, S., Kevau, I. H., Bullen, C., . . . Pulford, J. (2017). Prevalence of non-communicable disease risk factors in three sites across

- Papua New Guinea: A cross-sectional study. *BMJ Global Health*, 2(2), e00021.
<https://doi.org/10.1136/bmjgh-2016-000221>
- Rarau, P., Pulford, J., Gouda, H., Phuanukoonon, S., Bullen, C., Scragg, R., . . . Oldenberg, B. (2019). Socio-economic status and behavioural and cardiovascular risk factors in Papua New Guinea: A cross-sectional survey. *PLoS ONE*, 14(1), e0211068. <https://doi.org/10.1371/journal.pone.0211068>.
- Reilly, B., Brown, M., & Flower, S. (2014). *Political Governance and Service Delivery in Papua New Guinea: A Strategic Review of Current and Alternative Governance...*pg 1-88 : <https://www.researchgate.net/publication/270794493>
- Riley, I.D. (1979). *Pneumonia in Papua New Guinea. A study of the effects of western medicine upon disease in a developing country (MD thesis)*, Sydney: University of Sydney.
- Riley, I. (2009). Demography and the epidemiology of disease in Papua New Guinea. *Papua New Guinea Medical Journal*, 52(3–4), 83–95.
- Riley, I. D. (2010). Pneumonia research in Papua New Guinea: 1967–1986. *Papua New Guinea Medical Journal*, 53(3–4), 106–118.
- Romaine, S. (1992). *Language, education, and development: Urban and rural Tok Pisin in Papua New Guinea*. New York, NY: Oxford University Press.
- Roth, G. A., Abate, D., Abate, K. H., Abay, S. M., Abbafati, C., Abbasi, N., . . . Murray, C. J. L. (2018). Global, regional, and national age-sex-specific mortality for 282 causes of death in 195 countries and territories, 1980–2017: A systematic analysis for the Global Burden of Disease Study 2017. *The Lancet*, 392(10159), 1736–1788.
- Rouka, I., & Mathias, E. *Fellowship report: An analysis of cause of death data from Papua New Guinea*. CRVS country perspectives. Melbourne, Australia: Bloomberg Philanthropies Data for Health Initiative, Civil Registration and Vital Statistics Improvement, the University of Melbourne and National Department of Health, Papua New Guinea; 2018. Retrieved from <https://crvsgateway.info/file/9785/2376>

- Salomon, J.A., & Murray, C.J.L. (2002). The Epidemiologic Transition Revisited: Compositional Models for Causes of Death by Age and Sex. *Population and Development Review*, 28(2), 205-228
- Scragg, R.F.R. (1977). Historical epidemiology in Papua New Guinea. *Papua New Guinea Medical Journal*, 20(3), 102-109
- Scragg, R. F. R. (1954). *Depopulation in New Ireland: A study of demography and fertility* (MD thesis). Port Moresby, New Guinea: Administration of Papua and New Guinea.
- Serina, P., Riley, I., Stewart, A., Spencer, L.J., Flaxman, A.D., Lozano, R., . . . Lopez, A.D. (2015). Improving performance of the Tariff Method for assigning causes of death to verbal autopsies. *BMC Medicine* 13, 291. Available at <https://doi.org/10.1186/s12916-015-0527-9>
- Silva, R. (2010). Child mortality estimation: Consistency of under-five mortality rate estimates using full birth histories and summary birth histories. *PLoS Medicine*, 9(8), 1013.
- Tanser, F., Lesueur, D., Solarsh, G., & Wilkinson, D. (2000). HIV heterogeneity and proximity of homestead to roads in rural South Africa: an exploration using a geographical information system. *Tropical Medicine and International Health*, 5(1), 40–46.
- Taylor, R., Carter, K., Naidu, S., Linhart, C., Azim, S., Rao, C., & Lopez, A.D. (2013). Divergent mortality trends by ethnicity in Fiji. *Australia and New Zealand Journal of Public Health*, 37(6), 509-515. Available at <https://doi.org/10.1111/1753-6405.12116>
- Taylor, R., Dobson, A., & Mirzaei, M. (2006). Contribution of changes in risk factors to the decline of coronary heart disease mortality in Australia over three decades. *European Journal of Cardiovascular Preventive Rehabilitation*, 13(5), 760-8.
- Timaeus, I. (1992). The estimation of adult mortality from paternal orphanhood: A reassessment of a new approach. *Population Bulletin of the United Nations*, 33, 47-63
- Timaeus, I. (2013a). Indirect estimation of adult mortality from orphanhood. In T. Moultrie, R. Dorrington, A. Hill, K. Hill, L. Timaeus & B. Zaba (Eds.), *Tools for demographic*

- estimation* (pp. 222–243). Paris, France: International Union for the Scientific Study of Population.
- Timaeus, I. (2013b). Indirect estimation from orphanhood in multiple enquiries. In T. Moultrie, R. Dorrington, A. Hill, K. Hill, L. Timaeus & B. Zaba (Eds.), *Tools for demographic estimation* (pp. 293–308). Paris, France: International Union for the Scientific Study of Population.
- Townsend, P.K. (1985). Infant mortality in the Saniyo-Hiyowe Population, Ambunti District, East Sepik Province. *Papua New Guinea Medical Journal*, 28, 177-182.
- Tran, L. N., Bauze, A., Nguyen, K. H., Firth, S., & Jimenez-Soto, E. (2011). *Under-five mortality analysis for Papua New Guinea* (Investment Case MDGs 4 and 5). Brisbane, Qld: School of Population Health, University of Queensland.
- United Nations. (1982). *Model Life Tables for Developing Countries*. United Nations; New York, NY, USA. p. 351.
- United Nations Children’s Fund. (1999). *The state of the world’s children 1998*. New York, NY: Oxford University Press.
- United Nations Department of Economic and Social Affairs, Population Division. (2013). *World Population Prospects: The 2012 Revision, Volume I Comprehensive Tables*. New York. United Nations.
- United Nations Department of Economic and Social Affairs, Population Division. (2017). *World mortality report 2017, CD-ROM edition*. Retrieved from <http://www.un.org/en/development/desa/population/publications/mortality/world-mortality-cdrom-2017.shtml>
- United Nations Development Programme. (2005). Investing in Development. A Practical Plan to Achieve the Millennium Development Goals, New York: United Nations Development Programme. Available at <http://www.unmillenniumproject.org/documents/MainReportComplete-lowres.pdf>.

- United Nations Development Programme. (2015). Transforming our world: The 2030 Agenda for Sustainable Development. United Nations: New York. Available at <https://sustainabledevelopment.un.org/post2015/transformingourworld>
- United Nations Development Programme. (2017). *Human development report 2016: Human development for everyone*. New York, NY: UNDP.
- United Nations Inter-Agency Group for Child Mortality Estimation. (2017). Child mortality estimates. Retrieved from <http://www.childmortality.org>
- van de Kaa, D. J. (1971). *The demography of Papua New Guinea's indigenous population*. Canberra, ACT: Australian National University.
- Waiko, J.D. (2014). A Short History of Papua New Guinea. 2nd Eds, Melbourne, Australia: Oxford University Press, Australia.
- Wang, H., Dwyer-Lindgren, L., Lofgren, K. T., Rajaratnam, J. K., Marcus, J. R., Levin-Rector, A., . . . Lopez, A. D. (2012). Age-specific and sex-specific mortality in 187 countries, 1970–2010: A systematic analysis for the Global Burden of Disease Study 2010. *The Lancet*, 380(9859), 2071–2094.
- Wilmoth, J. R., Zureick, S., Canudas-Romo, V., Inoue, M., & Sawyer, C. (2012). A flexible two-dimensional mortality model for use in indirect estimation. *Population Studies*, 66(1), 1–28.
- World Bank. (2004). *Papua New Guinea: Poverty assessment (English)* (Working Paper No. 66746). Washington, DC: Author. Retrieved from <http://documents.worldbank.org/curated/en/500511468082129284/Papua-New-Guinea-poverty-assessment>
- World Bank. (2014). The costs of crime and violence in Papua New Guinea. Retrieved from <https://www.worldbank.org/en/news/feature/2014/08/15/the-costs-of-crime-and-violence-in-papua-new-guinea>

- World Health Organization. (2016). Global Health Observatory (GHO) data: Adult mortality rate, 2000–2016. Available at https://www.who.int/gho/mortality_burden_disease/mortality_adult/situation_trends_text/en/
- World Health Organization. (2014). Improving Mortality Statistics through Civil Registration and Vital Statistics Systems. Outcome of a technical meeting. Geneva: WHO. Available https://www.who.int/healthinfo/civil_registration/CRVS_MortalityStats_Guidance_No_v2014.pdf
- World Health Organization. (2018). Noncommunicable diseases country profiles 2018. Geneva: World Health Organization. Available at <https://www.who.int/nmh/publications/ncd-profiles-2018/en/>
- World Health Organization. (2018). Global Youth Survey Papua New Guinea 2016. Geneva: World Health Organization. Available at https://www.researchgate.net/publication/23758200_The_Global_Youth_Tobacco_Survey_G
- World Health Organization. (2017). WHO STEPS Surveillance Manual: The WHO STEPwise approach to noncommunicable risk factor surveillance. Geneva. WHO. Available at <https://www.who.int/ncds/surveillance/steps/en/>
- Zotnik, H., & Hill, K. (1981). The use of hypothetical cohorts in estimating demographic parameters under conditions of changing fertility and mortality. *Demography*, 18(1), 103–122.