



Population Data Collection and Assessment

THEMATIC REPORT ON MORTALITY AND FERTILITY

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Thematic Report on Mortality and Fertility

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List of abbreviations and acronyms

ADB	Asian Development Bank
AIDS	Acquired immunodeficiency syndrome
ANC	Antenatal care
ASFR	Age-specific fertility rate
DHS	Demographic and Health Survey
EC	European Commission
EVAW	Elimination of Violence Against Women
FP	Family Planning
GBV	Gender-based violence
GII	Gender Inequality Index
HCS	Health Care Service
HIV	Human immunodeficiency virus
ICPD	International Conference on Population and Development
IEC	Information, Education and Communication
IMR	Infant Mortality Rate
JICA	Japan International Cooperation Agency
MDGs	Millennium Development Goals
MICS	Multiple Indicators Cluster Survey
MNH	Maternal and Neonatal health
NGO	Non-governmental organization
OECD	Organization for Economic Cooperation and Development
PD	Population and Development
PDS	Population and Development Strategies
PHC	Primary Health Care
PRMR	Pregnancy-Related Mortality Ratio
RH	Reproductive Health
SBH	Summary Birth History
SDG	Sustainable Development Goals
SRH	Sexual and Reproductive Health
TFR	Total Fertility Rate
UN	United Nations
UNDP	United Nations Development Programme
UNFPA	United Nations Population Fund
UNHCR	United Nations High Commission for Refugees
UNICEF	United Nations Children’s Fund
VAW	Violence Against Women
WHO	World Health Organization

Glossary for the Report on Early Childhood Mortality

Age at first birth: The mean age in years of women at birth of first child. Coverage includes women of all marital statuses.

Average parity: The mean number of children ever born per woman, which is frequently calculated by the age of the women.

Age-specific probability of death: The probability that a person would not survive from a specific age x until the $x+n$ birthday, usually expressed per 1,000 persons. This indicator is represented with the symbol ${}_nq_x$ in the life table notation, with letter “ q ” indicating a mortality rate, the number “ x ” at the right-hand side of letter “ q ” indicating the exact age when the time of exposure to death starts, and number “ n ” at the left-hand side of letter “ q ” indicating the span of the exposure time interval, in years. The infant mortality rate and under-five mortality rates are particular cases of age-specific probabilities of death, having as starting age “zero” or the moment of birth, and exposure times of one and five years respectively: ${}_1q_x$, ${}_5q_x$.

Birth intervals: Time intervals between successive births to the same mother.

Birth order: Births are also classified by birth order for example, first births, second births, etc. A distinction by order of births is made with multiple births. Therefore, one twin is classified as being born before the other, no matter how close they come to being delivered simultaneously.

Child marriage: A marriage in which at least one of the parties is a child. According to the Convention on the Rights of the Child, a child is “every human being below the age of eighteen years unless under the law applicable to the child, majority is attained earlier”.

Cohort: A group of people sharing a common temporal demographic experience who are observed through time. For example, the birth cohort of 1900 is the people born in that year. There are also marriage cohorts, school class cohorts, etc.

Cohort analysis: Observation of a cohort’s demographic behaviour through life or through many periods. For example, examining the fertility behaviour of the cohort of people born between 1940 and 1945 through their entire childbearing years. Rates derived from such cohort analyses are cohort measures.

Children ever born (CEB): Information on number of children born alive (lifetime fertility) should include all children born alive (that is to say, excluding foetal deaths) during the lifetime of the woman reporting, up to the census date. The number recorded should include all live-born children, whether born in or out of marriage or whether living or dead at the time of the census.

Children surviving: Information on number of children ever born who are still alive at the time of the survey. The number recorded should include all live-born children, who are alive at the time of the survey, regardless of the place where they are living.

Complete fertility rate: The number of children born per woman to a cohort of women by the end of their childbearing years.

Early marriage: Marriage involving a person aged below 18 in countries where the age of majority is attained earlier or upon marriage. Early marriage can also refer to marriages where both spouses are 18 or older but other factors make them unable to consent to marriage. Such might include their level of physical, emotional, sexual and psychosocial development, or a lack of information regarding the person’s life options.

Early childhood mortality: Mortality indicators for a range of ages, generally younger than 15. It is frequently used in relation to indirect estimation methods which convert proportions of deceased children to mothers in different age groups, into conventional life table indicators, such as from birth to ages one, two, three, five, ten, fifteen. These are then converted into a unique indicator (most frequently infant mortality or under-five mortality rates), with the aim of facilitating the comparison of the mortality levels. Yet, the term “early childhood” is used to emphasise that the measurements originally obtained were not one single indicator (${}_1q_0$ or ${}_5q_0$) but a set of indicators for different age intervals, which were then converted into a single common interval.

Infant mortality rate: The probability that a child will survive from birth until their first birthday, i.e. age one, usually expressed per 1,000 live births. This indicator is represented with the symbol ${}_1q_0$ in the life table notation, with letter “ q ” indicating a mortality rate, the number at the right-hand side of letter “ q ” indicating the starting point of the exposure time to the risk of dying, in this case “0” which is the exact age zero or the moment of birth. The number at the left-hand side of letter “ q ” indicates the end of the interval of exposure time to the risk of dying, in this case “1” one-year exposure time, that is up to exact age one.

Live birth: The complete expulsion or extraction of a child from its mother, irrespective of the duration of pregnancy, which after such separation the child breathes or shows any other evidence of life, such as beating of the heart, pulsation of the umbilical cord or definite movement of voluntary muscles, whether or not the umbilical cord has been cut or the placenta is attached. Each product of such a birth is considered live-born.

Parity: The total number of live children a woman has borne. A woman who has not borne any live children is called a zero-parity woman; a one parity woman has borne one live child but no more, and so on.

Relational Gompertz Model: The model seeks to estimate age-specific and total fertility by determining the shape of the fertility schedule from data on recent births reported in censuses or surveys, while determining its level from the reported average parities of younger women. In producing estimates of age-specific and total fertility, the method seeks to remedy the errors commonly found in fertility data associated with too few or too many births being reported in the reference period, and the under-reporting of lifetime fertility and errors of age reporting among older women.

Sex ratio: The ratio of the number of men to the number of women in a population or other specific group, usually expressed as the number of men per one hundred women.

Under-five mortality rate: The probability that a child will not survive from birth to their fifth birthday or exact age five, expressed per 1,000 births. This indicator is represented with the symbol ${}_5q_0$, in the life table notation. Letter q indicates it is a mortality rate, the number at the right-hand side of letter q indicates the starting point of the exposure time to death, in this case "0": exact age zero or moment of birth. The number at the left-hand side of letter q indicates the end of the interval of exposure time to the risk of dying, in this case "5": a five-year time interval, or up to exact age five.

Sources for glossary

Population Reference Bureau

<https://www.prb.org/resources/glossary/>

Demopædia

<http://www.demopaedia.org/tools/?Index-search>

USAID’s Data for Impact (D4I)

http://www.cpc.unc.edu/measure/prh/rh_indicators/specific/fertility/age-at-first-birth

United Nations

World Population Prospects 2008

<http://www.un.org/esa/population/publications/WMD2008/Metadata/SMAM.html>

<http://unstats.un.org/unsd/demographic/sconcerns/mar/marmethods.htm>

http://www.un.org/esa/population/publications/WFR2009_Web/Data/Meta_Data/EVER%20MAR-RIED%20WOMEN%20AND%20MEN.pdf

http://www.un.org/esa/population/publications/WMD2008/Metadata/CUR_MAR.html

<http://unstats.un.org/unsd/demographic/sconcerns/natality/natmethods.htm#A>

Glossary of Demographic Terms

<http://esa.un.org/unpd/wpp/General/GlossaryDemographicTerms.aspx>

Preventing and eliminating child, early and forced marriage. Report of the Office of the United Nations High Commissioner for Human Rights. Twenty-sixth session. Agenda items 2 and 3, p. 3-4.

<https://digitallibrary.un.org/record/771507>

International Union for the Scientific Study of Population (IUSSP)

Overview of fertility estimation methods based on the P/F ratio

<http://demographicestimation.iussp.org/content/overview-fertility-estimation-methods-based-pf-ratio>

The relational Gompertz model

<http://demographicestimation.iussp.org/content/relational-gompertz-model>

Estimation of fertility by reverse survival

<http://demographicestimation.iussp.org/content/estimation-fertility-reverse-survival>







Executive Summary

The study of fertility and mortality constitute core components of the demographic dynamics and population situation of a country. The present report estimates fertility and mortality for Papua New Guinea (PNG), based on the information gathered I 2022 through the Socio-Demographic and Economic Survey (PNG 2022 SDES).

Age-specific fertility rates, total fertility rates, infant and under-five mortality rates and adult mortality estimates by sex were obtained, based on indirect estimation of relevant demographic indicators. By combining the mortality estimates pertaining the first years of life with probabilities of survivorship for adult ages by sex, abridged life tables by sex were developed, completing the relevant set of indicators of the demographic situation in PNG, excluding migration estimates.

Fertility estimation

The level of fertility and its age distribution were estimated based on Brass P/F ratio method and the relational Gompertz model method. The results obtained from these two methods were quite similar. Yet it was decided to adopt the fertility level and age distribution derived from W. Brass’s method since it retains more closely the patterns by age as reported in the survey. Since the basic data appears to be of good quality, it seems more reasonable to accept results that are closer to the basic information, adjusting the results only for the errors in the reporting period, which seems affected by an underestimation of a little over ten per cent in the level of fertility. Hence, the total fertility rate (TFR) was estimated to be of 3.72 children per woman.

This level of fertility confirms that PNG continues to experience a sustained fertility decline. The country registered a TFR of 6.26 children per woman in 1970 and has been steadily declining by about half child every decade, reaching 5.70 in 1980, 5.19 in 1990, 4.54 in 2000 and 3.89 in 2010 (United Nations, 2015). Fertility is higher in the rural than in urban areas. The PNG 2022 SDES registered a TFR of 3.95 in rural areas, and 2.61 children per woman respectively in urban areas.

Regarding the age distribution of fertility, the results obtained from Brass P/F method and the relational Gompertz method are very similar, with the main difference registered in the age distribution of fertility in the urban area. Consistent with the reported fertility in the SDES, in the urban area Brass’ method shows a higher fertility concentration in the central age groups from age 25 to age 35, comprising 54.7 per cent of total fertility. In the rural area this age interval concentrates 47 per cent of fertility, with relative higher participation of younger and older age groups, as compared to the urban area.

The total fertility rates and the age-specific fertility rates obtained from data collected in the PNG 2022 SDES, calculated from Brass P/F estimation method and are adopted as the most adequate estimation measures and are presented in Table 6 and Figure 8.

Estimation of under-five mortality rate (5q0) and infant mortality rates (1q0)

The mortality level in early childhood ages in this report is obtained by using indirect estimation methods, which were initially developed by William Brass (Brass W. , 1964), by using recent developments for the estimation process (Moultrie, et al., 2013).

The PNG 2022 SDES revealed that the COVID-19 pandemic has had a relevant impact on PNG’s mortality. Yet, indirect estimation is not adequate to quantify its effect, so the strategy followed was to derive the level of mortality and its trend, not including the point estimates affected by COVID-19. It is assumed that the linear trend would represent the underlying mortality, having isolated the effect of the pandemic.

Based on the PNG 2022 SDES data, using the methodology and assumptions as described in the previous paragraphs, the analysis performed in section 3.2 of the report indicate that infant and under-five mortality levels have been consistently declining over the last decade – except for the impact of the COVID-19 pandemic, as described above. The underlying mortality trends, excluded the COVID-19 pandemic, shows that by 2021 there are about 20 deaths of under-five year children per 1,000 live births; this represents a significant decline: about half that level of 40 per 1,000, which prevailed in 2008. In the same period, infant mortality declined to little over 14 deaths per 1,000 live births in 2021, from a level of 30 deaths per 1,000 live births in 2008 (Table 8 in section 3.2). This is a substantial decline to about half the level of mortality that was prevailing about 20 years earlier.

Differentials in infant and under-five mortality by sex

The same methodology and assumptions were utilized to establish the levels of infant and under-five mortality rates by sex. When the information is sex-disaggregated, the patterns are affected by some variations, probably associated to smaller numbers of observations, which raised some challenges in terms of discerning clear differentials by sex.

The trend lines derived from adjusting the estimated ${}_5q_0$ and ${}_1q_0$ mortality rates render a faster decline in female mortality in 2022, with a level of under-five female mortality of 15.4 deaths per 1,000 live births, compared to a male mortality of 22.1 deaths per 1,000 live births. In 2012, these levels were 37.1 and 34.6 respectively, a slightly higher mortality for females. In any case, except for this uncertainty in the differential for early dates, the trends and overall level seem consistent with other estimates obtained in these analyses.

Differentials in infant and under-five mortality by areas of residence

The estimates for the rural area show patterns of higher mortality level than in the urban area, and show more or less regular trends, except for those estimates dated about 2018 and more recent, when the level of mortality

increases sensibly for reasons already discussed. As expected, the estimates obtained for the urban areas present lower levels of mortality than those levels in the rural area. However, the trend is very irregular, affected by random variations associated to small number of observations in the urban area. Hence, the levels and trend for the urban area were obtained by adapting an estimation approach proposed for indirect estimation of mortality in small areas (Neupert, Fernandez Menjivar, & Fernandez Castilla, 2019). Through this methodology it was possible to derive a consistent time series for the estimates of the infant and under-five mortality rates for the urban area. These trends indicate a level of little more than 20 deaths (exactly 20.21) under-five years, per 1,000 live births in 2022 in the rural area, compared to a level of little over 14 deaths (exactly 14.35) in the urban area. For the infant mortality these values are 14 in rural areas and 10 per 1,000 live births for the urban area (see Table 10, Section 3.2).

Estimation of adult mortality rates ($_{45}q_{15}$) by sex, from orphanhood information

Accurate knowledge of adult mortality levels and trends in the developing world has been hampered by a widespread lack of complete vital registration systems.

The PNG 2022 SDES provides data on parental orphanhood, allowing estimating adult mortality using indirect techniques to calculate mortality risks at adult ages.

Adult mortality is usually defined as mortality at ages 15 and older. In some contexts, the term “adult mortality” refers solely to mortality between ages 15 and 60, to contrast it with older-age mortality, which refers to mortality at ages 60 and above. The conditional probability that a person alive on her 15th birthday would die before her 60th birthday ($_{45}q_{15}$, in the notation of the life table), has been widely used as an appropriate indicator of adult mortality and this is the indicator obtained from the PNG 2022 SDES data.

The calculation of the conditional probabilities was conducted through the Microsoft Excel worksheets available from the IUSSP manual (Moultrie, et al., 2013). In the respective section of this report, the estimated values for the female and male conditional probabilities of surviving ($_{45}q_{15}$), as well as their respective time location are presented in Table 12. Figure 18 presents the time series of adult mortality estimates by sex and the adjusted trend line. The adult mortality estimates show a consistent decline in the level of mortality for both sexes in the early part of the time series, up to approximately 2015, when a reversal of this trend is observed. This reversal in the trend determines that the adjusted trend lines do not follow a linear trend but is better represented by a second-degree parabolic. The higher level of mortality in recent years can be explained by the impact of the COVID-19 pandemic.

Since the estimation methodology does not measure mortality by time-periods, but rather derive mortality estimates from cohort indicators, the reversal of the declining trend is not determined exactly at the time of the pandemic, but at the average location derived for each cohort of respondents; in this way, the estimation methodology is smoothing these trends. Therefore, the impact of the pandemic does not appear as a sudden jump in the mortality level when the pandemic actually occurred in 2019, 2020 and 2021, but appears gradually before those dates. In any case, the adult mortality patterns derived from the PNG 2022 SDES data appear very consistent and reliable.

For the purposes of constructing life tables for year 2020, estimates in the section of these increasing trends were not considered. A linear trend was adjusted on the basis of points before the trend reversal, assuming that the underlying declining mortality trend reflected in these points would be maintained. This implies that the life table would evaluate the underlining mortality trend – excluding the impact of the pandemic – under the assumption that, when the effects of the pandemic were under control, such underlying trend would resume. Under these assumptions, the conditional probability of death from 15 to 60 ($_{45}q_{15}$) for females was estimated at a level of 0.12265 for females and 0.14896 for males, which are the values utilized in the section that follows, to derive life tables by sex for year 2020.

Calculating life tables by sex

Life tables by sex can be estimated by combining the estimates of mortality by sex in the early years of life represented by the under-five mortality rate ($_5q_0$), with estimates of adult mortality level by sex, represented by the conditional probabilities of dying between exact 15 and 60 ($_{45}q_{15}$). The methodology for constructing life tables from these two indicators is based on Brass’ relational logit model of mortality (Brass W. , 1971).

Brass’ logit model is based on a mathematical relation between the functions of two life tables. The life table functions are the age-specific survivorship function $I(x)$, which is the probability that a person would survive from birth to exact age x. Expressed as a probability of surviving for an individual person, the values of the $I(x)$ vary from zero to one ($0 < I(x) < 1$). The logit transformation of the survival function is defined as: $\text{logit } I(x) = -(0.5) \ln\{I(x)[1 - I(x)]\}$; the mathematical function linking the life table functions in the relational model is: $Y(x) = \alpha + \beta Y^{\text{st}}(x)$. The first parameter of this system of models, α , captures differences in the level of mortality between the populations. The second parameter, β , indicates differences in the relationship between the mortality in childhood ages and the mortality in adult ages in the standard life table as compared to the life table in the studied population.

Through this relational mortality model system, having as input for the model the estimated probabilities of death before age five, and the conditional probabilities of death from 15 to 60, by sex, it is possible to calculate all the functions of a life table. Life tables for PNG female and male populations were calculated for the age 2020, using this methodology. The life tables by sex were calculated using the conditional probability of death from 15 to 60 ($_{45}q_{15}$), which was estimated at a level of 0.12265 for females and 0.14896 for males, and the probability of dying before reaching age five ($_5q_0$), calculated as 0.01783 for girls and 0.02334 for boys. On the basis of these input values, the life expectancy at birth in 2020 was calculated as 70.92 years for women and 69.12 years for men. The life tables including all the functions are presented in the last section of analyses of this report.

Foreword by the National Statistician

It is my pleasure to release the 2022 Papua New Guinea Socio-Demographic and Economic Survey's (SDES) thematic report on Fertility and Mortality. The release of this report is another milestone achievement for the National Statistical Office (NSO) in its endeavour to provide comprehensive and quality statistics to the many users of the statistical information.

The 2022 SDES has given NSO the opportunity to introduce and experience improved statistical methodologies and standards supported by new technological innovations.

Apart from the Fertility and Mortality Report, the NSO is also in the process of releasing various thematic reports on Economic Wellbeing, Education, Migration, Youth, and Gender. Other than the mentioned reports there is also a combined thematic report based on in-depth analysis of demographic dividend. The Fertility and Mortality report is concerned with the fertility and mortality situation, trends and differentials in PNG.

In this report, the data obtained from the 2022 SDES was analysed in conjunction with data from the 2011 Census as well as that from the 2016-2018 Demographic and Health Survey (DHS). The analysis of SDES on Fertility and Mortality will support existing health and other related programs and projects like the Demographic Dividend target settings that can be incorporated in several national and sectoral policies and plans that are currently being reviewed and formulated, such as the National Population Policy (NPP) 2025-2034, and the assessment of the Medium-Term Development Plan (MTDP) IV 2023-2027.

Moreover, the findings in this report will be used for future monitoring and evaluation of the objectives and strategies of other existing national and sectoral policies and plans as well as those associated with the global agenda from the Sustainable Development Goals (SDG) and the Plan of Action of the International Conference on Population and Development (ICPD).

The conduct of the 2022 SDES would not have been possible without the financial support from the Australian Government through the "PNG Australia Partnership Program" in collaboration with the United Nations Population Fund (UNFPA), which provided the technical support for an in-depth analysis and production of the Fertility and Mortality Report.

Furthermore, I acknowledge the support from the Pacific Community (SPC) for technical assistance in using modern technology in collecting data from the field, which is the first for NSO in its endeavour to improve on its statistical methodologies.

Gratitude is also extended to all the field staff who worked hard to successfully implement the data collection phase of the survey. Further gratitude is due to the survey respondents who relentlessly continue to provide the information on which this report is based including the support from the Provincial and Local Level Governments during the data collection.

The Office of the National Statistician is also indebted to the NSO project Management Team for their tireless efforts in managing the technical and administrative aspects of this exercise for a successful conduct of the 2022 SDES.

I take this opportunity to urge all stakeholders and statistics producing agencies to foster and promote collaborative efforts which will contribute to making the PNG Statistical System effective. NSO as the central and mandated statistical agency has the legitimacy backed by the Statistical Services Act (1980) that ensures the confidentiality of raw data providers and assurance of integrity and accessibility for users.

Finally, with improved data sources, sound statistical methodologies and standards, new technologies and strengthen statistical system, these will enable the Government to formulate better policies and make evidence-based decisions for the betterment of PNG and its people.

Mr. John Aseavu Igitoi
National Statistician



1. Introduction

1.1 Fertility

The objective of this report is to estimate the level of fertility and mortality, and the evolution observed in the last decade in these demographic indicators, according to information collected in the PNG 2022 Socio-Demographic and Economic Survey (SDES). Together, these two demographic variables play a central role in the demographic transition, which impacts the age structure of the population and define the pace of natural growth of the population.

Regarding fertility, there has been a long debate on whether successful development leads to fertility decline or fertility decline leads to development. The evidence indicates that both statements are valid; literature on the subject is fairly profuse and will not be discussed here due to the nature of this report¹. However, it would be enough to recognize that high levels of fertility, under conditions of constraint resources may exacerbate poverty and environmental deterioration. At the same time, there are important feedback mechanisms between fertility decline and development. Indications on how fertility levels are influenced by development are expressed in the approximations provided by a model relating key development indicators to fertility trends in 87 developing countries (Bryant, 2007).

In particular, the fertility level and trends are at the centre of the agenda on gender equality and reproductive health and rights. This social and human rights nucleus determine the features that will mark the demographic process of the next decades. These dynamics have profound implication for changes in the age structure of the population and the dynamics for economic growth and development. In this context, access to reproductive health services is critical, particularly the choices and opportunities that girls may have during adolescence will determine whether they may begin adulthood as empowered, active citizens, capable of making significant contributions to their societies.

At the global level, as in any country, adolescent and child pregnancies are a serious concern: about 16 million babies are born to girls 15-19 in the world yearly. Reproductive ill health is related to the main causes of death among girls under 20 in developing countries. Adolescent pregnancy is “deeply rooted in poverty, gender inequality, violence, child and forced marriage, power imbalances between adolescent girls and their male partners and lack of education. All these reveal the failure of national systems and institutions to protect girl’s rights”². This report will not focus specifically on adolescents, but given the implications of very early fertility, evidence on its prevalence will be explored.

1.2 Mortality in early years of life

Studying the level and trends in mortality has been a central component of population studies from the earliest times that scientists have paid attention to the survival conditions of human populations. In particular, the levels of early childhood and infant mortality have been considered essential health markers. Moreover, these have been used as indicators of the quality of life and the level of social development of a country. Consequently, national governments as well as the international community address the estimation of these indicators and monitoring of their changes over time, as a matter of high priority. Indeed, reducing under-five mortality (symbolized here as ${}_5q_0$) was one of the targets of the Millenium Development Goals (MDGs) and continues to be a main concern within the new Sustainable Development Goal (SDG) agenda.

Other international agendas also pay close attention to these indicators: The World Summit for Children in 1990 adopted the goal of reducing ${}_5q_0$ by one-third between 1990 and 2000 while the International Conference on Population and Development in 1994 targeted reducing globally its rate below 45 per 1,000 by 2015.

The Commission on Information and Accountability for Women’s and Children’s Health, which was established by the United Nations Secretary-General, has also emphasized the relevance of monitoring and reporting on the ${}_5q_0$ level. Similar to the ${}_5q_0$ infant mortality (represented as ${}_1q_0$) is also included as an indicator in most international development frameworks and represents the probability of a child to dye in the period from birth to exact one year of age.

In addition to those international development agendas mentioned, these indicators, infant and under-five mortality, constitute specific targets within the SDG agenda (United Nations, 2015). The under-five mortality rate is the probability that a child may dye between birth and exact age five (${}_5q_0$). As such, it incorporates the infant mortality rate (${}_1q_0$), since it is the probability of dying from birth up to exact age one, that is within a period of time that is covered by ${}_5q_0$. Therefore, most of the analyses performed in this report will focus on under-five mortality, which has an implicit reference to infant mortality as the ${}_1q_0$ is incorporated within ${}_5q_0$. The conclusions and policy implications emanating from analyses based on ${}_5q_0$ are always extensive to infant mortality.

1.3 Mortality in adult ages

The analysis of adult mortality is relevant to understand the health situation of this population group, which constitutes the human capital that any country has for its development. Obtaining adequate estimates of adult mortality allows assessing the patterns and trends of adult mortality risks, contributing to better planning. This also supports the formulation of health policies addressing these types of risks, and informs the follow up and evaluation of social and health progress, assessing the effectiveness of government programs (United Nations, 1983). It also allows assessing the progress of the Sustainable Development Goals (United Nations, 2015).

Some of the constraints to the study of adult mortality are the limited or defective data, which is often incomplete

¹A seminal study discussing these relationships can be seen in: Coale, A. J., & Hoover, E. M. (1958). Population growth and economic development in low-income countries: A case study of India’s prospects. Princeton, N.J: Princeton University Press.

² UN-ECOSOC: Fertility, Reproductive Health and Development, Report of the UN Secretary General to the Commission on Population and Development, Forty-fourth Session, 18 January 2011.

due to limited coverage of vital statistics systems. Several authors (Bennet & Horiuchi, 1981; Brass W. , The relational Gompertz model of fertility by age of woman, 1978) (Hill, Choi, & Timæus, 2005) have addressed these limitations and proposed options to obtain adequate estimates. Hence, demographers have used indirect methods extensively over the last decades to provide estimates of mortality in contexts of poor or unavailable registration systems (Moultrie, et al., 2013). The PNG 2022 SDES collected information on both mothers' and fathers' survival, which allows for the application of an indirect estimation methodology, i.e. the orphanhood method. The orphanhood method was initially developed by Louis Henry (Henry, 1960) and later improved by other authors (Brass & Hill, 1973), (Timæus I. , 1992; Timæus I. , 1991), allowing the estimation of adult mortality on the basis of census and survey data.

Traditionally, mortality calculation requires prior estimates of number of deaths, age at death and exposure time. As an alternative, the orphanhood method is straightforward: deaths come from the proportion of orphans, exposure time is given by the respondent's age, and age at death can be estimated from the age distribution of mothers at the birth of their children. Hence, the method allows us to estimate what would be the female (mothers) and male (fathers) probability of surviving from the child's birth until the date when she or he answers the relevant questions during a census or survey interview.



2. Basic Data and Methodology to Estimate Fertility and Mortality

In statistically developed countries, vital registration systems constitute the primary source of information to estimate most vital statistic indicators, including fertility and mortality rates.

Yet, in countries that have no complete or reliable vital statistic systems, as it is the case of the majority of developing countries, the data sources for estimating these indicators are usually population censuses or demographic surveys. Depending on the nature of the surveys, the approach can be to collect “full birth histories”, as it is usually done through the Demographic and Health Survey (DHS). Full birth history methodology aims to reconstruct the reproductive experience of women, through a series of questions on marriage, pregnancies and childbirth, recording also the deaths/survival of each of their children.

In general, the data quality of this information is reliable, most frequently allowing estimating fertility and probabilities of survival of the children without any adjustments. The data collection approach in this type of survey is very demanding. Therefore, to facilitate statistical operations, the estimation methods are usually based on information from less demanding data collection methodologies.

A second approach utilized to collect data on fertility and mortality in surveys and censuses is through a “summary birth history” (SBH). This is the approach adopted in the PNG 2022 SDES. Under this methodology, the questions asked during the survey enable to collect information on aggregate numbers, such as the total number of children ever born by women in the household, and how many of them are surviving at the time of the survey, plus the number of children born during a recent period preceding the survey, and their survival status. Data of this type is then utilized for estimating the level of fertility and age distribution of fertility, as well as mortality, through methodologies based on William Brass original proposals or some variants of this approach, which were developed afterwards.

The same set of questions as described above for collecting data on fertility are also utilized to obtain the inputs for estimating the level and trends of mortality indicators for the early years in life.

In order to estimate mortality in adult ages, the approach adopted in censuses or household surveys is either to collect information on deaths that have occurred in the household in a recent period of time (usually one year, in some cases two years preceding the time of the interview), or collect information on the survivorship status of some relatives (most frequently the mother and father) but in some cases also about the survivorship of the spouse or siblings.

In the case of PNG 2022 SDES, the survey included questions on number of children ever born and on the last child born to women aged 15 to 49, for estimating fertility and mortality in early years of life, and questions on survivorship of the mother and survivorship of the father for adult mortality.

2.1 PNG 2022 SDES basic data on fertility and estimation methodology

The PNG 2022 SDES questionnaire incorporated section “G. Fertility Section”, which included the following set of questions to be asked to all women aged 15-49 years:

Children Born Alive

Q.29 How many live born children (male and female) have you given birth to?

Male |__| | Female |__| | “(if none, enter “00” in Male and Female and Go to Q5. For next HH Member. **DO NOT LEAVE BLANK**”

Q.30 How many of your own children (male and female) are living in this household?

Male|__| | Female|__|

Q.31 How many of your own children (male and female) are living elsewhere?

Male|__| | Female|__|

Q.32 How many of your live born children (male and female) are dead?

Male|__| | Female|__|

Last Child Born Alive

Q.33 What is the date of birth of your last child born alive?

d|__| m|__| y|__| (allowing two digits for “day”, “month” and “year”)

Q.34 Is this child a male or female?

1. Male 2. Female

Q.35 Is this child alive?

1. Yes 2. No

The essential data for the estimation of fertility are the number of children ever born alive (Q.29) to women interviewed in the household (the question is asked to all women, independent of the marital status), combined with data on the last child born alive Q.33. In the case of Q.33, the estimation procedure requires the tabulation of all children born in the interval of 12 months preceding the date of the interview.

The tabulations of children ever born alive to women aged 15 to 49, by five–year age group of the women, and children born in the last year preceding the survey constitute the basic data for calculating fertility through W.

Brass’ method (Brass W. , 1964), known in demographic literature as the P/F method, or some the variants of this method developed more recently (Moultrie, et al., 2013).

2.2 PNG 2022 SDES basic data on mortality and estimation methodology

Mortality in early years of childhood

The questions included in “**G. Fertility Section**”, discussed previously with reference to fertility, also provide the basic information to determine the probabilities of a child to survive from birth up to a series of ages: 1, 2, 3, 5, 10, 15, 20. Essentially, the proportions of children ever born to women in age cohorts from 15-19 up to 45-49, who are alive at the time of the interview, constitute an approximation to these probabilities of surviving.

W. Brass (Brass & Coale, 1968) developed the procedure that allows transforming the proportions of children surviving into conventional life table measurements. Other authors further refined this procedure (Moultrie, et al., 2013), developing the approach applied in this report. A more detailed description of the methodology is provided in the annexes.

The essential data for the estimation process are the number of children ever born alive (**Q.29**) to women interviewed in the household (the question is asked to all women, independent of the marital status), and the number of those children who are still alive (or have died) (**Q.32**) at the time of the survey. Experience has shown that additional questions, asking about how many children are living in the household (**Q.30**) and how many are living elsewhere (**Q.31**), although they are not utilized in the calculation, are very valuable. These additional questions help the respondent to remember about all children ever born, including those who have left home and are no longer living with the family. In this way the quality of the information can improve sensibly.

Other information on infant mortality

In addition to the questions on children ever born and children surviving, which constitute the basis for the indirect estimation techniques just described, the PNG 2022 SDES included another set of questions aimed to measure infant mortality. These additional data to measure infant mortality are derived from questions on the last child born alive and his survivorship at the time of the interview (**Q.35**). It is necessary to group all children born in the last 12 months before the survey and calculate the proportion of those who are still alive. indeed, it provides a direct estimation of the proportion of children still alive at the end of the year interval where they were born. This proportion is also equivalent to the time lived by children born during the last year preceding the survey, from the moment they were born until the time the interview took place. In terms of the life table notation, this is the indicator ${}_tL_0$. The indicator ${}_tL_0$ can be used to estimate infant mortality (${}_tq_0$), by using the “separation factor”. This factor is the proportion of children born during the last 12 months preceding the survey, who dye before reaching their first birthday, dying within the following 12 months after the interview, in relation to the total children born in the year preceding the interview, who die before their first birthday. Data constraints make difficult to obtain the exactly the value of this factor, but it is possible to select an adequate value for this factor from some life table, or model life table, which has a similar level of infant mortality as in the studied population. This would give an acceptable estimation for the separation factor; then, if the reports provided by the respondents were accurate, these data would allow obtaining a reasonable estimate of infant mortality. In practice, experience has shown that these reports are frequently affected by some inaccuracies.

Mortality in adult ages

The PNG 2022 SDES questionnaire incorporated section “**B Survivorship**”, for all persons in the household, with questions **Q.7** and **Q.8** asking respectively: “*Is ... own father still alive?*” and “*Is ... own mother still alive?*” which response options where “**1. Yes**”, “**2. No**”, “**3. Do not Know**”. Data collected through these questions facilitate the estimation of indicators of mortality at adult ages.

Essentially, the proportions of respondents who have their mother/father alive constitute approximations to the conditional probability that their parents, alive at the time of their birth, will survive from the age of the parents at the time of birth, for a period of time equal to the age their children have at the time of the survey. The estimation procedure relies on appropriate modelling to establish an adequate exact base year for this conditional probability of surviving, and the interval n through which the parent would survive (which is related to age of the respondent), in a way that would allow deriving a conventional life table indicator. A detailed description of the methodology is included in the annexes.

3. Data Analysis

3.1 Fertility estimation using PNG 2022 SDES data at national level

Brass P/F method to estimate fertility

The essence of Brass P/F ratio (Brass W. , 1964)method consist on comparing the reports on total children ever born, that is lifetime fertility or the level of parity (symbolized by P_i) reported by women in age group “i”³, to the level of cumulated fertility (or “synthetic parity”) up to a similar age as in P_i –symbolized by F_i - obtained on the basis of the number of children born in the last 12 months reported by women.

The number of children ever born reported by women in age group “i” divided by the number of women in age group “i” gives the level of parity in that age group, P_i . P_i represents an average parity for the women enumerated in the five-year age group i, which would be the midpoint of the age interval, assuming lineal variation in parity by single age within the interval. The “synthetic parity” F_i is obtained by adding up the age-specific fertility rates (ASFR) obtained on the basis of births reported in the last 12 months by age of the mothers, through a process which consists of first on obtaining the ASFR by dividing the number of births reported in the last 12 months (by age of the mothers), by the number of women in age group “i” symbolized by “ f_i ”. Then the ASFR need to be cumulated to simulate synthetic parities. Yet, by adding up values of f_i , multiplied by five (there are five single ages in a five-year age group), for example $5 \cdot (f_1 + f_2 + f_3)$, would provide the cumulated fertility up to the lower limit of age interval 30-34, or upper limit of age interval 25-29. Let’s represent recent fertility rates up to the lower limit of age group i, with the Greek letter “phi”: $\phi_i = 5$. These values would not be comparable to the parity P_i , since P_i is an average of parities by single year for women in the five-year age group i, and can be interpreted as cumulated lifetime fertility up to the midpoint of age interval i, assuming that parity by age increases linearly within the five- year age group.

To make cumulated synthetic fertility comparable to the respective parity in age group i, the method uses fertility modelling (Brass W. , 1975) (Moultrie, et al., 2013) to set cumulated ASFR up to the midpoint of each of the “i” age groups. The “synthetic parity” obtained in this way is symbolized F_i , and corresponds to exactly the same age point as the age parity P_i . The process utilizes adequate multipliers k_i , which applied to f_i allow to adjust the corresponding F_i to an age point comparable to that of P_i , in the following way: $F_i = \phi_i + k_i \cdot f_i = 5(\sum_{j=1}^{i-1} f_j) + k_i \cdot f_i$. With F_i determined in this manner, P_i and F_i can be compared by means of the ratio P_i / F_i , which lays at basis of the estimation method. For these two indicators (P_i and F_i) to be comparable, the adjustment introduced through the k_i factor should also take into account a shift in the ages for f_i , which emanates from the fact that at time of giving birth the reporting mothers would have been (on average) half a year younger than their age at the time of the survey, because these births took place 12 months before the survey. A more detail explanation of the methodological basis of Brass P/F ratio method is included in the annexes of this report.

Under conditions of constant fertility, the cumulated fertility of a cohort of women up to any given age will be the same as the cumulated fertility up to that same age in any given time period (like the last 12 months previous to the survey). An implicit assumption is that there is no correlation between the fertility and the level of mortality. In other words, women who have survived and reported on their fertility would have similar fertility experiences as those in the same age cohort, who have died before the time of the survey.

With F_i and P_i set at similar ages, and under constant fertility conditions, the P_i/F_i ratio should render values equal to one, if the information is free from errors. If fertility has been declining, then the series of P_i/F_i ratios would show increasing values for groups of higher ages: the parity of older women would incorporate the measures of higher fertility which had prevailed in the past. For younger age groups the expected values of this ratio should be closer to one, because the P_i indicators would reflect fertility levels that are closer in time to those reflected in F_i : P_i for young groups incorporate events occurred in recent periods, closer in time to F_i .

Data is usually affected by some type of error. According to Brass, the error affecting the P_i reports consisted of some omission in the number of children ever born, which increases with the age of mothers, while younger mothers would provide accurate reports on the number of children they have had. At the same time, the errors most frequently registered in the reports of children born in the last year before the survey consist on inadequate placing of births within the indicated time period; sometimes the last year is taken as the calendar year of the survey (which would shorten the time-period of reference), other times would extend the time reference by including some months from the previous calendar year which should not have been included. In any case, Brass discovered that this type of error (in the 12 months reference period) would occur in a similar manner along all age groups, for older or younger cohorts. Hence, the level of fertility from these reports may be inaccurate, if the reference period was shortened or expanded. However, the age distribution of fertility would be correct, since similar errors would occur independent of the age group of respondents. In this way, by adopting the age distribution of fertility as estimated from recent births and adjusting the level of fertility on the basis of the reports on total children ever born from the younger age groups of respondents, which are mostly accurate, the estimation procedure would render adequate estimates of the fertility level as well as a correct distribution of fertility by ages.

Calculating fertility level and age distribution of fertility through P/F method

Table 1 summarizes the input data for the P/F ratio and the main results of Brass P/F method. The complete calculation process is presented in the annex of the report.

The results of Brass P/F ratio method, presented in Table 1 indicate that fertility has been declining in PNG. This is visible through the increasing trend of P/F ratios by age group: the older the age cohort, the higher the value of P_i compared to F_i , which indicates higher lifetime fertility (P_i) experienced by each cohort of women in the survey, compared to the level of fertility in the last 12 months (F_i). The results also indicate that the fertility rates

³ Index “i” indicates the mother’s age group, with i = 1, 2, ... , 7 respectively for the mother’s age groups 15-19, 20-24, ... , 45-49.

calculated from births in the last 12 months need to be adjusted by almost 14 per cent (1.137 or 1.138), to make the level of recent fertility comparable to the level indicated by the average parity reported by young women. This adjustment would give a total fertility rate (TFR) of 3.72 children per woman.

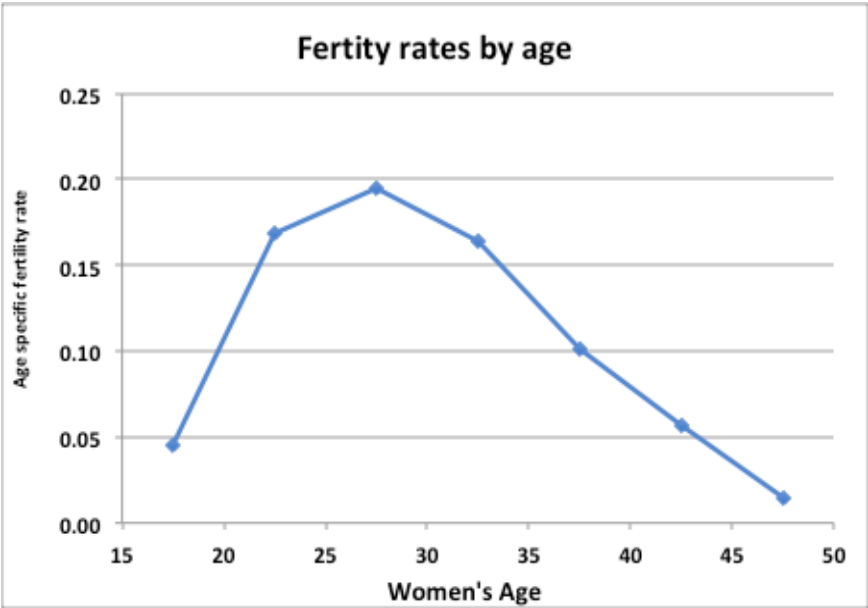
Table 1. Estimating fertility using Brass P/F method: input and outputs from the estimation worksheet

Age group	Number of women	CEB	Born last 12 months	Pi	fi (observed)	Fi	Pi/Fi	fi (adjusted by 13.7%)
15-19	1,215	83	39	0.068	0.032	0.0631	1.08	0.0451
20-24	1,085	670	150	0.618	0.138	0.5425	1.138	0.1683
25-29	999	1,552	172	1.554	0.172	1.3667	1.137	0.1945
30-34	868	2,218	131	2.556	0.151	2.1895	1.167	0.1641
35-39	789	2,604	73	3.300	0.093	2.7546	1.198	0.1011
40-44	590	2,282	31	3.868	0.053	3.0926	1.251	0.0567
45-49	561	2,384	9	4.250	0.016	3.31	1.284	0.0147
TFR:	3.72							

Source: PNG 2022 SDES.

Figure 1 presents the estimated age-specific fertility rates, with an age distribution determined by the last births reported during the 12 months preceding the survey. The level of the age-specific fertility rates – and therefore the TFR – are adjusted by the level of fertility determined by the number of children ever born reported by the young age groups of women (20-24 or 25-29), as indicated in the last column in Table 1.

Figure 1. PNG 2022 SEDS, Age-specific fertility rates estimated from P/F method



Source: PNG 2022 SDES

Relational Gompertz method to estimate fertility

The relational Gompertz method, also developed by William Brass, rests on the same principles as the original P/F ratio method. That is, the age distribution of fertility is adequately reflected on the reports of recent fertility preceding the census, while the level of fertility in these reports frequently shows some errors.

The method seeks to remedy the errors commonly found in recent fertility reports, which are too few or too many births being reported in the reference period. Hence, the method aims to adjust the fertility level by means of the level of parity reported by young age groups, which is usually accurate. It utilizes exactly the same input data as the P/F method, but incorporates fertility modelling through the Gompertz relational model (Brass W. , 1978). Basia Zaba (Zaba, 1981) further elaborated Brass’ original proposal for a relational Gompertz model. Among other differences, Zaba’s proposal compares recent fertility and lifetime fertility not on the basis of P and F values, but on the basis of ratios of P values in adjacent age groups, and ratios of F values also in adjacent age groups. This eliminates eventual fertility level variations between lifetime fertility and recent fertility, as a source of potential distortion in the comparisons. In relation to Brass’ Gompertz original model, Zaba’s proposal also eliminates the need to adopt a preliminary estimate of total fertility, because the fertility scale cancels out in the ratios of P values as well as ratios of F values, calculated respectively for adjacent age groups. Among the fertility estimation variants emanating from Gompertz relational model, Zaba’s relational Gompertz is the most frequently used. It can be seen as an improvement of the original version as it does not require an assumption of constant fertility; neither requires a preliminary adoption of a TFR. As already mentioned, the relational Gompertz model uses the same input data, and continues to rely on a comparison of lifetime and recent period fertility, while incorporating refinements in the estimation process. More detail discussion of the methodology is presented in the annexes to this report.

Calculating the fertility level and age distribution of fertility through Zaba’s relational Gompertz model

The calculation process for applying the relational Gompertz model was done by using the Microsoft Excel worksheet provided in the IUSSP manual (Moultrie, et al., 2013). The input data, as well as the output values from the Microsoft Excel worksheet are presented in Table 2. The model fit included all points when estimating the parameters of model fit. This fit could be assessed (and eventually improved) by careful analysis of the “gompits” points in the calculation worksheet and selecting/eliminating certain points in order to improve the model’s fit.

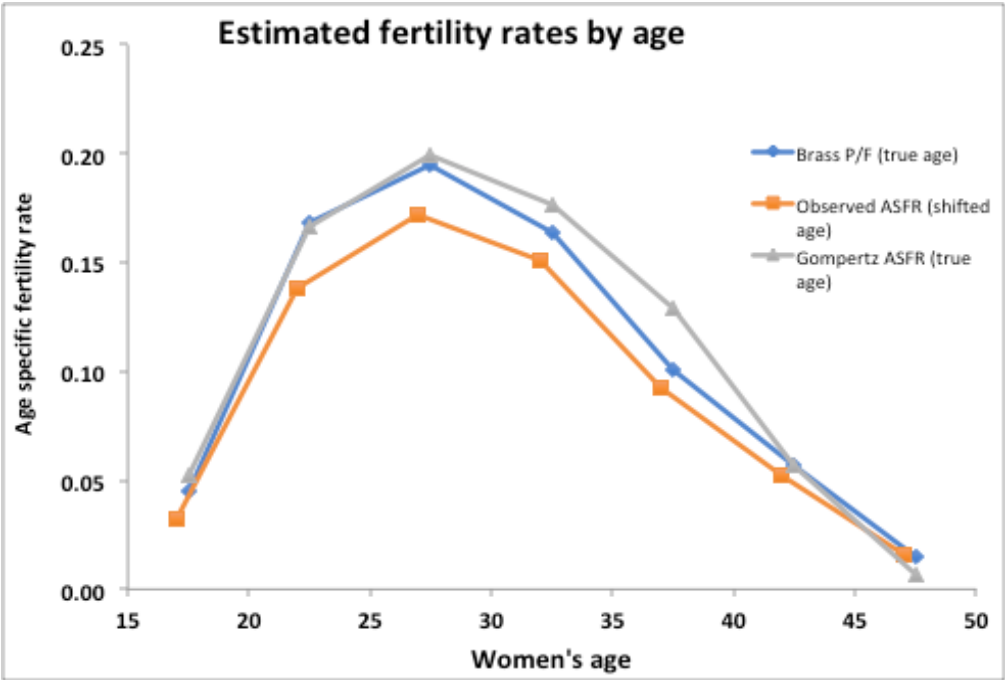
Table 2. Fertility estimation using the relational Gompertz model method: input data and outputs from the estimation worksheet

Age group	Number of women	CEB	Born last 12 months	Pi	fi (observed)	Fi	Pi/Fi	fi (adjusted by method)
15-19	1,215	83	39	0.06831	0.032	0.066		0.052
20-24	1,085	670	150	0.61751	0.138	0.635	1.130	0.166
25-29	999	1,552	172	1.55355	0.172	1.585	1.131	0.199
30-34	868	2,218	131	2.55530	0.151	2.545	1.170	0.177
35-39	789	2,604	73	3.30038	0.093	3.318	1.173	0.129
40-44	590	2,282	31	3.86780	0.053	3.793	1.214	0.057
45-49	561	2,384	9	4.24955	0.016	3.926	1.298	0.007
TFR:								3.93

Source: PNG 2022 SDES

The level of fertility (TFR) estimated through the relational Gompertz method and original Brass P/F ratio method were of 3.93 and 3.72 respectively. Figure 2 compares the age-specific fertility rates provided by both these methods, and the original, uncorrected SDES data.

Figure 2. PNG 2022 SDES, observed fertility rates and rates estimated from P/F method and relational Gompertz method



Source: PNG 2022 SDES

The characteristics of the fertility information from the PNG 2022 SDES can be assessed in Figure 2, as well as some features inherent to the estimation methodology. Comparing the orange and blue lines, the effects of the half year shift in age of the mothers inherent in the reports from births in the preceding 12 months are visible: the orange line rates correspond to mothers half year younger, which translate in slightly lower rates at young ages since fertility is sensibly lower for young ages at the beginning of the reproductive period. At older ages, as fertility declines with age, the half-year shift to younger ages reflects in slightly higher observed rates in older age groups. This shift is compensated in some way by the adjustment of the level, about thirteen per cent, introduced by the P/F method. At the central ages, the higher levels in the blue line relate mostly to the adjustment of the level due the method’s correction factor P/F. When we compare the estimated fertility rates from the relational Gompertz with the P/F method, the overall level is quite similar, although a little higher in the Gompertz, due to a higher correction factor.

A relevant difference between the P/F and the Gompertz estimates is a relative higher level in Gompertz’s rates between ages 30 to 40. This is probably associated to the pattern by age of the standard fertility distribution utilized in the Gompertz model. The quality of the SDES data appears to be satisfactory: the pattern by age shows a smooth curve, following the variation by age that is usually observed/expected in most countries at similar

stage of fertility transition At the same time, the P/F ratio series shows regularly increasing ratios as the age of women increases, revealing a fertility declining trend in the population. The results obtained from the P/F method are thus considered to be the most adequate estimates: while there is little difference in total fertility from the P/F and Gompertz methods, the P/F results retain the age distribution as reflected in the original data, adjusting only for the TFR level implicit in the reported parity from young age groups. Retaining Brass P/F method estimates rests on the essential rationale of the method: the age structure defined by information on the recent fertility is correct, but it may need to be adjusted by the level of fertility, as determined by information on children ever born – P_i being the value – as reported by young women. The same assumptions sustain the estimation of fertility using the relational Gompertz method. However, the age structure reflected in the standard fertility distribution – implicit in the Gompertz modelling – slightly distorts the age distribution as reflected on the observed fertility rates estimated from recent births. Since the differences in the level of fertility obtained from the two methods are small, it was decided to adopt as most appropriate those results from the Brass P/F method, which respects the observed age structure of fertility in line to the number of births recorded in the last 12 months preceding the survey, while adjusting the level in line with the parity reported by the younger age groups.

3.2 Fertility estimation using PNG 2022 SDES data for rural and urban areas

The level and age distribution of fertility by areas of residence were estimated using the same methodology as described in the previous section, i.e. using both Brass P/F method as well as the relational Gompertz model.

Estimating rural and urban fertility using Brass P/F ratio method

Table 3 presents the input data for the P/F estimation method, as well as the outputs obtained from the estimation process, by areas of residence.

Table 3. Fertility estimation by areas of residence using Brass P/F ratio method: inputs and outputs from the estimation worksheet

Age group	Number of women	CEB	Born last 12 months	Pi	fi (observed)	Fi	Pi/Fi	fi (adjusted)
Rural Area								
15-19	984	71	33	0.07215	0.03354		1.12	0.04714
20-24	847	585	131	0.69067	0.15466		1.15	0.18525
25-29	780	1274	140	1.63333	0.17949		1.10	0.20052
30-34	698	1859	111	2.66332	0.15903		1.14	0.17122
35-39	613	2072	60	3.38001	0.09788		1.15	0.10633
40-44	485	1918	29	3.95464	0.05979		1.20	0.06381
45-49	440	1875	8	4.26136	0.01818	3.55	1.20	0.01653
TFR	3.95							
Urban Area								
15-19	231	12	6	0.05195	0.02597	0.05638	0.92	0.03382
20-24	238	85	19	0.35714	0.07983	0.32271	1.11	0.09847
25-29	219	278	32	1.26941	0.14612	0.96647	1.31	0.16070
30-34	170	359	20	2.11176	0.11765	1.62981	1.30	0.12421
35-39	176	532	13	3.02273	0.07386	2.09459	1.44	0.07573
40-44	105	364	2	3.46667	0.01905	2.27000	1.53	0.02065
45-49	121	509	1	4.20661	0.00826	2.38	1.77	0.00739
TFR	2.61							

Source: PNG 2022 SDES

It should be noted that during the 12 months preceding the date of the survey, the numbers of births occurring to women by age interval are relatively small. Some random variations may be expected from the number of births in one age interval to the next. This is particularly true in the case of urban areas, where numbers are smaller. Still, the patterns observed are reasonably consistent. In the rural area the P/F ratios vary from 1.10 to 1.20. In the younger age groups ratios are in the range of 1.10 to 1.15, while ratios in older groups increase up to 1.20 (in last two groups). Probably the P_i of group 45-49 may be affected by relative higher omission in reports of children ever born, compared to the younger group, which leads to stabilization of the P/F ratio at 1.20, the same level as in group 40-44. The P/F series indicates a declining level of fertility in previous decades, although at a slower pace than that experienced in the urban area, as it is discussed in next paragraphs.

In the age groups 15-19 to 25-29, the P/F ratios in rural areas show some variations, most probably random, due to small numbers. Hence, to adjust the recent fertility level that is reflected in the births reported for the last 12 months, it seems most reasonable to adopt a correction factor that is the average of the ratios for groups 20-24 and 25-29. This gives a factor of 1.126, just over 12 per cent adjustment, which renders a TFR of 3.95 children per woman for rural PNG.

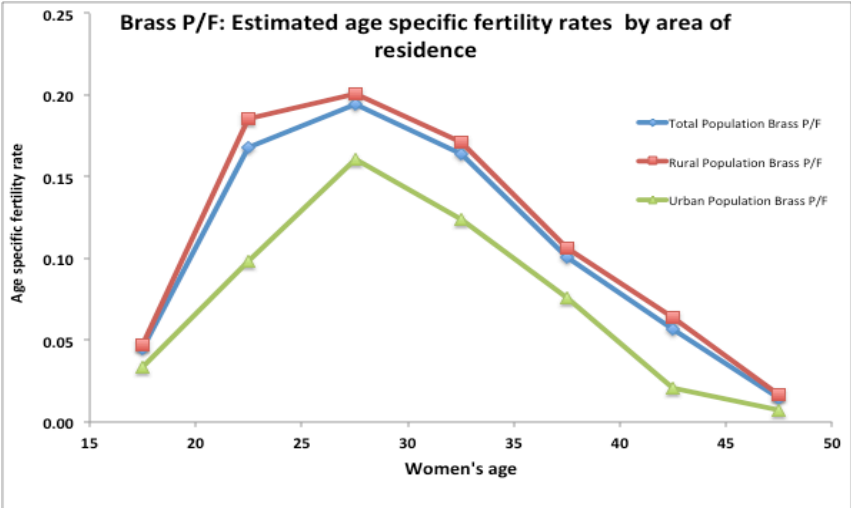
In the case of urban areas, the P/F series show ratios in a range from 0.92 in the youngest age group, to 1.77 in the group 45-49. This reveals a relevant and sustained decline in fertility in urban areas during the recent decades, steeper and larger decline than that experienced in the rural area. The pattern of variation of the P/F ratio by age is very consistent, although with some – probably random – fluctuations, like a small decline from 1.31 to 1.30 from age group 25-29 to group 30-34, instead of some increase that would be expected due to

declining fertility. Observing the P/F series, it seems most appropriate to adopt the ratio for age group 20-24 (which is 1.107), as the most reasonable factor to correct for the level of fertility. This is so because – in a context of consistent decline of fertility – the cumulate parity at a young age, like 20-24, would be closest to the prevalent recent fertility, as assessed by births in the last 12 months. The ratio from age group 15-19 is not used because it is affected by errors, more frequently than other groups: been random, some misreporting, or both. Hence, it is most reasonable to compare the recent parity level for group 20-24 (P_2) with equivalent synthetic parity for the same group (F_2), in order to assess the degree of accuracy in the level of fertility reported for the last 12 months. This indicates that the recent fertility (last 12 months) would be affected by 10.7 per cent of omission, which is corrected by the P_2/F_2 factor. This correction determines a TFR of 2.61 children per woman for the urban areas of PNG.

The results, as showed in in Table 3, indicate that the average fertility in rural areas is about 1.34 children per woman higher than the level of fertility in the urban areas. Given the predominance of rural residence in PNG, the level of fertility for the whole country is closer to the rural level, with a difference of only 0.23 children per woman lower at national level than the level observed in rural areas.

Figure 3 presents the age-specific fertility rates for the total population estimated through Brass P/F ratio method. Here again the predominance of rural residence in PNG reflects in the fertility patterns as well as level for the total population, which resemble much closer those features observed in the rural population than those prevailing in urban areas.

Figure 3. PNG 2022 SDES: Estimated age-specific fertility rates by areas of residence using Brass P/F method



Source: Age-specific fertility rates estimated, as presented in Tables 1 and 3, PNG 2022 SDES

Estimating rural and urban fertility using the Gompertz relational model method

Table 4 presents the input data for the estimation of fertility using the Gompertz relational model method, and the main outputs obtained from this estimation procedure; those outputs are included in the last three columns in Table 4.

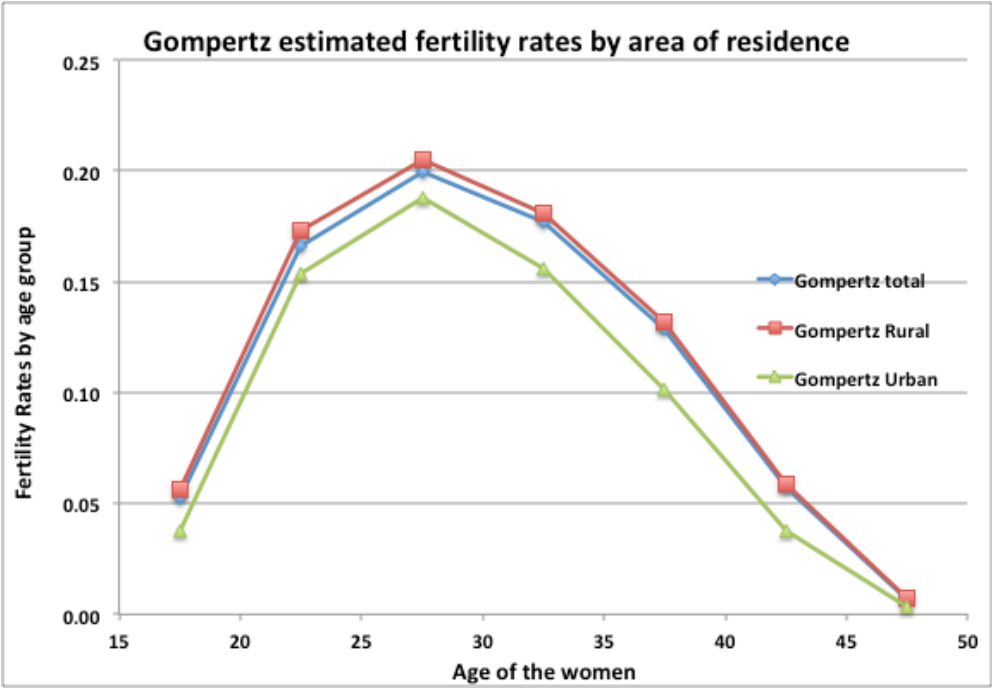
Table 4. Estimating fertility by areas of residence using the relational Gompertz method: inputs and outputs from the estimation worksheet

Age group	Number of women	CEB	Born last 12 months	Pi	fi (observed)	Fi	Pi/Fi	fi (adjusted)
Rural Area								
15-19	984	71	33	0.07215	0.03354	0.046	1.583	0.05613
20-24	847	585	131	0.69067	0.15466	0.580	1.191	0.17261
25-29	780	1274	140	1.63333	0.17949	1.446	1.130	0.20453
30-34	698	1859	111	2.66332	0.15903	2.298	1.159	0.18097
35-39	613	2072	60	3.38001	0.09788	2.969	1.139	0.13233
40-44	485	1918	29	3.95464	0.05979	3.372	1.173	0.05917
45-49	440	1875	8	4.26136	0.01818	3.470	1.228	0.00712
TFR	4.06							
Urban Area								
15-19	231	12	6	0.05195	0.02597	0.019	2.760	0.03756
20-24	238	85	19	0.35714	0.07983	0.434	0.824	0.15367
25-29	219	278	32	1.26941	0.14612	1.156	1.098	0.18773
30-34	170	359	20	2.11176	0.11765	1.794	1.177	0.15589
35-39	176	532	13	3.02273	0.07386	2.215	1.365	0.10152
40-44	105	364	2	3.46667	0.01905	2.415	1.436	0.03801
45-49	121	509	1	4.20661	0.00826	2.449	1.718	0.00344
TFR	3.39							

Source: PNG 2022 SDES

The estimation of fertility using the Gompertz relational model method shows some differences in the level of fertility and especially in the age distribution of fertility, compared to the results obtained from Brass P/F estimation method. The differences in the estimates for the rural area are relatively small, but for the urban areas the Gompertz approach render significant differences in both the level and the age structure of fertility, both when compared to Brass P/F method as well as to the observed fertility rates from births in the last 12 months preceding the survey. These patterns are showed in Figure 4, which presents analogous results as in Figure 3, but with estimates obtained using the relational Gompertz method.

Figure 4. PNG 2022 SDES: Estimated age-specific fertility rates by areas of residence, using the relational Gompertz estimation method



Source: Age-specific fertility rates estimated, as presented in Tables 2 and 4, PNG 2022 SDES

Since the fertility level and the age distribution obtained from the two methods have significant differences in the urban area, some additional analyses would be necessary to sustain a final decision on the most appropriate estimates.

The estimates obtained directly from the SDES reports on births in the last 12 months, as well as the estimates obtained from Brass P/F and relational Gompertz methods are presented in Table 5

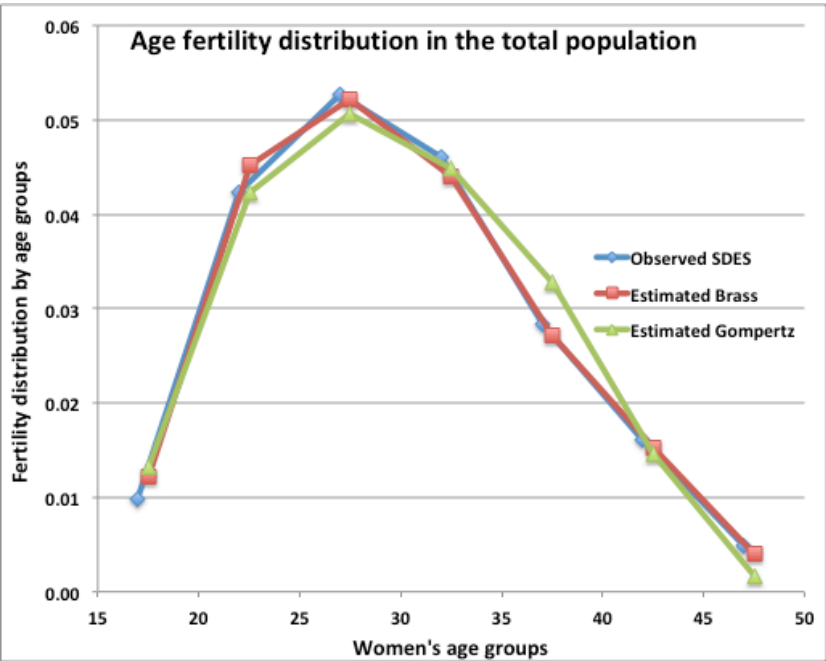
Table 5. PNG 2022 SDES: Fertility estimates and age distribution for total population and by areas of residence, obtained by using Brass P/F and relational Gompertz estimation methods

Age group	Total population			Reported SDES		Brass P/F		Relational Gompertz	
	Reported	Brass	Relational	Rural	Urban	Rural	Urban	Rural	Urban
	SDES	P/F	Gompertz						
	Shifted age	True age	True age	Shifted age	Shifted age	True age	True age	True age	True age
Age-specific fertility rates									
15-19	0.0321	0.0451	0.0521	0.0419	0.0260	0.0471	0.0338	0.0560	0.0420
20-24	0.1382	0.1683	0.1662	0.1646	0.0798	0.1853	0.0985	0.1730	0.1338
25-29	0.1722	0.1945	0.1993	0.1781	0.1461	0.2005	0.1607	0.2050	0.1592
30-34	0.1509	0.1641	0.1766	0.1521	0.1176	0.1712	0.1242	0.1810	0.1397
35-39	0.0925	0.1011	0.1287	0.0945	0.0739	0.1063	0.0757	0.1320	0.1006
40-44	0.0525	0.0567	0.0571	0.0567	0.0190	0.0638	0.0206	0.0590	0.0439
45-49	0.0160	0.0147	0.0068	0.0147	0.0083	0.0165	0.0074	0.0070	0.0051
TFR	3.27	3.72	3.93	3.51	2.35	3.95	2.60	4.06	3.12
Distribution of fertility by age groups									
15-19	0.0491	0.0606	0.0662	0.0596	0.0552	0.0596	0.0649	0.0689	0.0673
20-24	0.2112	0.2261	0.2112	0.2343	0.1695	0.2343	0.1891	0.2128	0.2143
25-29	0.2631	0.2612	0.2533	0.2535	0.3104	0.2536	0.3085	0.2522	0.2550
30-34	0.2306	0.2204	0.2245	0.2165	0.2498	0.2165	0.2384	0.2226	0.2238
35-39	0.1414	0.1358	0.1636	0.1345	0.1570	0.1344	0.1453	0.1624	0.1611
40-44	0.0802	0.0762	0.0726	0.0807	0.0404	0.0807	0.0395	0.0726	0.0703
45-49	0.0244	0.0197	0.0086	0.0209	0.0176	0.0209	0.0142	0.0086	0.0082
TFR	1	1	1	1	1	1	1	1	1

Source: PNG 2022 SDES

To better discern on probable sources of differences in the estimated results obtained from the two estimation methods used, the patterns of age distribution of fertility in the total population are explored in Figure 5. Figures 6 and 7 present those patterns for rural and urban areas respectively.

Figure 5. PNG 2022 SDES: Fertility distribution by age groups for the total population according to direct survey reports and estimated through Brass P/F and relational Gompertz methods

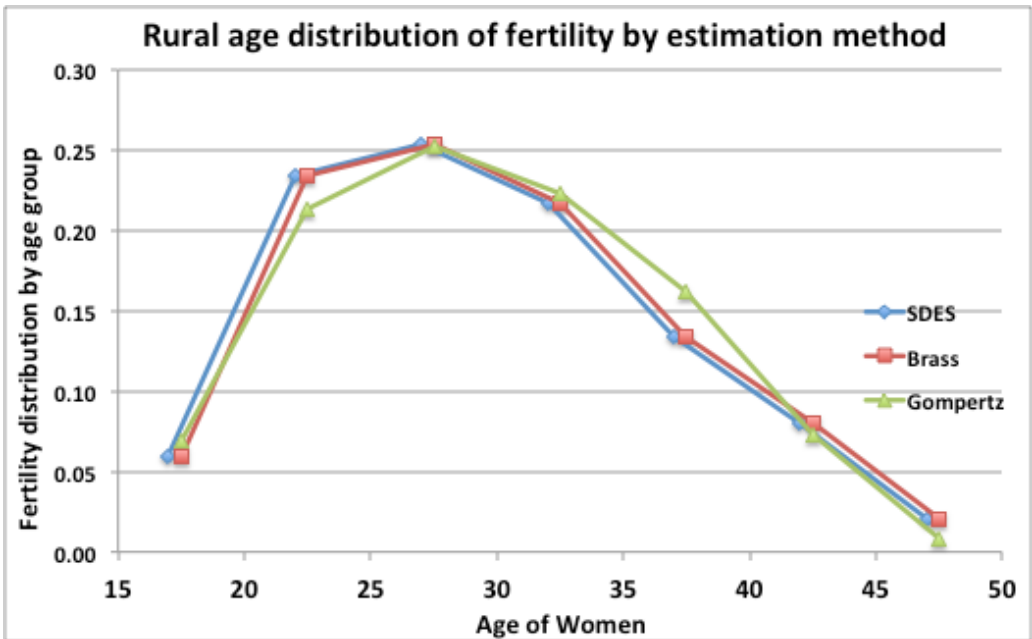


Source: Age-specific fertility rates estimated, as presented in Table 5, PNG 2022 SDES

The three patterns of age distribution for the total population presented in Figure 5 are in general consistent. The only difference appears in age group 35-39, where the estimates from the Gompertz relational show a relative higher concentration of fertility than the direct reports in the SDES and Brass P/F method. Naturally, since these are relative age distributions by age, in each series the total is equal to one. Therefore, the higher concentration in 35-39 compensates with a relative lower concentration in age 25-29 and to a lesser extent also in age 20-24.

As it is expected, the consistency in the distribution from Brass P/F and reported SDES is very high, since the assumption in this method is that reports on recent fertility are accurate in terms of age distribution, needing only to be adjusted by the level of fertility. As it is observed in Figure 5, differences between SDES reports and Brass P/F method mostly relate to the half-year shift in the age of the mothers at the birth of their children, in relation to ages of these women at the time of the interview. Since both P/F and relational Gompertz methods use the same input data, the differences in the age distribution between the two methods emanate from the methodological estimation process. In the case of Gompertz, the use of a standard fertility distribution brings about some modifications in the age distribution of the estimates, as compared to the age distribution in the original reports. A similar assessment is made for the fertility estimates obtained for the rural area, through the analysis of the patterns of fertility by age, as portrayed in Figure 6.

Figure 6. PNG 2022 SDES: Fertility distribution by age groups for the rural population according to direct survey reports and estimated through Brass P/F and relational Gompertz methods



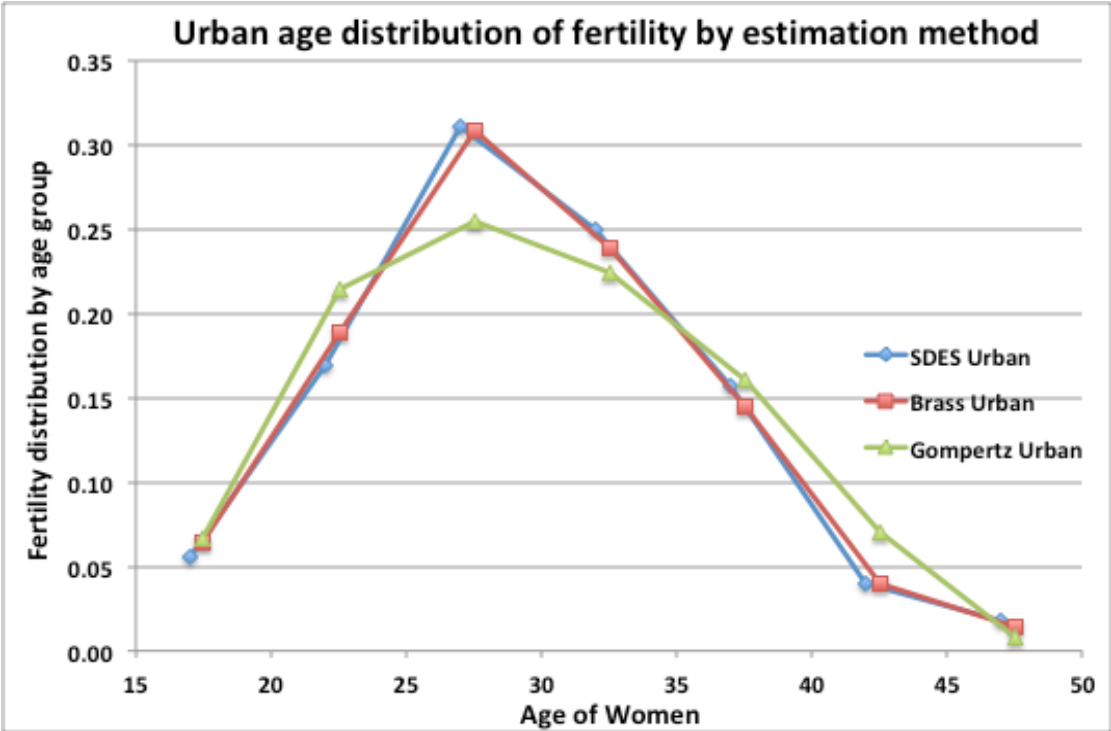
Source: Age-specific fertility rates estimated, as presented in Table 5, PNG 2022 SDES

The patterns of fertility by age for the three distributions in Figure 6 are very consistent. The estimates from both methods closely overlap, except for a little higher concentration of fertility in age group 35-39, in the Gompertz estimates, compensated with slightly lower relative fertility in the group 20-24. Results from Brass and SDES

reports show very small differences, mostly related to the half-year shift in the age interval. Essentially the three rural age distributions are very consistent.

The main differences observed the age distributions obtained from Brass and Gompertz methods appear in the results for the urban area, as shown in Figure 7.

Figure 7. PNG 2022 SDES: Fertility distribution by age groups for the urban population according to direct survey reports and estimated through Brass P/F and relational Gompertz methods



Source: Age-specific fertility rates estimated, as presented in Table 5, PNG 2022 SDES data

Figure 7 shows a significant difference in the age distribution of fertility for the urban area estimated with the relational Gompertz method, as compared to those from Brass P/F estimates and the SDES reported data on births that occurred in the last 12 months. It seems evident that these differences are mostly related to the age pattern of fertility of the standard distribution, which is utilized with the relational Gompertz model. Compared to Gompertz, the observed SDES age distribution of fertility, as well as that from Brass P/F, present in the urban area a relative higher concentration (54.6% of total fertility) in the central age groups, from 25 to 35, with lower fertility in younger and older age groups, which is characteristic in regimes of relative lower fertility, as it is the case of the urban areas in Papua New Guinea. The Gompertz age distribution concentrates 47.9 per cent in these central ages, which is closer to the percentage observed in the rural area (47% in ages 25 to 35). The standard incorporated in the relational Gompertz model seems to fit more closely to patterns of middle level fertility, and to some extent it adjusts the observed urban fertility, bringing the observed pattern closer to the standard.

Methodologically, this could be overcome by adopting a standard fertility model that resembles more closely the characteristics of the population under study. However, methodological adjustments of this type would not be necessary for the purposes of this study, because the results obtained from Brass P/F method appear consistent and reliable. Methodological adjustments would just reaffirm this fact. In any case, additional methodological adaptations would be beyond the scope of the present report, both in terms of time as well as contents.

Conclusions on fertility level and age distribution from PNG 2022 SDES

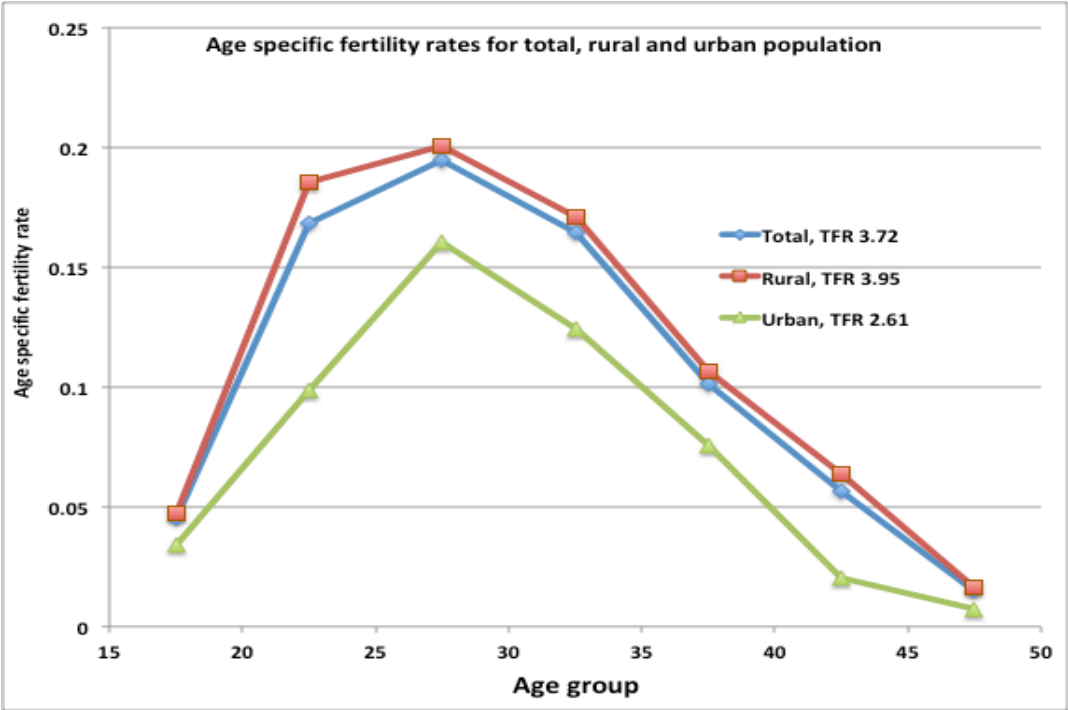
The conclusion from the above analyses leads to the adoption of the fertility rates and age distribution for PNG in 2022, which were obtained from Brass P/F estimation method and are presented in Table 6 and Figure 8. That is, a TFR of 3,72 children per woman for the total population, 3.95 for the rural area and 2.61 children in the urban area.

Table 6. PNG 2022 SDES: Total fertility rate (TFR) and age-specific fertility rates for the total population and by areas of residence

Age group	ASFR by Areas of Residence		
	Total population	Rural population	Urban population
15-19	0.0451	0.0471	0.0338
20-24	0.1683	0.1853	0.0985
25-29	0.1945	0.2005	0.1607
30-34	0.1641	0.1712	0.1242
35-39	0.1011	0.1063	0.0757
40-44	0.0567	0.0638	0.0206
45-49	0.0147	0.0165	0.0074
TFR:	3.72	3.95	2.61

Source: PNG 2022 SDES

Figure 8. PNG 2022 SDES: Age-specific fertility rates for the total population and by areas of residence



Source: PNG 2022 SDES

3.3 Estimation of early childhood mortality using PNG 2022 SDES data

The mortality level in early childhood ages will be obtained by using indirect estimation methods, developed by William Brass (Brass W. , 1964). It was widely disseminated (Brass & Coale, 1968) and extensively applied with very satisfactory results in most censuses and surveys conducted in developing countries around the world, during the last five decades. The technique has been applied either in its original version or in some variations of the method developed subsequently. As mentioned earlier, the necessary questions to apply this method were included in the PNG 2022 SDES.

The Rationale of the Methodology: Naturally, the proportion of children born alive who had died by the time when mothers were interviewed in the census, synthesizes the mortality level that has affected the children of these women. However, this measure is not a conventional life table concept and cannot be directly used to compare the levels of risk prevailing in different population groups. The proportion of children surviving (or dead) gives an indication on the level of mortality, but it does not provide information on the length of time that children were exposed to the risk of dying, neither on the age pattern of mortality during early childhood.

Ingeniously, Brass’ methodology derived conventional life table indexes by modelling the age pattern of child mortality as well as the age distribution of fertility, in order to convert the proportions of children dead into probabilities of dying from birth to an exact age $n(q_0)$. This conversion is done through adequate multipliers k_i , that translate the proportion of children dead (Q_i), classified by age group of the mothers, into conventional life table probabilities ${}_nq_0$: ${}_nq_0 = k_i Q_i$. The k_i can be obtained through different procedures, depending on the variation of the technique that would be utilized. The procedure used in this report is described in the manual for demographic estimation edited by IUSSP “**Tools for Demographic Estimation**” (Moultrie, et al., 2013). It obtains the k_i factors through the equation:

$k_i = a_i + b_i [P_1/P_2] + c_i [P_2/P_3] + d_i m;$ (1)

In equation 1 the values of a_i , b_i , c_i , and d_i correspond to the appropriate models, their values would vary with that model. Except for the UN mortality family models, which are utilized in this report (UN General and Far East models), the value d_i is zero. Each of the P_1 , P_2 , and P_3 values are the average number of children born (parity) to women in the age groups 15-19 (P_1), 20-25 (P_2) and 25-29 (P_3) respectively, which are estimated from the survey data. Also, m , which is the mean age of the fertility distribution, is calculated from the empirical survey data.

In a context of declining mortality, after determining the ${}_nq_0$ values it is necessary to establish the **time location** for these estimates. Naturally, as the level of mortality change, estimates that correspond to different points in time are not directly comparable. The difference in the indicator’s level (in relation to the lime elapsed from one indicator to another) will provide evidence on trends of change over time. The time location is obtained through the equation:

$t_i = e_i + f_i [P_1/P_2] + g_i [P_2/P_3];$ (2)

Where the values of e_i , f_i and g_i are modelled coefficients, and P_1 , P_2 and P_3 are the average parity of the reporting women in those age groups (Moultrie, et al., 2013).

The calculation process requires tabulations on:

- Number of women in each area or population group, for which the mortality estimates are going to be obtained, classified by five-year age group.
- Number of children ever born alive to those women by age group.
- Number of children born alive to women in each age group, who are still alive when women were interviewed in the survey.

⁴ Index “i” indicates the mother’s age group, as previously mentioned.
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- Number of live births to women by age group, born during the last year interval preceding the date of the survey/census.

On the basis of these tabulations, the proportions of children who had died (Q_i) can be calculated, as well as the average parity of women in age groups 15-19, 20-24 and 25-29 (P_1 , P_2 and P_3), and the mean age of fertility m . With these, the ${}_nq_0$ and the time location (t_i) for those probabilities can be calculated, completing the first stage of the calculation process, which consist of determining the level of mortality, expressed in terms of the series of ${}_nq_0$, with their respective time locations t_i .

However, since the values of ${}_nq_0$ correspond to different ages n , and different moments t_i in time, these values are not directly comparable. In order to assess the levels and trends of mortality in the early years of childhood, the successive ${}_nq_0$ values must be translated into a unique indicator, like ${}_1q_0$ or ${}_5q_0$. This is done in a next stage in the calculation process, which renders a series of ${}_1q_0$ and ${}_5q_0$ values, located at specific times t_i , preceding the survey. Hence, ${}_1q_0$ and ${}_5q_0$ can be compared in terms of their level and changes from one date to the next; therefore, the evolution of these indicators over time can be assessed.

These indirect estimates of mortality are subject to certain assumptions; the most relevant of which are;

- Changes in early childhood mortality in the recent past have been gradual and unidirectional (no ups and downs have occurred in the mortality trends);
- There is no association between the age of the mothers and the mortality risks of children;
- There is no correlation between the survival of mothers and the mortality risks of children, and
- The age pattern of fertility and of child mortality are adequately described by the models used to determine the coefficients a_i , b_i , c_i , e_i , f_i and g_i of the method.

Although it is difficulty to verify that these assumptions would be strictly complied with in practice, the method is quite robust to moderate deviations from these assumptions. A more detailed description of the methodology in presented in the annexes.

Calculation of early age mortality level and trends using indirect estimation methods

The estimation process, described in the previous paragraphs, was conducted using the Microsoft Excel worksheets available in the IUSSP/UNFPA manual. An initial estimation was conducted using both the UN General model life table as well as the UN Far East model. The estimated values for ${}_1q_0$ and ${}_5q_0$, and the respective time location obtained for these estimates are presented in Table 7.

Table 7. PNG 2022 SDES: Estimates of ${}_1q_0$ and ${}_5q_0$, using UN General and UN Far East models

UN General Model Life Table			UN Far East Model Life Table		
Time location	${}_1q_0$	${}_5q_0$	Time location	${}_1q_0$	${}_5q_0$
2020.9	51.33	73.13	2020.8	51.19	68.51
2019.9	41.43	59.29	2019.8	42.56	57.14
2018.5	26.78	38.59	2018.4	28.08	37.89
2016.5	18.11	26.19	2016.4	19.21	26.00
2014.1	21.70	31.33	2014.1	23.07	31.19
2011.3	24.48	35.31	2011.3	26.11	35.26
2008.0	28.24	40.65	2008.2	29.26	39.46

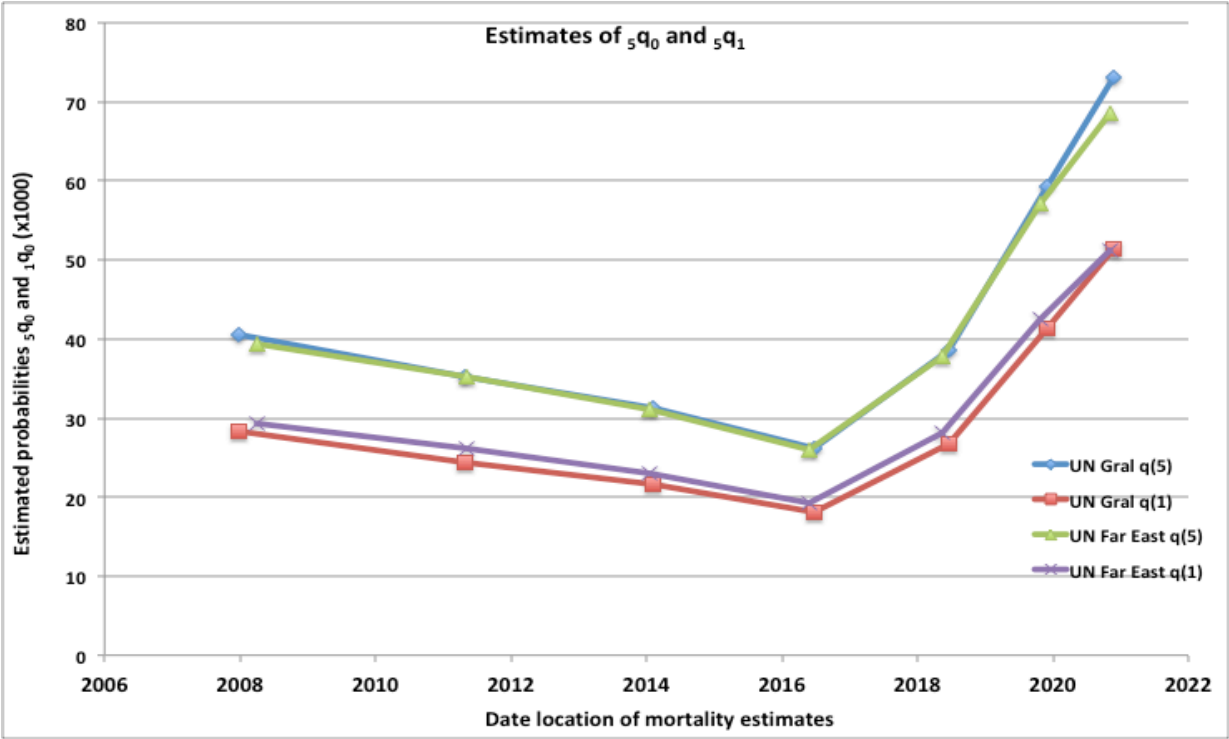
Source: PNG 2022 SDES

The estimates presented in Table 7 can be explored in a visual way in Figure 9. The most salient features observed in Figure 9 are, on the one hand, that there are no relevant differences in these results, whether they are based on one or the other model life table that were adopted for deriving the probabilities of dying from the proportions of children ever born and surviving. On these grounds, subsequent estimation of these probabilities will be done based solely on the UN General standard life table.

The strategy to be followed in the estimation procedure is to derive the level of mortality and its trend from the information from age groups over the age of 30. Estimates for more recent dates, obtained from information provided by women under age 30 are heavily affected by the two determinants: on the one hand a high proportion of children born during the COVID-19 pandemic; on the other hand, children born to women in age groups 15-19 and 20-24, who are affected by a selectivity of very young ages at birth, which increases the risk of mortality, especially if they are followed by subsequent births at short intervals. The combined effects of this selectivity, which renders higher mortality than that prevailing in the general population, and the effects of the pandemic greatly impact the proportion of children surviving reported by women in age cohorts under the age of thirty. This is clearly visible in the mortality trends, as represented in Figure 9.

It is not possible to discern what part of the excess mortality affecting the reports from age groups below age 30 can be attributed to the pandemic and what part to the mentioned age-birth-spacing selectivity effect. The strategy is to assume that the rates, which are derived from reports provided by women over age 30 would represent the underlying mortality trend for the general population, not significantly affected by the pandemic period or the selectivity of very young ages at birth. This is so because on the one hand the large majority of these births has occurred before the pandemic, and on the other hand those births have occurred over a wide range of ages, therefore representing a distribution of births that is representative of the whole population (that is, with no particular selectivity occurring in a limited period of very young ages).

Figure 9. PNG 2022 SDES: ${}_1q_0$ and ${}_5q_0$ estimates, UN General and UN Far East models



Source: PNG 2022 SDES

Hence, the linear adjustment of the time series of estimates from age cohorts over thirty would be a fair representation of the overall mortality, and the extrapolation of the linear trend calculated from those estimates would provide expected mortality levels under circumstances not affected by the pandemic. It is assumed that the linear trend would represent that underlying mortality, having excluded the effects of the pandemic. The adjusted rates presented in this report for dates corresponding to calendar years up 2018/2019 and projected to 2022 have to be interpreted under these assumptions. The excess mortality over the linear trend, observed for dates closer to the survey’s date cannot be attributed solely to the COVID, since such effects are compounded with excess mortality affecting children born to very young women, especially those are then followed by successive births at short birth intervals, as mentioned previously.

Observing Figure 9, the most remarkable feature that stands out in those patterns is the reversal of the mortality trend lines: from a steady decline in all dates up to 2017, the most recent three-point estimates show increasing levels of mortality. In the mortality estimates usually obtained from this methodology, the increasing mortality in recent dates only affects the estimates derived from the 15-19 and 20-24 reports. That is a feature observed in most data of this type, which is associated to selectivity in mortality risks of children born to very young women, particularly if they are followed by successive births at early ages with short birth intervals, as explained before. Births to mothers in older age groups represent a more balance mix of ages at birth and lengths of birth intervals, as in the general population, therefore are not affected by the type of selectivity observed in the younger age groups. Hence, the indirect estimation process usually relies on the mortality level and trend derived from reports of age groups from 25 and older ages, which most frequently show a steady and consistent trend of mortality.

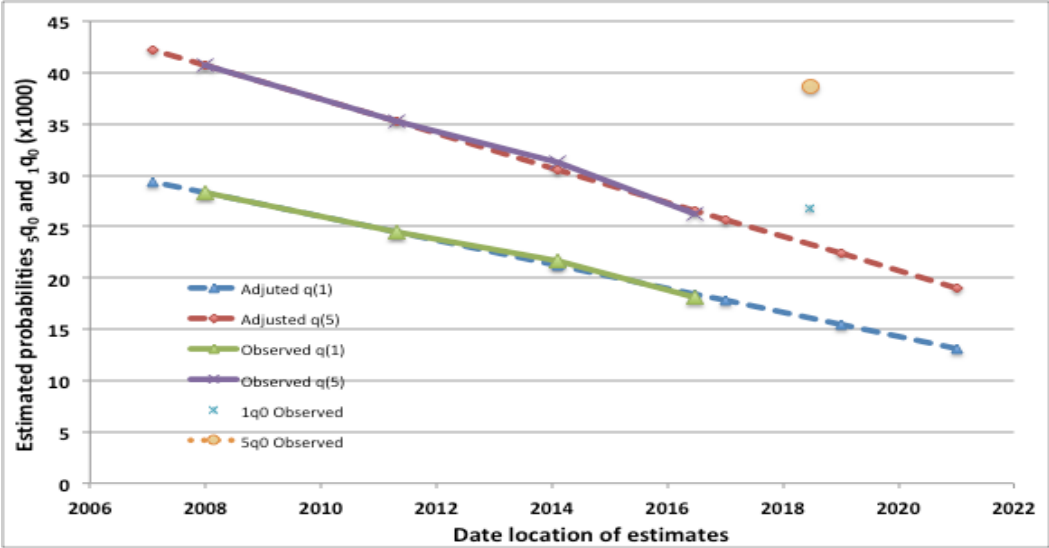
In the case of PNG, we find this particular situation: the point estimates with time locations 2018-2019 and more recent dates, would be affected by deaths associated to the 2020-2021 period of the COVID-19 pandemic. As mentioned before, in most countries the third point estimate, derived from respondents in age group 25-29, would fall in line with estimates from older age groups. Only the first two-point estimates reflect the selective higher mortality risks commented upon. The unusual higher level of the third point in Figure 9, which falls in line with the upturn of the first two points (derived from 15-19 and 20-24 age groups), would be reflecting higher mortality associated with the COVID-19 pandemic around those dates. This may also play a role in the higher than usual up turn of mortality risks registered by the first two-point estimates, which increased in a larger proportion than usually observed in this methodology. The higher scale of the trend reversal is most probably revealing a genuine reversal in the mortality decline, caused by the pandemic. At this stage we can only raise these points as a hypothesis, because no disaggregate information is available to assess/corroborate the scale of the COVID-19 impact. Strictly speaking, mortality rates at dates early than 2019 would not be affected by the impact of the pandemic. However, in the indirect estimation methodology used here, the time location of the estimates does not represent a fix point in time. The estimates derived through this methodology, and their time location, summarize the experience for a cohort that includes events occurring during a period of time, the time location being about the midpoint of such period. Hence even those estimates with time location before 2018, they incorporate in the cohort’s experience a number of events that have occurred after the estimated time location, and up to the day when the survey was conducted. Obviously, most recent events are less frequent in the cohort experience reported by older age groups; therefore reports from groups over age 30 incorporate a small number of events that occurred during the pandemic.

If the higher mortality associated with the epidemic is reflected in those higher probabilities located around 2019 and more recent dates, then it would be expected that the declining mortality trends observed in earlier dates are genuine. Also it would be expected that as the impact of the epidemic had passed, then the declining tendency (as reflected in past trends) would resume. Under this scenario the extrapolation of the declining trend may give reasonable estimates of mortality for recent dates after 2021, if the pandemic’s impact is entirely over. On this assumption the trend line was adjusted based on data from the older four age groups, and this tendency was used to derive more recent estimates. The first three-point estimates are not taken into account in the adjusted tendency, due to the probable impact of the pandemic and to the usual selectivity affecting estimates from

reports of age groups 15-19 and 20-24. This is reflected in the patterns of early age mortality presented in Figure 10.

Figure 10 presents the estimated ${}_1q_0$ and ${}_5q_0$ probabilities as obtained from the 2022 SDES reports (observed values), the adjusted ${}_1q_0$ and ${}_5q_0$ probabilities according to a linear trend line fitting the estimated point values dated from 2017 and before. The two-point values (${}_1q_0$ and ${}_5q_0$) derived from reports of 25-29-year-old women have been also plotted in this graph, for comparison with the adjusted tendency. It is clear that the values for these two-point estimates, which may be affected by events during the years of the COVID-19 pandemic, are well above the trend lines for the rest of the estimates. The rest of the point estimates show a very consistent pattern, which closely adjust to a declining linear mortality trend.

Figure 10. PNG 2022 SDES: Estimated level and trends of mortality in early years of life



Source: PNG 2022 SDES

The numeric values represented in Figure 10 are showed in Table 8. It can be seen that the first three estimated probabilities for recent dates are well above the trend, while the estimates for dates located before 2018 closely fit the adjusted trend line.

Table 8 PNG 2022 SDES: Estimated level of $1q_0$ and $5q_0$ (x1000) and adjusted mortality trends, both sexes

Time location of mortality estimates	Infant mortality level (IMR) ${}_1q_0$		Under-five Mortality level ${}_5q_0$	
	Estimated	Adjusted*	Estimated	Adjusted**
2024.0		10.48		14.40
2023.0		11.69		16.02
2020.8	51.2	14.31	68.5	19.53
2019.8	42.6	15.54	57.1	21.18
2018.4	28.1	17.30	37.9	23.53
2016.4	19.2	19.70	26.0	26.74
2014.0	23.1	22.56	31.2	30.58
2011.3	26.1	25.84	35.3	34.97
2008.2	29.3	29.60	39.5	40.00

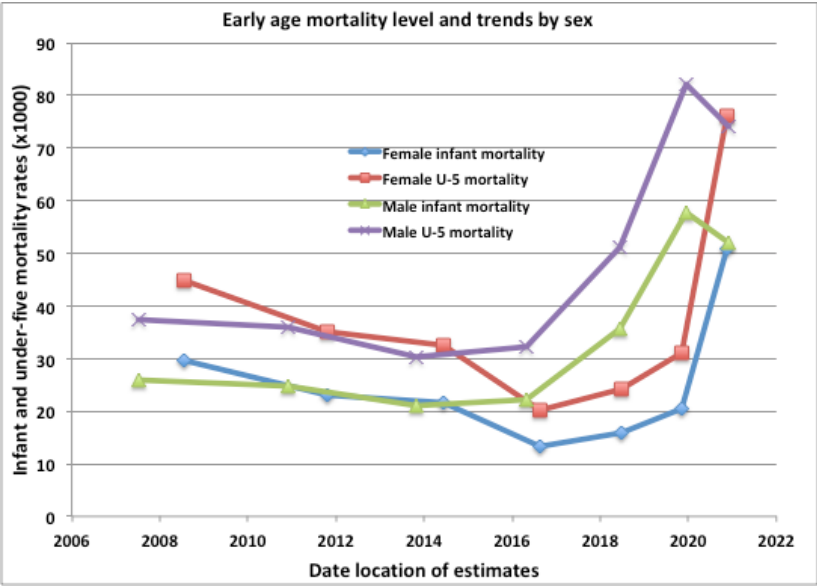
*Infant mortality trend line: $IMR = 2466.2 - 1.2133 t$
** Under-five mortality trend line: $U5MR = 3303.6 - 1.6251 t$

Source: PNG 2022 SDES

Early age mortality level and trends by sex

The same estimation process as described in the previous section for children of both sexes, is used to estimate infant and under-five mortality for female and male children, based on the numbers of children ever born and survived by sex. The calculated probabilities ${}_1q_0$ and ${}_5q_0$ by sex are presented in Figure 11.

Figure 11. PNG 2022 SDES: Estimated level and trends of mortality in early years of life, expressed in terms of the ${}_1q_0$ and ${}_5q_0$ mortality rates by sex



Source: PNG 2022 SDES

The same challenges discussed when analysing these trends for the total population (related to the variations in the point estimates located in the recent period preceding the survey) which were impacted by the effects of the COVID-19 pandemic, are faced when analysing the mortality trends by sex, as can be seen in Figure 11. The situation complicates further when trying to reconcile the variations in time and by sex, during this recent period previous to the survey: the reverse in the mortality trends characteristic in the estimates for the first two points derived from age groups 15-19 and 20-24, in this case extends also to the mortality rate estimated from the information of age group 25-29, a situation that was discussed in the previous section. Additionally, data for females from age group 35-39 show a slight jump to higher mortality, as compared to the overall trend determined by information from age groups in the interval of age 30 to 50.

Based on all these considerations, the points estimates in Figure 11, which are dated more recent than 2007, should not be considered when establishing the trends of the early age mortality, as they are affected by particular factors reflecting in higher mortality levels, as discussed earlier. The series of estimates located in time before 2017 are in general consistent in terms of their levels, although the differential by sex seem to be affected either by sampling or some reporting errors. The uncertainties in the estimates by sex are related either to lower male mortality level in the reports from age groups 35-39, 40-44 and 45-49, or else higher than expected female mortality in the reports from those age groups. The reports from age groups 35-39 and 40-44 show similar trends by sex, while the group 45-49 provides a mortality estimate that is higher for females.

In order to discern on the factors that may explain this divergence from expected results, which departs from the usual differential of higher mortality for males, available estimates from previous studies were explored. The values of these estimates are included in the annex of this report.

Estimates from censuses and surveys collected in the period from 1980 to 2018 were analysed (Bakker, 1986) (National Statistical Office, Papua New Guinea, 2012) (National Statistical Office, Papua New Guinea; ICF, 2019). The evidence indicates that in studies based on 1980 census data, 1990 census data, 1996 DHS and the 2000 census, early-age mortality estimates show sex differentials in the expected direction, with higher male mortality.

However, data from more recent studies, DHS 2006, and 2011 census reveal similar mortality levels by sex, and in the case of the DHS (2016-18) data, it indicates a higher level of under-five mortality for girls than boys (49 vs. 48 per 1,000). Hence, assuming that the data from these different sources are not affected by errors in a differential manner, the mortality trends in previous decades may indicate that female mortality has decreased less (or more slowly) than male mortality. Hence, at a later stage, when life tables by sex will be needed to calculate based on adult mortality derived from orphanhood data (mother and father) combined with early age mortality from children ever born and children surviving, a small differential by sex is going to be adopted, with slightly higher under-five male mortality level, than the under-five female mortality level.

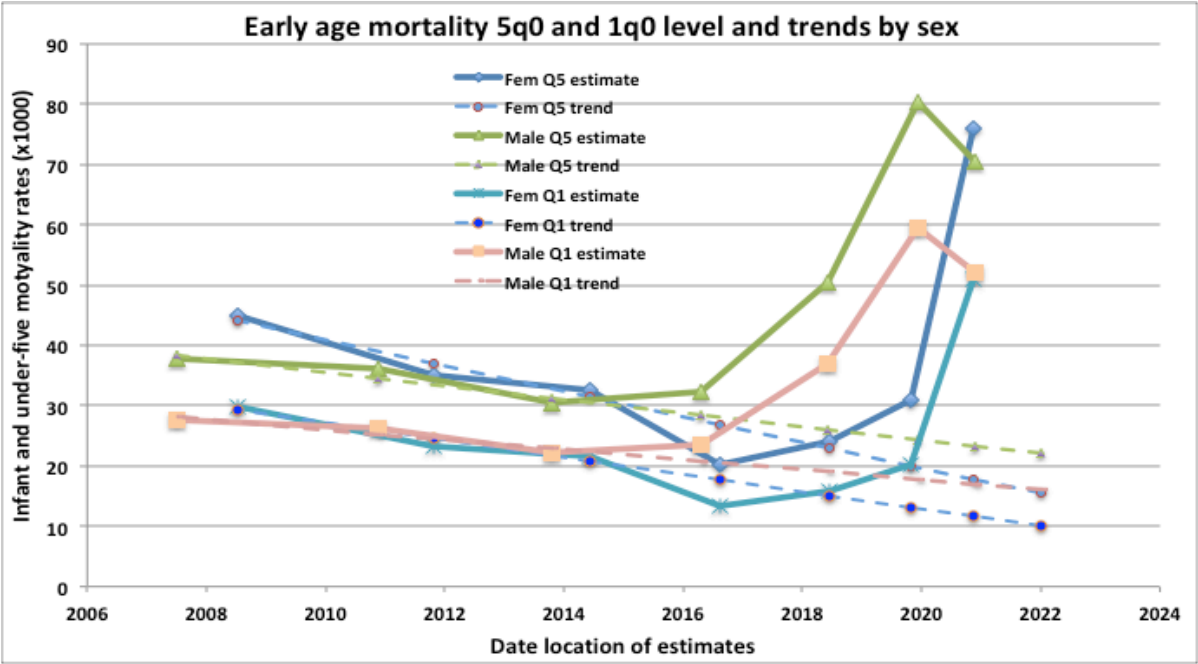
Summarizing, after due consideration of the patterns discussed in the previous paragraph, a linear trend was adjusted to estimates obtained from the point estimate series by sex, after leaving aside those point estimates that because of selectivity and/or some effect of the COVID-19 pandemic, may distort the underlying overall trend in early mortality. Table 9 shows estimated and adjusted values for ${}_1q_x$ and ${}_5q_0$ by sex, and the linear adjustment equations. The determination of the mortality trends for females is more challenging, as the estimate series show some oscillations in certain dates. In addition to the irregular patterns in recent dates, discussed above, most probably the point estimate obtained for girls from age group 45-49 is too high, either due to some age misreporting or random variation. Due to the very high estimate obtained from group 45-49's reports, the trend line that could be adjusted for female estimates probably register a slope that is too steep, leading to very low rates for the recent dates, compared to the male estimates. Figure 11 presents the results of these adjustments, which allow to better compare the differences in the estimated trends by sex.

Table 9 PNG 2022 SDES: Estimated level of 1q0 and 5q0, and adjusted mortality trends by sex

Time location of estimates		Infant mortality level (IMR) $_1q_0$				Under-five Mortality level $_5q_0$			
		Estimated		Adjusted*		Estimated		Adjusted**	
Female	Male	Female	Male	Female*	Male*	Female	Male	Female	Male
2022	2022	-	-	10.10	16.12	-	-	15.43	22.11
2020.9	2020.9	50.87	51.98	11.70	17.02	76.04	70.54	17.83	23.34
2019.8	2019.9	20.36	59.39	13.18	17.83	30.93	80.38	20.03	24.43
2018.5	2018.4	15.84	37.05	15.13	19.06	24.12	50.57	22.94	26.11
2016.6	2016.3	13.23	23.47	17.75	20.82	20.18	32.20	26.87	28.49
2014.4	2013.8	21.54	22.24	20.85	22.90	32.70	30.52	31.50	31.32
2011.8	2010.9	23.18	26.32	24.60	25.30	35.16	36.07	37.10	34.58
2008.5	2007.5	29.80	27.51	29.26	28.09	45.05	37.68	44.06	38.37

*Female infant mortality trend line: $IMR^f = 2887 - 1.4229 t$
*Male infant mortality trend line: $IMR^m = 1687.1 - 0.8264 t$
** Female under-five mortality trend line: $U5MR^f = 4314.4 - 2.1261 t$
** Male under-five mortality trend line: $U5MR^m = 2291.4 - 1.1223 t$
Source: PNG 2022 SDES

Figure 12. PNG 2022 SDES: Estimated level of $_1q_0$ and $_5q_0$, and adjusted mortality trends by sex



Source: PNG 2022 SDES, numeric values as presented in Table 9

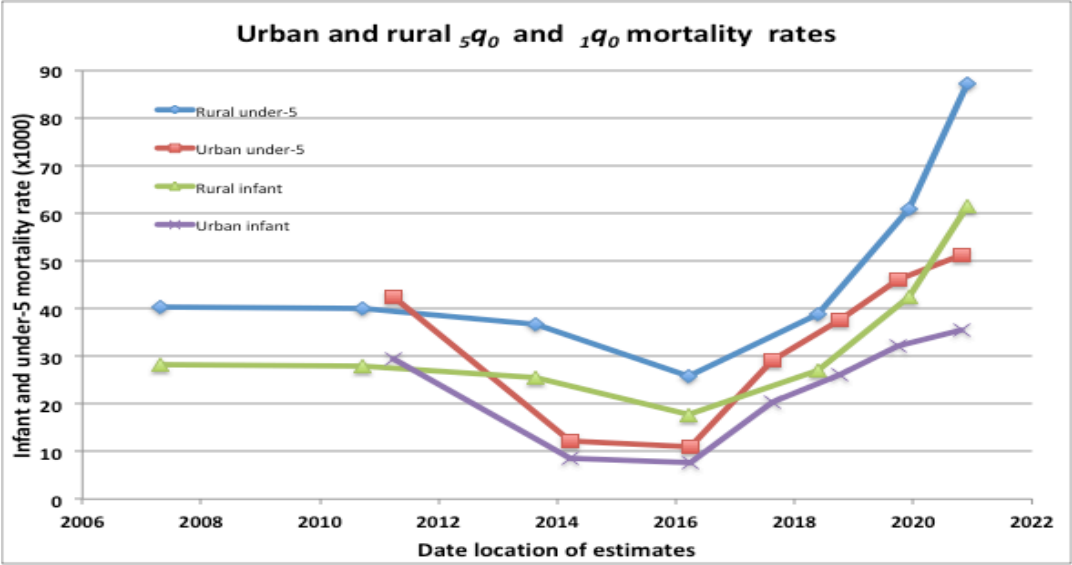
Early age mortality level and trends by rural and urban areas

The indirect estimation methods were also applied to information classified by areas of residence, firstly for both sexes in the rural and urban areas, before being performed for each area of residence by sex.

Infant and under-five mortality rates by areas of residence

Figure 13 presents the estimated mortality rates, $_5q_0$ and $_1q_0$, for rural and urban areas.

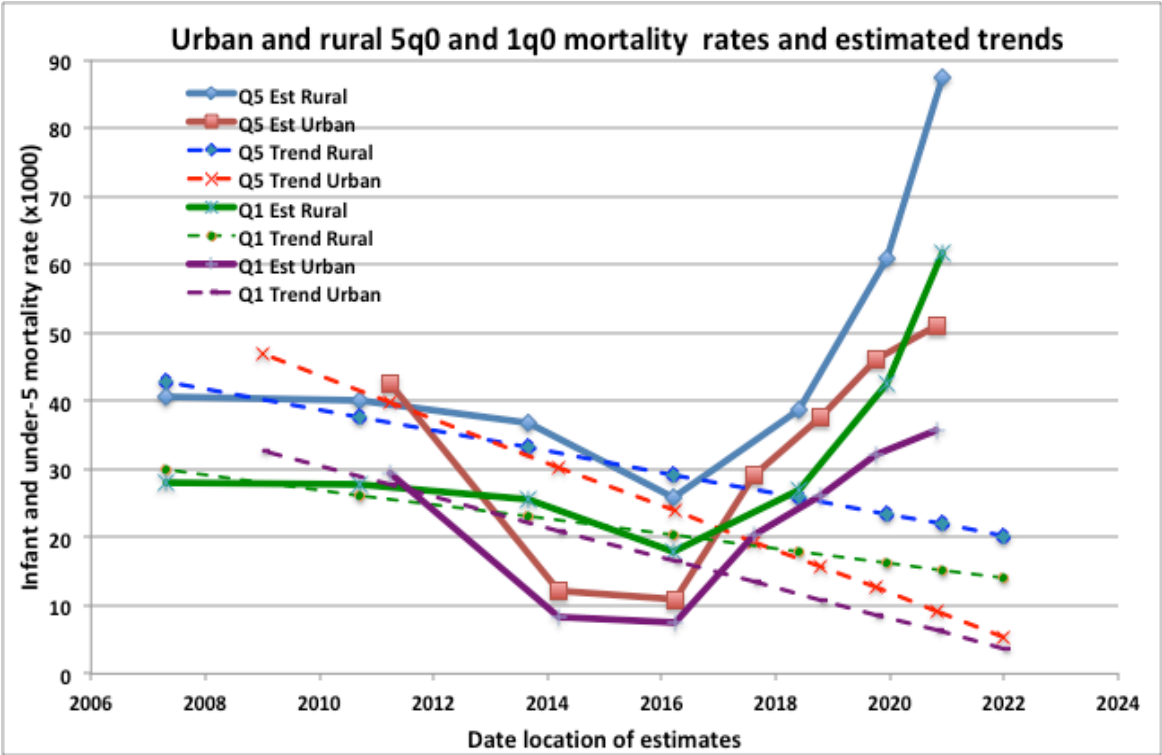
Figure 13. PNG 2022 SDES: Estimated mortality rates ($_1q_0$ and $_5q_0$) by areas of residence



Source: PNG 2022 SDES, numeric values as presented in Table 10

The estimates for the rural area show patterns of higher mortality level than in the urban areas, and show more or less regular trends, except for the estimates situated at dates about 2018 and more recently, when the level of mortality increases sensibly for reasons already discussed. On their part, the estimates obtained for the urban areas present levels of mortality that are lower than those in the rural area, as expected, however the trend is very irregular. The oscillations from one point estimate to another in the urban area make it difficult to establish a coherent trend line of mortality over time. Relevant inconsistencies emanate from a very high mortality level derived from age group 45-49 reports, which shows very high mortality, even higher than that in the rural area, combined with levels of mortality from groups 40-44 and 35-39, which are too low, excessively lower than those in the rural areas. Hence, estimation trends calculated from the observed rates indicate too high mortality for dates about 2012 and before (even higher than in rural areas), combined with levels excessively low for recent dates in the urban area; together these determine unlikely too steep declining trends in the urban area. These odd patterns, combined with the increases in mortality in the period from 2018 to the survey's date would not allow to establish any consistent mortality pattern over this time period for the urban area. The described inconsistencies in urban mortality trends can be observed in Figure 14, with their associated unreliable trends in time. The inconsistent time variations of mortality in urban areas may be associated with smaller numbers of observations by age group of respondents in this area, in the PNG 2022 SDES. Although less feasible, this could be combined with some misreporting in survey responses (either on age or children born or surviving).

Figure 14. PNG 2022 SDES: Estimated mortality rates, ${}_1q_0$ and ${}_5q_0$, and linear trends by areas of residence

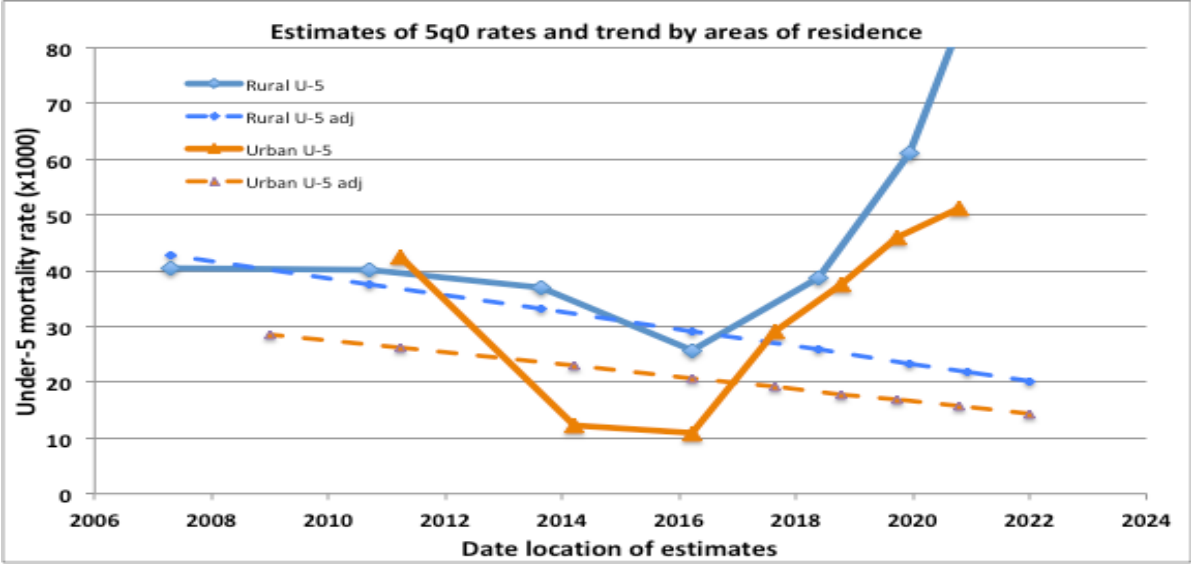


Source: PNG 2022 SDES, numeric values as presented in Table 10

There are no adequate methodological procedures to make sensible adjustments for solving this type of inconsistencies. Hence, an adaptation of a proposal developed by Neupert and Fernandez (Neupert, Fernandez Menjivar, & Fernandez Castilla, 2019) to estimate mortality for small areas, based on data on children ever born and surviving, has been used to derive reasonable mortality trends for the urban area on the basis of PNG 2022 SDES data. The odd patterns observed here approximates the challenge of estimation for small areas, therefore the methodology would be pertinent. The essence of the methodology is based on two assumptions:

- a) If the patterns of mortality by age are similar in larger and smaller areas, then the difference in the level of mortality between the areas could be established by expanding the age interval of the informants (e.g. using age groups 30-44 or 30-49, instead of five-year intervals) so that random variations in the proportion of children dead (due to small numbers) are sensibly reduced. In this way, the ratio of the proportion of children dead in the small area to that ratio in the large area would provide an adequate indicator of the difference in the scale of mortality between areas.
- b) If the patterns of mortality change over time are similar in the larger and smaller areas, then the trend of mortality in the larger area (in this case rural area) could be taken as an approximation for the trend in the urban area, and the level of mortality for the respective location dates can be adjusted by using the factor of scale (ratio of proportions dead in expanded age group) that link the level of mortality in rural to the level in the urban area, therefore establishing the estimated level of mortality and variation over time for the urban area. The proportion of children dead among those ever born in age group 30-49, in urban areas compared to that in rural areas was 0.71. This ratio was taken as scale factor to derive the mortality trends in the urban area, from those estimated for the rural area, based on PNG 2023 SDES data. Figure 15 presents the ${}_5q_0$ mortality level and trends calculated in this way for the urban areas, together with estimated values for rural and urban areas. Since the same procedure is used for the infant mortality rate, the values of ${}_1q_0$ are not included in Figure 5, in order to avoid congesting the line trends in the graph, because the same patterns as those observed for the ${}_5q_0$ would reproduce in relation to ${}_1q_0$ in Figure 15.

Figure 15. PNG 2022 SDES: Estimated mortality rates $_5q_0$ and trend in time, by areas of residence



Source: PNG 2022 SDES, numeric values as presented in Table 10

Obviously the trend line for the rural area closely follows the observed points (excluding the first three) in the series, while the observed points for the urban area are more dispersed (due to the random variations discussed before) in relation to the trend line for the urban area, which was derived from observed patterns in the rural area, adjusting for the scale of mortality, thus avoiding the constraints imposed by the irregular pattern of variation in time, registered in the estimated mortality indicators for the urban area, due to random sample variations. The numeric values for the estimated $_5q_0$ and $_1q_0$ mortality rates as well as the adjusted mortality trends are presented in Table 10.

Table 10. PNG 2022 SDES: Estimates of 5q0 and 1q0 mortality rates and trend, by area of residence

Rural area					Urban area				
Dates	$_5q_0$		$_1q_0$		Dates	$_5q_0$		$_1q_0$	
	SDES	Trend	SDES	Trend		SDES	Trend*	SDES	Trend*
2022	-	20.21	-	14.00	2022	-	14.35	-	9.94
2020.9	87.37	21.88	61.60	15.16	2020.8	51.14	15.66	35.65	10.85
2019.9	60.98	23.41	42.64	16.23	2019.7	46.07	16.83	35.65	11.67
2018.4	38.80	25.79	26.94	17.90	2018.8	37.69	17.89	32.06	12.42
2016.2	25.72	29.15	17.78	20.25	2017.6	29.24	19.15	26.16	13.30
2013.6	36.86	33.12	25.58	23.03	2016.2	10.91	20.67	20.24	14.37
2010.7	40.06	37.65	27.82	26.21	2014.2	12.21	22.90	7.50	15.93
2007.3	40.49	42.91	28.12	29.89	2011.2	42.46	26.17	8.41	18.21

Source: PNG 2022 SDES, and Trend * calculated based on small area estimation procedure (Neupert, Fernandez Menjivar, & Fernandez Castilla, 2019)

The mortality level and trends obtained for the rural area from the PNG 2022 SDES data show regular and reliable patterns. Therefore, the estimated values as adjusted from the trend line, presented in Table 10 can be considered a reasonable approximation for the adjusted $_5q_0$ and $_1q_0$ mortality rates at the dates indicated in Table 10. For the urban area the survey information is affected by random variations, as the number of cases observed by five-year age groups in the urban area are small. In this case it was considered more sensible to adopt estimates for $_5q_0$ and $_1q_0$ mortality rates that were derived through an alternative methodology, which has been developed for the estimation of mortality indicators for small areas (Neupert, Fernandez Menjivar, & Fernandez Castilla, 2019). The results of this procedure are also presented in Table 10 for $_5q_0$ and $_1q_0$ under the respective “Trend*” columns.

Hence, it can be concluded that the level of mortality in the rural area are higher than those in the urban area, and they present a consistent trend of declining mortality. For the rural area the level of under-5 mortality, $_5q_0$, declined from 42.9 children death before reaching age five, per 1,000 live births in 2007, to 20.2 deaths per 1,000 live births in 2022; that is a reduction to less than half the level of mortality about 40 years ago. In the same period the reduction in infant mortality, $_1q_0$, was from a level of 29.9 infant deaths per 1,000 live births to a level of 14.0 deaths, also less than half the level of mortality prevailing at the start of the analysed period. In the urban areas the level of under-five mortality was 26.2 in 2011, coming down to a level of 14.4 deaths before reaching age five, per 1,000 live births. It is also a considerable improvement in the survival rates, although a little lower than the observed trend in rural area. In terms of infant mortality, the reduction was from a level of 18.2 infant deaths in 2011 to a level of 9.9 deaths per 1,000 live births in 2022.

The analysis of differential mortality by sex within the areas of residence is not performed because of the limitations associated to the size of sample survey, which would produce too large random variations in the estimates.

3.4 Estimation of adult mortality using PNG 2022 SDES data

To larger extent than it was described for infant mortality, accurate knowledge of adult mortality levels and trends in the developing world has been hampered by a widespread lack of complete vital registration systems.

While knowledge of infant and child mortality have made most relevant advances through survey-based estimation techniques, such techniques for estimating adult mortality have not made a commensurate contribution; hence we know less about the latter than the former. Nevertheless, the option of using indirect techniques to estimate adult mortality has made a relevant contribution, and under favourable circumstances adequate calculation of mortality risks at adult ages can be obtained through these methods.

For the purposes of demographic analysis, adult mortality is usually defined as mortality at ages 15 and older. Nevertheless, in some contexts, “adult mortality” refers solely to mortality between ages 15 and 60, to contrast it with older-age mortality, which refers to mortality at ages 60 and above. The probability that a person alive on their 15th birthday would die before her 60th birthday ($_{45}q_{15}$ in the notation of the life table) has been widely used as an appropriate indicator of adult mortality. Hence, $_{45}q_{15}$ is frequently used to denote the level of adult mortality.

The indirect estimation of adult mortality, in a similar way as earlier discussed for estimating the level of mortality at early years of life, relies on information provided by respondents to censuses or surveys interviews. In the cases of adult mortality, the questions pertain to survivorship of relatives (most frequently their parents), but also widowhood or survivorship of siblings can be used to obtain indicators of mortality at adult ages.

In the case of PNG SDES, as indicated earlier, questions **Q.7 and Q.8** were incorporated in the survey to obtain measurements of adult mortality, which were included in section B of the questionnaire:

Q7: Is (name's) own father still alive? With possible responses: **1. YES; 2. NO ; 3. Do not know**

Q8: Is (name's) own mother still alive? With possible responses: **1. YES** (if member of this household, write mother's person number in the two boxes. If not a member of this household write “00” in the two boxes; **2. NO** (leaves person's name blank) ; **3. Do not know** (leaves person's name blank).

The identification of the mother's respondent, as seen in the questionnaire for persons with their mother alive in same household, is not used in the estimation of adult mortality. However, this constitutes important information for the study of fertility.

The Rationale of the Methodology: Obviously the level of parent's mortality is implicit in the proportions of orphans (derived from the answers to those questions in the PNG SDES questionnaire) without requiring respondents to recall the dates when deaths occurred or the ages at death of deceased individuals. The probabilities of survival implicit in those proportions are conditional probabilities, by the fact that the respondents' mothers (or fathers) necessarily were alive for the respondents to be born. The duration over which those mothers have been exposed to the risk of dying is given by the age of the respondents.

Life table survivorship from age 25 to age 25 plus a rounded number of years n , ${}_n p_{25} = l_{25+n}/l_{25}$ can be derived using age fertility distribution models and mortality age distribution models. The n number of year in the survivorship interval is related to the age of the respondents, while the base age **25** approximates (for the average of respondents) the moment in the past, when the respondent was born. The mean age at which the mothers gave birth in the population concerned – which is evaluated from the empirical data provided by the survey – would specify the necessary adjustment from this base age **25** to the adequate fertility distribution in the given population. In this way conventional life table measures (${}_n p_{25} = l_{25+n}/l_{25}$) for the female population can be obtained from the proportions of respondents who have their mothers alive at the time of the interview. Adequate age fertility distribution models and age mortality models can be used for translating the proportions not orphan into adequate probabilities of surviving. The estimation method provides a series of conditional probabilities of survival, where each of these probabilities relates to an age group of respondents.

Louis Henry (Henry, 1960) was the first to propose estimating adult mortality from proportions of orphans. The first author to formalize a procedure to derive female probabilities of survival from proportions of orphans was W. Brass (Brass W. , 1975). Brass established an equation relating the female probability of surviving from age 25 to age 25+ n , to the proportions of respondents in two contiguous five-year age groups whose mother was still alive at the time of the interview.

This equation has the form: $l(25+n)/l(25) = W(n) S(n-5) + (1-W(n)) S(n)$

Where **S(n)** is the proportion of respondents aged from n to $n+4$ with mother alive, and **W(n)** is a weighting factor employed (Coale & Trussell, 1974) to make allowance for typical age patterns of fertility and mortality. The set of **W(n)** values that Brass proposed were estimated on the basis of data simulated by using a single mortality pattern (the African standard) and model fertility schedules of fixed shape but variable age locations. Each age location of the fertility schedule is associated with a particular value of **M**, the mean age of women (or men) at the birth of their children. Thus, the weights, **W(n)**, depend both upon n , the central point of the age groups being considered, and upon **M**.

Subsequently, Hill and Trussell (Hill & Trussell, 1977) proposed another estimation procedure based on the following equation: $l(25+n)/l(25) = a(n) + b(n) M + c(n) S(n-5)$

In this equation **a(n)**, **b(n)** and **c(n)** are coefficients estimated by using linear regression to fit the estimation equation to data from 900 simulated cases. These simulated cases were obtained by using several fertility schedules generated by the Coale-Trussell's (Coale & Trussell, 1974) model and a broad variety of mortality schedules.

That is, in both methodological options previously mentioned, the coefficients in the respective estimation equations would link the conventional life table measurements $l(25+n)/l(25)$ to observed values from census/survey information on parents' survival; thus transforming the unconventional measurement of survivorship (proportion of mother/father surviving), obtained from the surveys or censuses, into a conventional life table probability of surviving.

Further developments of the methodology were introduced by Ian Timæus (Timæus I. , 1991) (Timæus I. , 1992), who introduced some refinements into the process of determining the exact exposure time of the respondents' parents to the risk of dying, such exposure times are implicit in the proportion of respondents with their parents still alive, classified by age. Timæus established the equation that transforms the proportions reported in the survey into probabilities of the type $l(25+n)/l(25)$, as:

$${}_n p_{25} = l(25+n)/l(25) = a(n) + b(n) M^f + c(n) {}_5 S_{n-5}$$

For example, ${}_n p_{25}$ will be calculated using the multipliers $a(10)$, $b(10)$ and $c(10)$ (values tabulated in IUSSP manual), the mean age at childbirth of mothers M^f and the proportion of surviving mothers ${}_5 S_{n-5} = {}_5 S_5$, as were reported by children in the age group 5-9 years old.

It is noted that the probability of surviving $l(25+n)/l(25)$, by definition, implies that the individual is alive at age 25, because it measures the probability that the person would survive from age 25, to age 25+n. That is, it measures the probability of surviving at least for n years after the 25th birthday. Hence, these are conditional probabilities: their measurement assumes a previous survivorship up to age 25. This is so, because the proportions $S(n)$ are indeed conditional survivorship measurements: obviously for sons/daughters to inform on survivorship of their parents, the parents were alive at a given age, which was the age parents had at the time of birth of the informant. In the case of the mother the conditional time is set at the exact time of childbirth, but for the father the conditional time would be at conception; hence, having a shift of 9 months back from the time of birth.

The probabilities of survival for the male population are obtained by using the proportions of respondents with fathers alive and adjusting for the mean age at which fathers have children. Since men tend to be older than their couples, the conditional probability is taken from a base age of 35, up to an age 35 + n where n is again linked to the age group of the respondents (${}_n p_{35} = (l_{35+n}) / (l_{35})$). Information on the ages of fathers at the birth of their children is not easily accessible. The mean age of fathers at birth of their children, need to specify the male fertility distribution. As an approximation, this is derived from the mean age of the women's fertility distribution, with reasonable adjustments that take into account the average age difference between spouses. Such adjustment is done by adding the difference between the median age of married men and married women, to the mean age of women at childbearing. These adjustments are explained in detail in the methodology section included in the annexes.

In a similar manner as described for estimating mortality at early ages, the derived probabilities of survival are for intervals up to different ages and correspond to different moments in time. To make these measures comparable, on the one hand the mortality risks measured through the probabilities of survival need to be expressed in terms of a unique mortality indicator; on the other hand, it is necessary to determine the exact location in time for these estimates. The first proposal for determining the time location of the estimates was done by Brass and Bamgboye (Brass & Bamgboye, 1981). Having the series of survival probabilities translated into a unified mortality index, with its corresponding location in time, it is then possible to assess the level of mortality at given dates and its evolution over a period of time before the survey.

Calculation of adult female and male mortality levels and trends using indirect estimation methods based on parental orphanhood

The calculation of the conditional probabilities of survival is done by means of the Microsoft Excel worksheets available from the IUSSP manual. The worksheet uses the estimation variant proposed by Ian Timæus. The manual's worksheet provides one sheet for the calculation of female mortality from maternal orphanhood and a separate sheet for paternal orphanhood.

The process requires to:

1. Select the model life table to be utilized.
2. Select the summary index of adult mortality to be obtained, tabulated and plotted for the analyses (${}_{45} q_{15}$ or ${}_{30} q_{30}$).
3. Enter the mean date when the interviews were conducted.
4. If information classified by female and male respondents is available, the worksheet provides for data to be entered by sex of the respondents (frequently the quality of data varies if it is provided by female or male respondents, so this would allow some assessment of data quality), the responses not knowing the status of parental survivorship are excluded.
5. The number of births in the last year preceding the survey are entered to calculate the mean age of childbearing, which is a parameter used in the calculations. In the case of paternal orphanhood, the mean age of childbearing for men is estimated from the mean age for women, plus the difference between the median age of married men minus the median age of married women.

The information on points 1, 2, and 3, listed above, are similar for maternal and paternal orphanhood. The calculation sheet for paternal orphanhood also provides for entering data by sex of the respondents (point 4). Then, to estimate the mean age of childbearing for men, the procedure requires to enter the number of currently married men and women; these are utilized to estimate the median age of the married by sex, and the difference

is added to the women mean age of childbearing in order to get a reasonable estimation of the mean age of childbearing for the male population. Table 11 presents the input data for adult mortality estimation based on parental orphanhood. For brevity purposes, this illustration includes only the maternal orphanhood input data, plus age distribution of married by sex. The complete information is included in the annexes.

Table 11. Summary of necessary inputs to estimate adult mortality from orphanhood

Inputs for maternal orphanhood worksheet				For estimating men's mean age at childbearing: include number of married by sex		
Model life table: UN Gral; Summary index: $_{45}q_{15}$; Date of survey: SDES, 1/06/2022						
Age	Number respondents (both sexes only)	Mother alive	Births last year	Age	Female	Male
5- 9	3,034	2,970		10-14	0	1
10-14	2,763	2,677		15-19	111	13
15-19	2,552	2,413	39	20-24	543	179
20-24	2,163	1,956	150	25-29	805	561
25-29	2,074	1,761	172	30-34	793	619
30-34	1,701	1,308	131	35- 39	749	672
35-39	1,549	990	73	40-44	572	523
40-44	1,137	607	31	45-49	556	569
45-49	1,151	456	9	50-54	389	463
				55-59	295	314
				60 +	571	657

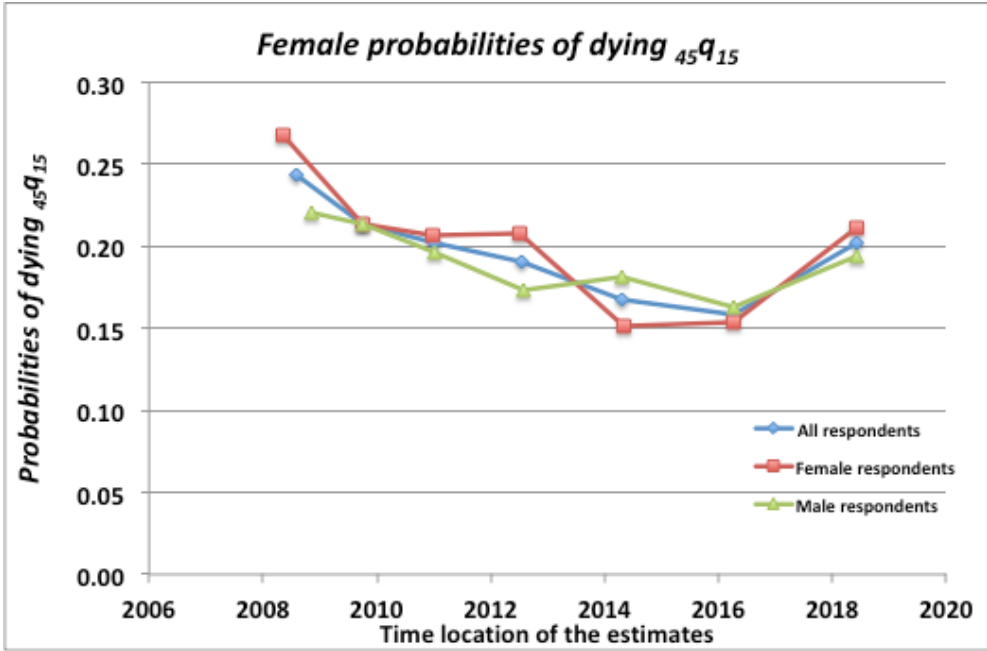
Source: PNG 2022 SDES

In the distribution of married males and females by age, which is used to obtain the differences in the median ages needed to estimate the mean age of men at childbearing, the open-ended age group can be from any starting age, provided it starts at an older age than the age group where the cumulated distribution has reached more than half the total number of married women and men.

Based on his experience from using these methodologies, Timæus (Timæus I. , 1992) suggest to tabulate the proportions of respondents with parents alive separately by sex of the informant, since the information provided by female informants is more reliable, as apparently women are more in touch with their families, informing more accurately on parental survival. This has been done in these applications of the methodology.

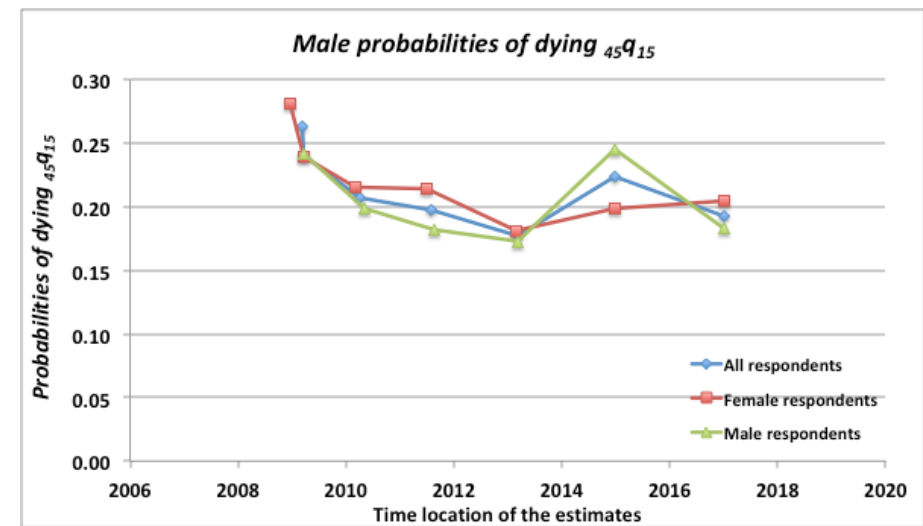
Figures 16 and 17 present respectively the estimated values for the female conditional probabilities of surviving ($_{45}p_{25}$) and male conditional probabilities of surviving ($_{45}p_{35}$), according to the sex of informant, which represent the outputs from the Microsoft Excel worksheet that were used in the calculation process.

Figure 16. PNG 2022 SDES: Female probabilities of dying at adult ages, $_{45}q_{15}$, by sex of the informant



Source: PNG 2022 SDES

Figure 17. PNG 2022 SDES: Male probabilities of dying at adult ages, $_{45}q_{15}$, by sex of the informant



Source: PNG 2022 SDES data

The analysis of the patterns in Figures 16 and 17 indicates that the suggestion to use female informant’s data seems to be adequate in the case of paternal orphanhood, but in the case of maternal orphanhood the information obtained from both sexes presents more regular patterns, which seems to cancel out irregular variations in the estimates derived separately from female and male informants. Hence, the estimates calculated from both sexes’ information would be adopted for female adult mortality, while mortality obtained from female informants will be retained for the estimates of the male adult mortality.

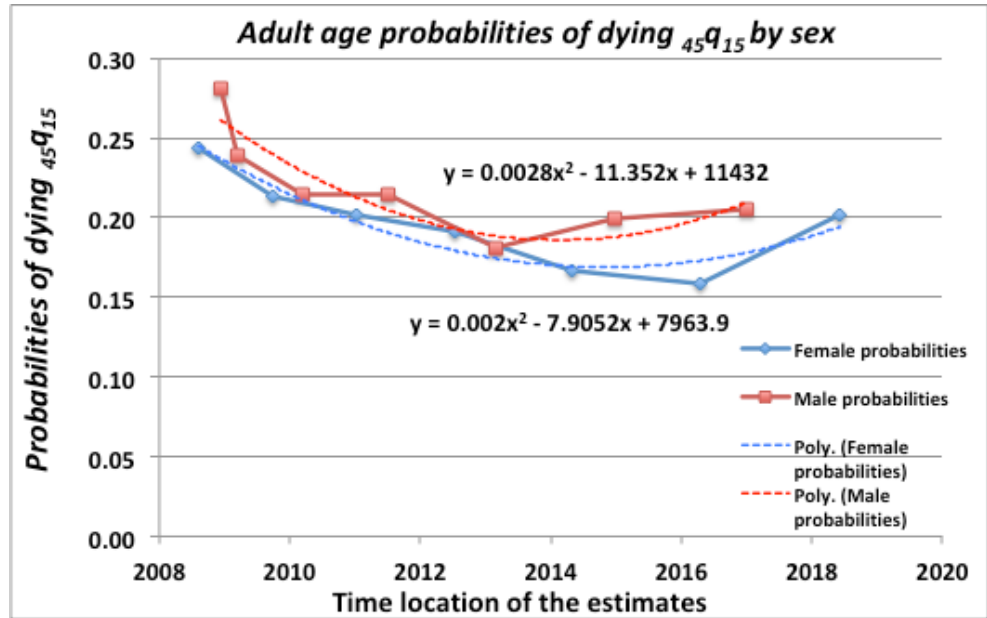
The estimated values for the female (${}_np_{25}$) and male (${}_np_{35}$) conditional probabilities of surviving, as well as their equivalent mortality level in terms of a unified index (which is $_{45}q_{15}$) and their respective time location are presented in Table 12, while Figure 18 presents the time series of adult mortality estimates by sex, and the adjusted trend line.

Table 12. PNG 2022 SDES: Estimated level and trends of adult male and female mortality ($_{45}q_{15}$) obtained from information on parental orphanhood

Age Group	Interval years (n)	Maternal orphanhood			Paternal orphanhood		
		${}_np_{25}$	$_{45}q_{15}$	Date	${}_np_{35}$	$_{45}q_{15}$	Date
5- 9	10	0.9756	0.20188	2018.4	0.9350	0.20460	2017.0
10-14	15	0.9691	0.15842	2016.3	0.9231	0.19901	2015.0
15-19	20	0.9498	0.16721	2014.3	0.9046	0.18113	2013.2
20-24	25	0.9145	0.19088	2012.5	0.8351	0.21438	2011.5
25-29	30	0.8685	0.20178	2011.0	0.7428	0.21465	2010.2
30-34	35	0.8002	0.21361	2009.7	0.5825	0.23921	2009.2
35-39	40	0.6802	0.24407	2008.6	0.4065	0.28111	2009.0
40-44	45	0.5808	0.22856				
45-49	50	0.4320	0.23172				

Source: PNG 2022 SDES

Figure 18. PNG 2022 SDES: Estimated level and trends of adult male and female mortality ($_{45}q_{15}$) obtained from information on parental orphanhood

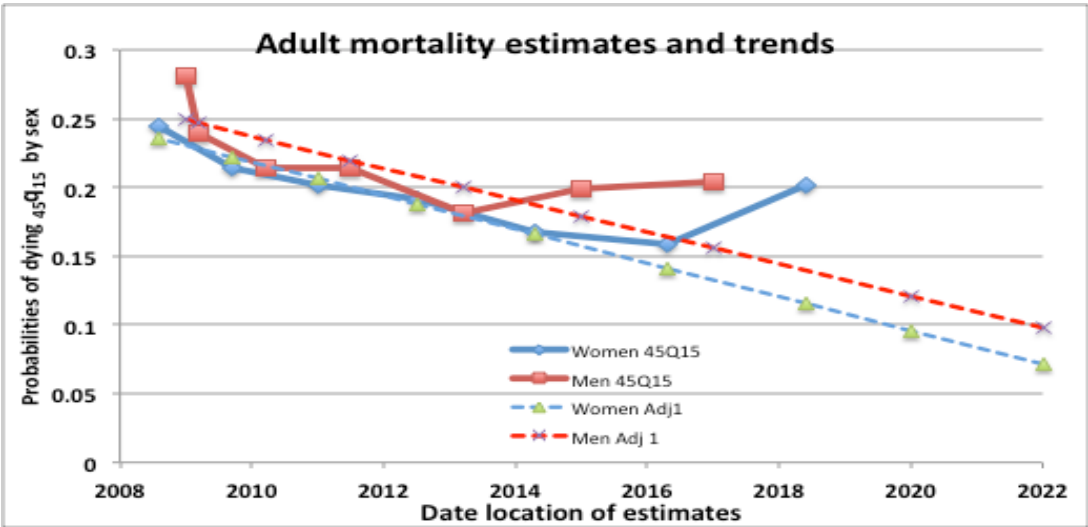


Source: PNG 2022 SDES

The adult mortality estimates presented in Figure 18 show a consistent decline in the level of mortality in both sexes in the early part of the time series, up to approximately 2015, when a reversal of this trend is observed. This trend reversal determines that the adjusted trend lines do not follow a linear trend but is better represented by a second-degree parabolic. The higher level of mortality in recent years may reflect the impact of the COVID-19 pandemic. Since the estimation methodology does not measure mortality by time-periods, but rather derive mortality estimates from cohort indicators, the time location of those indicators is established through modelling of those cohort observations. Hence the reversal of the declining trend is not determined exactly at the time of the pandemic, but at the average location derived for each cohort of respondents, therefore the underlying estimation methodology is smoothing those trends. This makes that the impact of the pandemic is gradually appearing for recent years and does not appear as a sudden jump in the mortality level exactly on years 2019, 2020 and 2021, when the pandemic exactly occurred. In any case, with due consideration to these caveats, the adult mortality patterns derived from the PNG 2022 SDES data appear very consistent and reliable.

The adult mortality trends presented in Figure 18 would represent most closely the experience throughout the span of time interval analysed. However, if we need to assess what the underlying trends would be –removing the pandemic effects-, it would be necessary to make a linear adjustment of past trends, without including the point estimates that are clearly affected by the impact of COVID, as well as other points that may be affected by random variations or misreporting. Those adjustments are presented in Figure 19, and Table 13 shows the numeric values visually presented in Figure 19.

Figure 19. PNG 2022 SDES: Estimated level and adjusted linear trends of adult male and female conditional probabilities of mortality ($_{45}q_{15}$) obtained from information on parental orphanhood



Source: PNG 2022 SDES

Table 13. PNG 2022 SDES: Estimated level and adjusted linear trends of adult male and female conditional probabilities of dying ($_{45}q_{15}$) obtained from information on parental orphanhood

Age Group	Interval years (n)	Maternal orphanhood			Female		Paternal orphanhood		
		$n p_{25}$	$_{45}q_{15}$	Date	trend		$n p_{35}$	$_{45}q_{15}$	Date
				2020	0.122651				2020
5-9	10	0.9756	0.20188	2018.4	0.136466	0.935	0.2046	2017	0.171175
10-14	15	0.9691	0.15842	2016.3	0.155491	0.9231	0.19901	2015	0.186124
15-19	20	0.9498	0.16721	2014.3	0.172832	0.9046	0.18113	2013.2	0.199663
20-24	25	0.9145	0.19088	2012.5	0.188462	0.8351	0.21438	2011.5	0.211919
25-29	30	0.8685	0.20178	2011	0.201939	0.7428	0.21465	2010.2	0.221721
30-34	35	0.8002	0.21361	2009.7	0.213174	0.5825	0.23921	2009.2	0.228955
35-39	40	0.6802	0.24407	2008.6	0.223224	0.4065	0.28111	2009	0.230807
40-44	45	0.5808	0.22856						
45-49	50	0.432	0.23172						

Source: PNG 2022 SDES

3.5 Construction of life tables by sex, based on mortality from birth to five-year age and adult mortality estimates, based on PNG 2022 SDES data

Life tables by sex can be estimated, including all its functions, comprising also the life expectation at birth as well as at other ages, on the basis of estimates of mortality by sex in the early years of life, represented by the under-five mortality rate ${}_5q_0$, combined with estimates of adult mortality level by sex, represented by the conditional probabilities of dying between exact age fifteen and exact age sixty, $_{45}q_{15}$. The methodology for constructing life tables from these two indicators (${}_5q_0$ and $_{45}q_{15}$), is based on Brass' relational logit model of mortality. (Brass W. , 1971).

The logit system model life table is a relational model to generate life tables. That is, the model is based on a mathematical relation between the functions of two life tables, which are conveniently transformed for this

mathematical relation. The life table functions are the age-specific survivorship function $l(x)$, which is the probability that a person would survive from birth to exact age x and is expressed on the basis on one individual. Therefore, the values of the $l(x)$ vary from zero to one ($0 < l(x) < 1$). The transformation of the $l(x)$, on which the relational model is based, is the logit transformation of $l(x)$, symbolized by $Y(x)$; $Y(x) = \text{logit } [l(x)]$; where the logit is defined as:

$$\text{logit } l(x) = -(0.5) \ln\{l(x)[1 - l(x)]\} \tag{1}$$

Then, the mathematical function relating the two life table functions in the relational model is: $Y(x) = \alpha + \beta Y^{\text{st}}(x)$ (2)

The first parameter of this system of models, α , captures differences in the level of mortality between the populations; then, if β is held constant and α changes, the results in term of $l(x)$ would be a parallel function, with values higher or lower than the original survival function. The second parameter, β , indicates differences in the relationship between the mortality in childhood ages and the mortality in adult ages in the standard life table as compared to the life table in the studied population; then, if α is held constant and β changes, the overall level of mortality would remain similar as in the original survival function, but the new function would show higher (or lower) $l(x)$ at the initial ages and lower (or higher) at adult ages, and the values would intercept at an age where $l(x)$ is 0.5. This way higher survival at the initial ages would compensate with lower survival at later ages and overall mortality would remain at the same level, changing only the shape of the survival function by age.

If the linear equation linking the logits of the two life tables (standard and studied population respectively) hold for any life tables, this would imply that all life tables could be generated from a single baseline or standard life table, $l^{\text{st}}(x)$, just by using an appropriate pair of values for the parameters α and β . In reality any pair of actual life tables would only approximately satisfy this equation linking the standard and observed logits. Yet, these approximations are close enough to warrant using this relationship to study and model observed mortality schedules.

The values of early mortality and adult mortality defined as inputs to determine the life tables by sex were: ${}_5q_0^f = 0.01783$, ${}_5q_0^m = 0.02334$; ${}_{45}q_{15}^f = 0.12265$, ${}_{45}q_{15}^m = 0.14869$. Based on these estimates and using the logit life table mortality model as well as the “Solve” Microsoft Excel optimization routine, the life tables by sex were calculated, as presented in Table 14.

Table 14. PNG 2020 SDES: Estimated life table mortality by sex, calculated based on estimates of under-five mortality and conditional probabilities of dying, obtained through indirect methods

PNG Female Life Table 2020							
Age	m_x	q_x	l_x	d_x	L_x	T_x	e_x
0	8.8	8.7	100,000	872	99,302	7,091,643	70.92
1	2.3	9.2	99,128	911	394,127	6,992,341	70.54
5	0.5	2.7	98,217	265	490,368	6,598,214	67.18
10	0.4	2.2	97,952	211	489,275	6,107,846	62.36
15	0.8	3.9	97,742	377	487,878	5,618,571	57.48
20	1.1	5.7	97,365	555	485,442	5,130,693	52.70
25	1.3	6.5	96,809	625	482,501	4,645,251	47.98
30	1.5	7.4	96,185	711	479,195	4,162,751	43.28
35	1.8	9.1	95,473	873	475,268	3,683,556	38.58
40	2.4	12.0	94,600	1,134	470,303	3,208,287	33.91
45	3.4	17.0	93,466	1,589	463,589	2,737,985	29.29
50	5.2	25.8	91,877	2,367	453,869	2,274,396	24.75
55	8.6	42.0	89,510	3,756	438,885	1,820,527	20.34
60	15.2	73.4	85,754	6,296	413,648	1,381,642	16.11
65	29.3	136.9	79,458	10,876	371,322	967,994	12.18
70	59.8	262.4	68,582	17,993	301,093	596,672	8.70
75	122.9	471.6	50,589	23,857	194,141	295,579	5.84
80	263.5	1000.0	26,732	26,732	101,438	101,438	3.79

PNG Male Life Table 2020							
Age	m_x	q_x	l_x	d_x	L_x	T_x	e_x
0	11.7	11.6	100,000	1,159	99,073	6,912,330	69.12
1	3.0	11.9	98,841	1,175	392,283	6,813,258	68.93
5	0.7	3.5	97,666	338	487,414	6,420,975	65.74
10	0.6	2.8	97,328	268	486,020	5,933,561	60.96
15	1.0	4.9	97,060	478	484,246	5,447,542	56.13
20	1.5	7.2	96,582	700	481,166	4,963,296	51.39
25	1.6	8.2	95,882	782	477,471	4,482,130	46.75
30	1.9	9.3	95,100	885	473,345	4,004,658	42.11
35	2.3	11.4	94,215	1,078	468,479	3,531,313	37.48
40	3.0	14.9	93,137	1,388	462,374	3,062,834	32.89
45	4.2	21.0	91,748	1,925	454,199	2,600,461	28.34
50	6.4	31.5	89,823	2,826	442,512	2,146,262	23.89
55	10.3	50.5	86,997	4,395	424,805	1,703,750	19.58
60	18.1	86.5	82,602	7,148	395,744	1,278,945	15.48
65	33.8	156.3	75,454	11,795	348,871	883,201	11.71
70	66.2	286.5	63,659	18,236	275,339	534,330	8.39
75	129.6	489.6	45,423	22,237	171,532	258,991	5.70
80	265.1	1000.0	23,185	23,185	87,459	87,459	3.77

Source: PNG 2022 SDES

4. Conclusions and recommendations

Fertility

Evidence from the PNG 2020 SDES confirms the sustained process of fertility decline, as observed in previous studies. The country registered a TFR of 6.26 children per woman in 1970, and has been declining by about half child every decade, reaching 5.70 in 1980, 5.19 in 1990, 4.54 in 2000 and 3.89, in 2010 (United Nations, 2015). Fertility is higher in the rural than in urban areas. The PNG 2022 SDES registered a TFR of 3.95 in rural areas, and 2.61 children per woman respectively in urban areas. For the total population the fertility level (TFR) was estimated to be of 3.72 children per woman.

Regarding the age distribution of fertility, the results obtained from Brass P/F method and relational Gompertz method are very similar for rural areas and the total population; the main difference registered in the age distribution of fertility in the urban area. In the urban area Brass' method shows a higher fertility concentration in the central age groups from age 25 to age 35, comprising 54.7 per cent of total fertility. In the rural area this age interval concentrates 47 per cent of fertility, with relative higher participation of younger and older age groups, as compared to the urban area. It is considered that the age distribution of fertility obtained from Brass P/F method is more adequate, as it follows closely the pattern of the reported data. From a reproductive health perspective, a higher concentration of fertility in the central ages of the reproductive period, as registered in the urban area is considered beneficial, since having births at too young ages or at older ages in the reproductive period are associated with higher reproductive risks.

As a policy recommendation, the results of these analyses would suggest emphasizing promotion of free and informed decisions on family formation, advising on the benefits of adequate birth spacing, discouraging adolescent and early pregnancies through information, education and access to safe and efficient prevention methods. Positive change has occurred in urban areas, which should be maintained, and further change in this direction should be promoted among the population in rural areas. Given the large concentration of population in rural areas in the country, positive changes in the reproductive health in the rural area would have a significant impact for the country as a whole.

Early age mortality

The negative impact of the COVID-19 pandemic has been assessed in the estimates of early age mortality, indeed for mortality at all ages. The reversal of declining mortality trends, evidenced in the PNG 2022 SDES data, is a most relevant feature in these analyses. However, even fully recognizing the importance of the pandemic on the health situation in general, no analytical effort in this report would target the pandemic beyond pointing out how it has affected survival indexes (hopefully only temporarily) reversing declining mortality trends. The methodology of demographic surveys and indirect estimation methods are not particularly suited to assess events of a nature like the COVID-19 pandemic. Hence, this report registers the impact of the pandemic but would not produce any detail assessment of this impact. The strategy is to consider it of a temporary nature, while the underlying trend of health improvement and mortality reduction will resume, maintaining its direction in future years.

The results of the PNG 2022 SDES confirm a significant decline in under-five and infant mortality levels, registering around 2020 about half the mortality level prevailing a decade before. There is some uncertainty when assessing mortality trends by sex, which indicate a relative higher level for females in the early dates of the series; this could be associated to random variations, yet in some other studies some small differential or even some points were higher female mortality were observed. Hence, it should be noted as an issue requiring further study as new data becomes available. The next national population census, which would not raise significant issues on statistical errors, could help to elucidate more efficiently this sex differential in early age mortality. In all case, the information from the SDES appears to be of good quality in general, revealing a significant declining trend in early age mortality, which should resume after the temporary setback of the pandemic.

The estimation of mortality in the urban area showed some variations due to small number of observations by age group of the informants. However, with some adaptation in the methodology the results indicate that mortality in urban areas is lower than in urban areas.

In conclusion, the results show that for recent dates the trend line indicates lower mortality for girls than for boys: in 2022: under-five mortality ${}_5q_0$ for girls was estimated as 15.4 deaths per 1,000 live births compared to 22.1 deaths per 1,000 live births for boys. For infant mortality ${}_1q_0$, these figures are estimated at 10.1 and 16.1 for girls and boys respectively. Regarding the area of residence, the estimated rural rates were 22.2 deaths under age five, ${}_5q_0$, per 1,000 live births, while in the urban areas these were 14.4. Regarding infant mortality, ${}_1q_0$, the rates were 14.0 and 9.9 respectively in the rural and urban area.

Summarizing, the analyses of the SDES data showed improved children's survival rates both in rural and urban areas. For the rural area the level of under-five mortality, ${}_5q_0$, declined from 42.9 children death before reaching age five, per 1,000 live births in 2007, to 20.2 deaths per 1,000 live births in 2022; that is a reduction to less than half the level of mortality about 40 years ago. In the same period, the reduction in infant mortality, ${}_1q_0$, was from a level of 29.9 infant deaths per 1,000 live births to a level of 14.0 deaths, also less than half the level of mortality prevailing at the start of the analysed period. In the urban areas the level of under-five mortality was 26.2 in 2011, coming down to a level of 14.4 deaths before reaching age five, per 1,000 live births. It is also a considerable improvement in the survival rates, although a little lower than the observed trend in the rural area. In terms of infant mortality, the reduction in urban areas was from a level of 18.2 infant deaths in 2011 to a level of 9.9 deaths per 1,000 live births in 2022.

Adult mortality

The adult mortality estimates calculated from the PNG 2020 SDES show a consistent decline in the level of mortality for both sexes in the early part of the time series, up to approximately 2015, when a trend reversal is observed (Figure 18). This reversal most probably reflects the impact of the COVID-19 pandemic. The indirect estimation methodology gives strong evidence of a significant setback in the progress attained on mortality reduction, but it does not allow to measure mortality for precisely established time-periods. Hence, it is not possible to precisely quantify the scale of the reversal caused by the COVID-19 pandemic. Indirect estimates derive cohort mortality estimates. The time location of these indicators is established through modelling of those cohort measures, and the date represent an average estimate, covering several calendar years. Hence the reversal of the declining trend is not determined exactly at the time of the pandemic, but at the average location derived for each cohort of respondents. In this way, the underlying estimation methodology smoothed these trends. This causes that the impact of the pandemic would gradually emerge in recent years, instead of appearing as a sudden jump in the mortality level exactly on years 2019, 2020 and 2021, when the pandemic really occurred. With these caveats in mind, the adult mortality patterns derived from the PNG 2022 SDES data appear very consistent and reliable.

When the impact of the COVID-19 pandemic is removed from the trends, by fitting a linear trend to point estimates preceding the reversal of the trend due to the pandemic, the level of female adult mortality shows an important decline (Figure 19). The female mortality ($_{45}q_{15}$) shows a declining linear trend from a level of 0.2232 in 2008, to an expected level (without COVID-19) of 0.12265 in 2022 (Table 13). This is about one half of the probability of dying that was prevailing 14 years ago. The adult mortality level also registered a very important reduction in the risk of dying at adult ages: in 2009 the $_{45}q_{15}$ for men was 0.230807 (almost one in four men would dye after their 15th birthday and before reaching the age of 60), this level of mortality in 2022 is expected to be 0.148958, that is about one in seven men would dye in this period of adult life. As stated before, these figures were obtained under the assumption that the linear adjusted trend, eliminating point estimates affected by the pandemic and some defective points, represent the underlying mortality trends, which are expected to adequately represent the trends that would prevail after controlling the effects of the pandemic.

Naturally, these trends are an approximate evaluation without the COVID-19 impact. In fact, the real trend in mortality is as observed in Figure 18, which shows a significant reversal in the declining trend. Yet it is still relevant to explore what the underlying mortality level would be, when the effects of COVID-19 are removed. Assuming the epidemic would only represent a time-constrained reversal with no permanent effects on the general mortality trends; then, it is reasonable to expect that this underlying mortality trend should be resumed, after the pandemic.

The estimated life expectancy, which obtained from the life tables based on the indirect estimation methodology combing the results obtained for under-five mortality with the results obtained for adult mortality by sex, show a life expectancy at birth of 70.92 years for women, and 69.12 years for men. As commented in the analysis of previous sections, the differential favouring women’ survival is relatively small, comparative to international standards. Further analysis would be necessary to better assess this situation.



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Brass P/F fertility estimation method

Professor William Brass (Brass W. , 1964) presented the earliest version of this fertility estimation method in the early 1960s, when the availability of data for fertility estimation was a serious constraint, except for statistically most advanced countries. Since then, the method has become an essential methodological resource to estimate the fertility level and age distribution. With some relative minor improvements in the estimation procedure, his method has been widely used globally with great success (Brass W. , 1975) (Moultrie, et al., 2013).

Data requirements and assumptions

On one hand, the success of this method rest on the simplicity of the tools to obtain the required basic information: brief and clear questions that can be incorporated in any census or surveys:

- 1. Number of children born to interviewed women in a recent period of time (usually 12 months before the date of the interview), and
- 2. Total number of children born alive to those women.

On the other hand, the method rest on simple assumptions, which have proved to function very well in most situations:

- 1. The reports on recent fertility may be affected by errors, like some children born within the reference period being omitted or sometimes an excess of children reported to have occurred during the period of reference, when in fact some of them were born outside of this period. Yet, the errors in the numbers of births reported are independent of the mothers’ age group and affect in a similar manner all reproductive age groups. Hence, even if the level of fertility may be over- or under-stated in those reports, the distribution of fertility by age groups is accurate.
- 2. The number of children ever born are accurately reported by women in young age groups (specially women under 30), although at older ages these reports are frequently affected by omission of some children, particularly when they were born further in the past and might have died soon after birth or have grown up and moved away from their parents.

Empirically those assumptions proved to hold true in most situations. On these basis, W. Brass proposed to adopt the age distribution of fertility as reported for the recent period, while adjusting the level of fertility rates observed in this recent period based on the level of fertility as measured through the reported parity by women in young age groups. The adjustment for the level of fertility is done by using an adequate correction factor, which is to be applied to recent fertility rates. This adjustment factor is derived from a comparison of the parity, as reported in the young age groups, to an equivalent measure obtained from the recent fertility measures.

The calculation process

To calculate this adjustment factor, it is necessary to derive a synthetic measure –or parity equivalent- which is symbolized **Fi**, calculated from the recent fertility rates. This synthetic parity **Fi**, is then compared to the actual parity reported by the same age group, **Pi**, where the index *i* represents the age group: *i* =1 for group 15-19, *i* =2 for group 20-24, ... , *i* =7 for group 45-49.

Two problems arise when obtaining a value of **Fi** that is comparable to the average parity, **Pi**, reported by women of each age group. **First**, because fertility data are ordinarily tabulated by five-year age group, the cumulated age-specific fertility rates for the recent period, multiplied five, would yield estimates of a synthetic parity (or cumulated fertility), for women who experienced those recent fertility rates, up to the age at the **end** of each five-year age group. That is to say, the synthetic parities would be up to exact ages 20, 25, 30, ... 50 when conventional five-year age groups are used. These estimates are not comparable with the average parities **Pi** calculated from data on children ever born, because the **Pi** values represent a mixed experience of women of different exact ages within each respective age interval.

Hence, some procedure is required for estimating the average cumulated fertility up to the midpoint of age interval –which would be the synthetic parity equivalent to the **Pi** values, or retrospective parity within each age group considered. Secondly, when the current fertility during the 12 months preceding the survey (or on date of the most recent birth), the births are generally tabulated by the mother’s age at the time of the survey, not at the time of the birth. If one assumes that births in a given year are uniformly distributed in time, the women who had a birth in the 12 months preceding the survey were, on average, six months younger at the time of the birth than their age at the time of the interview.

Therefore, the age-specific fertility rates that can be calculated from data on children born during the year before the survey classified by age of mother at the time of the survey correspond to unorthodox five-year age intervals, whose limits are (14.5-19.5), (19.5- 24.5), ... , (44.5, 49.5), rather than to the usual intervals with endpoints (15-20), (20- 25), ... , (45-50).

The synthetic parities up to endpoint of these cumulated unorthodox five-year age intervals: 19.5, 24.5, ..., 49.5 can be represented with the Greek letter “phi”: $\varnothing_i = 5$, where $\varnothing_i$ represents the synthetic parity up to the endpoint of age group “*i-1*”, or starting point of age group “*i*”.

When the source of information on current fertility is a vital registration system, this second problem should not arise, because births are supposed to be recorded near the time of occurrence and therefore the reported age of mother is likely to be the correct age she had at the time of the birth.

In order to obtain synthetic parities **Fi** comparable to reported parities **Pi**, when recent fertility rates correspond to age groups shifted by half year with respect to the age of women at the time of the survey, different procedures have been proposed. Currently the most utilized procedure is based on interpolations using model fertility schedules. This generates synthetic parity values **Fi** for the usual five-year age groups of women, on the basis of cumulated recent fertility rates. A similar procedure is applied to correct the displacement of six months in the age interval. Though this interpolation, based on model fertility schedules, the synthetic parities up to the age limit of the unorthodox five-year age intervals, as mentioned above, $\varnothing_i = 5$, are adjusted to become synthetic parities up to ages comparable to the age implicit in the **Pi**. This is done as $F_i = \varnothing_i + \frac{1}{k_i}$; where the factor **ki** when applied to the fertility rate in group “**i**” , would make the necessary correction to bring $\varnothing_i$ up to the midpoint of the age group, where the limits of the age group are now the conventional ages: 20, 25, ... , 50.

In this way, the estimated synthetic parities **Fi** can be compared to the **Pi**, and the ratio **Pi/Fi** indicates the implicit difference in the level of the recent fertility, as compared to the reported parity in the younger age groups. Hence the appropriate **Pi/Fi** ratio would provide for a correction factor to adjust the level of fertility in the recent period, becoming it comparable to the reliable level implicit in the reported parity of young women.

As mentioned in a previous paragraph, Brass **P/F** estimation method can also be applied to correct the level of fertility rates when they are calculated from vital registration data. Yet in this case the methodology does not incorporate any adjustment for displacement of ages in the recent fertility rates, as registration systems record the correct age of the mother at delivery. The following table, Table A-1, has reproduced from Table 7 taken from page 34 of the UN Manual X (United Nations, 1983) on indirect techniques for demographic estimation. The Table A-1 (or Table 7) provides the necessary coefficients for interpolating between cumulated recent fertility rates, $\varnothing_i$, in order to obtain the synthetic parity equivalents. Table 7 is comprised of four panels; the first two are to be used when the fertility rates correspond to births in a period of 12 months before the survey, which is the situation when the ages of the mothers at birth are half year younger than their age at the time of the interview. The first of these panels consist of two lines, which provide the coefficients to be used when the synthetic parities **Fi** are calculated by applying the original Brass’ equations (B.2 and B.3). Equation B.2 corresponds to age groups 15-19 to 40-44, (**i**= 1, 2, ... ,6):

$$F(i)= \varnothing(i-1) + a\ f(i) + b\ f(i+1) \tag{B.2}$$

$$\text{Equation B.3 is for age group 45-49, (i=7): } F(7)= \varnothing(6) + a^*\ f(6) + b^*\ f(7) \tag{B.3}$$

The values of coefficients **a** and **b** are in the first line of first panel, and the values for **a*** and **b*** are in the second line of the first panel. The numeric values in this first panel were obtained by evaluating mathematical equations that represent the relationships between the age-specific fertility rates **f(i)**, cumulated fertility $\varnothing(i)$ and synthetic parities **F(i)**. Those equations have the same structure for age groups up to age 45, and a different one for the last age group 45-49.

The second panel of the table consists of seven lines, each for one age group respectively, that provide the values for coefficients **a**, **b**, and **c**, for each of the age groups, corresponding to equation (B.4). In this approach additional flexibility is introduced, by allowing the relationships between the age-specific fertility rates **f(i)**, cumulated fertility $\varnothing(i)$ and synthetic parities **F(i)**, to vary according to the fertility function variation within each of the age groups, and not just changing in age group 45-49 with respects to the six younger groups (for which the relationship is maintained fix), which determine just two set of equations, as in B.2 and B.3. Hence, one set of values **a**, **b**, and **c**, is provided for each age group under equation B.4, to calculate the equivalent average parities **F(i)**, corresponding to each age group **i** (**i**= 1, ... 7). Note that the structure of equation B.4 is adjusted, when it is to be applied to the last age group, 45-49, as indicated in the footnote for the table.

$$F(i) = \varnothing(i-1) + a(i)\ f(i) + b(i)\ f(i+1) + c(i)\ \varnothing(7) \tag{B.4}$$

The two last panels in Table A-1 correspond to the same situations as described above, for equations B.2, B.3 and B.4, but their numeric values were evaluated for age groups that correspond to the same age as the age of the mothers at the time of survey; that is, these values are to be used when the method is applied to information where the age at birth is the same as the age at time of reporting. This is the situation observed for information that was collected through vital registration systems.

TABLE A-1: Coefficients for interpolation between cumulated fertility rates to estimate parity equivalents

TABLE 7. COEFFICIENTS FOR INTERPOLATION BETWEEN CUMULATED FERTILITY RATES TO ESTIMATE PARITY EQUIVALENTS					
Age group (1)	Index <i>i</i> (2)	Equation No. (3)	Coefficients		
			<i>a(i)</i> (4)	<i>b(i)</i> (5)	<i>c(i)</i> (6)
(a) Fertility rates calculated from births in a 12-month period by age of mother at end of period					
15-19-40-44	1-6	B.2	3.392	-0.392	-
45-49	7	B.3	0.392	2.608	-
15-19	1	B.4	2.531	-0.188	0.0024
20-24	2	B.4	3.321	-0.754	0.0161
25-29	3	B.4	3.265	-0.627	0.0145
30-34	4	B.4	3.442	-0.563	0.0029
35-39	5	B.4	3.518	-0.763	0.0006
40-44	6	B.4	3.862	-2.481	-0.0001
45-49	7	B.4	3.828	0.016 ^a	-0.0002
(b) Fertility rates calculated from births by age of mother at delivery					
15-19-40-44	1-6	B.2	2.917	-0.417	-
45-49	7	B.3	0.417	2.083	-
15-19	1	B.4	2.147	-0.244	0.0034
20-24	2	B.4	2.838	-0.758	0.0162
25-29	3	B.4	2.760	-0.594	0.0133
30-34	4	B.4	2.949	-0.566	0.0025
35-39	5	B.4	3.029	-0.823	0.0006
40-44	6	B.4	3.419	-2.966	-0.0001
45-49	7	B.4	3.535	-0.007 ^a	-0.0002

^a This coefficient should be applied to *f* (*i* - 1), not *f* (*i* + 1), that is, to *f*(6) instead of *f*(8).

Source: United Nations Manual X: Indirect Techniques for Demographic Estimation, page 34

After the calculation of the synthetic parities and evaluation of the series of P/F ratios, the age-specific fertility rates still have to be adjusted to conform to conventional age groups, correcting for the six-month displacement of age limits in the age distribution. This is done by using weighting factors *w(i)*, to derive adjusted age-specific fertility rates (*f*(i)*), for the correct age group at the time of the survey, by applying these weighting factors to the age-specific fertility rates obtained from reports on recent fertility (with 6-month displacement in age): *f*(i)* = (1-*w(i-1)*) * *f* (*i*) + *w(i)* * *f*(*i*+1), where the weighting factors *w(i)* are obtained through equation B.5, with coefficients *x(i)*, *y(i)* and *z(i)* as tabulated in Table A-2:

$w(i) = x(i) + y(i) f(i) / \varnothing(7) + z(i) f(i+1) / \varnothing(7)$

(B.5)

The coefficients *x(i)*, *y(i)* and *z(i)* for each age group can be obtained from the Table A-2, which presents values for these coefficients that were also extracted from the UN Manual X (United Nations, 1983) on indirect techniques for demographic estimation, Table 8, in page 34.

TABLE A-2: Coefficients to obtain weighting factors to adjust for 6-month displacement in age groups compared to age at time of the survey

Edad	<i>x(i)</i>	<i>y(i)</i>	<i>z(i)</i>
15-19	0.031	2.287	0.114
20-24	0.068	0.999	-0.233
25-29	0.094	1.219	-0.977
30-34	0.12	1.139	-1.531
35-39	0.162	1.739	-3.592
40-44	0.27	3.454	-21.497
45-49			

Source: United Nations Manual X: Indirect Techniques for Demographic Estimation, Table 8, page 34

The fertility relational Gompertz model

The rational of the relational Gompertz method is similar to the original P/F method:

It seeks to remedy the errors commonly found in fertility data associated with too few or too many births being reported in the reference period, on the one hand, and on the other the frequent under-reporting of lifetime fertility and errors of age reporting among older women.

The Gompertz function is an exponential function of the type *G(x)= exp(a.exp(bx))*, which has a very useful property for supporting the study of fertility⁵. The method relies on the characteristic of this function, which has a sigmoidal shape that resembles very closely the shape of cumulated fertility by age of the women, or average parities of women by age. Being a double exponential, the Gompertz function implies that a double logarithm of *G(x)* would approximate a straight line for most of the fertility age range. The double-log transform, *Y* (*x*) = -ln

5 The notes in this annex are based on the corresponding section of the IUSSP manual (Moultrie, et al., 2013).

$(-\ln(G(x)))$, is termed a “gompit”. This has a close analogue in the “logit” transform, extensively used in mortality analysis.

Brass (Brass W. , 1978) found that a much closer linear fit is obtained by using a relational model that expresses the gompits of an observed series of fertility data as a linear function of the gompits of a defined standard fertility schedule. In other words, $Y(x) = \alpha + \beta Y_s(x)$, where $Y_s(x)$ is the gompit of the standard fertility schedule.

Evidently, if $\alpha = 0$ and $\beta = 1$, the fertility schedule will be identical to the standard fertility schedule. The intercept in the linear equation (α) represents the extent to which the age location of childbearing in the population differs from that of the standard (negative values imply an older distribution of ages at childbearing than in the standard). The slope in the linear equation (β) is a measure of the spread of the fertility distribution (values greater than 1 imply a narrower observed distribution, compared to the standard).

Basia Zaba (Zaba, 1981) introduced further elaborations of the Gompertz relational model proposed by Brass, which overcome some limitations in its original version, such as the implicit assumption of constant fertility and the need to adopt an initial value for total fertility. Because of this added flexibility in Zaba’s proposal, this became the method most frequently utilized.

Zaba showed that the model could be expressed as:

$$z(x) - e(x) = \alpha + \beta g(x) + (c2)(\beta - 1)^2 \tag{1}$$

- Where $e(x)$, $g(x)$ and c are functions of the chosen standard, and $z(x)$ is the gompit of the ratios of adjacent cumulated period fertility measures, i.e. $F(x)/F(x+5)$. The gompit function $z(x)$ is calculated as:
 $z(x) = -\ln \{-\ln [F(x)/F(x+5)]\}$

For the parity data, the model is fitted to the ratios of adjacent average parities, $P(i)/P(i + 1)$. This means that the model can be used without the need to estimate total fertility before fitting the shape parameters.

From equation (1) above, it implies that a plot of $z(x) - e(x)$ against $g(x)$ should follow a straight line, with slope β and intercept $\alpha + 0.5 \cdot c (\beta - 1)^2$

Exactly the same reasoning holds for the evaluation of the parity data: on the basis of the ratios $P(i)/P(i+1)$, the plot of results $z(i) - e(i)$ to $g(i)$ should follow a linear equation with a formulation as expressed in equation (2):

$$z(i) - e(i) = \alpha + \beta g(i) + 0.5 c (\beta - 1)^2 \tag{2}$$

The model-fitting procedure should aim to find a combination of P and F points that are internally consistent with each other, which would be expressed through the two sets of points defining the same lines (or very close to one another). Then, these lines would be used to determine jointly the parameters α and β in Equations 1 and 2 above. The values of α and β are used to derive the relational gompits, $Y(x) = \alpha + \beta Y_s(x)$, and similarly for the gompits $Y(i)$.

The mathematical formulation of the relational Gompertz model is rather complex. A detailed description of the mathematical relations on which the model is based go beyond the scope of the present document. However, for most users and relevant applications of the methodology, it would suffice to indicate that the IUSSP/UNFPA Manual (Moultrie, et al., 2013) incorporates an extended description of this estimation model. In addition, it incorporates a Microsoft Excel workbook, which can be used to derive fertility estimations applying the relational Gompertz model. The Microsoft Excel workbook provides instructions on how it should be utilized and indicates the data input requirements.

Data input requirements

Fertility estimation through the relational Gompertz method requires a series of data inputs as follows:

- Average parity by age group, entered in cells B7-B15 of the Microsoft Excel worksheet.
- Observed age-specific fertility rates, entered in cells D7:D15 of the Microsoft Excel worksheet.
- If the age of the mothers at birth of the children is different from the age at the time of the survey, indicate the time period in which these births occurred (12, 24 or 36 months before the survey).
- Select the version of the model to be applied. Usually this would be the “shape of the distribution determined by recent fertility (F)”, and “level determined by reported parity “P””: - “Shape: F”, “Parity: P”. Yet, there may be situations when the level and shape are determined by recent fertility: - “Only F”.
- It is necessary to place “1” in each of the cells: C7:C15 and E7:E15, for which corresponding data on parity and recent fertility is available. Then, in the process of deciding on the best model fit, at the time of analysing plotted points in the scatter graph, certain points can be eliminated for determining the parameters of model fit; these would be done by excluding the “1” from the corresponding cells.

William Brass’s indirect methods for the estimation of infant and child mortality

The indirect estimation method proposed by William Brass derives probabilities of death from birth to exact ages, from information obtained from surveys or censuses. It is based on aggregate numbers of children ever born and children still alive (or dead) reported by women classified by age group (or alternatively grouped by time

since first birth, or marital duration). This information is frequently called the “summary birth history” (SBH). The essence of the estimation procedure rests on a mechanism for converting the proportions of children (dead or alive) into conventional life-table measurements of mortality.

Rationale of the methodology

If mortality has followed a steady or constant trend throughout the whole period of time during which women have been having children, and if there is no differential mortality by mother’s age at birth, birth order and total number of children attained by the women, then the **proportion of children deceased** among all children born to women aged *i* (we use *i*=1 for age group 15-19, *i*=2 for 20-24, and successively up to *i*=7 for 45-49) at the time of the interview, can be expressed as:

$$Q_i = \sum_{t=0}^{t=ti} (1 - Lt) ci (t) \tag{1}$$

Where *c_i* (*t*) is the proportion of children born during year “*t*” prior to the survey, among all children ever born to women aged *i* at the census/survey date, and *Lt* is the proportion of those children born in year *t* before the survey who have survived from birth up to the date of the survey (*t_i* in the upper limit of summation). Then, *1- Lt* is the probability of not surviving or probability of death for those children from birth to the date of the survey. Being *1- Lt* the probability that children born in time *t* would not survive, if *1-Lt* is multiplied by the *c_i* (*t*) proportion (weight) of those children (born in *t*) to the total number of children born to women of age *i* at the time of the survey, and these products are added, then the *Q_i* value that has been obtained is clearly the weighted average of the *Lt* probabilities for all the dates *t*, as in equation (1). From this, it becomes obvious that *Q_i* is the weighted average of the probabilities of death that have affected all those children, the weights being the proportions born in each year among all children born to women aged “*i*” at the time of the survey. Hence, *Q_i* (the proportion of children deceased) is in fact an average of all the probabilities of dying that have affected those children (born to women in age group “*i*”) from the moment they were born until the date of the survey.

Evidently *Q_i* is a measure of the mortality level that has affected the children of women in age group *i* at the time of the survey. However, as it is an average, the exact exposure time implicit in this average is not precisely defined. On the one hand, the exposure time depends on the fertility distribution, and on the other, it depends on the age pattern of mortality. The estimation method consists of modelling fertility and mortality; from there, the factors *k_i*, necessary for converting *Q_i* into precise probabilities of dying from birth up to an exact age *n*, can be obtained. These *k_i* will be the factors to be utilized in equation (2) below.

It is clear that the older the women, the longer the time their children were exposed to the risk of dying. Hence, for older age groups, the average probability of dying from birth up to a specific given age *n*, would correspond to higher values of *n*, that is, to older specific ages for the children. For instance, the proportion of children born to women in the age group 15-19 who have died is closer to the probability of dying from birth to age 1 (*₁q₀*): on average they were born recently and have been exposed for a relatively short period of time; for women in age group 20-24, the proportion of children who have died corresponds more closely to the children’s probability of death from birth to exact age two (*₂q₀*); for age group 25-29, the proportion is closer to the probability of death from birth up to age three (*₃q₀*); and successively, for women in age group 30-35, the probability is closer to exact age five (*₅q₀*), for women in age group 35-39, the probability is closer to exact age 10 (*₁₀q₀*), for women in age group 40-45, the probability is closer to exact age 15 (*₁₅q₀*), and for women in age group 45-49, the proportion of children who have died is closer to the probability of death from birth up to age 20 (*₂₀q₀*).

Therefore, the multiplying factors *k_i*, which would convert the *Q_i* into appropriate *_nq₀* are calculated in a way that makes these conversions into the closest appropriate *n* values for *_nq₀*. Through modelling the length of exposure based on fertility distribution models, and using an adequate model age pattern of mortality, adjustment factors *k_i* were estimated to convert the proportions *Q_i* into probabilities of dying from birth up to an exact age *n*. In the case of Papua New Guinea, the UN General and UN Far East model life tables were utilized, with very similar results, and the UN General model was retained for this report. The adjustments for age fertility patterns are based on age parity parameters: *P₁/P₂* and *P₂/P₃* where *P₁* is the total parity achieved by women in the age group 15-19, *P₂* is the total parity achieved by women in the age group 20-24, and *P₃* the total parity achieved by women in the 25-29 age group.

Once the appropriate model life table has been identified and the values for the *P₁/P₂* and *P₂/P₃* parameters have been established, the conversion of the *Q_i* into conventional life-table probabilities *_nq₀* is done by substituting into the following equation:

$$_nq_0 = k_i \cdot Q_i \qquad \text{(for } i= 1, 2, 3, 4, 5, 6, 7; \text{ and } n= 1,2, 3, 5, 10, 15, 20) \tag{2}$$

Where *k_i* is obtained from equation (3):

$$k_i = a_i + b_i [P_1/P_2] + c_i [P_2/P_3] \tag{3}$$

The index *i* indicates the age group of the mother and the multiplier *k_i* can be obtained through different procedures, depending on the variation of the technique that would be utilized. The procedure used in this report is as described in the IUSSP edited manual “**Tools for Demographic Estimation**” (Moultrie et al., 2013), where the values of coefficients *a_i*, *b_i*, and *c_i* are showed in Table 16.1 (in page 151) of the manual. Table 16.1 presents one set of *a_i*, *b_i*, *c_i* values for each model life table; in this case, as indicated earlier, the UN General model life table was adopted.

Once the *_nq₀* values are obtained, it is necessary to determine the moment in time these values correspond to. The time location for each of the *_nq₀* estimates is determined by using equation (4):

$$t_i = e_i + f_i [P_1/P_2] + g_i [P_2/P_3] \qquad \text{(for } i= 1, 2, 3, 4, 5, 6, 7) \tag{4}$$

The values of the coefficients e_i , f_i , and g_i are tabulated in Table 16.2 (in page 152) of the “*Tools for Demographic Estimation*” manual, and consistently the UN General model life table was used for Papua New Guinea.

Data requirements and assumptions

Tabulations required

- Number of women, grouped by five-year age groups
- Number of children ever born alive by women by age group
- Number of children born alive to women in each age group who have died before (or are still alive) at the time of the survey

Important assumptions

The age schedules of fertility and child mortality are adequately represented by the model patterns used in the internal calculation procedures of the method.

- In any time period, mortality of children does not vary according to the mothers’ age.
- No correlation exists between mortality risks of children and survival of mothers (by mortality or migration) in the population.
- Any changes in child mortality in the recent past have been gradual and unidirectional.
- The cross-sectional average numbers of children ever born by age of the mothers adequately reflect the appropriately defined cohort patterns of childbearing.

Interpretation of the results

From the tabulations described above, the proportion of children born alive to women in each age group i can be calculated, Q_i ; also the fertility parameters P_1/P_2 and P_2/P_3 are calculated from the figures in those tabulations. Once the model life table was selected (UN General model was used for Papua New Guinea), all the values required for equations 2, 3 and 4, indicated above, are determined. Hence, the calculations would provide the appropriate series of values for ${}_nq_0$ and the corresponding dates in time to which these values apply: t_i . Therefore, this produces a series of probabilities ${}_nq_0$ with their corresponding reference dates t_i . This provides all the elements to analyse the level of early childhood mortality and the trends for a period of time as indicated by the t_i values.

However, one problem with the above-mentioned time series is that each of the probabilities ${}_nq_0$ correspond to a different value of n , therefore they cannot be directly compared with one another so as to establish changes in time. Hence the next step in the process is to convert all the ${}_nq_0$ into one consistent probability of death from birth to a unique specific age. This is done by using the same model life table utilized in the calculation of the adjustment factors k_p – UN General model. Frequently, all the values of the series ${}_nq_0$ are converted into under-five probabilities of death, ${}_5q_0$; they can also be converted into infant mortality rates ${}_1q_0$, when this indicator is considered a better option because of policy perspectives or for any other reasons. Still, methodologically, ${}_5q_0$ would be more convenient because age five is more central to the range of ages involved in the ${}_nq_0$ series and would minimize possible distortions if the model life table does not exactly fit the true age pattern of mortality of the studied population.

The mortality indicator ${}_5q_0$ is primarily utilized in the analysis of this report, although values of ${}_1q_0$ are also obtained and presented in some tables or graphs.

Indirect methods to estimate adult mortality from information on status of survival of the father and mother of the informant (orphanhood)

Louis Henry (Henry, 1960) was the first to propose estimating adult mortality from proportions of orphans. Yet, in the present format, the first estimation method based on this type of data was developed by William Brass, who established an equation relating the female probability of surviving from age 25 to age 25+n, to the proportions of respondents in two contiguous five-year age groups whose mother was still alive at the time of the interview.

This equation has the form:

$$I(25+n)/I(25) = W(n) S(n-5) + (1-W(n)) S(n) \tag{1}$$

where $S(n)$ is the proportion of respondents aged from n to $n+4$ with mother alive, and $W(n)$ is a weighting factor employed to make allowance for typical age patterns of fertility and mortality.

The set of $W(n)$ values that Brass proposed was estimated on the basis of data simulated by using a single mortality pattern (the African standard) and model fertility schedules of fixed shape but variable age locations. Each age location of the fertility schedule is associated with a particular value of M , the mean age of women (or men) at the birth of their children. Thus, the weights, $W(n)$, depend both upon n , the central point of the age groups being considered, and upon M .

More recently, Hill and Trussell proposed another estimation procedure based on the following equation:

$$I(25+n)/I(25) = a(n) + b(n) M + c(n) S(n-5) \tag{2}$$

Where $a(n)$, $b(n)$ and $c(n)$ are coefficients estimated by using linear regression to fit equation (2) to data from 900 simulated cases. These simulated cases were obtained by using several fertility schedules generated by the Coale-Trussell’s model and a broad variety of mortality schedules.

That is, in both methodological options previously mentioned, the coefficients in the respective estimation equations would link the conventional life table measurements $l(25+n)/l(25)$ to observed values from census/survey information on parents' survival; thus transforming the unconventional measurement of survivorship (proportion of mother or father surviving), obtained from the surveys' interview, into a conventional live table probability of surviving. In this manner, the observed proportions of mother (father) surviving are transformed into a conventional life table measurement.

Further developments of the methodology were introduced by *Ian Timæus* into the process of determining the exposure time of the respondents' parents to the risk of dying, which are implicit in the proportion of respondents with their parents still alive (or dead). Timæus established the equation to transform the proportions reported in the survey into probabilities $l(25+n)/l(25)$ as:

$${}_n p_{25} = l(25+n)/l(25) = a(n) + b(n) M^f + c(n) {}_5 S_{n-5} \tag{A}$$

For example, ${}_{10} p_{25}$ will be calculated using the multipliers $a(10)$, $b(10)$ and $c(10)$, the mean age at childbirth of mothers M^f and the proportion of surviving mothers ${}_5 S_{n-5} = {}_5 S_5$, which was reported by children in the five-year age group 5-9 years old.

It is noted that the probability of surviving $l(25+n)/l(25)$, by definition, implies that the individual is alive at age 25, because it measures the probability that the person would survive from age 25, to age 25+n. That is it measures the probability of surviving at least for n years after its 25th birthday. Hence, these are conditional probabilities: their measurement assumes a previous survivorship up to age 25. This is so, because the proportions $S(n)$ are indeed conditional survivorship measurements: obviously for sons/daughters to inform on their parents' survival, the parents were alive at a given age – the age when they were conceived. In the case of the mothers, the conditional time is set at the exact time they were born, but for the fathers the conditional time would be at conception – hence, having a shift of 9 months back from the time they were born.

Obviously, the exposure time to the risk of dying will vary with the age of the respondent. For very young respondents the exposure time is relatively short: from the moment they were born to the moment of the survey interview; for older persons –say 20 years old and above- the time their parents would be exposed to the risk of dying would be 20 or more years. Strictly, the exact age at which these probabilities are conditional is also variable, since not all children were born when their mothers were twenty years old. However, setting this conditional survivorship age obeys to a practical option: on average, the average exposure time to the risk of dying –for the whole group of respondents- started at their mothers' the mean age at childbearing (M). In most populations the mean age at childbearing –or mean age of the fertility distribution- is relatively close to age 25. Therefore, for practical reasons, it is convenient to set the conditional age of survivorship at age 25. Then, through the process of calculation of the coefficients – which the methodology utilizes for transforming the S_n proportions into probabilities $l(25+n)/l(25)$ – an adjustment is incorporated to move the mean age at childbirth observed in the particular population, to exact age 25.

The coefficients utilized in the previous equation (A) to obtain the probabilities ${}_n p_{25} = l(25+n)/l(25)$ were calculated by Ian Timæus, and are presented in the following table:

Upper limit of age group (n)	a(n)	b(n)	c(n)
10	-0.2894	0.00125	1.2559
15	-0.1718	0.00222	1.1123
20	-0.1513	0.00372	1.0525
25	-0.1808	0.00586	1.0267
30	-0.2511	0.00885	1.0219
35	-0.3644	0.01287	1.0380
40	-0.5181	0.01795	1.0753
45	-0.6880	0.02343	1.1276
50	-0.8054	0.02721	1.1678

Source: Timæus (1992)

These coefficients are incorporated into the Microsoft Excel worksheet provided in the IUSSP manual, which has been used in this report and in the exercises developed during the workshop organized by UNFPA and the National Statistical Office of Papua New Guinea.

Calculation process to estimate female adult mortality from proportions of mothers surviving

In the following paragraphs, to simplify notation we will set the probability of surviving for a period of n years, starting at exact age twenty, as: ${}_n p_{25} = l(25+n)/l(25)$.

To apply the orphanhood method, one requires an estimate of the average age at which the parents had their children in order to control for variation in the age range over which they have been exposed to the risk of dying. Women's mean age of childbearing is usually calculated from census or survey data on recent births by five-year age group at interview of the women giving birth. The measure is simply the average age of women giving birth calculated without adjusting for the age structure of the population using the following formula:

$$\{\sum_{x=15}^{45} 5B_x (x + 2)\} / \{\sum_{x=15}^{45} 5B_x \}$$

In this equation, $5B_x$ represents the number of births to women in the age interval $x, x+4$; and $x+2$ is the average age of the women in this age interval, at the time their children were born. Since their children were born during the 12 months previous to the interview, it is assumed that women were on average 6 months younger (than their age at the interview) and because the midpoint of the age interval at time of the survey is $x+2,5$ years, then six months earlier these women were on average $x+2$ years old.

The following tabulation presents the input data to introduce into Microsoft Excel worksheet for the indirect estimation of female adult mortality from information on orphanhood. It is recommended that the tabulation should be based on female respondents, male respondents, and the total (male plus female respondents). Hence this tabulation should be replicated three times, once for each sex of respondents and also for the total of respondents (both sexes of respondents combined). From this information on proportions of respondents with mother alive, and the mean age at childbirth, the Microsoft Excel worksheet provides the estimates of the probabilities ${}_n p_{25} = I(25+n)/I(25)$

Age group	Total respondents	Mother alive	Proportion alive	Mean age at childbirth	Age n
5- 9					10
10-14					15
15-19					20
20-24					25
25-29					30
30-34					35
35-39					40
40-44					45
45-49					50

These are probabilities of women surviving from age 25 to age $25+n$, where “ n ” depends on the age of the respondents. Therefore, the series of ${}_n p_{25}$ values, which are obtained from this method, cannot be compared with one to another, because they correspond to different exposure times, depending on the “ n ” value, and also because the time location of these estimates varies with the age group of the respondents.

Similar to the procedure followed in the estimation of early childhood mortality, the Microsoft Excel worksheet will calculate a unified indicator (a probability of surviving from a given age, for a fixed number of years), which has an equivalent of the risk of dying as that implicit in the series of ${}_n p_{25}$ values. In this way, the different probabilities ${}_n p_{25}$ would be expressed in a unique indicator, which allows comparing one to another the series of risks located at different periods in time. The procedure offer the options to adopt as unified indicator the probability that a woman aged 30 may die before reaching exact age 60: ${}_{30}q_{30}$, or the probability that a woman aged 15 may die before reaching exact age 60: ${}_{45}q_{15}$. Indicator ${}_{45}q_{15}$ is most frequently utilized. The values of ${}_{45}q_{15}$ (or ${}_{30}q_{30}$) set at their corresponding time locations, constitute a time series of probabilities of dying representing the level and trends of female adult mortality for a period of time preceding the survey. Hence these values provide a consistent expression of level and changes of female adult mortality for a period of time from 10 to 15 years preceding the survey date.

Example of calculation of mean age at childbearing for women with hypothetical values, assuming the tabulations of births corresponds to the 12 months preceding the survey:

Calculation of the mean age at childbearing			
Age group	Births in the last year	Midpoint age	
	B(i)	N	B(i)*N
15-19	50,720	17	862,240
20-24	147,040	22	3,234,880
25-29	174,350	27	4,707,450
30-34	129,860	32	4,155,520
35-39	66,440	37	2,458,280
40-44	35,900	42	1,507,800
45-49	8,770	47	412,190
Totals:	613,080		17,338,360
		M =	28.28

Calculation process to estimate male adult mortality from proportions of fathers surviving

The rational on which the indirect methods for estimating adult male mortality, based on paternal orphanhood is exactly similar to that described for estimating female adult mortality, although some adjustments are necessary on the calculation process, in order to adapt to the characteristics of male’s fertility as well as the features that experience has shown that information of fathers’ survivorship usually presents in surveys and censuses. One aspect that is different from the estimation of female adult mortality is the mechanism to assess the exposure time to death implicit in the proportions of fathers surviving (or dead). For the indirect estimation of adult male mortality, based on reports of survival of their fathers collected in the survey, usually the information that would allow calculating the mean age of the father at birth of the child is not available, or is not reliable.

Instead, we need to estimate the median age of the married men enumerated in the survey, as well as the median age of the married female enumerated in the survey, to make adjustments on the mean age of mothers in order to approximate the unknown value of mean age of fathers at birth of their children, by adding to mean age of the mothers at birth of the children, the difference in the median age of married men minus the median age of married women. To estimate these parameters, we need tabulations as those presented here:

Calculation of median age of currently married women and men, with hypothetical data:

Age group	Married Men	Married Women	Cumulative % of Men	Cumulative % of Women
10-14	1,380	7,300	0.0005	0.0024
15-19	34,140	171,320	0.0122	0.0583
20-24	192,160	429,420	0.0782	0.1984
25-29	471,780	550,700	0.2401	0.3780
30-34	496,440	488,090	0.4105	0.5372
35-39	321,400	345,680	0.5208	0.6500
40-44	375,650	336,270	0.6497	0.7597
45-49	279,350	245,010	0.7456	0.8396
50- 54	224,610	164,470	0.8227	0.8933
55-59	166,800	115,380	0.8800	0.9309
60-64	105,760	75,470	0.9163	0.9555
65-69	99,360	63,890	0.9504	0.9764
70-74	59,000	37,220	0.9706	0.9885
75-79	41,110	19,700	0.9847	0.9949
80 +	44,430	15,570	1.0000	1.0000
Total	2,913,370	3,065,490	36.56	31.33

From this tabulation, we identify the age that divide the age distribution of men and women into two groups, in a way that half the number of persons in the distribution is below this value of median age, and half is above the median age –for both men and women-. The lower limit of the age interval which contains the age at which the accumulated proportion would equal 50%, added to the proportion of the length of the interval that reach that median age (assuming lineal increase in the age distribution within that interval), would give us the value of the median age distribution for men and women respectively:

Median for men = {32.5 + 5 * (0.5-0.4105)/(0.5208-0.4105)} = 36.56 and

Median for women = {27.5 + 5 * (0.5-0.378)/(0.5372-0.378)} = 31.33

For the process of estimating male adult mortality, we need the following tabulation, which illustrates the information necessary to enter into the Microsoft Excel worksheet, which facilitates the necessary calculations. These calculations would allow deriving from the proportions of “father alive” (S^m_n), a series of probabilities of men who are alive at age 35, to survive up to exact age 35+n. Similar to that described for female mortality estimation, the “n” value in these estimates depends on the age of the respondents:

$I(35+n)/I(35) = {}_n p_{35}$

The following tabulation exemplifies input data to introduce into the Microsoft Excel worksheet for indirect estimation of male adult mortality based on information on orphanhood:

Respondent's age group	Total respondents	Father alive	Proportion alive	Mean age at childbirth	Age n
5 - 9	1,442,900	1,388,100	0.9620	33.51	10
10-14	1,219,280	1,097,060	0.8998	33.51	15
15-19	1,104,880	924,330	0.8366	33.51	20
20-24	913,400	712,530	0.7801	33.51	25
25-29	817,290	563,710	0.6897	33.51	30
30-34	616,970	355,580	0.5763	33.51	35
35-39	368,600	176,100	0.4778	33.51	40
40-44	402,630	135,460	0.3364		

These data exemplify the Microsoft Excel worksheet’s necessary inputs, to calculate the values of the probabilities that men who are alive at age 35, would survive up to age 35+n, with the value “n” determined by the age of the respondents:

${}_n p_{35} = I_{35+n} \div I_{35}$

As indicated earlier when discussing female estimation from orphanhood, these probabilities of survival, ${}_n p_{35}$,

obtained through the calculation process in the Microsoft Excel worksheet, are not comparable because they measure survival from age 35 up to different exact ages (values depending on “n”), and also because they are located at different points in time. It is necessary to translate the risks implicit in the probabilities ${}_np_{35}$ into a consistent mortality indicator, allowing for comparisons of these probabilities derived from different groups of respondents. The method provides two options for this unified indicator: a series of probabilities of adult men dying in the interval from exact age 30 to exact age 60: ${}_{30}q_{30}$, or probabilities of adult men dying in the interval from exact age 15 to exact age 60, ${}_{45}q_{15}$, and their corresponding locations in time.

In a similar manner as described for adult female mortality, these series of probabilities: ${}_{30}q_{30}$, or ${}_{45}q_{15}$, and their time location describe the patterns of adult mortality level and trends for the surveyed population, for a period of time preceding the survey's date.

The calculation process to derive a life table from estimated values for under-five mortality and conditional probabilities of survival from age 15 to 60

Life tables by sex can be estimated, including all its functions, comprising also the life expectation at birth as well as life expectation at any other ages, based on estimates of mortality by sex in the early years of life, represented by the under-five mortality rate ${}_5q_0$, combined with estimates of adult mortality level by sex, represented by the conditional probabilities of dying between exact age fifteen and exact age sixty, ${}_{45}q_{15}$. The methodology for constructing life tables from these two indicators (${}_5q_0$ and ${}_{45}q_{15}$), is based on Brass' relational logit model of mortality (Brass W. , 1971).

The Brass' logit system of model life tables is a relational one, since the model is based on a mathematical relation between the functions of two life tables, which are conveniently transformed in order to adjust for this mathematical relation. The life table function utilized in the logit system is the age-specific survivorship function $l(x)$, which is the probability that a person would survive from birth to exact age x, and is expressed on the basis of probability of survival for one individual. Therefore, the values of the $l(x)$ function vary from zero to one ($0 < l(x) < 1$).

The logit transformation of the $l(x)$, on which the relational model is based, is symbolized by $Y(x)$; that is: $Y(x) = \text{logit } [l(x)]$; where the logit transformation is defined as:

$$\text{logit } l(x) = -(0.5) \ln\{l(x) \div [1-l(x)]\} \tag{1}$$

Then, the mathematical function relating the two life table functions in the relational model is:

$$Y(x) = \alpha + \beta Y^{st}(x) \tag{2}$$

The first parameter of this system of models, α , captures differences in the level of mortality between the populations; then, if β is held constant and α changes, the results in term of the $l(x)$ function would be a parallel function, with values higher or lower than the original survival function at each age x. The second parameter, β , indicates differences in the relationship between the mortality in childhood ages and the mortality in adult ages in the standard life table as compared to the life table in the studied population; then, if α is held constant and β changes, the overall level of mortality would remain similar as in the original survival function, but the new function would show higher (or lower) $l(x)$ at the initial ages and lower (or higher) at adult ages, and the values would intercept at the age x, where $l(x)$ is 0.5. This way higher survival at the initial ages would compensate with lower survival at later ages and the overall mortality would remain at a similar level, changing only the shape of the survival function by age.

If the linear equation linking the logits of the two life tables (standard and studied populations) hold for any life tables, this would imply that all life tables could be generated from a single baseline or standard life table, $l^{st}(x)$, just by using an appropriate pair of values for the parameters α and β . In reality any pair of actual life tables would only approximately satisfy this equation linking the standard and observed logits. Yet, these approximations are close enough to warrant using this relationship to study and model observed mortality schedules.

Under this relational model life table, having one value of the survival function $l(x)$ at early ages, like l_5 , which can be obtained directly from the ${}_0q_5$ values calculated from Brass' children ever born and surviving method ($l_5 = 1 - {}_0q_5$), and another value for $l(x)$ at any adult age, it is possible to determine two point in the coordinates, which would have the values of the logits of the standard life table ($Y^{st}(x)$) in the horizontal axis and in the vertical axis the values of the logits for the life table of the studied population ($Y(x)$). The two points in this plane determine a straight line, and from this straight line the values of the parameters α and β for the logit relational model $Y(x) = \alpha + \beta Y^{st}(x)$ can be established.

Some challenges need to be addressed first, in order to derive a good estimate for these two parameters, α and β , that would define the appropriate logit model life table, which will have similar mortality values as those obtained when estimating early age mortality and adult mortality.

Some of these challenges are:

- The adult mortality estimates need to be converted from their conditional form, as obtained in orphanhood method, into measures of survivorship from birth.
- The child and adult mortality estimates may implicitly conform to different patterns or levels of mortality, different time trends in mortality, or both; in this case, these need to be harmonized in order to define a consistent life table.
- Some data points may be defective or suffer from random fluctuations that distort the overall trend, which implies that the estimated trend may require smoothing or adjustment.
- The estimates of child and adult mortality typically refer to different dates and may span different periods of time, yet the estimated life has to refer to a unified time location.

- Neither the methods for estimating child mortality nor those for estimating adult mortality produce information on the mortality of some age groups, implying that to generate a complete life table it is necessary to use models (i.e. the logit model, with a given standard).

Issues related to the time location, as well as smoothing or adjusting estimates in the time series, routinely are dealt with in the process of estimation of early age mortality, as well as adult mortality estimated from orphanhood, and in fact have been done already in the respective sections of the report when those mortality estimates were obtained and the trends of mortality were established. The estimated trend lines can now be used to evaluate the mortality indicators at child ages (${}_0q_5$) as well as adult ages (${}_{45}p_{15}$), for the selected date for the life table.

Concerning the measure of adult mortality obtained from the orphanhood method, which is not a value for the survival function $l(x)$, but a value for the conditional probability of survival, that is, ${}_{45}p_{15} = l_{60}/l_{15}$, it is necessary to proceed by stages. This is done through an iterative process, that should gradually converge to a set of values for the survival function $l(x)$ that will reproduce the two input values (the estimated ${}_0q_5$ and ${}_{45}p_{15}$), obtained from the respective indirect mortality estimation methods, and at the same time the $l(x)$ would define the complete set of functions that are consistent with the values of $l(x)$ and determine the estimated life table.

The iterative adjustment method starts by obtaining a first approximation of the survival function at age fifteen by using the estimated value for age five ($l_5 = 1 - {}_5q_0$) and the corresponding value in the standard life table, assuming $\beta=1$. With this, a first approximation for l_{15} is obtained. Consistent with the calculations for obtaining indirect mortality estimates, the UN General model is utilized. Using this approximation for l_{15} , the set of conditional probabilities can be transformed in $l(x)$ values from birth, obtaining a first approximation for the complete life table. From these estimated $l(x)$ values a second estimate for the β parameter is obtained, and a process of successive iterations on β values is followed, until the estimated $l(x)$ values reproduce the input values for l_5 and the estimated value of ${}_{45}p_{15}$. The optimizing target for the iteration process is to arrive at values that minimize the differences between the results of the iterations, and the values of the two parameters in the input values, which are the estimated mortality indicators. That is the estimated values of ${}_5q_0$ and ${}_{45}p_{15}$ must be replicated through the optimization iterations and must be the same values obtained in the live table for the respective parameters. This iterative trial-and-error method, or optimizing routine, is conducted by using the "Solver" routine in the Microsoft Excel.







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