Modelling child mortality and its environmental impact in Nigeria

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B.Sc, M.Sc

Thesis by published works submitted for the degree of

Doctor of Philosophy

School of Medicine

University of Western Sydney

March 2015

Dedication

This thesis is dedicated to my late parents, Mr. and Mrs Edwin C Ezeh

Acknowledgements

I would like to thank my supervisors, Dr Kingsley E. Agho, Professor. Michael J. Dibley, Associate Professor. John J. Hall, and Professor Andrew N. Page for their guidance, expertise, time and constructive feedback that provided valuable knowledge during my candidature. A special thanks to Dr Kingsley E. Agho, for his excellent supervision, constructive criticisms, extensive statistical and STATA programming guidance, promptness in reading my write-ups and encouragement from the inception of my PhD.

More importantly, I would like to thank Measure DHS ICF International for granting me permission to use the data sets for this thesis.

Author's Declaration

This thesis is submitted to the University of Western Sydney in accordance with the requirements of the UWS Policy DDS, Doctor of Philosophy Rules (100-103), September, 2009 ('Thesis as a Series of Papers').

The work presented in this thesis is, to the best of my knowledge and belief, original except as acknowledged in the text. I hereby declare that I have not submitted this material, either in full or in part, for a degree at this or any other institution.

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Osita Kingsley Ezeh

Abstract

Nigeria has the world's second highest rate of deaths under 5 years of age, following India. This high rate of under-5 mortality in Nigeria can be attributed to demographic, socioeconomic, and environmental factors because children younger than 5 years are vulnerable to environmental health hazards. This thesis used the Cox proportional hazards regression model to examine risk factors for child mortality and its environmental determinants in Nigeria. Specifically, this thesis aimed to examine the following: (1) the relationship between socioeconomic and demographic factors and neonatal mortality; (2) common factors associated with post-neonatal, infant, child, and under-5 mortality, (3) the effect of water and sanitation on childhood mortality, and (4) the effect of solid fuel use on death of children under 5 years old. The data used in addressing these specific aims were the 2003, 2008, and 2013 Nigeria Demographic and Health Surveys. Additionally, published papers that addressed the research aims have been integrated to form the core of this thesis.

The determinants of neonatal mortality in Nigeria were analysed and are reported in **Chapter 3**. There was an increased risk of neonatal death related to mothers younger than 20 years, mothers residing in rural areas, a small or very small newborn size, and newborns delivered by caesarean section. Additionally, fourth or higher birth order of newborns with a short birth interval ≤ 2 years was significantly associated with neonatal mortality. **Chapter 4** focuses on the common factors associated with post-neonatal, infant, child, and under-5 mortality. A decreased level of risk of mortality across the four age ranges was associated with children born to mothers who had a secondary or higher education, and mothers residing in urban areas. The

risk of mortality was also decreased for children born to mothers from rich households.

Chapter 5 presents the effect of water and sanitation at 0–28 days (neonatal), 1–11 months (post-neonatal), and 12–59 months (child) by combining the three most recent Nigeria Demographic and Health Survey (NDHS) data sets. Unimproved water and sanitation significantly increased the risk of post-neonatal and child mortality. Common factors associated with under-5 mortality included household wealth index (middle and poor) and current breastfeeding status. **Chapter 6** shows the effect of household use of solid fuel on neonatal, post-neonatal, and child mortality by using the 2013 NDHS data set. A total of 0.8% of neonatal deaths, 42.9% of post-neonatal deaths, and 36.3% of child deaths could be attributed to the use of solid fuels. In addition to the effect of solid fuels on childhood mortality, living in rural areas and poor households were associated with an increased risk of death during the three mortality periods.

In summary, findings from these four studies highlight the need for policy-makers and public health researchers to direct resources to the most vulnerable segments of the population, and thus make better use of resources in Nigeria. However, community-based education interventions are also required to reduce avoidable child deaths and interventions should target households with a low socioeconomic status.

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Publications arising from the thesis

This thesis is presented for examination as a thesis containing published work. Chapters 3 to 6 presented in this thesis have been published in peer-reviewed journals. The principal author of each paper is the candidate.

Chapter 3 **Ezeh OK**, Agho KE, Dibley MJ, Hall J, Page AN. Determinants of neonatal mortality in Nigeria: evidence from the 2008 demographic and health survey. BMC Public Health 2014; 14:521. *(Publication 1)*

Chapter 4 **Ezeh OK**, Agho KE, Dibley MJ, Hall J, Page AN. Risk factors for post- neonatal, infant, child and under-five mortality in Nigeria: A pooled cross-sectional analysis. BMJ Open 2015; 5:e006779 *(Publication 2).*

Chapter 5 **Ezeh OK**, Agho KE, Dibley MJ, Hall J, Page AN. The impact of water andsanitation on childhood mortality in Nigeria: evidence from demographic and health surveys, 2003-2013. Int J Environ Res Public Health 2014; 11: 9256-72*(Publication 3)*

Chapter 5 **Ezeh OK**, Agho KE, Dibley MJ, Hall J, Page AN. The effect of solid fuel useon childhood mortality in Nigeria: evidence from the 2013 cross-sectionalhousehold survey. Environ Health 2014;13:113. *(Publication 4)*

Author's Contribution

The work presented in this thesis was conducted by the candidate under the supervision of Dr Kingsley E Agho, School of Science and Health, University of Western Sydney; Professor Andrew N Page, School of Science and Health, University of Western Sydney; Professor Michael J Dibley, Sydney School of Public Health, University of Sydney; and Associate Professor John J Hall, School of Medicine and Public Health, University of Newcastle.

In all the analyses presented in this thesis, the candidate planned the research, conducted the literature review, carried out the analyses, interpreted the findings as well as drafted and revised the manuscripts for submission to peer-reviewed journals. The candidate organised, compiled and wrote this thesis.

SECTION I

Overview

CHAPTER ONE
Introduction

Child mortality, also known as under-5 mortality, refers to death of children aged between 0 and 59 months of life and can be disaggregated as neonatal mortality (0–28 days), post-neonatal mortality (1–11 months), infant mortality (0–11 months), child mortality (12–59 months), and under-5 mortality (0–59 months).[1,2] Worldwide, death of children < 5 years old remains a major public health problem, particularly in sub-Saharan African countries, including Nigeria. Nearly 50% of the world's estimated deaths in children < 5 years old occur in the sub-Saharan African region, and Nigeria accounts for approximately 13% of these deaths.[1] The majority of these deaths are caused by preventable or treatable diseases, such as water and sanitation-related diseases (diarrhoea), which contribute to approximately 9% of these deaths.[3]

The high rate of under-5 mortality in low- and middle-income countries can be attributed to demographic, socioeconomic, and environmental factors. Environmental risk factors have been estimated to account for approximately one-fifth of the total burden of disease in low-income countries.[4] Environmental health risk factors are broadly classified into two types: traditional and modern hazards.[5] Traditional hazards include waste disposal, vector-borne diseases, inadequate sanitation, indoor air pollution, and unimproved sources of water, while modern hazards consist of urban air pollution, exposure to agro-industrial chemicals, and wastes.

A recent public health review undertaken in 38 developing countries indicated that access to safe water and sanitation reduced child mortality by approximately 20%.[6] Additionally, each year, this access prevented approximately 2.2 million deaths in children younger than 5 years from developing countries, excluding China.[6] The World Health Organisation (WHO) also reported that more than 50% of the deaths of children younger than 5 years are attributed to acute lower respiratory infections caused by particulate matter inhaled from indoor air pollution (IAP) from cooking with solid fuels.[7] Children younger than 5 years are more vulnerable to the environmental health hazards associated with solid fuel use[8] and unsafe water and sanitation[9] because their immune, respiratory, and digestive systems are still developing.

Evidence from the three most recent Nigeria Demographic and Health Surveys (NDHSs) showed that over a 10-year period (2003–2013), the under-5 mortality rate declined by approximately 36% (from 201deaths per 1,000 live births to 128), the neonatal mortality rate (NMR) declined by 22.9% (from 48 to 37), the post-neonatal mortality rate declined by 40% (52 to 31), the infant mortality rate (IMR) declined by 31% (from 100 to 69), and the child mortality rate (CMR) declined by 43% (from 112 to 64).[2,10,11] The findings from the NDHSs show that at least a 9% average annual reduction in under-5 mortality, which is required to achieve the Millennium Development Goal (MDG) number 4, remains evasive. [12] The rationale of the present study formed the basis of discussion in the following section.

1.1 Rationale of the study

The Nigerian government has formulated and implemented a number of policy initiatives, as well as intervention programmes, including the Midwives Service

Scheme (MSS), Integrated Maternal, Newborn and Child Health (IMNCH), Kangaroo Mother Care (KMC), Integrated Management of Childhood Illness (IMCI), and Baby-friendly Hospital Initiatives (BFHI), which aim at continued improvements in childhood survival. Despite these policy and intervention initiatives, currently, Nigeria has the highest reported number of under-5 deaths in Africa and ranks as having the second highest number of deaths (after India) globally.[1]

Previous studies on the death of children < 5 years old in Nigeria have been conducted mostly with hospital-based case-control and experimental studies, and few population-based studies.[13-20]The limitations of the hospital-based studies are that children who died at home were not included, and that control groups were not population-based, which may not be generalisable to the wider Nigerian population. Evidence from the last three NDHSs (2003, 2008, and 2013) showed that more than 60% of children were delivered at home.[2,10,11] Therefore, estimates obtained in hospital-based studies may be underestimated or overestimated because children delivered at home were not included, and control groups were not population-based. In addition, these studies did not exclude multiple births in their analyses, because compared with singletons, multiple births are associated with a high childhood mortality risk.[21-27] Therefore, including multiple births in the analyses of child mortality may also produce misleading/inaccurate mortality estimates.

Environmental factors (indoor air pollution caused by solid fuel use, and water and sanitation) have been neglected by public health researchers, despite their large effect on child survival. Researchers have estimated that over 95,000 and approximately 150,000 Nigerians, including children < 5 years old, die annually from exposure to firewood smoke and access to unimproved water and sanitation in Nigeria.[7,28] Prior to the current study, no population-based studies examined the effect of sanitation and sources of water on childhood mortality in Nigeria, as well as the effect of solid fuel use on childhood mortality.

Therefore, the current study was performed because of this lack of knowledge in the existing public health literature on childhood mortality and its environmental impact. This study used population-based sample data to examine the determinants of childhood mortality, and the effect of solid fuel use, water, and sanitation on reducing childhood deaths in Nigeria. The next two sections discuss research aims and the approach adopted in answering these research questions.

1.2 Research objectives

The main aim of this study was to examine the determinants of childhood mortality and its environmental impact using a population-based cross-sectional household survey. Specifically, this study aimed to examine the following research objectives:

1. To examine the socioeconomic and demographic factors associated with neonatal mortality using the 2008 NDHS.

2. To identify common factors associated with post-neonatal, infant, child, and under-5 mortality using pooled sample data of 2003, 2008 and 2013 NDHSs.

3. To investigate the effect of water and sanitation on childhood mortality by combining sample data of 2003, 2008 and 2013 NDHSs.

4. To examine the effect of solid fuel use on childhood mortality using the 2013 NDHS.

1.3 Quantitative analysis

In this thesis, only quantitative methods were used to answer the research questions. The statistical method that was used for all of the quantitative analyses presented in this thesis was the Cox proportional hazards model. This method is discussed in detail in each of the publications arising from the thesis.

1.4 Thesis outline

The thesis is categorised into four sections. **Section 1** is an overview of the research, which includes an introduction (**Chapter 1**), and background, and literature review (**Chapter 2**).

Section 2 consists of two chapters. **Chapter 3** examines the determinants of neonatal mortality in Nigeria using the 2008 NDHS (publication 1).[29] **Chapter 4** presents the risk factors for post-neonatal, infant, child, and under-5 mortality in Nigeria using the data from the 2003 to 2013 NDHSs (publication 2).[30]

In **Section 3**, the effects of environmental factors are discussed using pooled sample data of the 2003, 2008, and 2013 NDHSs, as well as using the most current NDHS (2013). This section includes **Chapters 5** and **6**. In **Chapter 5,** the effect of water and sanitation on childhood mortality is examined (publication 3).[31] In **Chapter 6,** the effect of solid fuel use on childhood mortality is examined (publication 4).[32]

Section 4 presents the final chapter (**Chapter 7**). Major findings are summarised, and limitations of the research are also discussed as well as recommendations for future research.

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CHAPTER TWO

Literature Review

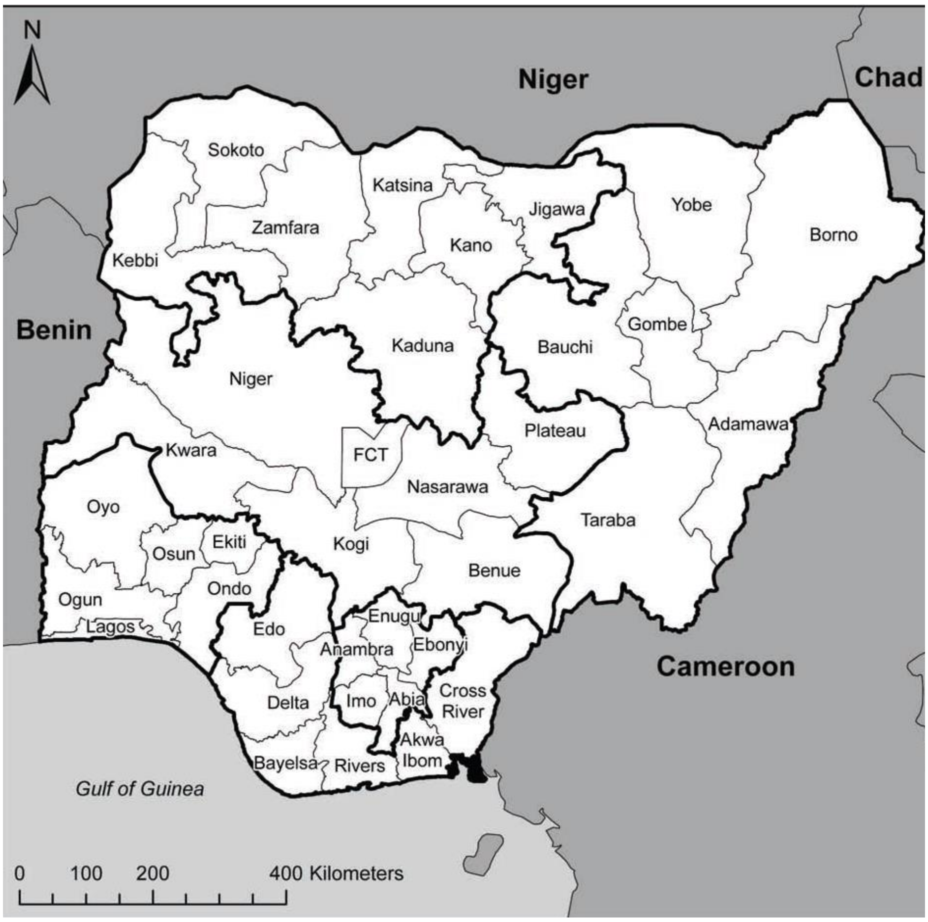
2.0 Introduction

This chapter reviews the existing literature on childhood mortality and its environmental effects. Section 2.1 discusses the geographical structure of the study area. Section 2.2 describes the NDHS, including the sampling design. The Mosley and Chen theoretical framework of childhood survival is discussed in Section 2.3. Previous studies on individual, household, community, and environmental characteristics that affect child mortality are reviewed and presented in Section 2.4. Finally, Section 2.5 discusses the statistical modelling adopted in examining and identifying factors associated with death of children < 5 years old in Nigeria.

2.1 Location of the study area

Nigeria is the world's seventh most populous nation, with over 160 million people,[1] and an annual growth rate estimated at 3.2%, based on the 2006 census.[2] Nigeria is located in the West Africa sub-region, bordered by four countries, Niger, Chad, Cameroon, and Benin (Figure 2.1).

Figure 2.1 Map of Nigeria



Source: NDHS, 2008**.**

At present, there are 374 identifiable ethnic groups, with lgbo, Hausa, and Yoruba as the major ethnic groups. Nigeria comprises 36 states and Federal Capital Territory (FCT) (Figure 2.1). Each of the states and FCT consists of constitutionally recognised local government areas (LGAs). These states are grouped into six geopolitical zones, which include north-central, northeast, northwest, south-south, southeast, and southwest. Geopolitical zones are defined based on ethnic homogeneity of near perfect political, administrative, and commercial cities in Nigeria.[3]The economic strength of the country is derived mainly from its oil and gas reserves.[2] A recent report by the World Bank (WB) indicated that Nigeria has a gross domestic product (GDP) of $262.6 billion.[4]

2.2 Demographic and health surveys

A demographic and health survey (DHS) is a nationally representative survey that gathers health and socio-demographic data of the population in a host country. The DHS is mostly used in low- and middle-income countries because of inadequate vital registration of birth and death. The DHS is conducted by the participating countries in conjunction with ICF International. The DHS programme is largely sponsored by the United States Agency for International Development (USAID), with additional funds from other donors (UKaid and UNFPA) and host countries. More than 260 DHS surveys in over 90 countries, including Nigeria, have been conducted since 1984.[5] Participating countries adopt standardised uniform questionnaires, manuals, and field procedures that are developed by the DHS to gather information that is comparable across countries.

The DHS core instruments are the household, and women's and men's questionnaires. The household questionnaire records all of the usual residents of the selected household and their characteristics, such as age, sex, education, and features of the household dwelling unit. This questionnaire is administered to the head of the household. The women's questionnaire is administered to eligible women aged 15–49 years. They are asked about their demographic and health issues including, but not limited to, birth history, childhood mortality, antenatal care, delivery, postnatal care, vaccinations, and childhood illnesses, as well as prevention and treatment of malaria. The men's questionnaire is the same as the women's questionnaire, except that it does not contain a detailed reproductive history, maternal and child health, or nutrition.

The first NDHS was conducted in 1990, and was carried out by the Federal Office of Statistics (FOS). Since then, four NDHSs have been conducted (1999, 2003, 2008, and 2013 NDHS) in Nigeria approximately every 5 years by the National Population Commission (NPC) in conjunction with technical assistance from ICF international. The NDHS programme collects data nationally on a wide range of socio-demographic and health characteristics by interviewing women and men of reproductive age from 15 to 49 and 15 to 59 years old, respectively, in all the states and FCT.

The NDHS uses a stratified, two-stage (cluster), random sampling design. Each state was stratified into two distinct groups of urban and rural areas. The census enumeration areas were used as the clusters for the NDHS survey. In the first stage, clusters were selected based on probability proportionate to the population size among its urban and rural areas. In each of the selected clusters, a complete listing of households was obtained. The listed households then served as the sampling frame for the selection of households to be interviewed in the second stage. Thereafter, systematic sampling with equal probability was used in the second stage in selecting the specified number of households in each cluster for interview.[2,6] A structured questionnaire is used for interviewing the selected households for the NDHS survey.

The information gathered from interviewees is recorded in three separate DHS questionnaires as previously mentioned.

Table 2.1 shows the sample sizes of all NDHS datasets used in this thesis. The NDHS usually covers all the selected clusters, but in the 2008 NDHS, two clusters were not accessed because of flood and inter-communal disturbances. As shown in Table 2.1, the sample size of the 2003 NDHS was relatively smaller than sample sizes of the 2008 and 2013 NDHS because additional information on violence against women and the FCT were included in the 2008 and 2013 NDHSs.[2,6]

Table 2.1 Number of households, and women and men successfully interviewed in the Nigeria Demographic and Health Surveys (NDHSs) 2003–2013

Year of survey NDHS	Number of households (response rate)	Number of women (response rate)	Number of men (response rate)
2003	7,225 (98.6%)	7,620 (95.4%)	2,346 (91.2%)
2008	34,070 (98.3%)	33,385 (96.5%)	15,486 (92.6%)
2013	38,522 (99.0%)	38,948 (97.6%)	17,359 (95.2%)

Source: 2003, 2008, and 2013 NDHS final reports.

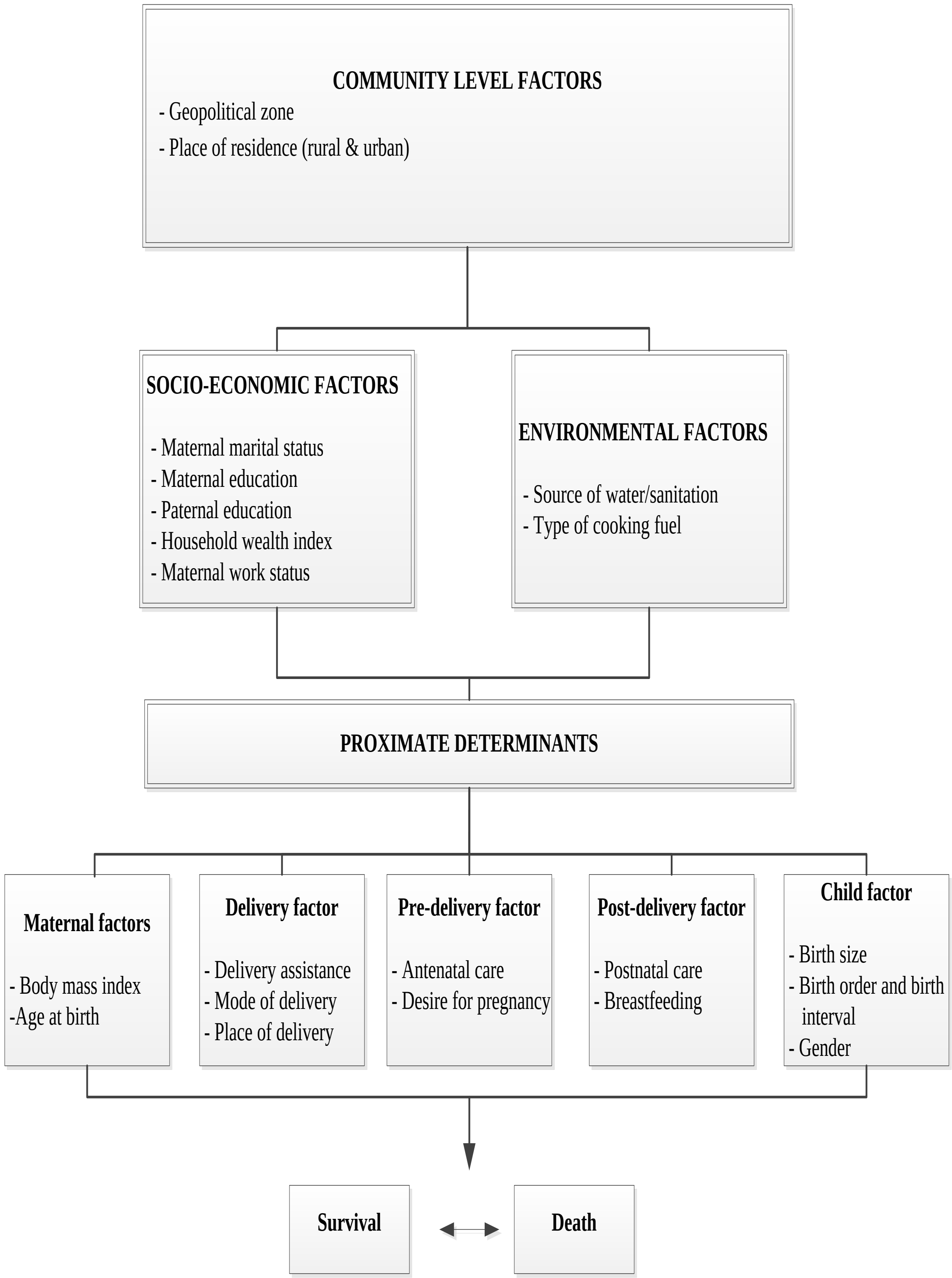
2.3 Mosley and Chen theoretical framework

A conceptual framework of childhood survival in developed and developing countries has been developed by other authors.[7-9] However, the model by Mosley and Chen[7] is regarded as the most comprehensive and systematic conceptual framework[10] for analysing childhood mortality. Berger et al[11] acknowledged the usefulness of the

Moseley and Chen model for study of determinants of childhood mortality at various levels of causality, particularly in developing countries. Eberstein[12] also suggested that the Moseley–Chen model is appropriate for the study of child survival in low- and middle-income countries. This is because the Mosley and Chen model bridged the gap between medical and social science researchers by integrating social science models and medical research models into a unifying general theoretical model. Their model identified the socioeconomic characteristics that influence childhood death, as well as the underlying biological factors affecting it.

Numerous studies have used the Mosley and Chen model in analysing and reporting childhood mortality. An example of one of these studies was a cross-sectional study on the determinants of neonatal mortality that was conducted in Indonesia in 2008 and conceptualised based on the Mosley and Chen framework.[13]This previous study found that individual, community, and household characteristics affect neonatal mortality. Omaribaet al[14] used the Mosley and Chen model to analyse and report the determinants of infant and child mortality in Kenya. Additionally, a cross-sectional study conducted in five developing countries (Cameroon, Egypt, Peru, Uganda, and Vietnam) on the effect of water and sanitation on child survival adopted a conceptual framework that was proposed by Mosley and Chen.[15] As a result, this thesis adapted the Mosley and Chen conceptual framework as the basis for identifying important risk factors affecting childhood survival in Nigeria.

Figure 2.2 Conceptual framework for analysing factors associated with death of children < 5 years old in Nigeria.



Source: Adapted from Mosley and Chen (1984).

The Mosley and Chen model suggested that factors that affect childhood mortality operate through a set of proximate determinants that influence disease and the disease process. The proximate determinants include maternal and demographic factors, environmental factors, nutrient deficiency, injury, and control of personal illness (Figure 2.2). Mosley and Chen also found that socioeconomic factors affect childhood death and they classified socioeconomic factors into four distinct groups: individual-level, household-level, community-level, and environmental factors. These factors were used in the current study to identify risk factors associated with childhood mortality and are discussed below.

2.4 Previous studies on child mortality and its environmental effect

Several studies have examined the risk factors associated with childhood mortality in developing and developed countries. Therefore, the following sections discuss previous literature on independent characteristics that were classified into four groups: individual, household, community, and environmental level characteristics that are related to child mortality.

2.4.1 Individual-level factors

The individual-level factors consist of attributes from the mothers, fathers and children. These attributes are discussed below.

Mother's education

Caldwell[16] demonstrated that maternal education is an important determinant of child survival in low- and middle-income countries, and this has been confirmed by other subsequent studies.[17-21] Educated mothers can understand health care practices and hazards related to contraception, nutrition, hygiene, and solid fuel use. Anyamele[22] concluded that mothers who have a formal education are significantly associated with improved child survival, and there is no minimal level of maternal education that needs to be achieved before yielding positive effects in child survival.[23] However, Madise et al[24] found that mothers with higher levels of education (secondary school or higher) exert more influence on their child's health.

Maternal age

Some studies[25,26] have shown that there is a relationship between maternal age at birth and child survival. In addition, Ezehet al[27] also showed that neonates born to mothers aged younger than 20 years had a significantly higher risk of mortality than those born to mothers aged 20–29 years, 30–39 years, and 40–49 years. However, their findings contradict that of Mahmood[28] who found that neonates and post-neonates of older mothers aged 30–39 years were more likely to die than those of younger mothers. Other studies conducted in Swaziland[29] and Tanzania[30] showed no significant relationship between maternal age and neonatal mortality.

Child's sex

Several studies have shown mortality differential by sex; female mortality is lower during the neonatal period compared with male mortality.[13,27,31] Higher male mortality in the neonatal period may be attributed to high vulnerability of infectious disease,[32] and late development of early foetal lung maturity in the first week of life.[33] However, studies have suggested that during the post-neonatal and child periods, females were more likely to die than males.[34-36] This may be related to behavioural attitude through neglect and inadequate parental care of female children.[37] However, researchers have argued that the effect of sex discrimination against females or males is negligible on child survival[17] and its effect is weak in children born to educated mothers.[38]

Birth order

Studies have shown that first born and a high birth order are associated with childhood mortality.[39,40]Davanzo et al[41] suggested that first-born children are at a disadvantage due to biological effects of primiparity and young maternal age. However, Hobcraft,[39] established that if women delay their first birth until they are 18 years or older, they can decrease the risk of first-born death by up to 20% on average.

Birth interval

Several studies have concluded that short spacing of children affects the survival of children < 5 years of age.[13,27,42] A number of studies have suggested pathways through which a short child-spacing interval may influence children's survival. Inadequate time for physical and nutritional recovery,[43] and behavioural effects associated with competition among siblings[31,39] have been frequently reported as an obvious pathway for how a short birth interval may affect child survival. In addition, Davanzoet al[41] suggested that inadequate attention to a child and disease transmission are possible contributors to the effect of closely spaced children. However, in this thesis, birth order and birth interval were combined together in the analyses because the effect of birth order may be mediated by the birth interval between children. Previous studies conducted in Zimbabwe and Indonesia used combined birth order and birth interval in their analyses of childhood mortality.[13,44]

Mother's perceived birth size

The birth weight of a child is generally considered as a factor that is associated with childhood mortality, particularly in the neonatal and post-neonatal periods. This relationship has been consistently reaffirmed by past reviews.[45-48] However, in the present study, the variable of birth weight was not used because more than half of the children were not weighed at the time of birth. However, perceived newborn size at birth by mothers (small or very small, and average or large) was used instead of birth weight. This was based on a previous study, which showed that there is a close relationship between mean birth weight and perceived newborn size by the mother.[49] A recent cross-sectional study conducted in Indonesia in 2008 reported that small or very small-sized neonates were more likely to die than average or larger-sized neonates.[13] Similarly, a report from a cross-sectional study that was performed in five Asian countries (India, Indonesia, Nepal, Bangladesh, and the Philippines) in 2008 also showed that smaller than average neonates had an increased risk of neonatal deaths than average or larger-sized neonates in four of the five countries with data on perceived newborn size.[50]

Mode of delivery

The effect of mode of delivery on childhood mortality in low- and middle-income countries has been established in previous reviews.[27] However, this relationship is not consistent. Studies conducted in Egypt and Swaziland indicated a non-significant association between the mode of delivery and neonatal mortality.[29,51] A recent study on caesarean section and perinatal mortality in South Western Nigeria indicated that nearly 84% of early neonatal deaths occurred in pregnant mothers who delivered their newborns by emergency caesarean section.[52] This may be attributed to the fact that pregnant mothers presented to a health facility after experiencing labour at home or elsewhere, with life-threatening complications for emergency caesarean section.[53]

Location of birth

Previous studies have shown that children who are delivered at home are more likely to die compared with those delivered at health facilities.[54,55] Evidence from the NDHS showed that home delivery in Nigeria remains high. An example of this situation is in the three NDHSs (2003, 2008, and 2013), which showed that at least 62% of children were delivered at home[2,6,56] because of inadequate health facilities, insufficient skilled health professionals, and a lack of modern medical equipment, which have undermined the Nigerian healthcare system, particularly in rural areas.[57]

Assistance during delivery

According to the NDHS, only 38% of all deliveries in the 5 years preceding the 2013 survey were assisted by trained birth attendants (doctor, nurse, and midwife). Forty-five percent of births were assisted by untrained birth attendants, such as traditional birth attendants, and relatives or other persons. Some studies have suggested that there is a correlation between untrained birth attendants and deaths among children < 5 years old.[58,59]

Father's education

Education of the father has been found to be correlated with neonatal, infant, and child mortality.[25,26] In Nigeria, as in many low- and middle-income countries, the father is the head of the family and decision maker, as well as the main income earner. Educated fathers are more likely to gain better paid work than uneducated fathers, which in turn improves access to healthcare facilities, healthy nutrition, housing environment, and a good life style for the family.

Mother's work status

Previous reviews have shown a divergent view on the association between the mother's work status and childhood mortality. A cross-sectional study conducted in Jordan in 1983 indicated that the mother's work status is significantly related to childhood mortality.[60]However, a study in Malaysia showed no significant relationship between the mother's work status and childhood mortality[41]

2.4.2 Household-level factors

Income/wealth effect is strongly correlated with a range of goods and services, as well as assets at the household level. This in turn affects child health and mortality.

Household wealth index

Economic status of a household is associated with childhood mortality, and more importantly, with infant and child mortality.[25,61-63] The positive influence of a higher income level of a household includes, but is not limited to, access to healthcare facilities, food availability, improved water supply, improved sanitation facilities, access to modern stoves and cleaner energy, and housing conditions.

Inadequate or non-availability of either income or expenditure data in sample surveys, particularly those conducted in low- and middle-income countries, have prompted the use of household assets as a proxy to measure household economic status.[64,65]In this study, a household wealth index variable was constructed using household assets because NDHSs contain no data on income or on household consumption expenditure. As a result, the household wealth index was calculated using household assets and facilities that were available to respondents.

The household assets and facilities were weighted using principal component analysis.[65]The assets that were included werea television, radio, refrigerator, telephone, car, bicycle, motorcycle and canoe, and ownership of agricultural land, a livestock farm, or a bank account. In addition, the source of drinking water, type of toilet, electricity, and type of building materials used in the place of dwelling were included. However, in the pooled analysis, only assets that were consistent across the three NDHSs for the years of 2003, 2008, and 2013 were considered.

In the NDHS data set, the household wealth variable was categorised into five quintiles: poorest, poorer, middle, richer, and richest. However, in this thesis, the household wealth index was re-categorised into three groups. The bottom 40% of households was arbitrarily referred to as poor households, the next 40% as middle-income households, and the top 20% as high-income households.

2.4.3 Community-level factors

Community-setting attributes that were considered were the type of residence and geopolitical zone that may affect access to healthcare institutions, and social and economic infrastructure.

Place of residence

The respondent's living location at the time of the surveys was used to classify the residence, and was classified as urban or rural. The place of residence affects children's survival, particularly in low- and middle-income countries. Numerous studies have shown that children born to mothers residing in rural areas are more likely to die than those who reside in urban areas.[26,27,66-69] Limited access to health facilities and maternal healthcare services disproportionally hinders rural dwellers from receiving adequate healthcare services, resulting in a high probability of child death.

Geopolitical zone

As previously mentioned, Nigeria is made up of six geopolitical zones. There is geopolitical disparity in the patterns of deaths of children < 5 years old. Antai[70] suggested that under-5 mortality in Nigeria is significantly higher in some zones compared with other zones.

2.4.4 Environmental-level factors

Of the 10 identified leading risks of mortality in low- and middle-income countries, including Nigeria, unsafe water and sanitation ranked second, while solid fuel use ranked fourth.[71] Approximately one-fifth of the total burden of disease in low-income countries is attributed to environmental risk factors.[72] Several studies have found that environmental factors (source of drinking water, sanitation facilities, and cooking fuels) are associated with infant and child mortality,[73-75] which makes these variables vital predictors for childhood mortality.

Source of water and access to sanitation

According to WHO, an improved water source, is a source, which by the nature of its construction, is adequately protected from contamination, particularly faecal matter, while an improved sanitation facility is one that hygienically separates human excreta from human contact.[76] Figures 2.3 and 2.4 show the distribution of the type of water supply and sanitation facility by year of the NDHS, respectively. The grey bars represent the percentage of the Nigerian population who have access to unimproved water sources and sanitation facilities. Over a 10-year period (from 2003 to 2013), the proportion of the population with access to unimproved water sources decreased from approximately 55–41% (Figure 2.3), while the proportion of the population with access to unimproved sanitation facilities declined by 15% (from 80% to 65%) (Figure 2.4).

Unimproved water and sanitation are major causes of diarrhoea, which globally account for approximately 1.4 million child deaths each year. Previous studies have shown that access to improved water and sanitation leads to a reduction in childhood mortality, as well as child diarrhoea.[50,77] A recent large cross-sectional study that was undertaken in 38 developing countries concluded that complete access to improved water and sanitation can reduce child mortality by approximately 20% and prevent approximately 2.2 million deaths in children younger than 5 years each year in low-income and middle-income countries, excluding China.[78]

Figure 2.3 Distribution of the population who use improved or unimproved water, by year of the NDHS.

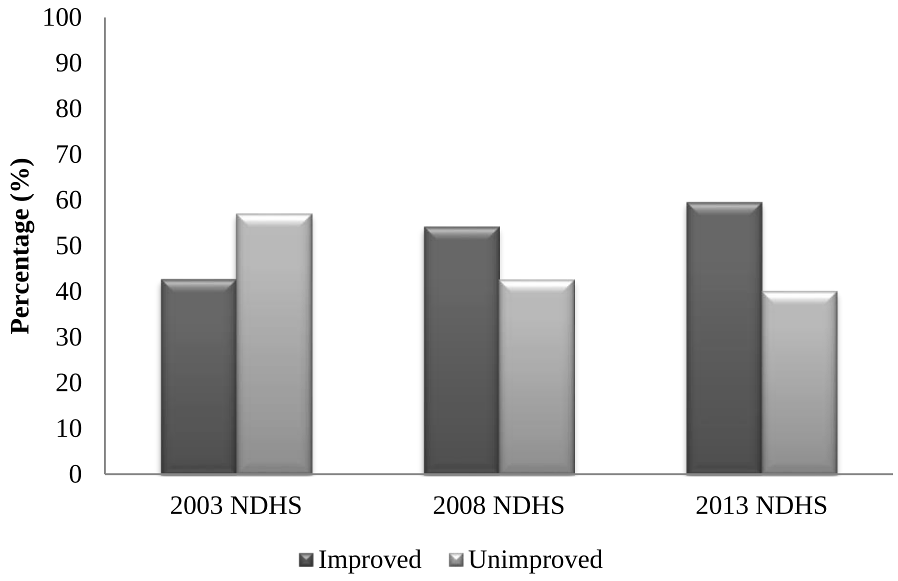
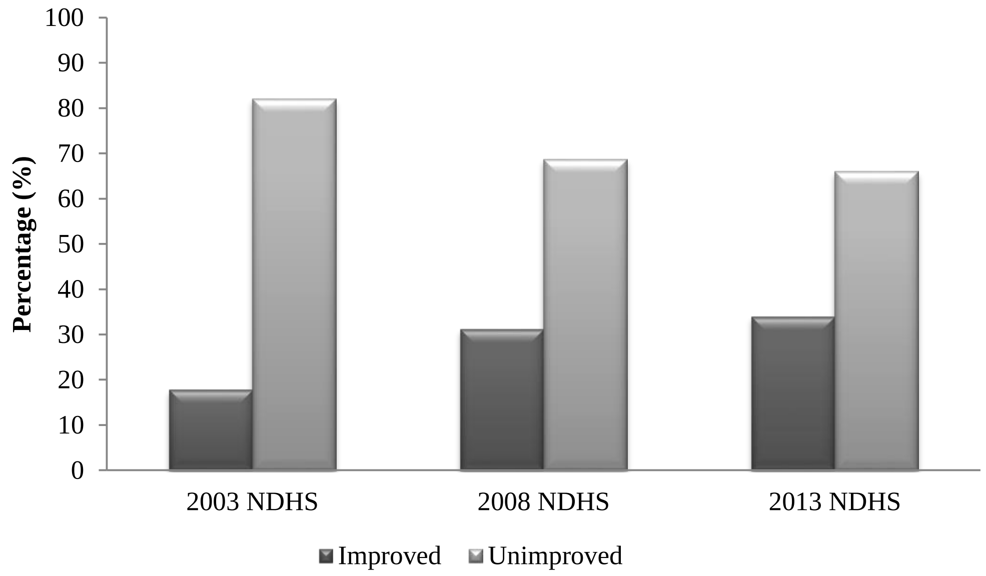


Figure 2.4 Distribution of the population who use improved or unimproved sanitation facilities, by year of the NDHS.



Type of cooking fuel

The main source of domestic energy in low- and middle-income countries is traditional solid fuels, such as wood, charcoal, animal dung, coal, and crop waste. Solid fuel use remains the major contributor of indoor air pollution in developing countries, such as Nigeria. Approximately 69% of the Nigerian population still use solid fuels as their primary source of domestic energy for cooking and heating homes.[6] In 2014, the WHO indicated that > 50% of the deaths of children < 5 years of age were attributed to acute lower respiratory infections triggered by solid fuel use.[72] Children < 5 years of age living in homes using solid fuels for cooking are at a greater risk of dying from acute respiratory illnesses.[79,80]

The previously discussed potential confounding variables (individual, household, community, and environmental level factors) were fitted in the models described by Cox[81] to measure their effect on neonatal, post-neonatal, infant, child and under-5 mortality in Nigeria. The Cox proportional hazards model was used in this study, because in the NDHS data sets, there is a complete birth history (date of birth and date of death), which permits modelling of time to death. Additionally, the NDHS accounts for survival times and censoring information unlike logistics regression models that are commonly used in modelling child mortality in Nigeria. The formula for the Cox proportional hazards model is stated below in the following section.

2.5 Cox proportional hazards model

The letters $h(t, P)$ denote the hazard function defined as the risk of dying at time t based on an n-dimensional vector of predictor variables $P = (p_{1,}\ p_2, \ldots, p_n)$, as shown in equation (1).

$$h(t, P) = h_o(t)\ exp(\sum_{i=1}^{n} \omega_i\, p_i) \qquad (1)$$

$h_o(t)$denotes the baseline hazard at time t, where the exponential of the sum of ω_i and p_i provide the proportional change in hazard function in relation to changes in the predictor variables. The coefficients $\omega_1 \ldots \omega_n$ are estimated by Cox regression. The hazard ratio is then obtained by dividing both sides of equation (1) by $h_o(t)$ and taking logarithms, which yields equation 2.

$$\ln\left(\frac{h(t,P)}{h_o(t)}\right) = \omega_1 p_1 + \omega_2 p_2 + \omega_3 p_3 + \ldots + \omega_n p_n \qquad (2)$$

By applying equation (2), the hazard ratios of the effect of the previously discussed predictor variables were obtained for neonatal, post-neonatal, infant, child, and under-5 mortality.

2.6 Summary

In many low- and middle-income countries where vital registration of birth and death is inadequate, DHS data have been used to approximate the number of children's deaths. The variables used in DHS data are consistent across participating DHS countries.

The conceptual framework proposed by Mosley and Chen for child survival is of principal importance to this study because it is widely used for design and analyses of epidemiological studies, particularly in low- and middle-income countries. Additionally, their framework integrates potential socioeconomic and biological characteristics that may affect a child's survival into a unifying conceptual model. The current study used the Mosley and Chen framework as the basis for identifying potential factors that may be related to child health.

Previous studies have examined community, household, individual, and environmental level factors on child mortality. There are strengths of each of these independent variables and advantages of using the mother's perceived birth size as a proxy to birth weight. The Cox proportional hazards model provides a better estimate than logistics regression because it adjusts for time to events. The next Chapters focus on publications arising from the modelling of child mortality and its environmental effect in Nigeria based on application of the Mosley and Chen conceptual framework and Cox proportional hazards models.

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SECTION II

Risk factors for children under 5 years old in Nigeria

This section presents two manuscripts titled "Determinants of neonatal mortality in Nigeria: evidence from the 2008 demographic and health survey data" *(publication 1)* and "Risk factors for post-neonatal, infant, child, and under-5 mortality in Nigeria: A pooled cross-sectional analysis" *(publication 2).*

CHAPTER THREE

Determinants of neonatal mortality in Nigeria: evidence from the 2008 NDHS

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BMC Public Health. 2014;14:521

(publication 1)

Ezeh et al. BMC Public Health 2014, 14:521
http://www.biomedcentral.com/1471-2458/14/521

BMC Public Health

RESEARCH ARTICLE Open Access

Determinants of neonatal mortality in Nigeria: evidence from the 2008 demographic and health survey

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Abstract

Background: Nigeria continues to have one of the highest rates of neonatal deaths in Africa. This study aimed to identify risk factors associated with neonatal death in Nigeria using the 2008 Nigeria Demographic and Health Survey (NDHS).

Methods: Neonatal deaths of all singleton live-born infants between 2003 and 2008 were extracted from the 2008 NDHS. The 2008 NDHS was a multi-stage cluster sample survey of 36,298 households. Of these households, survival information of 27,147 singleton live-borns was obtained, including 996 cases of neonatal mortality. The risk of death was adjusted for confounders relating to individual, household, and community level factors using Cox regression.

Results: Multivariable analyses indicated that a higher birth order of newborns with a short birth interval ≤ 2 years (hazard ratio [HR] = 2.19, confidence interval [CI]: 1.68–2.84) and newborns with a higher birth order with a longer birth interval > 2 years (HR = 1.36, CI: 1.05–1.78) were significantly associated with neonatal mortality. Other significant factors that affected neonatal deaths included neonates born to mothers younger than 20 years (HR = 4.07, CI: 2.83–5.86), neonates born to mothers residing in rural areas compared with urban residents (HR = 1.26, CI: 1.03–1.55), male neonates (HR = 1.30, CI: 1.12–1.53), mothers who perceived their neonate's body size to be smaller than the average size (HR = 2.10, CI: 1.77–2.50), and mothers who delivered their neonates by caesarean section (HR = 2.80, CI: 1.84–4.25).

Conclusions: Our study suggests that the Nigerian government needs to invest more in the healthcare system to ensure quality care for women and newborns. Community-based intervention is also required and should focus on child spacing, childbearing at a younger age, and poverty eradication programs, particularly in rural areas, to reduce avoidable neonatal deaths in Nigeria.

Keywords: Determinants, Neonatal mortality, Cox regression, Nigeria

Background

Neonatal mortality is still a significant public health problem worldwide, and accounts for more than 60% of newborn deaths before their first birthday [1]. Of the world's 7.7 million deaths in those aged younger than 5 years, 3.1 million occurred after birth through to 1 month of life (neonatal deaths) [2]. Nearly 99% of these neonatal deaths occur in low- and middle-income countries, mostly in sub-Saharan Africa, including Nigeria [3]. The majority of these deaths are caused by preventable or treatable diseases, such as infectious diseases, which contribute to approximately 36% of these deaths [3]. Previous studies have shown that the global decline in neonatal mortality rates has been slower compared with infant and under-5 years of age mortality rates, especially in the sub-Sahara African region [1,2,4].

Globally, Nigeria ranks second to India with the highest number of neonatal deaths, with the highest reported number in Africa [5]. Each year in Nigeria, more than a quarter million neonates die, which translates to approximately 700 neonates every day [5]. Neonatal mortality remains disturbingly high in Nigeria, despite the significant

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decline in most parts of the developing world, including some sub-Sahara African countries, such as Ghana and Uganda [6]. A recent United Nations (UN) report on childhood mortality reported that over the last 2 decades, the Nigerian neonatal mortality rate (NMR) dropped by only 20.4%, from 49 deaths per 1000 live births in 1990 to 39 in 2011 [5]. Similarly, evidence from the Nigeria Demographic and Health Survey (NDHS) also indicated a marginal decline of 4.8% (42 deaths per 1000 live births in 1990 to 40 in 2008) [7]. The 39 and 40 neonatal deaths per 1000 live births reported by the UN and NDHS, respectively, can be interpreted as approximately one in every 25 neonates born in Nigeria died in the first month of life.

Previous studies on neonatal mortality in Nigeria have indicated that low birth weight, lack of antenatal care, maternal illness, mother's age, prematurity, and birth asphyxia are linked with neonatal mortality, but these studies were all hospital-based case–control and experimental studies [8-11]. Limitations of these hospital-based case–control and experimental studies are that neonates delivered at home were not included and that control groups were not population based, and may not be generalizable to the wider Nigerian population. Evidence from the NDHS showed that home delivery in Nigeria remains high. An example of this situation is in the 1999 NDHS, where approximately 58% of neonates were delivered at home [12], and this number rose to 66% in the 2003 NDHS [13], and was 62% in the 2008 NDHS [7]. Importantly, neonatal mortality rates play an increasingly important role in childhood mortality, and there are currently no effective community based intervention programs in Nigeria specifically targeting neonatal mortality.

The main goal of this study was to determine factors associated with neonatal mortality using the 2008 NDHS. Findings from the study would be useful to public health researchers and policy makers in reviewing and designing new community based intervention strategies aimed at reducing neonatal mortality in Nigeria. Therefore, this study presents population-based data on risk factors associated with neonatal mortality in Nigeria.

Methods

This study was based on a public domain dataset that is freely available online. The data were collected for the NDHS 2008 [7]. The survey was conducted by the National Population Commission in conjunction with the ICF Macro, Calverton, MD, USA, in 36 states and the federal capital territory [7].

The 2008 NDHS was a stratified two-stage cluster design. Each state was stratified into two distinct groups of urban and rural areas. The census enumeration areas of the 2006 population census were used as the clusters for the 2008 NDHS. In the first stage, clusters were selected based on probability proportionate to the population size among its urban and rural areas. In each of the selected clusters, a complete listing of households was obtained. The listed households then served as the sampling frame for the selection of households to be interviewed in the second stage. Thereafter, a systematic sampling with equal probability was used in the second stage in selecting the specified number of households in each cluster for interview [7].

A structured questionnaire was used for interviewing the selected households for the 2008 NDHS. The questionnaires that were administered to the respondent household members were the household questionnaire, the women's questionnaire, and the men's questionnaire. These questionnaires consisted of a series of questions on population and health issues. The household questionnaire recorded all of the usual residents of the selected household and their characteristics, such as age, sex, education, and their relationship with the head of the household, as well as information on amenities and features of the household's dwelling unit. Additionally, the survey collected data on height and weight measurements for children aged younger than 5 years, and women aged 15–49 years. The women's questionnaire consists of information included, but not limited to, birth history, childhood mortality, fertility preferences, knowledge and use of family planning methods, antenatal care, delivery, postnatal care, vaccinations, and childhood illnesses, as well as malaria prevention and treatment. The 2008 NDHS men's questionnaire was the same as the women's questionnaire, but did not contain a detailed reproductive history, maternal and child health, or nutrition. However, notably, gestational age, intrapartum-related complications, and birth asphyxia, which could potentially improve neonatal data, were not collected in the 2008 NDHS.

A total of 888 clusters were selected for the 2008 NDHS sample survey. Of these clusters, a total of 36,298 households were selected for interview in the 2008 NDHS. At the time of the survey, nearly 5% of the households were not occupied. However, more than 98% of the occupied households were successfully interviewed. A total of 34,596 eligible women aged between 15 and 49 years were interviewed, yielding a response rate of 96.5%. The analysis was restricted to all singleton live births for a 5-year period preceding the 2008 NDHS to reduce recall bias about birth and death dates reported by mothers.

Descriptive study variables

A conceptual framework of child survival in developed and developing countries has been developed by other authors [14-17]. However, the model by Moseley [15] is regarded as the most elaborate and systematic conceptual framework [18], and is frequently referenced in other studies on childhood mortality [19]. As a result, our study used the Moseley [15] conceptual framework as the basis for identifying important risk factors for neonatal mortality in Nigeria.

The outcome variable for this study was neonatal death as reported by the mothers who participated in the survey, and it was defined as the death of a neonate between birth and 1 month of life. This takes a binary form, such that neonatal death will be regarded as a success (1 = if death occurs in the specified age period) or failure (0 = if the newborn is alive in the specified age period). The outcome variable was examined against all confounding variables, and these variables were classified into three distinct groups: community level factors, household factors, and individual level factors consisting of socioeconomic factors (Table 1). These variables were used in the study to identify risk factors associated with neonatal mortality. Based on the adapted conceptual framework, all of the confounding variables influencing neonatal mortality along with their categorisations are shown in Table 1.

There were two community level factors used, residence type and geopolitical zone, while the wealth index variable measured the economic status of the household. The wealth index variable was constructed using household facilities and assets, which were weighted, using a principal components analysis [20]. The range of assets considered were a television, radio, and fridge, and ownership of a car, bicycle, and motorcycle. Household facilities were also included, such as the source of drinking water, type of toilet, electricity, and type of building materials used in the place of dwelling. Among the individual factors, there were 14 variables of maternal and child characteristics (Table 1).

In this analysis, two perinatal healthcare variables, antenatal care and postnatal care, were not included because nearly one third of the information was missing. Additionally, we did not include birth weight of neonates because almost half of the neonates were not weighed at the time of birth. However, perceived newborn size at birth by mothers (small or very small, and average or large) was used instead of birth weight because a previous study showed that there is a close relationship between mean birth weight and perceived newborn size by the mother [21].

Table 1 Definition and categorisation of potential variables used in identifying risk factors associated with neonatal mortality

POTENTIAL VARIABLES	CATEGORISATION
Community level factors	
Residence	Type of the residence (1 = urban; 2 = rural)
Geopolitical zone	Zone (1 = North Central; 2 = North East; 3 = North West; 4 = South East; 5 = South West; 6 = South South)
Household factor	
Wealth index	Wealth (1 = Poor; 2 = Middle; 3 = Rich)
Individual level factors	
Maternal religion	Maternal religion (1 = traditionalist or other; 2 = Islam; 3 = catholic or other Christian)
Maternal working status	Maternal working status (1 = not working; 2 = working)
Maternal BMI	Maternal BMI (1 = BMI >18.5; 2 = BMI ≤18.5)
Maternal age at first child	Age at first birth (1 = < 20; 2 = 20–29; 3 = 30-39; 4 = 40-49)
Maternal age	Mother's age (1 < 20; 2 = 20-29; 3 = 30–39; 4 = 40–49)
Maternal literacy level	Literacy level (1 = Able to read parts of & whole sentence; 2 = Cannot read at all)
Paternal education	Education status (1 = No education; 2 = Primary; 3 = Secondary or higher)
Maternal education	Education status (1 = No education; 2 = Primary; 3 = Secondary or higher)
Sex	Sex of the neonate (1 = Female; 2 = Male)
Birth order and birth interval	Birth order and birth interval of neonate (1 = Second or third child, interval > 2 years; 2 = First child; 3 = Second or third child, interval ≤ 2 years; 4 = Fourth or higher child, interval > 2 years; 5 = Fourth or higher child, interval ≤2 years)
Birth place	Place of delivery of the neonate (1 = Home; 2 = Health facility)
Mother's perceived baby size	Maternal assessment of the neonate size at birth (1 = Average or Larger; 2 = Small or very small)
Antenatal care	Antenatal care received by mother's (1 = Yes; 2 = No)
Mode of delivery	Mode of delivery (1 = non-caesarean; 2 = caesarean section)
Delivery assistance	Birth attendant during delivery (1 = Health professional; 2 = non-Health professional)
Desire for pregnancy	Mother's desire for baby (1 = Wanted then; 2 = Wanted later; 3 = Wanted no more)
Postnatal care	Postnatal care of mother's after birth (1 = Yes; 2 = No)

Statistical analysis

The NMR was calculated by using a similar method described by Rutstien and Rojas [22]. The crude hazard ratios (HRs) for factors associated with neonatal death were determined by univariate analyses, which were performed using a Cox proportional hazards regression model. In addition, multivariable analysis was used to examine the association between the potential independent variables and the study outcome. Analyses were performed using STATA/MP version 12.0 (StataCorp, College Station, TX,

Table 2 Neonatal mortality rates (NMR) with 95% confidence interval (CI)

Covariates	Total live births	Neonatal deaths	NMR [95% CI]
Community level factors			
Residence type			
Urban	8070	253	31.3 (29.2- 33.4)
Rural	19077	743	38.9 (36.6- 41.3)
Geopolitical zone			
North Central	3693	122	32.6 (30.6- 34.9)
North East	4452	176	39.6 (37.2- 42.0)
North West	8529	310	35.7 (33.5- 37.9)
South East	2611	107	41.5 (39.1- 43.9)
South West	3516	150	43.4 (40.9- 45.9)
South South	4345	132	30.4 (28.3- 32.5)
Household wealth index			
Poor	12542	499	39.3 (36.9- 41.7)
Middle	10013	355	35.6 (33.4- 37.8)
Rich	4592	142	31.6 (29.5- 33.5)
Individual related factors			
Mother's religion			
Traditionalist and other	464	19	42.2 (39.8- 44.6)
Islam	15018	520	34.2 (32.0- 36.4)
Catholic and other Christian	11517	451	39.7 (37.3- 42.1)
Missing	148	5	
Mother's age at first birth			
Less than 20 years	15755	598	37.6 (35.3- 39.9)
20 - 29 years	10702	363	34.2 (32.0- 36.4)
30 - 49 years*	690	35	52.8 (50.1- 55.3)
Mother's age			
< 20	1471	92	65.0 (62.0- 68.0)
20-29	13096	451	34.5 (32.3- 36.7)
30-39	9797	327	33.1 (30.9- 35.3)
40-49	2783	126	44.7 (42.2- 47.2)
Mother's literacy level			
Cannot read at all	15391	616	38.1 (35.8- 40.4)
Able to read	10634	370	34.1 (31.8- 36.2)
Mother's education			
No education	12685	470	36.6 (34.3- 38.9)
Primary	6255	246	39.5 (37.1- 41.9)
Secondary or higher	8207	280	34.6 (32.4- 36.8)

Table 2 Neonatal mortality rates (NMR) with 95% confidence interval (CI) *(Continued)*

Covariates	Total live births	Neonatal deaths	NMR [95% CI]
Mother's desire for pregnancy			
Wanted then	23880	824	34.7 (32.5-36.9)
Wanted later	1669	59	31.2 (31.0- 35.4)
Wanted no more	1150	43	38.3 (36.0- 40.6)
missing	448	71	
Mother's body mass index (BMI)			
BMI > 18.5	23508	868	37.0 (34.7- 39.3)
BMI ≤ 18.5	3062	110	35.0 (32.8- 37.2)
Missing	577	18	
Mother's working status			
Not working	9389	332	35.8 (33.5- 38.0)
Working	17121	638	37.1 (34.8- 39.4)
Missing	64	2	
Sex of child			
Female	13342	424	31.7 (29.6- 33.8)
Male	13806	572	41.4 (39.0- 43.8)
Mother's perceived baby size			
Small or very small	3743	210	57.0 (54.2- 59.8)
Average or larger	22778	685	30.0 (27.9- 32.1)
Missing	626	102	
Birth order and birth interval			
First child	5331	249	47.6 (45.0- 50.2)
2 or 3 child, interval > 2	6444	160	24.3 (22.5- 26.2)
2 or 3 child, interval ≤ 2	2652	135	50.2 (47.5- 52.9)
4 or more child, interval > 2	9369	258	27.3 (25.3- 29.3)
4 or more child, interval ≤ 2	3352	194	57.6 (54.7- 60.5)
Mode of delivery			
Non-caesarean	26660	951	35.8 (33.5- 38.1)
Caesarean section	452	40	89.9 (86.3- 93.5)
Missing	35	5	
Baby weight at birth			
Less than 2500 grammes	349	16	46.6 (44.0- 49.2)
2500 - 3500 grammes	3110	45	14.7 (13.3- 16.1)
Greater than 3500 grammes	1458	15	9.2 (8.1- 10.3)
Not weighed	18923	767	40.7 (38.3- 43.1)
Missing	3307	153	

Table 2 Neonatal mortality rates (NMR) with 95% confidence interval (CI) *(Continued)*

Delivery assistance			
Health professional	10331	381	37.0 (34.7- 39.3)
non-Health professional	16440	555	33.8 (31.6- 36.0)
Missing	377	61	
Postnatal check-up			
0 - 2 days	4372	112	26.1 (24.2- 28.0)
3 - 41 days	3001	78	26.0 (24.1- 27.9)
Don't know/missing	19774	806	
Birth place of child			
Health facility	9917	361	36.8 (34.5- 39.1)
Home	16962	579	34.1 (31.9- 36.3)
Missing	268	56	
Antenatal care			
Yes	9421	232	24.6 (22.7- 26.5)
No	6316	169	26.5 (24.6- 28.4)
Missing	11411	595	

*Interval for 30–39 years and 40–49 years were merged.
NMR not calculated for missing values.

USA). Cox proportional hazards models were fitted using STATA survey commands to adjust for the cluster sampling design, weights, and the calculation of standard errors.

The multivariable analysis models conducted used a stepwise backwards elimination procedure to identify independent variables that were significantly associated with the study outcome. To avoid any statistical bias, we double checked our backward elimination method by using the following procedures: (1) we entered only potential risk factors with a p value < 0.20 obtained in the univariable analysis for backward elimination process, (2) we tested the backward elimination by including all of the variables (all potential risk factors), and (3) we tested and reported any collinearity in the final model. HRs and 95% confidence intervals (CIs) were calculated to assess the adjusted risk factors that affect study outcome, and those with p < 0.05 were retained in the final model.

Results

Table 2 shows the number of live births, the number of neonatal deaths and NMR by community, the household wealth index, and individual level factors. A weighted total of 27,147 singleton live births of children aged younger than 5 years occurred within the 5-year period preceding the 2008 NDHS, of which the total neonatal deaths over this period was 996 (Table 2). Neonates born to mothers residing in rural residences had a higher NMR than those living in urban residences (NMR: 38.9 vs 31.3). The NMR for neonates born to mothers in poor households was higher than that in mothers in middle-class households (NMR: 39.3 vs 35.6). Neonates whose mothers perceived them as small or a smaller size, had a greater NMR than those of average or larger size (NMR: 57.0 vs 30.0). The majority of live-born neonates were not weighed at birth, and more than half of the neonatal deaths occurred at home.

Neonates delivered by caesarean section had a higher NMR than those born vaginally (NMR: 89.9 vs 35.8). The NMR for male neonates was higher than that for female neonates (NMR: 41.4 vs 31.7).

Multivariable analysis

Newborns born to mothers residing in rural areas had a higher risk of neonatal mortality than those who lived in urban areas (HR = 1.26, 95% CI: 1.03–1.55, p = 0.026). Compared with neonates born to mothers aged between 30 and 39 years, neonates born to younger mothers (<20 years) (HR = 4.07, 95% CI: 2.83–5.86, p < 0.001) reported a significantly higher risk of neonatal deaths. When the place of residence was replaced by household wealth index in the final model, neonates born to mothers in poor households had a high risk of neonatal death, although this was not statistically significant (HR = 1.24, 95% CI: 0.93–1.65).

Male neonates were more likely (HR = 1.30, 95% CI: 1.12–1.53, p = 0.001) to die than female neonates in the first month of life. Neonates delivered by caesarean section had a significantly higher risk of neonatal mortality (HR = 2.80, 95% CI: 1.84–4.25, p <0.001) compared with non-caesarean delivery. Neonates whose birth size were perceived by their mothers as small or smaller were also more likely to die than those of average or larger-sized neonates (HR = 2.10, 95% CI: 1.77–2.50, p < 0.001).

As shown in Table 3, there was a significantly higher risk of neonatal death for fourth or higher birth order neonates with a short birth interval ≤ 2 years (HR = 2.19, 95% CI: 1.68–2.84, p < 0.001), second or third birth order neonates with a short birth interval ≤2 years (HR = 1.75, 95% CI: 1.31–2.34, p < 0.001), and fourth or higher birth order with a longer birth interval > 2 years (HR = 1.36, 95% CI: 1.05–1.78, p = 0.022) compared with second or third birth order neonates with a longer birth interval > 2 years.

Discussion

The overall aim of this study was to identify risk factors associated with neonatal mortality in Nigeria using a nationally representative sample. This study showed several factors that were significantly associated with neonatal mortality after adjusting for confounding factors, and each of these factors are discussed below.

Table 3 Adjusted and unadjusted hazard ratios (95% confidence interval [CI]) for variables associated with neonatal mortality

Variables	Unadjusted			Adjusted^		
	HR	[95% CI]	*P*	HR	[95% CI]	*P*
Community level factors						
Residence type						
Urban	1.00			1.00		
Rural	1.36	(1.11-1.66)	0.003	1.26	(1.03-1.55)	0.026
Geopolitical zone						
North Central	1.00					
North East	1.23	(0.98-1.55)	0.072			
North West	1.07	(0.85-1.37)	0.540			
South East	1.12	(0.79-1.59)	0.536			
South West	1.28	(0.97-1.68)	0.079			
South South	0.82	(0.59-1.14)	0.235			
Household wealth index						
Poor	1.45	(1.11-1.89)	0.006			
Middle	1.20	(0.91-1.59)	0.189			
Rich	1.00					
Individual related factors						
Mother's religion						
Traditionalist and other	1.00					
Islam	0.80	(0.48-1.31)	0.370			
Catholic and other Christian	0.88	(0.53-1.45)	0.605			
Mother's age at first birth						
Less than 20 years	1.00					
20 - 29 years	0.88	(0.75-1.04)	0.127			
30 - 49 years*	1.34	(0.85-2.13)	0.209			
Mother's age						
< 20	4.02	(2.99-5.40)	< 0.001	4.07	(2.83-5.86)	< 0.001
20-29	1.12	(0.93-1.33)	0.226	1.22	(1.00-1.49)	0.056
30-39	1.00			1.00		
40-49	1.34	(1.04-1.71)	0.023	1.27	(0.99-1.63)	0.063
Mother's education						
No education	1.17	(0.96-1.43)	0.138			
Primary	1.20	(0.95-1.51)	0.168			
Secondary or higher	1.00					
Mother's literacy level						
Cannot read at all	1.23	(1.03-1.46)	0.020			
Able to read	1.00					
Mother's desire for pregnancy						
Wanted then	1.00					
Wanted later	1.07	(0.78-1.48)	0.670			
Wanted no more	1.17	(0.78-1.76)	0.442			

Table 3 Adjusted and unadjusted hazard ratios (95% confidence interval [CI]) for variables associated with neonatal mortality *(Continued)*

Individual related factors						
Mother's body mass index						
BMI > 18.5	1.00					
BMI ≥ 18.5	1.08	(0.84-1.38)	0.566			
Missing						
Mother's working status						
Not working	1.00					
Working	0.97	(0.83-1.15)	0.749			
Missing						
Sex of child						
Female	1.00			1.00		
Male	1.29	(1.11-1.51)	0.001	1.30	(1.12-1.53)	0.001
Mother's perceived baby size						
Small or very small	2.17	(1.82-2.58)	< 0.001	2.10	(1.77-2.50)	< 0.001
Average or larger	1.00			1.00		
Birth order and birth interval						
First child	1.77	(1.38-2.25)	< 0.001	1.32	(1.01-1.72)	0.040
2 or 3 child, interval > 2	1.00			1.00		
2 or 3 child, interval ≤ 2	1.78	(1.34-2.38)	< 0.001	1.75	(1.31-2.34)	< 0.001
4 or more child, interval > 2	1.28	(1.01-1.62)	0.039	1.36	(1.05-1.78)	0.022
4 or more child, interval ≤ 2	2.10	(1.64-2.70)	< 0.001	2.19	(1.68-2.84)	< 0.001
Mode of delivery						
Non-caesarean	1.00			1.00		
Caesarean section‴	2.33	(1.54-3.51)	< 0.001	2.80	(1.84-4.25)	< 0.001
Delivery assistance						
Health professional	1.00					
non-Health professional	1.99	(0.84-1.17)	0.924			
Birth place of child						
Health facility	1.00					
Home	1.00	(0.84-1.17)	0.955			

‴Caesarean section is a combination of both elective and emergency caesarean.
*Interval for 30–39 years and 40–49 years were merged.
^2,465 missing information were not included in the analysis.
HR, hazard ratio; P-values based on Cox regression.

We found that the NMR for singleton live-born infants between 2003 and 2008 was 36.7 (95% CI: 34.4–39.0). However, a preliminary report from the 2013 NDHS indicated that the NMR slightly fell by approximately 8% from 40 deaths per 1000 live births in 2008 to 37 in 2013 [23]. Despite this decline, Nigeria still has a long way to go in achieving the Millennium Development Goal 4 target for the under-5 years of age mortality rate.

Our study showed that male neonates had a significantly higher risk of dying during the neonatal period compared with female neonates. This finding is consistent with a cross-sectional study conducted in Indonesia in 2008, which indicated that male neonates were more likely to die than female neonates [19]. Additionally, a cross-sectional study performed in Bangladesh in 2009 reported a lower relative risk for female neonates compared with male neonates [24]. An increased risk of dying in the first month of life among male neonates may be attributed to high vulnerability to infectious disease [25]. Another possible reason for the low rate of neonatal deaths among girls may be because of the development of early fetal lung maturity in the first week of life [26], resulting in a lower incidence of respiratory diseases in female neonates compared with male neonates.

Globally, it is estimated that approximately 23% of newborn deaths are attributed to respiratory problems [27].

In our study, mothers who perceived the size of their newborns to be small or very small had a 2.26 times greater risk of dying in the first month of life than those mothers who perceived their neonates to be of average or larger size. Similarly, findings from a cross-sectional study conducted in five Asian countries (India, Indonesia, Nepal, Bangladesh, and the Philippines) in 2008 also showed that smaller than average neonates had an increased risk of neonatal deaths than average or larger sized neonates in four of the five countries with data on perceived newborn size [28]. Even though our finding on perceived size of newborns were significant, we need to exercise caution in interpreting this result because the rationale mothers used in estimating the size of their neonates is unclear. However, this measure is not an unreasonable proxy for birth weight because a previous study showed a correlation between perception of birth weight and actual birth weight [21].

Our study showed that neonates delivered by caesarean section had a higher relative risk of neonatal mortality compared with vaginal deliveries. This result contradicts previous reports, which indicated a statistically insignificant relationship between the mode of delivery and neonatal mortality [29]. A similar study conducted in Swaziland reported a higher risk of death for neonates delivered by caesarean section than vaginal delivery, but this was not significant [30]. The significantly high risk of caesarean section observed in our study may be attributed to negative perceptions, such as misconception, fear, and aversion to caesarean section among mothers in Nigeria [31,32]. This could explain why pregnant mothers are presented to health facilities after experiencing labor at home or elsewhere, with life-threatening complications for emergency caesarean section [33]. This is also supported by a recent study on caesarean section and perinatal mortality in South Western, Nigeria, which found that nearly 84% of early neonatal deaths occurred in pregnant mothers who delivered their newborns by emergency caesarean section [34].

The current study observed that neonates born to mothers aged younger than 20 years had a significantly higher risk of mortality than those born to mothers aged 20–29 years, 30–39 years, and 40–49 years. This finding is similar to that reported in previous studies [35,36]. However, our analysis is not consistent with cross-sectional studies conducted in Swaziland and Tanzania, which found no significant relationship between maternal age and neonatal mortality [30,37]. This significantly higher rate of death in Nigeria could be related to inadequate use of maternal health services, physical immaturity, poor nutritional status, inexperience regarding child rearing among younger mothers, and poor maternal health outcomes, such as pregnancy complications. These factors are more common in younger mothers, and are all possible factors that could lead to higher adverse effects of neonatal and child health outcome in young motherhood [35].

We found that children of birth order (2 through 4 or higher) born with a shorter birth interval (≤2 years) were at higher risk of dying than those with a longer birth interval (>2 years). This finding is similar to a cross-sectional study carried out in India, which showed that neonates of fourth or higher birth order with a shorter birth interval of < 2 years have an increased risk of death compared with those of second and third birth order with a longer birth interval of > 2 years [38]. Maternal depletion syndrome could be attributed to this finding. Short-interval births could have adverse effects on the mother's biological well-being and there could be economic resource competition between infants, especially in poor households, as well as inadequate care given to infants compared with high-ranked infants [39].

The current study showed that neonates born to mothers residing in rural areas had a higher risk of neonatal mortality compared with those living in urban areas. This finding is consistent with previous studies [40,41], which attributed this finding to limited access to health facilities and maternal healthcare services, such as delivery assisted by a healthcare professional, and prenatal and postnatal care. This disproportionally hinders rural dwellers from receiving adequate healthcare services, resulting in a high probability of neonatal death. In Nigeria, as in many developing countries, the majority of well-equipped hospitals and health centers are typically located in urban areas. However, neonatal jaundice and sepsis, as well as gestational age, which were previously found to be significantly associated with neonatal morality in most hospital-based studies [42,43], were not examined in our study. These variables could potentially be determinants of neonatal mortality in Nigeria.

The strengths and weaknesses of this study need to be considered when drawing specific inferences. This study was a nationally representative survey, with a stratified two-stage cluster sampling design, which achieved a 98.3% response rate. Additionally, recall errors arising from dates of birth and death given by women interviewed in the survey were minimized by restricting our analyses to births within the 5-year period preceding the survey. Third, the proportion of missing data was relatively small, such that it may not have influenced findings in our study. Despite these strengths, a number of weaknesses were also present in the study and they are as follows. (1) Only surviving women were interviewed, which may have led to under-reporting of the number of newborn deaths because of the association of neonatal death with maternal death [22]. (2) Gestational age, which may be an important risk factor for neonatal mortality, was not examined in this study. (3) Other factors previously found to be associated with neonatal mortality, such as antenatal care, postnatal care, and birth weight at birth, were lacking in information in the 2008 NDHS. (4) The Demographic and Health Surveys are the largest source of national data, but they are expensive and time consuming, and in Nigeria, this survey is usually conducted once in every 5 years. (5) Causal effects could not be measured because the study was based on a retrospective cross-sectional study.

A community-based interventional study on reducing neonatal death in Nigeria should be performed to focus on using verbal autopsy and birth weight. To reduce the recall period of using these instruments, a verbal autopsy should be undertaken before the culturally prescribed mourning period [44]. In addition, traditional birth attendants should be provided training or refresher training on delivery, how to recognise signs of pregnancy complications, and how to measure the newborn's weight at birth because approximately 62% of mothers in Nigeria deliver their newborns at home [7].

Conclusions

Our analysis of factors associated with neonatal mortality in Nigeria revealed that living in rural areas, child bearing at a younger age, birth order and birth interval, sex of the newborn (being male), caesarean delivery, and mothers who perceive their newborns as smaller than average at birth significantly increased the risk of neonatal death. Our findings indicate the need to implement community based newborn care interventions particularly, educating community health workers and traditional birth attendants about safe delivery practice, the benefits of Kangaroo mother care method on low birth weight newborns, child spacing and promote delay of first pregnancy will contribute to the improvement of neonatal mortality statistics in Nigeria.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

OKE and KEA were involved in the conception and design of this study. OKE carried out the analysis and drafted the manuscript. KEA, MJD, JH, and ANP gave advice on interpretation and revised and edited the manuscript. All authors read and approved the final manuscript.

Acknowledgements

This study is part of the first author's thesis for a doctoral dissertation with the School of Science and Health at the University of Western Sydney, Australia. We are grateful to Measure DHS, ORC Macro, Calverton, MD, USA for providing the 2008 NDHS data for this analysis.

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Received: 9 July 2013 Accepted: 19 May 2014
Published: 29 May 2014

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doi:10.1186/1471-2458-14-521
Cite this article as: Ezeh *et al.*: **Determinants of neonatal mortality in Nigeria: evidence from the 2008 demographic and health survey.** *BMC Public Health* 2014 **14**:521.

CHAPTER FOUR

Risk factors for post-neonatal, infant, child and under-5 mortality in Nigeria: A pooled cross-sectional analysis

Ezeh OK, Agho KE, Dibley MJ, Hall JJ, Page AN.

BMJ Open 2015; 5:e006779

(publication 2)

BMJ Open

Risk factors for postneonatal, infant, child and under-5 mortality in Nigeria: a pooled cross-sectional analysis

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To cite: Ezeh OK, Agho KE, Dibley MJ, *et al*. Risk factors for postneonatal, infant, child and under-5 mortality in Nigeria: a pooled cross-sectional analysis. *BMJ Open* 2015;**5**:e006779. doi:10.1136/bmjopen-2014-006779

▶ Prepublication history for this paper is available online. To view these files please visit the journal online (http://dx.doi.org/10.1136/bmjopen-2014-006779).

Received 29 September 2014
Revised 3 March 2015
Accepted 4 March 2015

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ABSTRACT

Objectives: To identify common factors associated with post-neonatal, infant, child and under-5 mortality in Nigeria.

Design, setting and participants: A cross-sectional data of three Nigeria Demographic and Health Surveys (NDHS) for the years 2003, 2008 and 2013 were used. A multistage, stratified, cluster random sampling method was used to gather information on 63 844 singleton live-born infants of the most recent birth of a mother within a 5-year period before each survey was examined using cox regression models.

Main outcome measures: Postneonatal mortality (death between 1 and 11 months), infant mortality (death between birth and 11 months), child mortality (death between 12 and 59 months) and under-5 mortality (death between birth and 59 months).

Results: Multivariable analyses indicated that children born to mothers with no formal education was significantly associated with mortality across all four age ranges (adjusted HR=1.30, 95% CI 1.01 to 1.66 for postneonatal; HR=1.38, 95% CI 1.11 to 1.84 for infant; HR=2.13, 95% CI 1.56 to 2.89 for child; HR=1.19, 95% CI 1.02 to 1.41 for under-5). Other significant factors included living in rural areas (HR=1.48, 95% CI 1.16 to 1.89 for postneonatal; HR=1.23, 95% CI 1.03 to 1.47 for infant; HR=1.52, 95% CI 1.16 to 1.99 for child; HR=1.29, 95% CI 1.11 to 1.50 for under-5), and poor households (HR=2.47, 95% CI 1.76 to 3.47 for postneonatal; HR=1.40, 95% CI 1.10 to 1.78 for infant; HR=1.72, 95% CI 1.19 to 2.49 for child; HR=1.43, 95% CI 1.17 to 1.76 for under-5).

Conclusions: This study found that no formal education, poor households and living in rural areas increased the risk of postneonatal, infant, child and under-5 mortality among Nigerian children. Community-based interventions for reducing under-5 deaths are needed and should target children born to mothers of low socioeconomic status.

Strengths and limitations of this study

- This study is based on nationally representative household surveys that reflect every locality in Nigeria.
- Data were pooled together to create large sample sizes of deaths reported within 5 years preceding the surveys.
- Analyses were restricted to births within 5 years of each of the surveys to reduce recall bias by mothers interviewed and to minimise bias that may have arisen from changes in household characteristics.
- Newborns' dates of birth and death given by mothers may have been misreported—particularly those that had occurred a few months or years before the survey.
- Causes of death and medical conditions of children were unknown at the time of survey.

INTRODUCTION

Globally, the mortality rate of children aged under 5 years has reduced from 90 deaths per 1000 live births in 1990 to 48 deaths in 2012; but the rate still remains very high in sub-Saharan Africa (from 177 to 98 deaths). In 2012, approximately half the world's estimated 6.6 million deaths in children aged less than 5 years occurred in sub-Saharan Africa, and Nigeria accounted for approximately 13% of these deaths.[1] The majority of these deaths are caused by communicable diseases such as malaria, diarrhoea, measles, cholera and respiratory infections. While these deaths are both preventable and treatable, the lack of effective health intervention policies has resulted in a high under-5 child mortality rate (U5MR) in the region.

Childhood mortality remains a major public health challenge in Nigeria despite the substantial global decline in childhood deaths. Currently, the country has the highest reported number of under-5 deaths in Africa and ranks as having the second highest number (after India) worldwide. Nearly one million children aged under 5 years die in Nigeria annually and more than 60% of these deaths occur between 1 and 59 months of life.[1] Evidence from the

Nigeria Demographic and Health Surveys (NDHS) showed that over a 10-year period (from 2003 to 2013), infant mortality rates (IMR) fell by 31% (from 100 to 69 deaths per 1000 births); postneonatal mortality rates (PMR) dropped by approximately 40% (from 52 to 31 deaths); and child mortality rates (CMR) declined by approximately 43% (from 112 to 64 deaths). Similarly, U5MR decreased by approximately 36% (from 201 to 128 deaths).[2 3] The current U5MR of 128 deaths per 1000 live births reported by the NDHS implies that approximately one in every eight children aged under 5 years in Nigeria dies before having a fifth birthday—approximately 21 times the average rate for developed countries (6 deaths per 1000 live births).[1] With this marginal reduction in childhood deaths, it is more likely that Nigeria will not achieve the Millennium Development Goal target of 76 deaths per 1000 live births by 2015.

Previous studies on childhood mortality in Nigeria have included multiple births in their analyses by primarily using one single data set to examine factors associated with under-5 child mortality.[4–10] However, these studies have limited generalisability, in part, because of the limited number of deaths recorded in any single NDHS. Other studies have also found that including multiple births in the analysis of factors associated with under-5 child mortality may produce inaccurate mortality risk estimates compared with using only singleton births in the analysis.[11–18]

Inadequate health facilities, insufficient skilled health professionals and lack of modern medical equipment have undermined the Nigerian healthcare system, particularly in rural areas.[19] As a result, the Nigerian Government launched and implemented a National Health Policy (NHP) and Ward Health System (WHS) whose core targets include reduction of under-5 mortality rate.[3] Despite all these initiatives, deaths of children <5 years of age still remain high in Nigeria. Hence, this present study aimed to identify common factors that affect childhood mortality in Nigeria in different age ranges of the first 59 months of life (infant, 0–11 months; postneonatal, 1–11 months; child, 12–59 months; and under-5, 0–59 months). Using pooled data may provide an important framework for public health researchers and policymakers in reviewing and designing new child survival intervention strategies.[20]

METHODS

The data sets used in this study were the 2003, 2008 and 2013 NDHS surveys, pooled together to maximise the sample sizes of deaths. Information on births and deaths of children aged younger than 5 years was obtained from 79 953 eligible women, aged 15–49 years, who participated in the surveys.[2 3 21]

From these women, data on a (weighted) total of 66 154 live-born infants were obtained, including singleton and multiple births of the mothers' most recent birth within 5 years prior to the survey date. The number of live births included was 6219 from the 2003 survey; 28 107 from the 2008 survey and 31 828 from the 2013 survey. A total of 2310 multiple births were excluded in the final analyses. The analyses were restricted to live births and most recent births during the 5 years preceding the surveys to limit mothers' potential for differential recall of events, as deliveries had occurred at different points in time prior to the interview. Detailed sampling methods used in gathering the data have been reported elsewhere.[2 3 21]

Study outcome variables

The main outcome variables in the study were postneonatal mortality (death between 1 and 11 months), infant mortality (death between birth and 11 months), child mortality (death between 12 and 59 months) and total under-5 mortality (death between birth and 59 months). Each death case was coded as 1, and each non-death (alive) case was coded as 0.

Study factors

Study factors for this study were based on the Mosley and Chen framework of factors influencing child survival in developing countries;[22] other previous studies[23–29] on childhood mortality (particularly in the sub-Saharan Africa region) also played a role in the assessment of potential study variables. These variables were adapted to the data available in the merged data set and comprised geographic location of place of residence (categorised as urban-rural residence), a household measure of income and a range of individual-level factors.

Individual-level factors consisted of maternal characteristics (religion, education, literacy level, age, body mass index, occupation and desire for pregnancy); child characteristics (sex, birth place, size, mode of delivery, delivery assistance, and a combination of birth order and birth interval) and paternal education.

The only household-level factor used was the wealth index variable, which measured the economic status of the households interviewed in the survey. A principal components analysis was used in constructing the wealth index.[30] Weights were assigned to the household facilities and assets of respondents. The facilities and assets included were those that were consistent across the pooled NDHS data: television, radio, refrigerator, car, bicycle, motorcycle, source of drinking water, type of toilet facility, electricity and type of building materials used in the place of dwelling. In the NDHS data set, the household wealth index was categorised into five quintiles: poorest, poorer, middle, richer and richest. However, in the analysis, the household wealth index was recategorised into three groups: the bottom 40% of households were referred to as poor households, the next 40% as middle households and the top 20% as rich households.

Statistical analysis

First, an estimation of mortality rates for singleton live births in each of the measured age ranges was conducted according to the year of survey, using a method similar to that described by Rutstein and Rojas.[31] This step was followed by a multivariable analysis that independently assessed the effect of each factor for each of the study outcome variables after adjusting for potential confounding variables; Cox proportional hazard regression models were used in this assessment.

The multivariable analysis model for each of the study outcomes performed used a stepwise backwards elimination process to identify independent variables that were significantly associated with the study outcomes. To reduce any statistical error in our analyses, we double checked our backward elimination method by using the following procedures: (1) we entered only potential risk factors with a p value <0.20 obtained in the univariable analysis for the backward elimination process, (2) we tested the backward elimination by including all of the variables (all potential confounding factors) and (3) we tested and reported any collinearity in the final model.

The HRs and their 95% CIs obtained from the adjusted Cox proportional models were used to measure the effect of predictor variables with the study outcomes (infant, postneonatal, child and under-5 deaths). All statistical analyses were conducted using 'SVY' commands in STATA/MP V.12.0 (StataCorp, College Station, Texas, USA) to adjust for the cluster sampling survey design, weights and SEs.

RESULTS

A weighted total of 6285 deaths of children aged under 5 years occurred within the 5-year period preceding the survey interview dates: 1859 deaths between 1 and 11 months (postneonatal mortality); 4113 deaths occurred between birth and 11 months (infant mortality); and 2172 deaths between 12 and 59 months (child mortality). The distribution of 6285 children who died before their fifth birthday according to community-level, individual-level and household-level characteristics are presented in table 1. In the pooled NDHS data, more than 74% of the postneonatal, infant, child and under-5 deaths occurred in the rural areas. Delivery assisted by non-health professionals had the highest per cent of deaths compared with those assisted by health professionals (56.4% postneonatal, 51.2% infant, 65.6% child and 56.1% under-5).

Between 2003 and 2013, IMR for singleton live-born infants decreased by approximately 30%, from 84 deaths per 1000 live births in 2003 to 59 deaths in 2013; PMR fell by approximately 40%, from 43 to 26 deaths; CMR declined by 44%, from 48 to 27 deaths; and U5MR dropped by 36%, from 132 to 85 deaths (figure 1).

Risk factors for postneonatal mortality (1–11 months)

Postneonates born to younger mothers (age <20 years) reported a significantly higher risk of postneonatal deaths (HR=3.45, CI 2.19 to 5.46) compared with those born to mothers aged between 30 and 39 years. Postneonates living in rural areas were also more likely to die (HR=1.48, CI 1.16 to 1.89) than those living in urban areas. When place of residence was replaced by household wealth index in the final model, there was a significantly higher risk of postneonatal death for those born to mothers from poor households (HR=2.47, CI 1.76 to 3.47) and middle-class households (HR=1.93, CI 1.40 to 2.67) as compared with wealthy households. Other factors that were significantly associated with postneonatal deaths included having a mother with no formal education (HR=1.30, CI 1.01 to 1.66); having a birth size that was perceived as small or smaller (HR=1.44, CI 1.14 to 1.81); and having a fourth or higher birth order with a short birth interval ≤2 years (HR=1.92, CI 1.40 to 2.64; table 2).

Risk factors for infant mortality (0–11 months)

Infants born to mothers from poor households (HR=1.40, CI 1.10 to 1.78) and middle-class households (HR=1.37, CI 1.11 to 1.69) had a higher risk of infant mortality than those born in wealthy households. Infants whose birth size was perceived as small or smaller had a 1.74 times greater risk of dying than those perceived as average or larger in size. Male infants were also more likely to die (HR=1.23, CI 1.09 to 1.39) than female infants, as were infants living in rural areas (HR=1.23, CI 1.03 to 1.47). Other significant factors that affected infant mortality included infants born to mothers <20 years old (HR=3.04, CI 2.28 to 4.05); infants of fourth or higher birth order with a birth interval ≤2 years (HR=1.94, CI 1.56 to 2.41); infants of illiterate mothers (HR=1.38, CI 1.11 to 1.84) and infants whose deliveries occurred by caesarean section (HR=1.74, CI 1.24 to 2.45; table 2).

Risk factors for child mortality (age 12–59 months)

Children aged between 12 and 59 months had a significantly higher risk of child mortality if their mothers had either no formal education (HR=2.13, CI 1.56 to 2.89) or else had only a primary education (HR=1.58, CI 1.13 to 2.20). Similar findings were observed when we replaced maternal education with paternal education in the final model; children whose fathers had no formal education were more likely to die (HR=1.73, CI 1.34 to 2.22). Children from poor households were also more likely to die (HR=1.72, CI 1.19 to 2.49), as were children whose mothers resided in rural areas (HR=1.52, CI 1.16 to 1.99; table 3).

Risk factors for under-5 mortality (age 0–59 months)

Multivariable analyses indicated significant associations with under-5 mortality in those of a fourth or higher birth order with a short birth interval ≤2 years (HR=1.89, CI 1.58 to 2.26); children of a second or third higher birth order with a short birth interval ≤2 years were also more likely to die (HR=1.49, CI 1.20 to 1.85). Additional

Table 1 Distribution of postneonatal, infant, child and under-5 mortality, reported in three demographic and health surveys in Nigeria, 2003–2013 (N=6285)

Variables	Postneonatal, n (%)	Infant, n (%)	Child, n (%)	Under-5, n (%)
Community-level factors				
Residence type				
Urban	444 (23.9)	1042 (25.3)	379 (17.4)	1421 (22.6)
Rural	1416 (76.1)	3071 (74.7)	1793 (82.6)	4864 (77.4)
Geopolitical zone				
North Central	250 (13.5)	521 (12.7)	211 (9.7)	732 (11.6)
North East	377 (20.3)	806 (19.6)	486 (22.4)	1291 (20.5)
North West	721 (38.8)	1530 (37.2)	1052 (48.5)	2583 (41.1)
South East	193 (10.4)	405 (9.9)	135 (6.2)	540 (8.6)
South West	174 (9.4)	438 (10.6)	169 (7.8)	607 (9.7)
South South	143 (7.7)	413 (10.0)	119 (5.5)	533 (8.5)
Household wealth index				
Poor	845 (45.4)	1784 (43.4)	1088 (50.1)	2872 (45.7)
Middle	760 (40.9)	1658 (40.3)	867 (39.9)	2525 (40.2)
Rich	254 (13.7)	671 (16.3)	218 (10.0)	889 (14.1)
Individual-related factors				
Mother's religion*				
Traditionalist and other	190 (10.3)	366 (9.0)	252 (11.6)	618 (9.9)
Islam	1030 (55.7)	2226 (54.4)	1410 (65.0)	3636 (58.1)
Catholic and other Christian	618 (33.4)	1472 (36.0)	495 (22.8)	1966 (31.4)
Mother's age at birth				
<20	125 (6.7)	322 (7.8)	91 (4.2)	413 (6.6)
20–29	886 (47.7)	1929 (46.9)	1023 (47.1)	2952 (47.0)
30–39	641 (34.5)	1394 (33.9)	780 (35.9)	2174 (34.6)
40–49	206 (11.1)	468 (11.4)	278 (12.8)	746 (11.9)
Mother's education				
No education	1078 (58.0)	2213 (53.8)	1435 (66.1)	3648 (58.0)
Primary	382 (20.5)	917 (22.3)	432 (19.9)	1350 (21.5)
Secondary or higher	399 (21.5)	983 (23.9)	305 (14.0)	1287 (20.5)
Mother's literacy level*				
Cannot read at all	1312 (70.6)	2755 (67.0)	1691 (77.9)	4446 (70.7)
Able to read	542 (29.1)	1330 (32.3)	465 (21.4)	1795 (28.6)
Mother's desire for pregnancy*				
Wanted then	1611 (86.6)	3541 (86.1)	1909 (87.9)	5450 (86.7)
Wanted later	112 (6.1)	234 (5.7)	107 (4.9)	341 (5.4)
Wanted no more	53 (2.9)	124 (3.02)	48 (2.2)	172 (2.7)
Mother's body mass index*				
Greater than 18.5	1621 (87.2)	3634 (88.3)	1892 (87.1)	5526 (87.9)
Less than or equal to 18.5	201 (10.8)	408 (9.9)	241 (11.1)	650 (10.3)
Mother's working status*				
Not working	632 (35.2)	1402 (35.4)	784 (37.2)	2186 (36.0)
Working	1158 (64.5)	2548 (64.3)	1320 (62.6)	3867 (63.7)
Father's education*				
No education	865 (46.5)	1762 (42.8)	1151 (53.0)	2913 (46.4)
Primary	388 (20.9)	867 (21.1)	450 (20.7)	1316 (20.9)
Secondary or higher	552 (29.7)	1360 (33.1)	509 (23.5)	1869 (29.7)
Sex of child				
Female	887 (47.7)	1838 (44.7)	1057 (48.7)	2895 (46.1)
Male	973 (52.3)	2275 (55.3)	1115 (51.3)	3390 (53.9)
Mother's perceived baby size*				
Small or very small	301 (16.2)	795 (19.3)	352 (16.2)	1148 (18.3)
Average or larger	1446 (77.8)	3006 (73.1)	1702 (78.4)	4708 (74.9)
Birth order and birth interval				
First child	347 (18.7)	947 (23.0)	370 (17.0)	1317 (21)
2 or 3 child, interval >2	337 (18.1)	699 (17.0)	398 (18.3)	1098 (17.5)
2 or 3 child, interval ≤2	229 (12.3)	497 (12.1)	218 (10.0)	715 (11.4)

Continued

Table 1 Continued

Variables	Postneonatal, n (%)	Infant, n (%)	Child, n (%)	Under-5, n (%)
4 or more child, interval >2	542 (29.1)	1114 (27.1)	700 (32.2)	1814 (28.9)
4 or more child, interval ≤2	404 (21.7)	856 (20.8)	486 (22.4)	1341 (21.3)
Mode of delivery*				
Non-caesarean	1831 (98.5)	3978 (96.7)	2149 (98.9)	6127 (97.5)
Caesarean section	17 (0.9)	103 (2.5)	13 (0.6)	115 (1.8)
Delivery assistance*				
Health professional	493 (26.5)	1307 (31.8)	411 (18.9)	1718 (27.3)
Non-Health professional	1049 (56.4)	2104 (51.2)	1424 (65.6)	3528 (56.1)
Birth place of child*				
Health facility	271 (25.3)	1239 (30.1)	386 (17.8)	1625 (25.9)
Home	1307 (70.3)	2673 (65.0)	1693 (78.0)	4367 (69.5)

N, weighted total.
*Percentages did not add up to 100% because of missing values; n (%), frequency (and proportion dead) across variables.

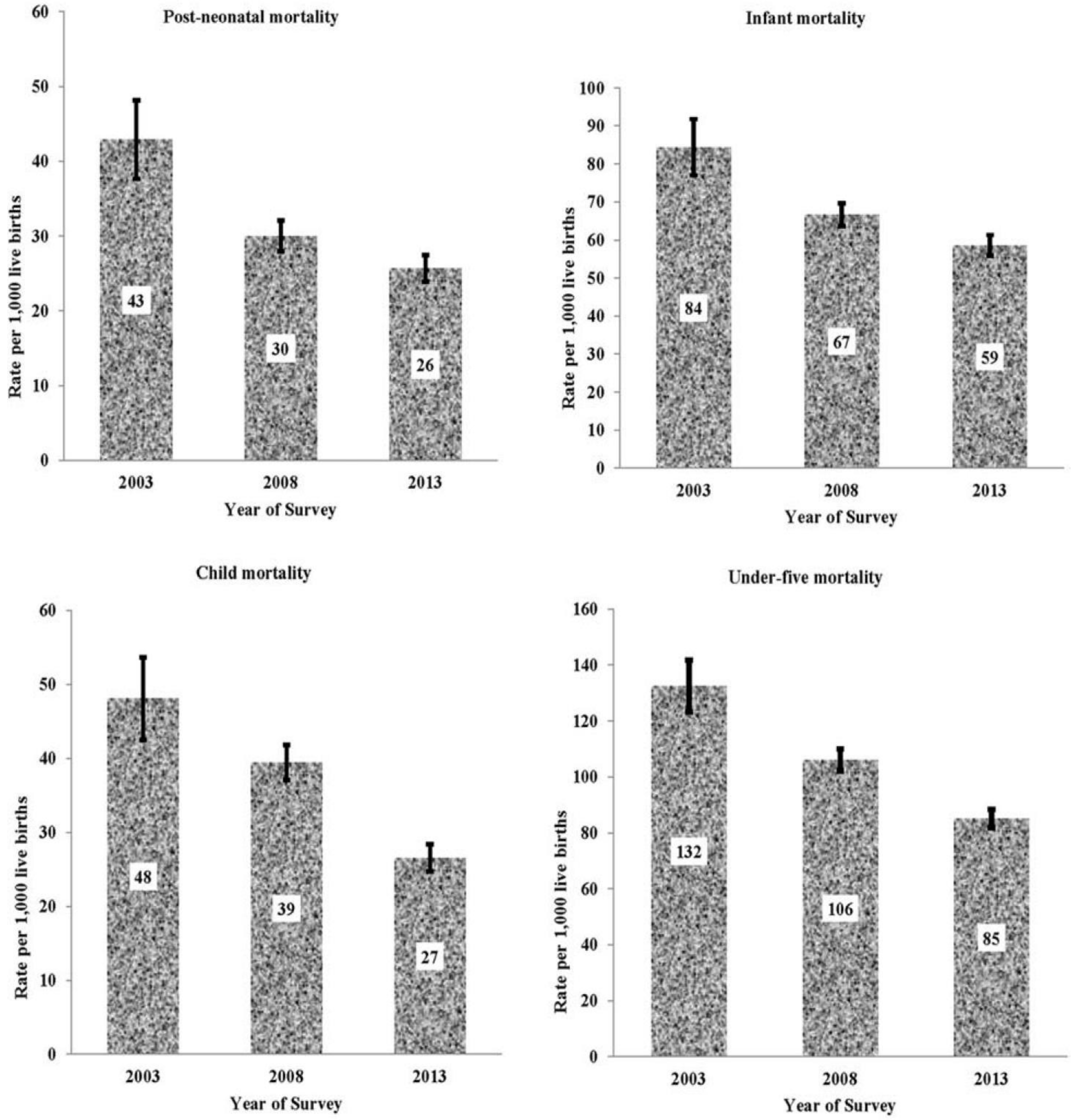

Figure 1 Postneonatal, infant, child and under-5 deaths per 1000 live births (singleton), with 95% CI by year of Nigeria Demographic and Health Surveys (NDHS), 2003–2013.

Table 2 Adjusted HR (95% CI) for variables significantly associated with postneonatal and infant mortality

	Postneonatal (1–11 months)			Infant (0–11 months)		
Variables	HR*†	(95% CI)	p Value	HR*†	(95% CI)	p Value
Year of survey						
2003	1.00			1.00		
2008	0.70	(0.53 to 0.93)	0.014	0.80	(0.64 to 0.99)	0.038
2013	0.52	(0.38 to 0.71)	<0.001	0.66	(0.53 to 0.83)	<0.001
Residence type						
Urban	1.00			1.00		
Rural	1.48	(1.16 to 1.89)	0.002	1.23	(1.03 to 1.47)	0.023
Household wealth index						
Rich				1.00		
Middle	–	–	–	1.37	(1.11 to 1.69)	0.003
Poor	–	–	–	1.40	(1.10 to 1.78)	0.006
Individual-level factors						
Mother's education						
Secondary or higher	1.00			1.00		
Primary	1.13	(0.86 to 1.48)	0.388	1.01	(0.95 to 1.39)	0.418
No education	1.30	(1.01 to 1.66)	0.044	1.38	(1.11 to 1.84)	0.039
Mother's age (years)						
30–39	1.00			1.00		
Less than 20	3.45	(2.19 to 5.46)	<0.001	3.04	(2.28 to 4.05)	<0.001
20–29	1.59	(1.23 to 2.04)	<0.001	1.31	(1.12 to 1.54)	0.001
40–49	1.08	(0.82 to 1.42)	0.578	1.09	(0.90 to 1.31)	0.385
Mother's perceived baby size						
Average or large	1.00			1.00		
Small or very small	1.44	(1.14 to 1.81)	0.002	1.74	(1.50 to 2.02)	<0.001
Birth order and birth interval						
2nd or 3rd child, interval >2 years	1.00					
1st child	1.13	(0.80 to 1.61)	0.488	1.38	(1.10 to 1.72)	0.005
2nd or 3rd child, interval ≤2 years	1.64	(1.13 to 2.37)	0.009	1.52	(1.18 to 1.97)	0.001
4th or higher child, interval >2 years	1.39	(1.05 to 1.85)	0.024	1.30	(1.06 to 1.60)	0.014
4th or higher child, interval ≤ 2 years	1.92	(1.40 to 2.64)	<0.001	1.94	(1.56 to 2.41)	<0.001
Sex of child						
Female	–	–	–	1.00		
Male	–	–	–	1.23	(1.09 to 1.39)	0.001
Mode of delivery						
Non-caesarean	–	–	–	1.00		
Caesarean section‡	–	–	–	1.74	(1.24 to 2.45)	<0.001

*Independent variables adjusted for: place of residence, wealth index, mother's (religion, education, age, body mass index, work status and desire for pregnancy), father's education, child's (sex, birth place, body size, mode of delivery, delivery assistance, birth order and birth interval).
†Multiple births were excluded from the analysis; p values based on Cox regression.
‡Caesarean section is a combination of both elective and emergency caesarean—variables that were not statistically significant.

associations included having a mother aged <20 years (HR=1.47, CI 1.27 to 1.71) and having a mother with no formal education (HR=1.19, CI 1.02 to 1.41). Children from poor households were about one and a half times as likely to die within 59 months of life as compared with those from rich households (HR=1.43, CI 1.17 to 1.76). Other significant factors that influenced a child's under-5 mortality included having a birth size that was perceived by the mother to be smaller than the average size (HR=1.47, CI 1.29 to 1.68); being of male gender (HR=1.24, CI 1.12 to 1.38); having had a caesarean section delivery (HR=1.74, CI 1.25 to 2.42) and mother residing in a rural rather than an urban area (HR=1.29, CI 1.11 to 1.50) (table 3).

DISCUSSION

We found that over the past 10 years, there has been a steady decline in the rates of infant, postneonatal, child and under-5 mortalities in Nigeria. While this trend shows that Nigeria is making progress, the pace of this progress still remains too slow to achieve the Millennium Development Goal of reducing Nigeria's child mortality to 76 deaths per 1000 live births by the year 2015.

The findings from this present study show that child mortality risk factors were consistent across each of the four age ranges and related to living in a poor household, living in a rural area and having a mother with no schooling. Infant, postneonatal and under-5 deaths were also associated with having a younger mother (<20 years),

Ezeh OK, et al. BMJ Open 2015;5:e006779. doi:10.1136/bmjopen-2014-006779

Table 3 Adjusted HR (95% CI) for variables significantly associated with child and under-5 mortality

	Child (12–59 months)			Under-5 (0–59 months)		
Variables	**HR*†**	**(95% CI)**	**p Value**	**HR*†**	**(95% CI)**	**p Value**
Year of survey						
2003	1.00			1.00		
2008	0.71	(0.54 to 0.93)	0.015	0.75	(0.63 to 0.90)	0.002
2013	0.50	(0.38 to 0.68)	<0.001	0.63	(0.52 to 0.76)	<0.001
Residence type						
Urban	1.00			1.00		
Rural	1.52	(1.16 to 1.99)	0.002	1.29	(1.11 to 1.50)	0.001
Household wealth index						
Rich	1.00			1.00		
Middle	1.63	(1.14 to 2.32)	0.007	1.42	(1.18 to 1.70)	0.001
Poor	1.72	(1.19 to 2.49)	0.004	1.43	(1.17 to 1.76)	0.001
Individual-level factors						
Mother's education						
Secondary or higher	1.00			1.00		
Primary	1.58	(1.13 to 2.20)	0.007	1.11	(0.93 to 1.32)	0.244
No education	2.13	(1.56 to 2.89)	<0.001	1.19	(1.02 to 1.41)	0.032
Mother's age (years)						
30–39				1.00		
Less than 20	–	–	–	1.44	(1.13 to 1.85)	0.004
20–29	–	–	–	1.04	(0.92 to 1.19)	0.519
40–49	–	–	–	1.47	(1.27 to 1.71)	<0.001
Mother's perceived baby size						
Average or large				1.00		
Small or very small	–	–	–	1.47	(1.29 to 1.68)	<0.001
Birth order and birth interval						
2nd or 3rd child, interval >2 years						
1st child	–	–	–	1.42	(1.17 to 1.71)	<0.001
2nd or 3rd child, interval ≤2 years	–	–	–	1.48	(1.19 to 1.84)	<0.001
4th or higher child, interval >2 years	–	–	–	1.10	(0.93 to 1.30)	0.288
4th or higher child, interval ≤2 years	–	–	–	1.89	(1.58 to 2.26)	<0.001
Sex of child						
Female	–	–	–	1.00		
Male	–	–	–	1.24	(1.12 to 1.38)	<0.001
Mode of delivery						
Non-caesarean	–	–	–	1.00		
Caesarean section‡	–	–	–	1.74	(1.25 to 2.42)	0.001

*Independent variables adjusted for: place of residence, wealth index, mother's (religion, education, age, body mass index, work status and desire for pregnancy), father's education, child's (sex, birth place, body size, mode of delivery, delivery assistance, birth order and birth interval).
†Multiple births were excluded from the analysis; p values based on Cox regression.
‡Caesarean section is a combination of both elective and emergency caesarean—variables that were not statistically significant.

being perceived as a small or very small newborn by their mothers, and having a higher birth order with a birth interval ≤2 years. Previous delivery by caesarean section and being of the male gender were significantly associated with infant and under-5 child mortality.

Our study's findings of greater mortality risk for children of all four age ranges living in poor households are similar to those reported in earlier reviews. Economic status has been reported as having a great impact on children, particularly those in the postneonatal stage.[32–34] In Nigeria, more than two-thirds of the population live below the international poverty line of $1.25 per day.[35] Such poverty limits the opportunities for most mothers to access appropriate healthcare services for their children, resulting in a high probability of infant and child deaths.

Past studies have also shown that there are high risks of mortality among children aged less than 5 years whose mothers had no schooling.[33 36–38] Our study also found that children of mothers with no schooling are at a greater risk of death across all four age groups compared with those whose mothers had a secondary or higher level of education. Educated mothers are more likely to have better knowledge about child health and modern healthcare services; thus, the mother's education is a key determinant of poor child health.[39] Improved maternal healthcare-seeking behaviours,[40 41] such as immunisation and feeding practices, may in turn positively influence child survival. Educated mothers are additionally more likely to reside in socially and economically developed areas that have well-equipped medical facilities, and good water and sanitation infrastructure.[42]

The current study found that children aged under 5 years born to mothers living in rural areas had a higher mortality risk compared with those living in urban areas. This finding is consistent with mortality study conducted in Bangladesh,[36] Burkina Faso[43] and Rwanda.[44] The significantly higher risk of death among children who live in rural areas in Nigeria, noted in the present study, may be attributed to limited access to healthcare facilities, poor educational and transport services, unavailability of a safe water supply and inadequate basic sanitation facilities. Such conditions disproportionally hinder rural dwellers from receiving adequate healthcare and social and economic services, which adversely affects child survival.[45]

Children born to mothers younger than 20 years of age were at a greater risk of infant, postneonatal and under-5 mortality. Factors contributing to this finding could include physical immaturity, pregnancy complications, poor nutritional status, inadequate use of maternal health services and inexperience in child rearing among younger mothers.[46]

The risks of infant and under-5 mortalities were significantly higher for male children than for female children; postneonatal and child mortalities did not significant differ by gender in the multivariable analyses. Biological factors[47–49] may be possible explanations to the increased risk of male deaths. The high rate of infant and under-5 deaths among male children may be due to late development of fetal lung maturity in the first week of life,[50] resulting in a higher incidence of respiratory diseases in male children compared with female children.

Findings from this study indicate that children of fourth or higher birth order born with shorter birth intervals (≤2 years) were at a greater risk of dying at infant, postneonatal and under-5 ages. This result is consistent with previous studies conducted in India and Kenya,[51–53] and may reflect that short-interval births may adversely affect maternal health and well-being, and cause economic resource competition among infants, particularly in poorer households.[51] We also found that the risk of infant, postneonatal and under-5 mortality was significantly higher for children whose mother perceived their size to be small or very small after birth compared with those who were perceived as average or larger size. This observation may be explained by the influence of biologically associated risk factors such as low birth weight, poor nutritional status and prematurity birth.[54 55]

A higher likelihood of infant and under-5 deaths was associated with mothers who delivered by caesarean section compared with vaginal deliveries. This finding is not in agreement with study conducted in Sao Paulo, Brazil, which indicated a statistically insignificant relationship between caesarean delivery and infant mortality.[56] Additionally, a cross-sectional study conducted in India in 2012 also reported an insignificant relationship between under-5 mortality and caesarean delivery.[23] The possible explanation for the high risk associated with caesarean section in our current study may be attributed to negative perceptions, such as misconception, fear and aversion to caesarean section, among mothers in Nigeria.[57 58] This could explain why pregnant mothers are presented to health facilities after experiencing labour, at home or elsewhere, with life-threatening complications for emergency caesarean section.[59]

Limitations

Some limitations that need to be considered when interpreting the results of this study include: (A) the cross-sectional design limits any conclusions about causality of the factors we have examined; (B) the antecedent health and nutritional status history of children under 5 years old, especially for those children who had died, and causes of death were lacking in the NDHS surveys, and (C) this study did not adjust for effect of small-scale geographical inequality as demonstrated by previous studies.[44 60] However, this study adjusted for intracluster correlation which is an appropriate statistical method for examining mortality from complex cluster sample survey data.[61]

CONCLUSION

This study found that under-5 mortality has declined significantly by 37% over a 10-year period after adjusting for individual-level, household-level and community-level factors. Our findings indicated that living in poor households, living in rural areas and having mothers with no schooling are common significant risk factors for mortality across all four age ranges (infant, postneonatal, child and under-5) in Nigeria. Community-based interventions that target mothers living in rural areas and mothers with low socioeconomic status are needed for improving child survival in Nigeria.

Contributors OKE and KEA were involved in the conception and design of this study. OKE conducted the literature review, carried out the analysis and drafted the manuscript. KEA, MJD, JJH and ANP provided advice on interpretation, and revised and edited the manuscript. All authors read and approved the manuscript.

Funding This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None.

Ethics approval This study was based on an analysis of existing public domain survey data sets that is freely available online with all identifier information removed. The first author communicated with MEASURE DHS/ICF International, and permission was granted to download and use the data for his doctoral dissertation by the School of Medicine at the University of Western Sydney, Australia.

Provenance and peer review Not commissioned; externally peer reviewed.

Data sharing statement No additional data are available.

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SECTION III

Effect of environmental factors on children under 5 years old in Nigeria

This section presents two manuscripts titled “The impact of water and sanitation on childhood mortality in Nigeria: evidence from demographic and health surveys, 2003–2013” *(publication 3)* and “The effect of solid fuel use on childhood mortality in Nigeria: evidence from the 2013 cross-sectional household survey” *(publication 4).*

CHAPTER FIVE

The impact of water and sanitation on childhood mortality in Nigeria: evidence from demographic and health surveys, 2003–2013

Ezeh OK, Agho KE, Dibley MJ, Hall JJ, Page AN.

Int. J. Environ. Res. Public Health 2014; 11: 9256-72

(publication 3)

Int. J. Environ. Res. Public Health **2014**, *11*, 9256-9272; doi:10.3390/ijerph110909256

OPEN ACCESS

International Journal of
Environmental Research and Public Health
ISSN 1660-4601
www.mdpi.com/journal/ijerph

Article

The Impact of Water and Sanitation on Childhood Mortality in Nigeria: Evidence from Demographic and Health Surveys, 2003–2013

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Received: 30 June 2014; in revised form: 13 August 2014 / Accepted: 29 August 2014 / Published: 5 September 2014

Abstract: In Nigeria, approximately 109 million and 66 million people lack access to sanitation facilities and water, respectively. This study aimed to determine whether children under 5 years old without access to improved water and sanitation facilities are at higher risk of death in Nigeria. Pooled 2003, 2008 and 2013 Nigeria Demographic and Health Survey data were used to examine the impact of water and sanitation on deaths of children aged 0–28 days, 1–11 months, and 12–59 months using Cox regression analysis. Survival information of 63,844 children was obtained, which included 6285 deaths of children under 5 years old; there were 2254 cases of neonatal mortality (0–28 days), 1859 cases of post-neonatal mortality (1–11 months) and 2,172 cases of child mortality (1–4 years old). Over a 10-year period, the odds of neonatal, post-neonatal and child deaths significantly reduced by 31%, 41% and 47% respectively. The risk of mortality from both unimproved water and sanitation was significantly higher by 38% (Adjusted hazard ratios (HR) = 1.38, 95% confidence interval (CI): 1.14–1.66) for post-neonatal mortality and 24% (HR = 1.24, 95% CI: 1.04–1.48) for child mortality. The risk of neonatal mortality increased by 6% (HR = 1.06, 95% CI: 0.85–1.23) but showed no significant effect.

The Nigerian government needs to invest more in water and sanitation to reduce preventable child deaths.

Keywords: mortality; water; sanitation; children; Nigeria

1. Introduction

Access to unimproved water and sanitation among children under 5 years old is a serious public health problem in many developing countries, including Nigeria [1]. Globally, nearly a billion people still lack access to improved sources of drinking water, and about 2.5 billion lack improved sanitation [2]. Unimproved water and sanitation are major causes of diarrhoea, which globally accounts for approximately 1.4 million child deaths each year. The majority of these deaths occur in sub-Saharan Africa where nearly half the population lacks access to improved water and sanitation [3]. Children are more vulnerable to the health hazards associated with unimproved water supply and sanitation; their immune, respiratory, and digestive systems are still developing [4], and children play in areas where contaminants may accumulate [5].

The impact of unimproved water and sanitation as a leading cause of childhood diarrhoea has long been recognized and documented in the public health literature. In response to this, in the past two decades the Nigerian government has launched and implemented the National Water Supply and Sanitation Policy, Presidential Water Initiative, and National Economic Empowerment and Development Strategy [6,7]. Despite all these initiatives, a recent report on global progress on sanitation and drinking water indicates that approximately 109 million and 66 million people in Nigeria still lack access to basic sanitation facilities and improved drinking water, respectively [2].

Past studies have shown that access to improved water and sanitation leads to a reduction in childhood mortality as well as child diarrhoea [8,9]. A recent large cross-sectional study undertaken in 38 developing countries concluded that access to improved water and sanitation can reduce child mortality by approximately 20%, and each year prevent about 2.2 million deaths in children aged under 5 years old from low-income and middle-income countries, excluding China [10].

The number of people with access to improved water and sanitation in Nigeria is very low, particularly in rural areas (48% for water and 28% for sanitation) [11], and could be one of the reasons why Nigeria still has the highest reported number of childhood deaths in Africa [12]. Each year in Nigeria, approximately 150,000 children under 5 years old, die from diarrhoea [13]. Therefore, a detailed understanding of the impact of water and sanitation on childhood mortality is needed to develop effective community mobilisation interventions aimed at reducing unimproved water and sanitation related deaths. Hence, this study aimed to use pooled data from the 2003, 2008 and 2013 Nigeria Demographic and Health Surveys (NDHS) to examine whether children under 5 years old without access to improved water sources and sanitation were at a greater risk of dying compared with children under 5 years old with access to improved water sources and sanitation. Specifically, we examined how well the combined effect of water and sanitation correlated with neonatal mortality (0–28 days), post-neonatal mortality (1–11 months), and child mortality (12–59 months).

2. Methods

2.1. Data Source

Data for this study were obtained from NDHS, which are available online with ethics approval from ICF International (Calverton, MD, USA). NDHS have been conducted in Nigeria approximately every 5 years old since 1990 by the National Population Commission (NPC) in conjunction with ORC Macro international, and are largely sponsored by the United States Agency for International Development (USAID). The NDHS program collects data nationally on a wide range of socio-demographic and health characteristics such as childhood mortality, childhood illnesses, birth history, sex, education, and maternal and child health by interviewing women and men of reproductive age 15–49 and 15–59 years old, respectively. The information gathered from interviewees is recorded in three separate questionnaires. A multi-stage, stratified, cluster random sampling method was used to gather the information. This method has been discussed in detail elsewhere [11,14,15].

The data for the study were from the 2003, 2008 and 2013 NDHS. In this pooled dataset, information was available from 79,953 married women aged 15–49 years old, consisting of 7620 women from the 2003 survey, 33,385 women from the 2008 survey, and 38,948 women from the 2013 survey. The analyses used survival information from 63,844 singleton live-born infants of the most recent birth of a mother within five years prior to the mother's interview [11,14,15]. Only each mother's most recent birth was used in the analyses because only these births had detailed information on the use of perinatal health services, and to limit the potential for differential recall of events from mothers who had delivered at very different durations prior to the interview. Participation in NDHS has always been high with an average individual response rate of more than 94% for the surveys examined.

2.2. Outcome Variables

The main outcome variables in the study were neonatal mortality (death between birth and 28 days), post-neonatal mortality (death between 1 month and 11 months), and child mortality (death between 12 and 59 months). The outcome variables took a binary form such that child death was considered a "success" (1 = if death occurred in the specified age periods) or "failure" (0 = if child was alive in the specified age periods).

2.3. Exposure Variables

The key exposure variables examined were the main source of water and type of sanitation (or toilet) facilities available to members of the households. In the merged data set, there were 12 different categories of water source and 11 different categories of sanitation facility available to household members. In the analysis, these categories were classified as improved and unimproved according to WHO/UNICEF guidelines (Table 1).

In the analysis, water source and sanitation facilities were classified into four categories: improved water and improved sanitation, improved water and unimproved sanitation, unimproved water and improved sanitation, and unimproved water and unimproved sanitation facilities. The primary aim was to examine whether the combined impact of unimproved water and sanitation was associated with childhood mortality.

Table 1. Classification of water sources and sanitation facilities based on WHO/UNICEF guidelines [2].

Variable	Improved	Unimproved
Water source	Piped water connection to household, public taps or standpipes, boreholes or tube wells, protected dug well, protected spring and rainwater collection.	Unprotected dug well, unprotected spring, cart with small tank or drum, surface water (e.g., river, dam, lake, pond, stream, canal or irrigation channel) and bottled water.
Sanitation facility	Pour-flush system, piped sewer system, septic tank, ventilated improved pit latrine (VIP) and pit latrine with slab.	Pit latrine without slab, bucket, hanging toilet or latrine, no facilities, bush or field and shared or public facility.

Note: N.B. sanitation refers to toilet facility.

2.4. Potential Confounding Variables

The confounding variables considered in the analyses were based on previous literature on water, sanitation, and child survival [4,10,16–18]. These confounding variables were classified into two distinct groups: *socioeconomic level factors*, and *demographic level factors*. The socioeconomic variables examined consisted of place of residence (urban or rural areas), mother's education, and mother's work status. Other socioeconomic variables included were *household wealth index*, *mother's literacy level*, and *father's level of education*. The three demographic level factors assessed were *mother's age at child's birth*, *perceived newborn size by the mother,* and *sex of child*. Perceived newborn size at birth by mothers *(small* or *very small*, and *average* or *large)* was used instead of birth weight at birth because more than half of the newborns were not weighed at birth. This measure was a reasonable proxy because a previous study showed that there is a close relationship between mean birth weight and perceived newborn size by the mother [19].

A household wealth index was constructed using a principal component analysis (PCA) [20]. Weights were assigned to the household facilities and assets of respondents. The assets included were those that were consistent across the pooled NDHS data; these were radio, television, fridge, bicycle, motorcycle, car, telephone, electricity, and type of floor material used in rooms. In the NDHS data set, the household wealth index was categorized into five quintiles: *poorest, poorer, middle, richer,* and *richest*. However, in the analysis, the household wealth index was re-categorised into three groups. The bottom 40% of households was arbitrarily referred to as poor households, the next 40% as middle households, and the top 20% as rich households.

2.5. Statistical Analysis

Initially, a frequency tabulation of all the potential confounding variables was conducted by the year of survey to describe the data used in the study, followed by estimation of the mortality rates by combined water sources and sanitation facilities, using a similar method to that described by Rutstien and Rojas [21]. To examine the impact of combined water sources and sanitation facilities, a multivariable analysis was conducted using a Cox proportional hazard regression model.

For the multivariable model, a staged modelling technique was used. In the first stage, all the socioeconomic and demographic variables were entered into the baseline multivariable model to assess their relationship with the study outcomes. A stepwise backwards elimination process was conducted and variables that were significantly associated with the study outcomes at a 5% significance level were retained in the model (*model 1*).

In the second stage, *water source* was independently investigated with the socioeconomic and demographic variables that were significantly associated with the mortality outcomes, and those variables with p-values < 0.05 were retained (*model 2*). In the third stage, *sanitation facility* was independently examined with the socioeconomic and demographic variables that were significantly associated with the mortality outcomes. As before, those variables with p-values <0.05 were retained (*model 3*). In the final stage, a similar procedure was used for the combined exposure variables (water and sanitation), which were entered into *model 1*, and those variables with p-values <0.05 were retained in the final model (*model 4*).

The hazard ratios (HR) and their 95% confidence intervals obtained from the adjusted Cox proportional Hazard models were used to measure the impact of the combined effect of water sources and sanitation facilities on neonatal, post-neonatal, and child mortality. All analyses were conducted using "SVY" commands in STATA version 12.0 (Stata Corporation, College Station, TX, USA) to adjust for the cluster sampling survey design, weights, and calculate standard errors.

3. Results and Discussion

A weighted total of 63,844 most recent live births of children younger than 5 years old occurred within the 5 year period prior to the survey interview date, including 6285 deaths. Of these deaths, 2254 occurred between birth and 28 days (neonatal mortality), 1859 between 1 and 11 months (post-neonatal mortality) and 2172 between 1 and 4 years old (child mortality). Table 2 shows the distribution of the exposure and confounding variables by year of survey. Place of residence was nearly equally represented in the three study periods. The proportion of children whose mothers had secondary or higher education slightly increased from 24.5% in 2003 to 31.5% in 2013. Both male and female children were nearly equally represented in the three study periods, while the proportion of children whose mothers were from poor households decreased from 42.3% in 2003 to 33.6% in 2013. In 2003, approximately 60% of children under 5 years old lived in households having both unimproved water and sanitation, and this decreased to 27.8% in 2008, and was 27.5% in 2013.

The neonatal mortality rate (NMR) was found to be higher among newborns born to mothers in households with access to both unimproved water sources and unimproved sanitation facilities (NMR: 38.2 *vs.* 32.6). The post-neonatal mortality rate (PMR) in households with access to unimproved water sources and sanitation was greater than those with access to improved water and sanitation (PMR: 35.7 *vs.* 20.2). Similarly, the child mortality rate (CMR) for children aged 1–4 years old was higher in households with no access to both improved water sources and sanitation facilities (CMR: 40.8 *vs.* 23.9).

Table 2. The prevalence of singleton live birth of infants under 5 years old as reported by mothers interviewed during demographic and health surveys in Nigeria, 2003–2013 (n = 63,844).

Variable	Total Live Births		% of Weighted	Prevalence × by Survey (%)		
	Unweighted ᴚ	Weighted ×	Total ×	2003	2008	2013
Household environmental factor						
Water (n = 61,995)						
Improved water	31,530	32,821	51.4	35.4	50.4	55.4
Unimproved water	30,531	29,174	45.7	62.9	47.7	40.6
Sanitation (n = 62,994)						
Improved	28,416	30,086	47.1	12.6	51.1	50.3
Unimproved	34,511	32,908	51.6	85.8	47.0	48.9
Combined water and sanitation (n = 61,648)						
Improved water, improved sanitation	18,106	19,680	30.8	9.7	31.2	34.6
Improved water, unimproved sanitation	13,299	13,013	20.4	25.7	18.8	20.7
Unimproved water, improved sanitation	9420	9370	14.7	2.9	19.1	13.1
Unimproved water, unimproved sanitation	20,878	19,585	30.7	60.0	27.8	27.5
Socioeconomic factor						
Residence type						
Urban	19,305	20,478	32.1	28.8	29.7	34.8
Rural	44,553	43,366	67.9	71.2	70.3	65.2
Household wealth index						
Poor	25,243	23,783	37.3	42.3	40.2	33.6
Middle	25,262	25,569	40.1	40.5	37.7	42.0
Rich	13,353	14,492	22.7	17.2	22.1	24.3
Mother's education						
No education	31,203	30,947	48.5	51.8	46.7	49.4
Primary	13,871	13,539	21.2	23.6	23.0	19.1
Secondary or higher	18,784	19,357	30.3	24.5	30.2	31.5
Mother's literacy level (n = 63,532)						
Cannot read at all	38,905	38,283	60.0	63.9	59.4	59.7
Able to read	24,668	25,249	39.6	35.8	40.1	39.8
Father's education (n = 61,964)						
No education	24,634	24,365	38.2	39.7	37.1	38.8
Primary	12,825	12,843	20.1	23.0	21.5	18.4
Secondary or higher	24,431	24,756	38.8	34.0	38.2	40.2
Mother's working status (n = 61,857)						
Not working	21,544	21,289	33.3	37.4	34.6	31.5
Working	40,328	40,568	63.5	62.6	63.1	64.1
Demographic factor						
Currently breastfeeding						
Yes	35,885	35,691	55.9	58.2	56.4	55.0
No	27,973	28,153	44.1	41.8	43.6	45.0

Table 2. *Cont.*

Variable	Total live births		% of weighted	Prevalence ˣ by survey (%)		
	Unweighted ¤	Weighted ˣ	total ˣ	2003	2008	2013
Mother's age (years)						
<20	3460	3473	5.4	7.3	5.4	5.1
20–29	30,822	30,870	48.4	51.6	48.2	47.8
30–39	23,035	23,136	36.2	32.6	36.1	37.1
40–49	6541	6366	10.0	8.6	10.3	10.0
Sex of child						
Female	31,385	31,491	49.3	48.8	49.1	49.6
Male	32,473	32,353	50.7	51.2	50.9	50.4
Mother's perceived baby size (n = 62,563)						
Small or very small	9107	9023	14.1	14.2	13.8	14.4
Average or larger	53,448	53,540	83.9	84.5	83.9	83.7

Notes: ¤ The total unweighted number varies between categories because of some missing values. ˣ Weighting was applied to compensate for the multistage sampling design.

3.1. The Combined Effect of Water and Sanitation on Neonatal-Mortality

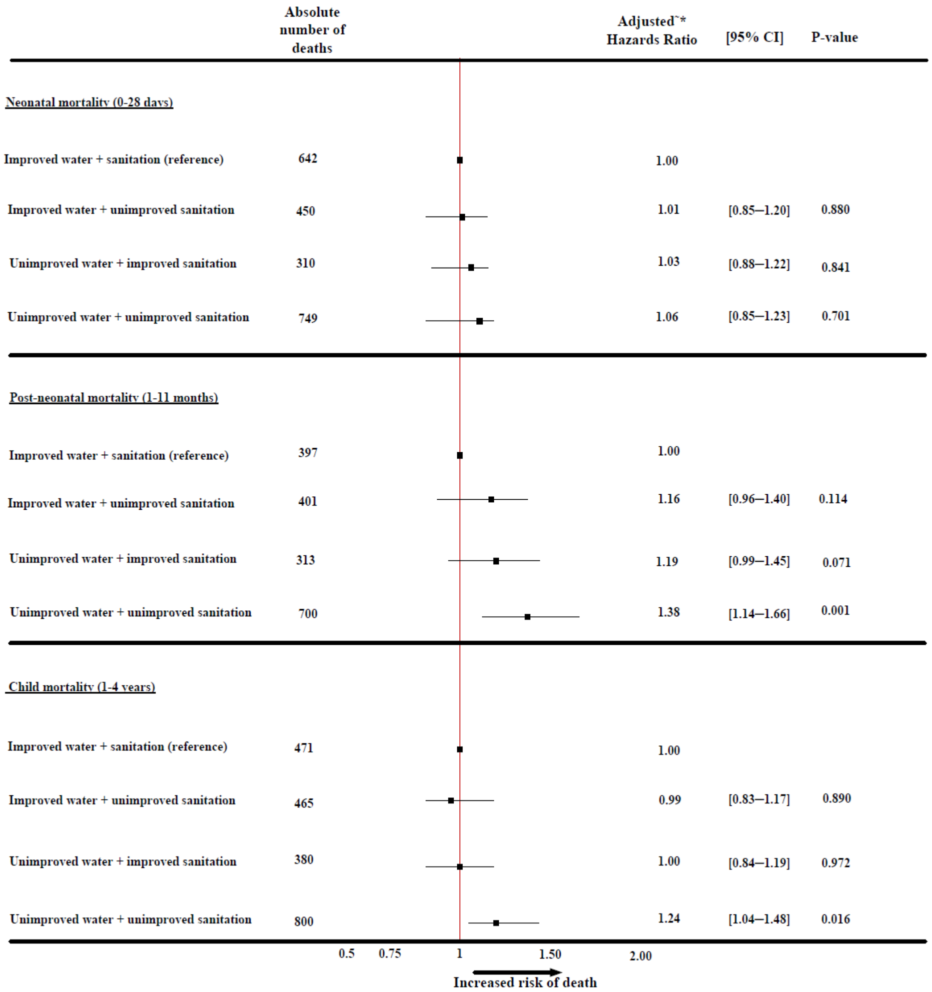
Figure 1 presents findings from the multivariate analyses of the combined effect of water and sanitation on neonatal, post-neonatal, and child mortality after adjusting for confounding factors. The results show that neonates born to mothers in households with access to both unimproved water and sanitation had a higher risk of neonatal death (HR = 1.06; CI: 0.85—1.23) compared with the reference category (improved water and improved sanitation), though it was not statistically significantly different.

Table 3 (*model 4*) shows other significant factors that affected neonatal deaths in addition to unimproved water and sanitation including neonates born to mothers under 20 years old (HR = 3.45; CI: 2.79–4.27), newborns whose body size was perceived by their mothers as small or smaller (HR = 1.93; CI: 1.70–2.20), male newborns (HR = 1.38; CI: 1.24–1.55), newborns from poor households (HR = 1.36; CI: 1.12–1.65), and newborns not currently breastfed were 1.95 times at higher risk of neonatal death (HR = 1.95; CI: 1.73–2.20). In the final model, we removed the household wealth index and replaced it with place of residence. In addition to the impact of water and sanitation, newborns born to mothers residing in rural areas had a significantly higher risk of neonatal death (HR = 1.35; CI: 1.17–1.57) than those newborns born in urban areas.

3.2. The Combined Effect of Water and Sanitation on Post-Neonatal Mortality

Compared with the reference category in Figure 1, households with an unimproved source of water and unimproved sanitation (HR = 1.38; CI: 1.14–1.66) reported a significantly higher risk of post-neonatal mortality. Table 4 (*model 4*) shows other factors that significantly affected post-neonatal deaths in addition to households having both unimproved source of water and unimproved sanitation. Infants whose fathers had no formal education were more likely to die (HR = 1.22; CI: 1.05–1.42), as were infants whose birth size was perceived as small or smaller (HR = 1.18; CI: 1.03–1.36). Infants that were not currently breastfed had a significantly higher risk of post-neonatal mortality (HR = 1.52; CI: 1.34–1.71) compared with currently breastfed infants.

Figure 1. The combined effect of water and sanitation on neonatal, post-neonatal and child mortality in Nigeria, 2003–2013.



Notes: * Independent variables adjusted for were: place of residence, wealth index, mother's (education, literacy level, working status, age), father's education, child's gender, currently breastfeeding and baby size. ˘ Missing values were not included.

Table 3. Model for neonatal mortality.

Variables	**(Model 0) ˇ**	**(Model 1) ^**	**(Model 2) ^**	**(Model 3) ^**	**(Model 4) ^**
	HR (95% CI)	**HR (95% CI)**	**HR (95% CI)**	**HR (95% CI)**	**HR (95% CI)**
Year of survey					
2003	*Ref*	*Ref*	*Ref*	*Ref*	*Ref*
2008	0.83 (0.69–1.01)	0.86 (0.71–1.03)	0.86 (0.71–1.03)	0.86 (0.71–1.04)	0.86 (0.71–1.04)
2013	0.68 (0.56–0.82)	0.69 (0.57–0.83)	0.69 (0.57–0.84)	0.69 (0.57–0.84)	0.69 (0.57–0.85)
Socioeconomic factor					
Residence type					
Urban	*Ref*				
Rural	1.46 (1.27–1.67)				

Table 3. *Cont.*

Variables	(Model 0) ˇ	(Model 1) ^	(Model 2) ^	(Model 3) ^	(Model 4) ^
	HR (95% CI)	**HR (95% CI)**	**HR (95% CI)**	**HR (95% CI)**	**HR (95% CI)**
Household wealth index					
Rich	*Ref*				
Poor	1.51 (1.28–1.78)	1.38 (1.16–1.64)	1.37 (1.14–1.64)	1.37 (1.13–1.65)	1.36 (1.12–1.65)
Middle	1.28 (1.08–1.52)	1.23 (1.04–1.46)	1.22 (1.03–1.46)	1.22 (1.02–1.46)	1.22 (1.02–1.46)
Mother's education					
Secondary or higher	*Ref*				
No education	1.24 (1.07–1.44)				
Primary	1.24 (1.06–1.46)				
Mother's literacy level					
Able to read	*Ref*				
Cannot read at all	1.24 (1.10–1.40)				
Father's education					
Secondary or higher	*Ref*				
No education	1.15 (1.02–1.31)				
Primary	1.14 (0.98–1.32)				
Mother's working status					
Not working	*Ref*				
Working	0.83 (0.75–0.94)				
Demographic factor					
Mother's age					
30–39	*Ref*	*Ref*		*Ref*	*Ref*
<20	3.69 (2.98–4.58)	3.46 (2.79–4.28)	3.45 (2.79–4.27)	3.46 (2.79–4.28)	3.45 (2.79–4.27)
20–29	1.17 (1.03–1.32)	1.17 (1.03–1.33)	1.17 (1.03–1.33)	1.17 (1.04–1.33)	1.17 (1.03–1.33)
40–49	1.21 (1.00–1.47)	1.09 (0.90–1.33)	1.09 (0.90–1.33)	1.09 (0.90–1.33)	1.09 (0.90–1.33)
Sex of child					
Female	*Ref*	*Ref*	*Ref*	*Ref*	*Ref*
Male	1.37 (1.23–1.53)	1.39 (1.24–1.55)	1.39 (1.24–1.55)	1.39 (1.24–1.55)	1.38 (1.24–1.55)
Mother's perceived baby size					
Average or larger	*Ref*	*Ref*	*Ref*	*Ref*	*Ref*
Small or very small	1.97 (1.74–2.34)	1.93 (1.70–2.20)	1.93 (1.70–2.20)	1.94 (1.70–2.20)	1.93 (1.70–2.20)
Currently breastfeeding					
Yes	*Ref*	*Ref*	*Ref*	*Ref*	*Ref*
No	1.83 (1.62–2.06)	1.95 (1.73–2.20)	1.95 (1.73–2.20)	1.95 (1.73–2.20)	1.95 (1.73–2.20)
Household environmental factors					
Source of water					
Improved	*Ref*		*Ref*		
Unimproved	1.18 (1.06–1.33)		1.02 (0.91–1.15)		
Type of sanitation facility					
Improved	*Ref*			*Ref*	
Unimproved	1.20 (1.07–1.35)			1.02 (0.89–1.16)	

Notes: ^ Independent variables adjusted were: year of survey, place of residence, wealth index, mother's (education, literacy level, working-status, age), father's education, child's gender, currently breastfeeding and baby size; ˇ Model 0—unadjusted independent variables; Model 1—Independent variables associated with child mortality; Model 2—Model 1 plus water; Model 3—Model 1 plus sanitation; Model 4—Model 1 plus combined water and sanitation.

As shown in Table 4 (*model 4*), there was a significantly higher risk of post-neonatal death for infants born to mothers from poor households (HR = 1.60; CI: 1.27–2.03) and middle-class households (HR = 1.46; CI: 1.18–1.80) compared with infants from rich households. Infants born to mothers under 20 years old had a 3.07 times greater risk of dying than those born to mothers aged 20 years old or more (HR = 3.07; CI: 2.42–3.90).

Table 4. Model for post-neonatal mortality.

Variables	(Model 0) ˇ	(Model 1) ^	(Model 2) ^	(Model 3) ^	(Model 4) ^
	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)
Year of survey					
2003	*Ref*	*Ref*	*Ref*	*Ref*	*Ref*
2008	0.70 (0.58–0.85)	0.73 (0.61–0.89)	0.75 (0.62–0.91)	0.74 (0.60–0.90)	0.73 (0.60–0.90)
2013	0.55 (0.45–0.67)	0.57 (0.47–0.70)	0.59 (0.48–0.73)	0.58 (0.47–0.71)	0.59 (0.47–0.72)
Socioeconomic factor					
Residence type					
Urban	*Ref*				
Rural	1.51 (1.30–1.75)				
Household wealth index					
Rich	*Ref*	*Ref*	*Ref*	*Ref*	*Ref*
Poor	2.08 (1.72–2.51)	1.75 (1.42–2.15)	1.64 (1.32–2.04)	1.73 (1.37–2.18)	1.60 (1.27–2.03)
Middle	1.72 (1.42–2.07)	1.56 (1.28–1.89)	1.51 (1.23–1.84)	1.55 (1.26–1.89)	1.46 (1.18–1.80)
Mother's education					
Secondary or higher	*Ref*				
No education	1.57 (1.34–1.83)				
Primary	1.21 (1.01–1.45)				
Mother's literacy level					
Able to read	*Ref*				
Cannot read at all	1.54 (1.35–1.76)				
Father's education					
Secondary or higher	*Ref*	*Ref*	*Ref*	*Ref*	*Ref*
No education	1.53 (1.33–1.75)	1.24 (1.07–1.45)	1.23 (1.06–1.43)	1.25 (1.07–1.45)	1.22 (1.05–1.42)
Primary	1.32 (1.11–1.57)	1.15 (0.97–1.37)	1.15 (0.96–1.36)	1.15 (0.97–1.37)	1.14 (0.96–1.36)
Mother's working status					
Not working	*Ref*				
Working	0.86 (0.77–0.96)				
Demographic factor					
Mother's age					
30-39	*Ref*	*Ref*	*Ref*	*Ref*	*Ref*
< 20	3.54 (2.80–4.47)	3.10 (2.44–3.95)	3.08 (2.42–3.91)	3.10 (2.44–3.95)	3.07 (2.42–3.90)
20-29	1.18 (1.04–1.33)	1.15 (1.02–1.31)	1.15 (1.02–1.31)	1.15 (1.02–1.31)	1.15 (1.02–1.31)
40-49	1.01 (0.83–1.23)	0.89 (0.74–1.09)	0.90 (0.74–1.09)	0.89 (0.74–1.09)	0.90 (0.74–1.09)
Sex of child					
Female	*Ref*				
Male	1.03 (0.92–1.15)				

Table 4. *Cont*.

Variables	(Model 0) ˇ HR (95% CI)	(Model 1) ^ HR (95% CI)	(Model 2) ^ HR (95% CI)	(Model 3) ^ HR (95% CI)	(Model 4) ^ HR (95% CI)
Mother's perceived baby size					
Average or larger	*Ref*	*Ref*	*Ref*	*Ref*	*Ref*
Small or very small	1.29 (1.12–1.49)	1.19 (1.03–1.37)	1.18 (1.03–1.36)	1.17 (1.02–1.35)	1.18 (1.03–1.36)
Currently breastfeeding					
Yes	*Ref*	*Ref*	*Ref*	*Ref*	*Ref*
No	1.37 (1.22–1.55)	1.51 (1.34–1.70)	1.51 (1.34–1.71)	1.51 (1.34–1.70)	1.52 (1.34–1.71)
Household environmental factors					
Source of water					
Improved	*Ref*		*Ref*		
Unimproved	1.44 (1.27–1.62)		1.16 (1.02–1.31)		
Type of sanitation facility					
Improved	*Ref*			*Ref*	
Unimproved	1.35 (1.19–1.53)			1.02(0.88–1.17)	

Notes: ^ Independent variables adjusted were: place of residence, wealth index, mother's (education, literacy level, working status, age), father's education, child's gender, currently breastfeeding and baby size; ˇ Model 0—unadjusted independent variables; Model 1—Independent variables associated with child mortality; Model 2—Model 1 plus water; Model 3—Model 1 plus sanitation; Model 4—Model 1 plus combined water and sanitation.

3.3. The Combined Effect of Water and Sanitation on Child Mortality

As shown in Figure 1, children aged between 1 and 4 years old living in households with access to both an unimproved source of water and sanitation facilities had a greater risk of child mortality (HR = 1.24; CI: 1.04—1.48) compared with the reference category. Table 5 (*model 4*), shows other factors associated with a significantly higher risk of child mortality in addition to unimproved water and unimproved sanitation.

Table 5. Model for child mortality.

Variables	(Model 0) ˇ HR (95% CI)	(Model 1) ^ HR (95% CI)	(Model 2) ^ HR (95% CI)	(Model 3) ^ HR (95% CI)	(Model 4) ^ HR (95% CI)
Year of survey					
2003	*Ref*	*Ref*	*Ref*	*Ref*	*Ref*
2008	0.76 (0.62–0.93)	0.79 (0.66–0.95)	0.80 (0.67–0.97)	0.76 (0.63–0.92)	0.76 (0.63–0.92)
2013	0.52 (0.42–0.63)	0.54 (0.45–0.66)	0.55 (0.45–0.67)	0.52 (0.43–0.64)	0.53 (0.43–0.64)
Socioeconomic factor					
Residence type					
Urban	*Ref*				
Rural	2.31 (1.98–2.69)				
Household wealth index					
Rich	*Ref*	*Ref*	*Ref*	*Ref*	*Ref*
Poor	3.21 (2.68–3.84)	2.29 (1.87–2.79)	2.21 (1.80–2.71)	2.45 (1.97–3.06)	2.33 (1.86–2.90)
Middle	2.37 (1.98–2.84)	1.95 (1.61–2.36)	1.91 (1.58–2.32)	2.03 (1.67–2.47)	1.95 (1.60–2.37)

Table 5. *Cont.*

Variables	(Model 0) ˇ	(Model 1) ^	(Model 2) ^	(Model 3) ^	(Model 4) ^
	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)
Mother's education					
Secondary or higher	*Ref*				
No education	3.13 (2.64–3.72)				
Primary	2.04 (1.68–2.47)				
Mother's literacy level					
Able to read	*Ref*				
Cannot read at all	2.46 (2.14–2.84)				
Father's education					
Secondary or higher	*Ref*	*Ref*	*Ref*	*Ref*	*Ref*
No education	2.36 (2.05–2.71)	1.80 (1.54–2.09)	1.78 (1.53–2.08)	1.79 (1.53–2.08)	1.76 (1.51—2.06)
Primary	1.78 (1.53–2.07)	1.45 (1.24–1.69)	1.44 (1.24–1.68)	1.45 (1.24–1.69)	1.44 (1.23—1.68)
Mother's working status					
Not working	*Ref*				
Working	0.81 (0.72–0.91)				
Demographic factor					
Mother's age					
30–39	*Ref*				
<20	1.54 (1.15–2.05)				
20–29	1.10 (0.98–1.22)				
40–49	1.20 (1.03–1.41)				
Sex of child					
Female	*Ref*				
Male	1.05 (0.95–1.17)				
Mother's perceived baby size					
Average or larger	*Ref*				
Small or very small	1.35 (1.17–1.55)				
Currently breastfeeding					
Yes	*Ref*	*Ref*	*Ref*	*Ref*	*Ref*
No	1.03 (0.93–1.14)	1.13 (1.02–1.25)	1.13 (1.02–1.26)	1.13 (1.02–1.25)	1.13 (1.02—1.26)
Household environmental factors					
Source of water					
Improved	*Ref*		*Ref*		
Unimproved	1.50 (1.33–1.69)		1.09 (0.96–1.23)		
Type of sanitation facility					
Improved	*Ref*			*Ref*	
Unimproved	1.34 (1.19–1.51)			0.89 (0.79–1.02)	

Notes: ^ Independent variables adjusted were: place of residence, wealth index, mother's (education, literacy level, working status, age), father's education, child's gender, currently breastfeeding and baby size; ˇ Model 0—unadjusted independent variables; Model 1—Independent variables associated with child mortality; Model 2—Model 1 plus water; Model 3—Model 1 plus sanitation; Model 4—Model 1 plus combined water and sanitation.

These include children that were not currently breastfed (HR = 1.13; CI: 1.02–1.26), children whose fathers had no formal education (HR = 1.76; CI: 1.51–2.06), and children from poor households (HR = 2.33; CI: 1.86–2.90).

3.4. Discussion

In this study, the impact of water and sanitation on neonatal, post-neonatal, and child mortality was examined. We found that unimproved water and sanitation significantly increased the risk of post-neonatal and child mortality; however, it had no significant effect on the risk of neonatal mortality. This pattern is consistent with previous studies conducted in Egypt and Eritrea [17,22]; these authors reported that the impact of household environmental factors is very weak during the neonatal period; however, there was a large and statistically significant impact during the post-neonatal and child periods. A possible explanation of our findings is that exclusive breastfeeding has important protective effects on the survival of infants, increases immunity, and decreases the risk of prolonged diarrhoea; neonates are less likely to be exposed to pathogens in contaminated water [23–26]. The large impact of breastfeeding observed during the neonatal and post-neonatal periods reaffirms the protective effects of breastfeeding in reducing the risk of infant mortality.

The effect of unimproved water and sanitation was substantial during the post-neonatal period. Children learn to crawl and walk during this period, and they experience increased exposure to pathogens that cause diarrhoea from a variety of environmental sources, including contaminated water [5]. It is also during this period that the weaning process commences, and low income households often use unimproved water to prepare weaning foods, thereby transmitting pathogens to infants that cause diarrheal diseases, which has been shown to result in high mortality [27–29]. Similarly, children aged between 1 and 4 years old exposed to unimproved water and sanitation had increased mortality risk, though the effect was lower compared with that of the post-neonatal period. The lower mortality risk reported among children aged between 1 and 4 years old could be attributed to their relatively well developed immune response to pathogens compared with that during the infancy period; for example, maternal immunoglobulin is weak, short lived, and of low avidity during the first year of life [30].

Findings from this study showed that household economic status influenced survival of children under 5 years old. During all age periods, children from poor households had a significantly higher risk of mortality compared with children from rich households [17,31]. This finding is not surprising because wealthier households were more likely to have improved water sources and excreta disposal facilities than poor households. There was a strong effect in the final model when we replaced the household wealth index with place of residence, indicating that household dwelling had a significant influence on neonatal, post-neonatal, and child mortality. This finding is supported by other studies [32,33] that have found rural dwellings to be a strong predictor of mortality of children under 5 years old. Limited access to health facilities and maternal healthcare services disproportionally hinders rural dwellers from receiving adequate healthcare services, resulting in a high probability of child death. In Nigeria, as in many low and medium income countries, the majority of well-equipped hospitals and health centres are located in urban areas.

We found that male neonates had a significantly higher risk of dying during the neonatal period compared with female neonates. This finding is consistent with a cross-sectional study conducted in

Kenya in 2007, which reported that male neonates were 1.34 times at greater risk of dying than female neonates [34]. Biological factors are a possible explanation for this disparity [35]. The findings further indicated that maternal age at birth (<20 years old) and perception of newborn size at birth (small or very small) by mothers were strongly related to both neonatal and post-neonatal mortality, though they were not significantly related to child mortality. Paternal education had a strong impact on post-neonatal and child mortality. Children whose fathers had a secondary education or higher had significantly lower risk of death than those whose fathers had a primary or no formal education. This finding is consistent with studies in Bangladesh and Pakistan [31,36] which showed a strong relationship between childhood mortality and the level of education of the father. The lower risk of death observed for children whose fathers were educated may be because educated fathers are more likely to invest in both improved water sources and sanitation facilities [16].

The definitions of indicators (*water and sanitation*) used in this study were based on those recommended by WHO; other important strengths of the study were restricting analyses to the most recent births within 5 years prior to each survey to minimise any recall bias on birth and death dates reported by mothers, using a nationally representative survey with appropriate adjustment for sampling design and sampling weight, and the high response rate (95%) to the survey. However, limitations to be considered when interpreting the results include that no firm conclusions can be made on causes and effects in a cross-sectional design, and that other factors such as water storage facilities, quality and safety of the water sources as well as information on maintenance of existing water supply infrastructure [37] were not considered. Another possible limitation of this study is that information on medical status of children under 5 years old and causes of death were lacking in the NDHS data.4.

4. Conclusions

Our analyses of the impact of water and sanitation in Nigeria indicated that children under 5 years old in households with access to both unimproved water sources and sanitation facilities had increased risk of neonatal, post-neonatal, and child death than children with access to improved water sources and sanitation. In addition to the effect of unimproved water and sanitation, the results revealed that households in rural areas, poor households, mother's age at birth (<20 years old), mothers who perceived their newborns to be smaller than average at birth, and illiterate parents had a significantly higher risk of neonatal, post-neonatal, and child mortality. The findings from the study showed that Water and Sanitation community-based interventions are needed to prevent child deaths, and that such interventions should target low socioeconomic households in Nigeria.

Acknowledgments

This study was part of the first author's thesis for a doctoral dissertation with the School of Medicine, at the University of Western Sydney, Australia. We are grateful to Measure DHS, ORC Macro, Calverton, MD, USA for providing the 2003, 2008 and 2013 NDHS data for this analysis.

Author Contributions

Osita K. Ezeh and Kingsley Agho were involved in the conception and design of this study. Osita K. Ezeh conducted the literature review, carried out the analysis, and drafted the manuscript. Kingsley Agho, Michael J. Dibley, John Hall, and Andrew N. Page gave advice on interpretation, and revised and edited the manuscript. All authors read and approved the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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CHAPTER SIX

The effect of solid fuel use on childhood mortality in Nigeria: evidence from the 2013 cross-sectional household survey

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Environ Health. 2014; 13:113

(publication 4)

Ezeh et al. Environmental Health 2014, 13:113
http://www.ehjournal.net/content/13/1/113

ENVIRONMENTAL HEALTH

RESEARCH Open Access

The effect of solid fuel use on childhood mortality in Nigeria: evidence from the 2013 cross-sectional household survey

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Abstract

Background: In Nigeria, approximately 69% of households use solid fuels as their primary source of domestic energy for cooking. These fuels produce high levels of indoor air pollution. This study aimed to determine whether Nigerian children residing in households using solid fuels at <5 years of age were at higher risk of death.

Methods: The 2013 Nigeria Demographic and Health Survey data were analysed in Cox regression analyses to examine the effects of solid fuel use on deaths of children aged 0–28 days (neonatal), 1–11 months (post-neonatal), and 12–59 months (child).

Results: The results indicated that approximately 0.8% of neonatal deaths, 42.9% of post-neonatal deaths, and 36.3% of child deaths could be attributed to use of solid fuels. The multivariable analyses found that use of solid fuel was associated with post-neonatal mortality (hazard ratio [HR] =1.92, 95% confidence interval [CI]: 1.42–2.58) and child mortality (HR = 1.63, CI: 1.09–2.42), but was not associated with neonatal mortality (HR = 1.01, CI: 0.73–1.26). Living in rural areas and poor households were associated with an increased risk of death during the three mortality periods.

Conclusion: Living in a rural area and poor households were strongly associated with an increased risk of a child > 1 to < 60 months dying due to use of solid fuels. The health effects of household use of solid fuels are a major public health threat that requires increased research and policy development efforts. Research should focus on populations in rural areas and low socioeconomic households so that child survival in Nigeria can be improved.

Keywords: Indoor air pollution, Solid fuels, Nigeria, Childhood mortality

Background

Indoor air pollution (IAP) emanating from burning solid fuels (wood, charcoal, animal dung, coal and crop waste) for cooking and home heating remains a major environmental and public health challenge in developing countries. Worldwide, approximately 4.3 million people have died as a result of illnesses attributed to IAP; these deaths include 534,000 children <5 years of age [1]. Most of the deaths occur in low- and middle-income countries, including Nigeria. However, the use of solid fuels and health effects of the mix of chemical components (e.g., carbon monoxide, sulphur oxides, nitrogen oxides, particulates, benzene, formaldehyde, polyaromatic compounds, arsenic, lead) from solid fuel use [2,3] are not well understood even though household indoor cooking could result in high levels of these chemical components. Children <5 years of age are one of the vulnerable groups most likely to experience ill health caused by solid fuel use, as they are with their mothers whilst they are cooking [4].

Results of previous studies have indicated that children <5 years of age living in homes using solid fuels for cooking are at a greater risk of dying from acute respiratory illnesses [5,6]. Respiratory and immune system development occurs during this period, which may impair the immune response and lead to more severe infection

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and progression into the lower respiratory, particularly during the first year of life [7,8]. In 2014, the World Health Organization (WHO) indicated that >50% of the deaths of children <5 years of age were attributed to acute lower respiratory infections triggered by solid fuels use [1]. Poverty is one of the main drivers for solid fuel use in many low- and middle-income countries.

Evidence from the Nigeria Demographic and Health Surveys (NDHS) indicated that in the past decade (from 2003–2013), the proportion of Nigerian households using solid fuels as their primary source of domestic energy for cooking remained constant at approximately 69% [9,10]. Each year, over 95,000 Nigerians, including children <5 years of age, die from exposure to firewood smoke [11]. The health effects of household solid fuel use, and the increased risk of childhood mortality, have been somewhat neglected by public health researchers and policy makers in Nigeria.

We present new and emerging evidence on the effects of solid fuel use on childhood mortality in Nigeria. We examined the relationship between household solid fuel use and death rate of children <5 years for age groups (0–28 days, 1–11 months, and 12–59 months) because the effects of environmental, demographic, and socio-economic factors may be amongst these groups [12,13].

Methods

The dataset used for this study was from the 2013 NDHS. The dataset is available online from ICF international, Rockville, MD, USA, after ethics approval is obtained [10]. The National Population Commission (NPC) conducts the NDHS in conjunction with ICF International. The United States Agency for International Development (USAID) is the main sponsor of the NDHS. Approximately every 5 years, the NDHS collects information on demographic and health issues (e.g., maternal and child health, childhood mortality, and education) from nationally representative households located in rural and urban areas. The 2013 NDHS data were obtained by interviewing eligible reproductive age women and men, aged 15–49 and 15–59 years, respectively, who participated in the household survey. The information obtained was recorded in three questionnaires (i.e., household, and women's and men's questionnaires). The detailed sampling procedures used in the NDHS have previously been published [10].

A total of 38,522 households were interviewed during the 2013 NDHS survey period. Of these households, 38,948 women and 17,359 men were successfully interviewed, corresponding to response rates of 97.6% and 95.2%, respectively. A total of 30,726 singleton live-births were reported for the 5-year period prior to the interview date. Multiple births were excluded from our analysis because compared with singletons, multiple births are associated with higher childhood mortality risk [14,15]. The analysis was restricted to births that occurred within the previous 5 years to minimise recall bias in the birth and death dates reported by the mothers. In addition, children < 5 years of age are most likely to be indoors under their mother's supervision whilst cooking occurs.

Descriptive study variables

Outcome variables

The main outcome variables were neonatal mortality (death between birth and 28 days of age), post-neonatal mortality (death between 1 and 11 months of age) and child mortality (death between 12 and 59 months of age). Binary outcome variables were used in the analysis. Child death was considered a 'case' (= 1) if death occurred during the specified age period and a 'non-cases' (= 0) if the child was alive throughout the specified age period.

Main study factor

The main study factor was the main type of cooking fuels available to household members at the time of survey. The respondents were asked "What type of fuel does your household mainly use for cooking", which was followed by 11 categories of cooking fuels, including electricity, liquefied petroleum gas, natural gas, biogas, kerosene, coal/lignite, charcoal, wood, straw/shrubs/grass, agricultural crop and animal dung. For the analysis, these 11 categories were classified into two groups based on NDHS definitions, solid (coal/lignite, charcoal, wood, straw/shrubs/grass, agricultural crop, animal dung) and non-solid (electricity, liquefied petroleum gas (LPG), natural gas, biogas, kerosene) fuels.

Potential confounding variables

The potential confounding variables considered were based on previous literature on the effects of cooking fuels on childhood mortality [16-18], particularly in developing countries. These variables were adapted to the data available in the 2013 NDHS. Potential child-related confounders were sex, mother's perception of her newborn's size at birth, and breastfeeding. The child's sex was also included in the analysis because results of a study in Bangladesh indicated that boys spend less time indoors compared with girls [19]. Therefore, girls are more likely to inhale IAP than boys, and girls are more likely than boys to be admitted for acute respiratory diseases [20]. The mother's perception of her newborn's size was categorised into two groups (small or very small, and average or large), and was used as a proxy for birth weight because >50% of children are not weighed at birth [10]. Results of recent studies in India and Guatemala indicated that children born in households using high-polluting solid fuels were 73 g and 63 g, respectively, lower in birth weight compared with children born in households using low-polluting fuels [21-23]. We considered breastfeeding in the analysis because it has a protective effect on the risk of respiratory disease [24,25], especially in the first year of an infant's life.

Confounders associated with maternal characteristics included education, working status and age at the birth of the child. Level of the mother's education is correlated with child survival, particularly during the post-neonatal and child period [26,27]. Compared with less educated mothers, educated mothers were more likely to obtain paid employment, which results in household members being exposed to solid and non-solid fuel combustion for shorter periods of time. Educated mothers can understand the health hazards of solid fuel use, and are more likely to purchase non-solid fuels. Educated mothers are also more likely to appropriately use healthcare services than their less educated peers. The level of education attained by mothers was categorised into three groups (no education, primary and secondary or higher education). Employment status was divided into two categories (working and not working). Mother's age at birth of the child was adjusted for because the frequency of exposure to cooking fuel smoke may vary as mothers grow older. It was categorised into four groups (age <20, 20–29, 30–39 and 40–49 years).

The respondent's living location at the time of the survey was used to classify the residence, and was classified as urban or rural. More than two-thirds of households using solid fuels are in rural areas [10,28]. Household economic status is associated with use of high-polluting fuels [29]. As higher income levels are achieved, households are more likely to switch to more modern stoves and cleaner fuels, regardless of cultural traditions [30]. A household wealth index variable was constructed using household assets, which were weighted using a principal component analysis [31]. The assets considered were presence of a television, radio, refrigerator, telephone, car, bicycle, motorcycle and canoe, and ownership of agricultural land, a livestock farm or a bank account. In the NDHS data set, the household wealth variable was categorised into five quintiles: poorest, poorer, middle, richer, and richest. However, in the analysis the household wealth index was re-categorised into three groups. The bottom 40% of households was arbitrarily referred to as poor households, the next 40% as middle-income households, and the top 20% as high-income households.

Location of household kitchen was categorised into three groups (separate building, outdoor and in the house). However, frequency of cooking, ventilation facility, and duration of cooking variables were not included in this analysis because they were not collected. The previously mentioned potential confounding variables were used to measure the effects of use of solid fuels on neonatal, post-neonatal and child mortality.

Statistical analysis

Initially, mortality rates categorised by the two groups based on type of cooking fuel were estimated using a method similar to that described by Rutstien and Rojas [32]. Cox proportional hazards regression models were then used for multivariable analyses that independently examined the effect of each factor after adjusting for potential confounding variables.

A staged modelling technique was employed in the multivariable modelling. In the first stage, all potential confounding variables were entered into the baseline multivariable model to assess their relationship with the study outcomes. A stepwise backwards elimination process was performed, and variables that were associated with the study outcomes at a 5% significance level were retained in the model (model 1). In the final stage of the analysis, the main study factor (type of cooking fuels) was entered into model 1, and variables with a p-value <0.05 were retained in the final model (model 2).

The hazard ratios (HRs) and their 95% confidence intervals (CIs) obtained from the adjusted Cox proportional hazards models were used to measure the effect of the type of cooking fuels on neonatal, post-neonatal and child mortality. The "SVY" commands in STATA version 12.0 (Stata Corporation, College Station, TX, USA) were used in all analyses to adjust for the cluster sampling survey design, weights, and the calculation of standard errors.

The population attributable risk (PAR) was calculated to estimate total risk of neonatal, post-neonatal and child mortality in the general population that was attributable to household air pollution from smoke emanating from solid fuel use between 2009 and 2013. PAR was obtained using the following formula, which is recommended for multivariate-adjusted relative risks [33,34]:

$$\begin{aligned} PAR = \ & proportion\ of\ deaths \\ & (neonatal,\ post\text{–}neonatal,\ and\ child) \\ & associated\ with\ using\ solid\ fuels\ for\ cooking, \\ & X\ [(aHR - 1)/aHR] \end{aligned}$$

where aHR was the adjusted hazard ratio for (neonatal, post-neonatal, and child) mortality from use of solid fuel.

Results

A weighted total of 30,726 singleton live-births of children occurred within the 5-year period prior to the 2013 NDHS survey interview date. Of the total live births, 2,615 children died within the 5-year period. These deaths consisted of 1,011 neonates (first day of life to 28 days of age), 789 post-neonates (between 1 and

11 months of age), and 815 young children (between 12 and 59 months of age).

Table 1 presents the results for the percentage distribution of neonatal, post-neonatal, and young child deaths by selected background characteristics. In the 2013 NDHS, approximately 82% of neonates died in households using solid fuels for cooking. This number increased to 90% for the post-neonatal group and was 94% for the young child group. Wealthy households had the lowest percent of deaths compared with poor and middle-income households (13.8% neonatal, 9.0% post-neonatal, and 4.2% child). Greater than 70% of the neonatal, post-neonatal, and child deaths occurred in the rural areas.

Table 1 Percentage distribution of neonatal, post-neonatal and child mortality by background characteristics

Variables	Neonatal deaths (n = 1,011)	Post-neonatal deaths (n = 789)	Child deaths (n = 815)
Residence type			
Urban	29.1	26.9	17.1
Rural	70.9	73.1	82.9
Household wealth index			
Poor	52.2	60.6	71.2
Middle	34.0	30.4	24.6
Rich	13.8	9.0	4.2
Mother's education			
No education	52.1	59.8	69.2
Primary	21.9	17.5	17.5
Secondary or higher	25.9	22.7	13.3
Mother's working status*			
Not working	35.0	33.9	33.2
Working	64.5	66.1	66.8
Mother's age			
< 20	7.9	7.1	4.8
20—29	47.4	44.8	46.1
30—39	33.3	36.3	36.7
40—49	11.4	11.8	12.4
Mother's perceived baby size*			
Small or very small	23.5	16.9	18.7
Average or larger	68.2	76.9	76.0
Sex			
Female	42.6	49.0	48.7
Male	57.4	51.0	51.3
Currently breastfeeding			
Yes	28.7	35.6	43.1
No	71.3	64.4	56.9
Location of Kitchen*			
Separate building	17.6	19.7	16.1
Outdoor	22.8	25.2	22.6
House	59.3	54.3	61.2
Type of cooking fuel*			
Solid fuel	82.2	89.6	93.8
Non-solid fuel	16.4	9.6	5.6

*Percentages did not add up to 100% because of missing values.

The neonatal mortality rate (NMR) was higher among neonates born to mothers in households using solid fuels for cooking (NMR: 33.4 vs 29.6). The post-neonatal mortality rate (PMR) in households using solid fuels for cooking was greater than in households using non-solid fuels (PMR: 28.4 vs 13.6). Similarly, the child mortality rate (CMR) for children aged 12–59 months was higher in households using solid fuels for cooking compared with households not using solid fuels for cooking (CMR: 30.7 vs 8.2).

Approximately, 0.8% of neonatal deaths (PAR: 0.8; CI: −7.8—2.8), 43% of post-neonatal deaths (PAR: 42.9; CI: 31.9—61.4) and 36% of child deaths (PAR: 36.3; CI: 33.1—52.1) for the 5-year period prior to the 2013 NDHS survey may be attributed to the use of solid fuels.

The effect of solid fuel use on neonatal mortality

Table 2 presents the results for the effect of cooking fuel on neonates survival after adjusting for potential confounding factors. Neonates born to mothers in households using solid fuels for cooking had a slightly higher risk of neonatal death (HR = 1.01; CI: 0.73—1.26) compared with neonates in households using non-solid fuel. This difference was not statistically significant.

Table 2 (model 2) presents the results for other significant factors that affected neonatal deaths. These factors were neonates born to mothers <20 years of age (HR = 3.16; CI: 2.12–4.74), neonates whose body size was perceived by the mother as small or smaller (HR = 1.86; CI: 1.55–2.24), male neonates (HR = 1.33; CI: 1.13–1.64), neonates born to mothers residing in rural areas (HR = 1.32; CI: 1.06–1.64), and neonates not currently breastfed (HR = 2.12; CI: 1.75–2.55). When the place of residence was replaced by the household wealth index in the final model, children from poor households had a significantly high risk of infant death (HR = 1.55; CI: 1.13–2.13).

The effect of solid fuel use on post-neonatal mortality

Table 3 presents the results for the effect of cooking fuel on post-neonatal mortality after adjustment for confounding factors. Compared with the reference category (Table 3, model 2), infants in households cooking with solid fuels (HR = 1.92; CI: 1.42–2.58) had a significantly higher risk of post-neonatal mortality.

Model 2 (Table 3) revealed significant factors, other than households using solid fuels for cooking, that affected

Table 2 Neonatal mortality model

Variables	(Model 0)[n] HR (95% CI)	(Model 1)[‴] HR (95% CI)	(Model 2)[^~] HR (95% CI)
Residence type			
Urban	Ref	Ref	
Rural	1.36(1.13—1.65)	1.30(1.07—1.58)	1.32(1.06—1.64)
Household wealth index			
Rich	Ref		
Poor	1.43(1.09—1.88)		
Middle	1.14(0.86—1.52)		
Mother's education			
Secondary or higher	Ref		
No education	1.26(1.01—1.56)		
Primary	1.20(0.94—1.52)		
Mother's working status			
Not working	Ref		
Working	0.76(0.64—0.91)		
Mother's age			
40—49	Ref	Ref	
< 20	3.14(2.09—4.70)	3.17(2.12—4.74)	3.16(2.12—4.74)
20—29	1.11(0.81—1.51)	1.22(0.90—1.66)	1.22 0.90—1.65)
30—39	0.90(0.64—1.24)	0.99(0.71—1.37)	0.98(0.71—1.36)
Mother's perceived baby size			
Average or larger	Ref	Ref	Ref
Small or very small	1.95(1.63—2.34)	1.86(1.55—2.24)	1.86(1.55—2.24)
Sex			
Female	Ref	Ref	Ref
Male	1.31(1.11—1.55)	1.33(1.13—1.57)	1.33(1.13—1.64)
Breastfeeding currently			
Yes	Ref	Ref	Ref
No	1.98(1.64—2.38)	2.12(1.76—2.55)	2.12(1.75—2.55)
Location of kitchen			
Separate building	Ref	Ref	Ref
Outdoors	0.88(0.68—1.15)		
House	1.15(0.92—1.44)		
Cooking fuel			
Non-Solid fuel	Ref		Ref
Solid fuel	1.16(0.91—1.47)		1.01(0.73—1.26)

[^]Independent variables adjusted were: place of residence, wealth index, child size, child's gender, currently. Breastfeeding and mother's (education, working status, age); [n]Model 0 – unadjusted independent variables; [‴]Model 1 – independent variables associated with neonatal mortality; Model 2 – Model 1 plus type of cooking fuels; [~]Missing values were excluded from model 0, 1, and 2.

post-neonatal deaths. There was a significantly higher risk of infant death for infants born to mothers residing in rural areas (HR = 1.16; CI: 1.01–1.46), compared with infants in urban areas. When the place of residence was replaced by a household wealth index in the final model, infants born to mothers from poor households had a significantly high risk of infant death (HR = 1.81; CI: 1.15–2.83). Infants born to mothers <20 years of age had a 3.63 times greater risk of dying compared with infants of mothers aged ≥20 years (HR = 3.63; CI: 2.41–5.46). There was a significantly higher risk of post-neonatal death for infants not currently breastfed (HR = 1.46; CI: 1.22–1.74).

Table 3 Post-neonatal mortality model

Variables	(Model 0)^{n} HR (95% CI)	(Model 1)$^{'''}$ HR (95% CI)	(Model 2)$^{\wedge\sim}$ HR (95% CI)
Residence type			
Urban	Ref	Ref	Ref
Rural	1.48 (1.17—1.88)	1.44(1.15—1.80)	1.16(1.01—1.46)
Household wealth index			
Rich	Ref		
Poor	2.48 (1.78—3.45)		
Middle	1.63 (1.16—2.29)		
Mother's education			
Secondary or higher	Ref		
No education	1.51 (1.20—1.91)		
Primary	1.13 (0.85—1.50)		
Mother's working status			
Not working	Ref		
Working	0.79 (0.67—0.94)		
Mother's age			
40—49	Ref	Ref	
< 20	3.76 (2.45—5.79)	3.62(2.41—5.45)	3.63(2.41—5.46)
20—29	1.12 (0.84—1.52)	1.17(0.87—1.57)	1.19(0.89—1.60)
30—39	0.99 (0.73—1.34)	1.03(0.77—1.39)	1.07(0.80—1.45)
Mother's perceived baby size			
Average or larger	Ref		
Small or very small	1.28 (1.04—1.59)		
Sex			
Female	Ref		
Male	0.98 (0.82—1.18)		
Breastfeeding currently			
Yes	Ref	Ref	Ref
No	1.38 (1.14—1.67)	1.41(1.18—1.69)	1.46(1.22—1.74)
Location of kitchen			
Separate building	Ref		
Outdoors	0.92 (0.69—1.22)		
House	0.90 (0.71—1.14)		
Cooking fuel			
Non-solid fuel	Ref		Ref
Solid fuel	2.16 (1.58—2.96)		1.92(1.42—2.58)

$^{\wedge}$Independent variables adjusted were: place of residence, wealth index, child size, child's gender, currently breastfeeding and mother's (education, working status, age); ^{n}Model 0 – unadjusted independent variables; $^{'''}$Model 1 – independent variables associated with post-neonatal mortality; Model 2 – Model 1 plus type of cooking fuels; $^{\sim}$Missing values were excluded from model 0, 1 and 2.

The effect of solid fuel use on child mortality

Table 4 presents the results for the effect of cooking fuels on young children after adjustment for confounding factors. As indicated in model 2 results, children aged between 12 and 59 months and living in households using solid fuels for cooking had a greater risk of child mortality (HR = 1.63; CI: 1.09–2.42), compared with children in households using non-solid fuels.

There were other factors associated with a significantly higher risk of child mortality (Table 4,

Table 4 Child mortality model

Variables	(Model 0)[n] HR (95% CI)	(Model 1)[™] HR (95% CI)	(Model 2)[^~] HR (95% CI)
Residence type			
Urban	Ref	Ref	Ref
Rural	2.45(1.95—3.07)	1.75(1.39—2.22)	1.59(1.25—2.03)
Household wealth index			
Rich	Ref		
Poor	4.80(3.89—8.64)		
Middle	2.52(1.64—3.88)		
Mother's education			
Secondary or higher	Ref	Ref	Ref
No education	3.20(2.45—4.19)	2.46(1.85—3.26)	2.13(1.58—2.87)
Primary	1.99(1.46—2.73)	1.74(1.26—2.39)	1.55(1.12—2.15)
Mother's working status			
Not working	Ref		
Working	0.94(0.77—1.14)		
Mother's age			
40—49	Ref		
< 20	1.60(0.99—2.58)		
20—29	0.92(0.70—1.19)		
30—39	0.88(0.67—1.16)		
Mother's perceived baby size			
Average or larger	Ref	Ref	
Small or very small	1.45(1.15—1.82)	1.26(1.01—1.58)	
Sex			
Female	Ref		
Male	1.06(0.89—1.26)		
Breastfeeding currently			
Yes	Ref		
No	0.97(0.83—1.15)		
Location of kitchen			
Separate building	Ref		
Outdoors	1.16(0.86—1.57)		
House	1.40(1.08—1.81)		
Cooking fuel			
Non-solid fuel	Ref		Ref
Solid fuel	3.48(2.46—4.93)		1.63(1.09—2.42)

[^]Independent variables adjusted were: place of residence, wealth index, child size, child's gender, currently breastfeeding and mother's (education, working status, age); [n]Model 0 – unadjusted independent variables; [™]Model 1 – independent variables associated with post-neonatal mortality; Model 2 – Model 1 plus type of cooking fuels; [~]Missing values were excluded from model 0, 1, and 2.

model 2). Children had a significantly higher risk of death if their mothers had no formal education (HR = 2.13; CI: 1.58–2.87) or had a primary education (HR = 1.55; CI: 1.12–2.15). A significantly higher risk of death was also observed for children whose mothers resided in rural areas (HR = 1.59; CI: 1.25–2.03). When the place of residence was replaced by the household wealth index in the final model, children from poor households had a significantly high risk of child death (HR = 3.73; CI: 2.07–6.73).

Discussion

Household use of solid fuels was associated with an increased risk of neonatal, post-neonatal and child mortality after controlling for potential confounders including household wealth status, place of residence, mother's level of education, mother's perceived size of her child at birth, sex, breastfeeding, mother's age and mother's employment status. Household use of solid fuels was not significantly associated with neonatal mortality. These findings are consistent with the results of a study conducted in India, which indicated that the association between household use of solid fuels and neonatal mortality is not significant [35]. Explanations for the lack of association include contribution from biological factors, such as low birth weight and prematurity, and complications related to pregnancy and delivery [36], rather than household environmental health hazards. Breastfeeding, including exclusive breastfeeding, may also protect against the development of respiratory diseases [25,37]. The strong effect of breastfeeding observed during the neonatal and post-neonatal mortality periods examined in this study reaffirms the protective effects of breastfeeding on improving the growth, health, and survival of children <5 years of age.

The effect of household use of solid fuels on mortality increased significantly during the post-neonatal period. This may be attributable to the fact that infants in their first year of life are usually carried on their mother's back or stand beside their mother while she is cooking, thus exposing the infant to high concentrations of pollutants from solid fuel for considerable periods. This result is in line with observations from a case–control study performed in Gambia that found that there is a significantly higher risk of mortality from acute lower respiratory infection among children often carried on their mother's back during cooking [38]. This practice is common in sub-Saharan African countries, including in Nigeria. Close proximity to a pollution source and time spent in the vicinity is likely to increase the level of exposure to pollution, which may lead to adverse health problems [39]. We noted that household use of solid fuels increased the risk of death for post-neonates by 92%, compared with a 63% increased risk for children between 12 and 59 months. Compared with the infancy period, the lower mortality risk reported during the child period could be linked to their relatively well-developed lungs and immune response to pathogens [40].

Findings from this study indicate that during all age periods, children <5 years residing in rural areas had a significantly higher risk of mortality compared with their peers in urban areas. This finding is supported by results from other studies [41,42], which indicated that residence in rural areas is a strong predictor of mortality of children <5 years of age. Clear urban–rural differences in household use of solid fuel are apparent in many sub-Saharan African countries. More than two-thirds of rural dwellers rely exclusively on gathered wood, charcoal, animal dung, crop waste, and coal waste for domestic energy [10,28]. Socioeconomic status (e.g., poor households) is one of the major factors affecting solid fuel use [29]. The significant effect of economic status was also apparent in all three age groups when place of residence was replaced by household wealth index in the final model. This finding reaffirms that wealth has a positive effect on child survival. Limited access to cleaner energy (electricity, LPG, gas) may also hinder rural residents from using efficient cooking fuels. Only 34% of the rural residents in Nigeria have access to electricity [10].

In addition to solid fuel use, other factors that were significantly associated with an increased risk of neonatal, post-neonatal, and child mortality included the mother's perception of her newborn's size at birth (small or very small), sex (male neonate), maternal age (<20 years), and mother's level of education (no education). These results are consistent with the results of previous studies that examined the effect of cooking fuels on childhood mortality [18,23,41,43].

It is possible that the estimates we reported in our study may have been underestimated because of the following reasons. (1) Children aged between 1 and 4 years are more likely to move around, as a result they may be exposed to both household and ambient air pollution. (2) NDHS did not gather information about the history of cooking fuel use. This is imperative because previous study indicated that household income is a strong predictor for switching to cleaner fuels [30].

This study has some limitations. First, data on households that use a combination of solid and non-solid fuels were not available from the NDHS database, and misclassification of use of cooking fuels may have occurred. Results of a study performed in India revealed that households reporting kerosene as their primary fuel for domestic energy but that they frequently switched to solid fuels reported higher levels of exposure to household air pollution [44]. A second limitation was that causal effects could not be measured because the analyses were based on a retrospective cross-sectional study. The third limitation was that detailed health assessments of the child and mother were not available at the time of the survey. Finally, other important variables such as ventilation facility, duration of cooking, and frequency of cooking were not used in this analysis because they were not collected in the 2013 NDHS. Strengths of this study included that the indicators used for cooking fuels was based on WHO recommendations. Recall errors arising from dates of birth and death given by mothers interviewed during the survey were minimised by restricting the analyses to births within the 5-year period preceding the survey. Data used in this study were from a nationally representative survey, which had a 97.6% response rate.

Conclusions

Our analyses examined whether children <5 years of age residing in households using solid fuels were at higher risk of death. The results indicate that use of solid fuels increased the risk of post-neonatal and child deaths.

In addition to the effect of solid fuel use on childhood mortality, children from households in rural areas, children from poor households, children delivered by younger mothers (<20 years of age), children perceived by their mothers to have been smaller than average at birth, and children with illiterate mothers had a significantly higher risk of neonatal, post-neonatal and child mortality. Findings from this study indicate the need to create public awareness of the health risks of using solid fuel and to implement community-based domestic energy interventions. To improve child survival in Nigeria, these interventions should target rural and low socioeconomic status households.

Abbreviations

IAP: Indoor air pollution; NDHS: Nigeria demographic and health survey; NPC: National population commission; WHO: World health organisation; LPG: Liquefied petroleum gas; HR: Hazard ratio; aHR: Adjusted hazard ratio; PAR: Population attributable risk; CI: Confidence interval; NMR: Neonatal mortality rate; PMR: Post-neonatal mortality; CMR: Child mortality rate.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

OKE and KEA were involved in the conception and design of this study. OKE performed the literature review and analysis and drafted the manuscript. KEA, MJD, JH, and ANP provided advice on interpretation and revised and edited the manuscript. All authors read and approved the manuscript.

Acknowledgements

This study was part of the first author's thesis for a doctoral dissertation with the School of Medicine at the University of Western Sydney, Australia. We are grateful to Measure DHS, ICF International, Rockville, MD, USA for providing the 2013 NDHS data for this analysis.

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Received: 27 August 2014 Accepted: 28 November 2014
Published: 16 December 2014

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doi:10.1186/1476-069X-13-113
Cite this article as: Ezeh *et al.*: The effect of solid fuel use on childhood mortality in Nigeria: evidence from the 2013 cross-sectional household survey. *Environmental Health* 2014 **13**:113.

SECTION IV

This section presents the overall summary of the research findings, policy implications, future research, and strengths and limitations of the study.

CHAPTER SEVEN

Summary

According to the WHO/UNICEF, Nigeria is making progress in reducing child mortality rates.[1]Despite this improvement, this country is still well behind in achieving the Millennium Development Goal number 4 of reducing child mortality by two-thirds by the year 2015. This chapter presents an overview of the major findings that will aid public health researchers and policy makers to improve child mortality statistics.

7.1 Overview of the main findings

Four specific objectives were addressed in this study. First, the determinants of neonatal mortality in Nigeria were examined. Second, the common risk factors associated with post-neonatal, infant, child, and under-5 mortality were examined. Third, the extent to which water and sanitation affects childhood mortality was examined. Last, the effect of solid fuel use on childhood mortality in Nigeria was also examined.

Determinants of neonatal mortality in Nigeria: evidence from the 2008 demographic and health survey[2]

At the community level, the place of residence (rural) was found to be significantly related to the risk of neonatal deaths.[2]At the household level, wealth index was not significantly associated with neonatal mortality. This finding supports previous findings that economic status is less important, particularly during the neonatal period.[3]At the individual level, fourth or higher birth order of neonates with a short birth interval ≤ 2 years and neonates with a higher birth order with a longer birth interval > 2 years significantly increased neonatal death. Other significant individual-level factors that were associated with neonatal mortality included male neonates, caesarean delivery, smaller than averaged size at birth, and child bearing at a younger age (< 20 years).

Risk factors for post-neonatal, infant, child, and under-5 mortality in Nigeria: A pooled cross-sectional analysis[4]

Living in a poor household, living in a rural area, and having a mother with no schooling were consistently related to death of children < 5 years old across each of the four age ranges (0–11 months, 1–11 months, 12–59 months, and 0–59 months). Other factors related to children's death are discussed in each of the age ranges below.

Post-neonatal (1–11 months): In this study, post-neonates born to mothers from poor or middle-class households were significantly associated with post-neonatal death. Living in a rural area was also found to be a risk factor associated with post-neonatal death. At the individual level, post-neonatal death was significantly increased in post-neonates whose mothers had no formal education, mothers whose age was < 20 years, and fourth or higher birth order with a short birth interval ≤ 2 years. A birth size that was perceived by mothers as small or smaller was also significantly related to post-neonatal mortality.

Infant (0–11 months): The risk of infant death was significantly increased in infants whose mothers were from poor or middle-class households. Infants whose birth size was perceived by mothers as small or smaller and infants born to younger mothers (< 20 years) were identified as factors hindering child survival. Additionally, this study showed that infants of illiterate mothers, infants whose deliveries occurred by caesarean section, infants living in rural areas, infants of fourth or higher birth order with a birth interval ≤ 2 years, and male infants were significantly associated with infant mortality.

Child (12–59 months): Children whose mothers had either no formal education or had a primary education reported a significantly increased risk of child mortality. In addition, children from poor households and children whose mothers resided in rural areas were significantly associated with child mortality.

Under-5 (0–59 months): Analysis of pooled 2003, 2008, and 2013 NDHS data showed that the likelihood of deaths of children < 5 years old was associated with living in rural areas, households with poor economic status, or mothers with no formal education. Fourth or higher birth order with a short birth interval ≤ 2 years was also found among smaller than average size at birth as perceived by mothers, child bearing at a younger age (< 20 years), birth through caesarean section, and being a male child.

Impact of water and sanitation on childhood mortality in Nigeria: evidence from demographic and health surveys, 2003–2013[5]

Neonatal (0–28 days): Findings from analysis of pooled 2003, 2008, and 2013 NDHS data indicated that neonates born to mothers in households with access to unimproved water and sanitation had a slightly increased risk of neonatal mortality, but this was not statistically significant. Other significant factors that affected neonatal death in addition to unimproved water and sanitation were neonates born to mothers younger than 20 years old, neonates whose body size was perceived by their mothers as small or smaller, neonates from poor households, neonates not currently breastfed, and male neonates.

Post-neonatal: The risk of post-neonatal deaths was significantly associated with the combined effect of unimproved water and sanitation. In addition to households having both unimproved water and sanitation, post-neonates had a significantly higher risk of death if their fathers had no formal education or post-neonates whose birth size was perceived as small or smaller by their mothers. Post-neonates who were not currently breastfed were significantly associated with post-neonatal mortality.

Child: Children having access to both unimproved water and sanitation had a significantly increased risk of child mortality. Other factors significantly associated with child mortality in addition to unimproved water and sanitation were children who were not currently breastfed, children whose fathers had no formal education, and children from low economic households.

Effect of solid fuel use on childhood mortality in Nigeria: evidence from the 2013 cross-sectional household survey[6]

Neonatal: Approximately, 0.8% of neonatal deaths between 2008 and 2013 could be attributed to the use of solid fuels. Neonates born to mothers in households using solid fuels for cooking had a slightly elevated risk of neonatal mortality, but this was not significant. Other significant factors associated with neonatal deaths were neonates born to mothers < 20 years of age, male neonates, neonates born to mothers living in rural areas, neonates not currently breastfed, and neonates whose body size was perceived by their mothers as small or smaller. A household with a low economic status was also significantly related to neonatal mortality.

Post-neonatal: Approximately 43% of the post-neonatal deaths for the 5-year period preceding the 2013 NDHS survey could be attributed to the use of solid fuels. The effect of solid fuel use was pronounced during the post-neonatal period. Post-neonates had the highest significant risk of mortality among the other ages. Other significant risk factors associated with post-neonatal death included post-neonates whose mothers resided in rural areas, post-neonates born to mothers younger than 20 years of age, and post-neonates not currently breastfed. In addition to households using solid fuel for cooking, post-neonates whose mothers were from poor households had a significantly increased risk of death.

Child: Approximately 36% of the child deaths for the 5-year period prior to the 2013 NDHS survey may have been attributed to the use of solid fuels. Children aged between 12 and 59 months living in households using solid fuels for cooking had a greater risk of death. Other significant factors associated with child mortality included children whose mothers had no formal education or had a primary education, children of mothers residing in rural areas, and children from low economic households.

7.2 Policy implications of the findings

The findings presented in this thesis indicate the importance of formulating and implementing effective policies, plans, and strategies to enhance child health in Nigeria. To successfully accomplish these goals, economic, social, and political commitments from the three tiers of government (federal, state, and LGA) are crucial to effectively reduce deaths of children < 5 years of age and to increase investment in water, sanitation, and clean cooking stoves.

Community orientation and awareness on the importance of improving child health

Adequate promotional programmes for orienting and educating the community regarding major factors associated with an increased risk of neonatal death and death during the post-neonatal periods (post-neonatal, infant, and child) will greatly help to improve child survival in Nigeria. Therefore, public health interventions specifically targeting risk groups in the community to reduce preventable neonatal death should focus on educating community health workers and traditional birth attendants on safe delivering practice because the majority of newborn deliveries in Nigeria occur at home.[7-9] Such intervention programmes should also include the benefits of KMC methods on low birth weight newborns or small-sized newborns, spacing of children, and delay of the first pregnancy, especially women who marry below the age of 20 years. Similarly, the high mortality in the post-neonatal, infant, and child periods observed in the current study strongly supports intervention initiatives targeting mothers living in rural areas and mothers with low socioeconomic status, which will contribute to improvement of under-5 mortality statistics in Nigeria.

Availability and accessibility of improved water and sanitation

Access to improved water and sanitation in children < 5 years old is essential. Therefore, concerted efforts by the three tiers of government in Nigeria are required to formulate and implement policies, plans, and strategies that will encourage and promote public and private stakeholders to increase investment in water and sanitation. Unimproved water and sanitation in the community increased the risk of death among children under 5 years old in the current study. The present study showed that improved water and sanitation community-based interventions are crucial for preventing under-5 death, and that such interventions should target low socioeconomic households in Nigeria.

Improving the availability and accessibility of efficient cooking stoves

This study established that household use of solid fuel (wood and coal) for cooking and heating homes increased the risk of post-neonatal and child mortality. The benefit of households using efficient cooking fuel for reducing deaths of children < 5 years old indicates the importance of implementing policies that will provide affordable and accessible efficient cooking stoves, particularly in rural areas. Findings of this study suggest the need to adequately create and promote public awareness of the health hazard of using solid fuel and to implement community-based domestic energy interventions targeting rural and low socioeconomic status households to enhance child survival in Nigeria.

7.3 Strengths and limitations of the research

The strengths and weaknesses of this study need to be considered when drawing specific inferences. The strengths of this study are as follows. (1) Data used for this study were obtained from the NDHS, a nationally representative survey, which reflects every ethnic and local group in Nigeria. The survey method used in the NDHSs is a well-established survey design to minimise selection bias, with high levels of participation across each of the surveys (ranging from 95% to 98%). In the current study,[5] data of three NDHSs were pooled to provide a large sample size of deaths to examine the effect of water and sanitation on neonatal, post-neonatal, and child mortality, as well as risk factors associated with under-5 mortality. (2) Recall errors arising from dates of birth and death provided by women who were interviewed and bias that may have arisen from changes in household characteristics were minimised by restricting all analyses to births within the 5-year period preceding each of the surveys. (3) Estimates provided in this study were population-based, which increases the validity, and can be generalisable to the wider Nigerian population (> 350 ethnic groups with different cultures, religions, and life style). (4) To the best of my knowledge on the Nigeria public health literature, this study is the first to perform a nationally representative analysis of determinants of neonatal mortality, effects of water and sanitation, as well as effects of solid fuel use on childhood mortality in Nigeria. (5) The definitions of water and sanitation indicators, and cooking fuel indicators that were used were based on those recommended by the WHO. (6) The proportion of missing data was relatively small, such that it may not have affected estimates in this study.

Despite the strengths outlined above, a number of limitations were also present in the study and they are as follows. (1) The DHSs are the largest source of national data, but they are expensive and time-consuming, and in Nigeria, this survey is usually conducted once in every 5 years. (2) Only surviving mothers were interviewed, which may have led to under-reporting of the number of neonatal deaths because of the relationship of newborn death with maternal death.[9] (3) Information on the medical status of children younger than 5 years old and causes of death was lacking in the NDHS data. (4) Quality of the water sources, as well as information on maintenance of existing water supply infrastructure[10], was not considered. (5) Information on households that use a combination of solid and non-solid fuels was not available from the NDHS, and misclassification of use of cooking fuels may have occurred. (6) Other important variables, such as gestational age, birth weight at birth, ventilation facility, duration of cooking, and frequency of cooking, were lacking in information in the NDHS. (7) Causal effects could not be measured because the analyses were based on a retrospective, cross-sectional study.

7.4 Future research

The research in this thesis has identified a number of areas that could be further explored that may aid the government of Nigeria to formulate and adjust health policies to improve child healthcare services. They are as follows.

1. Evidence from the NDHSs has shown that nearly 70% of births in Nigeria occur at home. Therefore, qualitative studies are required to investigate the quality of care provided to mothers who deliver using traditional birth attendants, particularly in rural communities. This will aid in providing appropriate training or refresher training to traditional birth attendantsto improve the quality of care provided to newborns in Nigeria.

2. The effects of medical status, verbal autopsy, and birth weight at birth on children < 5 years old need to be further investigated using a community-based, randomised, controlled trial approach. This is because the medical status of these children is unknown at the time of the NDHSs and the majority of the infants are not weighed at birth. The mother's perceived size of their newborns was used in place of birth weight at birth in this study. However, the rationale that mothers used in estimating the size of their newborn remains unclear.

3. Quality and safety of the water sources, as well as water storage facilities, were not considered in this study, even though the water was from improved sources. Therefore, further exploration of the quality of water sources is important. The results of such study would provide guidance on water indicators that are safe to use in the Nigerian context.

4. Children aged between 1 and 4 years are mobile. As a result, they are more likely to be exposed to indoor and outdoor air pollution, and only indoor pollution was considered in this study. Therefore, incorporating outdoor air pollution in future studies is important to validate the estimates obtained in this study.

7.5 Conclusion

Modelling child mortality and its environmental effects provides an important framework for public health researchers and policy makers in reviewing and designing new effective intervention programmes that aim at improving child health. The relevance of this thesis in the field of global health and medical statistical application are as follows:

1.) Public health researchers should consider using the Cox regression method in modelling child mortality to produce a better estimate than logistic regression because it adjusts for time to events.

2.) Public health researchers should consider adjusting for potential confounding variables by using the Mosley and Chen conceptual framework to eliminate any confounders.

3.) The neonatal mortality rate in Nigeria is still high and is driven by child spacing, child bearing at a younger age, and newborns born in rural areas. These findings indicate that the present family programme in Nigeria should be reviewed and strengthened to ensure that women who marry below the age of 20 years are adequately informed and encouraged to delay their first pregnancy and perform birth spacing. In addition, addressing the infrastructural imbalance in rural communities by providing well-equipped health facilities will play a major role in reducing neonatal mortality.

4.) Similarly, the high number of deaths in the post-neonatal, infant, and child periods are mainly affected by mothers with no formal education, a poor household, and rural dwelling. These findings imply that public health programmes in Nigeria should engage in providing effective training to illiterate women, particularly those in rural communities on how best to care for infant and child health. This training should include the importance of early and exclusive breastfeeding, complementary feeding at approximately 6 months of age, benefits of using health facilities to care for ill infants, and addressing harmful practices that may affect the infant's growth.

5.) Access to unimproved water and sanitation facilities significantly increases the risk of post-neonatal and child death during the period under study. Adequate provision of infrastructural amenities, such as portable water, electricity, and improved sanitation facilities through public-private partnership initiatives are required, especially in economically deprived communities to prevent child death.

6.) Use of solid fuel for cooking and heating homes was also found to increase the risk of post-neonatal and child deaths. Effective strategies need to be implemented to improve access to modern cooking fuels, such as liquefied petroleum gas, particularly in rural communities that heavily depend on traditional cooking stoves. Effective public awareness of the risks of using solid fuel should include effects on health, burns and scalding from open fire, injury sustained while collecting firewood, and increased deforestation.

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