Social determinants and child survival in Nigeria in the era of Sustainable Development Goals: Progress, challenges, and opportunities

By

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A Thesis submitted to the College of Graduate and Postdoctoral Studies
University of Saskatchewan
In Partial Fulfillment of the Requirements of the Degree of

Doctor of Philosophy
In
Community and Population Health Sciences

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Abstract

Introduction: Like in many low- and middle-income settings, childhood mortality remains a big challenge in Nigeria—being the second largest contributor to under-five mortality globally, after India. Currently, there is little local evidence to guide policymakers in Nigeria to tailor appropriate social interventions to make the Sustainable Development Goal (SDG) targets of child survival (SDG-3), gender equality (SDG-5), and social inclusiveness (SDG-10) achievable by 2030. In addition, lack of methodological rigor and theoretical foundations of child survival research in Nigeria limit their use for proper planning of child health services.

Aims: The basis of this thesis is to understand the complex issues relating to child survival and recommend new approaches to guide policymakers on interventions that will improve child survival in Nigeria. The overarching goal of this thesis is to address the methodological and theoretical shortcomings identified in the previous studies conducted in Nigeria. Using robust interdisciplinary analytic techniques, this thesis assessed the following specific objectives.

Objective 1: (a) Compare predictive abilities of the most used conventional statistical time-series methods—ARIMA and Holt-Winters exponential smoothing models, with artificial intelligence technique such as group method of data handling (GMDH)-type artificial neural network (ANN), and (b) estimate the age- and sex-specific mortality trends in child-related SDG indicators (i.e., neonatal and under-five mortality rates) over the 1960s-2017 period, and estimate the expected annual reduction rates needed to achieve the SDG-3 targets by projecting rates from 2018 to 2030.

Objective 2: (a) Identify the social determinants of age-specific childhood (0-59 months) mortalities, which are disaggregated into neonatal mortality (0-27 days), post-neonatal mortality (1-11 months) and child mortality (12-59 months), and (b) estimate the within- and between-community variations of mortality among under-five children in Nigeria.

Objective 3: Identify the critical pathways through which social factors (at maternal, household, community levels) determine neonatal, infant, and under-five mortalities in Nigeria.

Objective 4: (a) Determine patterns and determinants of geographical clustering of neonatal mortality at the state and regional levels in Nigeria, (b) assess gender inequity for neonatal mortality between urban and rural communities across the regions in Nigeria, and (c) measure gaps in SDG-3 target for neonatal mortality at the state and regional levels in Nigeria.

Methods: This thesis is a quantitative study which used two secondary datasets—aggregated historical childhood mortality data from 1960s to 2017 (objective 1), and the latest (2016/2017) Nigeria Multiple Indicator Cluster Survey (MICS) for 36 states and Federal Capital Territory (FCT) in Nigeria (objectives 2-4). To minimize recall bias, analysis was limited to a weighted nationally representative sample of 30,960 live births delivered within five years before the survey. The selection of relevant social determinants of child survival was primarily informed by Mosley-Chen framework. The candidate variables were layered across child, maternal, household, and community-levels. The analytic approaches include artificial intelligence technique (i.e., group method of data handling (GMDH)-type artificial neural network, and multilayer perceptron (MLP) neural network), autoregressive integrated moving average (ARIMA), Holt-Winters exponential smoothing models, spatial cluster analysis, hierarchical path analysis with time-to-event outcome, and multilevel multinomial regression.

Results: Progress towards achieving SDG targets – Nigeria is not likely to achieve SDG targets for child survival and, within, gender equity by 2030 at the current annual reduction rates (ARR) under-five mortality rate (U5MR): 1.2%, and neonatal mortality rate (NMR): 2.0%. If the current trend continues, U5MR will begin to increase by 2028. Also, at the end of SDG-era, female deaths will be higher than male deaths (80.9 vs. 62.6 deaths per 1000 live births). To make child-related SDG targets achievable by 2030, Nigeria needs to reduce annual U5MR by 9 times and annual NMR by 4 times the current rate of decrease.

Social determinants of childhood mortality – At each stage of early childhood development, there are different factors relating to survival outcomes. Surprisingly, attendance of skilled health providers during delivery was associated with an increased neonatal mortality risk, although its effect disappeared during post-neonatal and toddler/pre-school stages. The observed association requires cautious interpretation because of unavailability of variables on quality of care in MICS dataset to assess how skilled birth delivery impacts child survival in Nigeria. However, there is a possibility of under-reporting under-five mortalities at the community level. Also, it could indicate a functioning referral system that sends the high-risk deliveries to health facilities to a greater extent. There is a large variation (39%) of under-five mortalities across the Nigerian communities, which is accounted for by maternal-level factors (i.e., maternal education, contraceptive use, maternal wealth, parity, death of previous children and quality of perinatal care).

Pathways to childhood mortality – Region and area of residence (urban/rural), infrastructural development, maternal education, contraceptive use, marital status, and maternal age at birth were found to operate indirectly on neonatal, infant and under-five survival. Female children, singleton, children whose mothers delivered at least two years apart and aged 20-34 years survived much longer. Specifically, women from Northern areas of Nigeria were less likely to reside in urban cities and towns than those in the Southern areas. This, in turn, limited their access to social infrastructure and acted as a barrier to maternal education. Without adequate education, women were less likely to use contraceptive methods. Women with no history of contraceptive use were more likely to have childbirths closer together (less than two-year gap), which in turn, negatively impacted child survival.

Regional inequities in childhood mortality – There was significant state-level clustering of NMR in Nigeria. The states with higher neonatal mortality rates were majorly clustered in the North-West and North-Central regions, and states with lower neonatal mortality rates were clustered in the South-South and South-East regions. Gender inequity was worse in the rural areas of Northern Nigeria, while it was worse in the urban areas of Southern Nigeria. NMR was disproportionately higher among females in urban areas (except North-West and South-West regions). Conversely, male neonates had higher mortality risks in the rural areas for all the regions.

Conclusions: This thesis provides more refined age- and sex-specific mortality estimates for Nigeria. At the current rates, Nigeria will not meet SDG targets for child survival. In addition, this thesis identifies the critical intervention pathways to child survival in Nigeria during the SDG-era. The new estimates may be used to improve the design and accelerate the implementation of child health programmes to attain the SDG targets. Also, it is important for stakeholders to implement more impactful policies that promote maternal education and improve living conditions of women (especially in the rural areas). To address gender inequities, gender-sensitive policies, and community mobilization against gender-based discrimination towards girl-child should be implemented. Further research is required to assess the quality of skilled birth attendants in Nigeria.

Acknowledgments

My foremost gratitude goes to God for giving me the strength to complete the PhD programme.

I am forever indebted to my supervisor and mentor (Prof. Nazeem Muhajarine) for his tireless guidance, constant support and critical feedback/edits that shaped the outcome of this work. His exemplary mentorship has made the whole journey rewarding. The dedication of my thesis advisory committee members (Prof. Anne Leis (Committee Chair), Prof. Punam Pahwa, Prof. Pammla Petruka, and Dr. Isaac Elon) are highly appreciated. I wish to extend my heartfelt gratitude to the administrative staff and my teachers for their willingness to share knowledge and continuous support. I would also like to appreciate feedback received from my professional learning circle (Dr. Daphne McRae, Dr. Dinesh Dharel, Mrs. Isabella Dena, Mrs. Vaidehi Pisolkar, and Dr. Fernanda Andre).

Furthermore, I would like to express my gratitude to the College of Medicine, University of Saskatchewan for the College of Medicine Graduate Awards (CoMGRAD) which afforded me the opportunity of studying at the University.

Much appreciation to my wife (Mrs. Amaka Catherine Adeyinka) for her unflinching love, trust, and supportive roles throughout the academic journey. I wish to thank my parents for setting my feet on the right path early in life and my siblings for their words of encouragement. I acknowledged the valuable words of encouragement from my In-law (Mrs. Aworh), and friends (Dr. Babayemi Olakunde, Dr. Oluwafemi Oluwole, and Mr. Kehinde Dada).

Dedication

This thesis is dedicated to my loving wife (Mrs. Amaka Adeyinka) and my children (Adebare, Adeiye and Ademidun Adeyinka). Thank you for your love and encouragement despite the long distance between us. Also, this work is dedicated to my parents who made sacrifice for me so that I can become treasured in life. To my maternal grandmother who showed me love and care but could not live to this moment to share my joy. Also, this work is dedicated to all under-five children.

Thesis structure

This thesis is presented in a manuscript-style, consisting of five interrelated series of manuscripts prepared for journal publication. This thesis is organized into 10 chapters. The references are listed chapter-by-chapter. Chapter 1 provides background to the study (in relation to the child health targets of the Millennium Development Goals and Sustainable Development Goals) and discusses the existing gaps in child healthcare in Nigeria. The chapter highlights the significance of the study, its anticipated impacts, originality, and specific objectives. Chapter 2 introduces the theoretical frameworks and literature review. It identifies the methodological issues in child survival and highlights the key social determinants of health considered from the conceptual model (majorly developed from Mosley-Chen framework). Chapter 3 discusses child and maternal health in Nigeria, and government's efforts at reducing childhood mortality. Chapter 4 introduces the study design, data sources, data quality checks, ethical considerations, and overview of analytic approach. Chapters 5 to 9 are the individual manuscripts, addressing the specific objectives of this thesis. The last chapter (Chapter 10) provides general discussion, theoretical and methodological considerations, conclusion, suggestions for future research, knowledge translation plan, and recommendations for policy actions. For ease of referencing, supplementary materials are attached as appendices A-G.

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List of Abbreviations

ACF:	Autocorrelation function
AFT:	Accelerated Failure Time
AIC:	Akaike's information criterion
AIDS:	Acquired Immune (or immuno-) Deficiency Syndrome
ANC:	Antenatal care
ANN:	Artificial neural network
ARIMA:	Autoregressive integrated moving average
ARR:	Annual rate of reduction
BFHI:	Baby-Friendly Hospital Initiative
BIC:	Bayesian information criterion
CDC:	Centers for Diseases Control and Prevention
CHEW:	Community Health Extension Workers
CHO:	Community Health Officers
CI:	Confidence interval
CRC:	Convention on the Rights of the Child
DAG:	Directed Acyclic Graphs
DF test:	Dickey-Fuller test
DHS:	Demographic and Health Surveys
DM test:	Diebold-Mariano test
DV:	Dependent variable
EA:	Enumeration Areas
EHO:	Environmental Health Officers
EML:	Essential Medicines and Equipment List
FCT:	Federal Capital Territory
FG:	Federal Government
FMC:	Federal Medical Centre
FMOH:	Federal Ministry of Health
GDP:	Gross Domestic Product
GIS:	Geographic Information System
GMDH:	Group method of data handling
HBI:	Healthy Beginning Initiative
HIV:	Human Immunodeficiency Virus
HW:	Holt-Winters
ICC:	Intra-cluster correlation
ICCM:	Integrated Community Case Management
IMCI:	Integrated Management of Childhood Illness
IRB:	Institutional Review Boards
JMP:	Joint Monitoring Programme
KMO:	Kaiser-Meyer-Olkin

LGA:	Local Government Areas
LISA:	Local spatial autocorrelation
LMICs:	Low- and middle-income countries
LPG:	Liquefied petroleum gas
MAE:	Mean absolute error
MAPE:	Mean absolute percentage error
MDG:	Millennium Development Goals
MICS:	Multiple Indicator Cluster Surveys
MLP:	Multilayer perceptron
MNCH:	Maternal, Newborn and Child Health
MOR:	Median odds ratio
MSS:	Midwives Service Scheme
NBS:	National Bureau of Statistics
NCWC:	National Child Welfare Committee
NDHS:	National Demographic and Health Surveys
NGA:	Nigeria
NGO:	Non-governmental organizations
NHIS:	National Health Insurance Scheme
NHREC:	National Health Research Ethics Committee
NISH:	National Integrated Survey of Households
NMR:	Neonatal mortality rate
NPC:	National Population Commission
NPHCDA:	National Primary Health Care Development Agency
NPOA:	National Program of Action
NSE:	Nash-Sutcliffe efficiency coefficient
OAU:	Organization of African Unity
OPEC:	Organization of Petroleum Exporting Countries
OR:	Odds ratio
PACF:	Partial autocorrelation
PCA:	Principal Components Analysis
PCV:	Proportional change in variance
PHC:	Primary Health Care
PI:	Prediction interval
PNC:	Postnatal care
PPP:	Purchasing Power Parity
PSU:	Primary sampling unit
RMAE:	Root mean absolute error
RMSE:	Root mean squared errors
ROC:	Receiver operating characteristics
RRR:	Relative risk ratio

SAP: Structural adjustment programmes
SD: Standard deviation
SDG: Sustainable Development Goals
SEM: Structural equation model
SOML: Saving One Million Lives
SURE-P MCH: Subsidy Reinvestment and Empowerment Programme for Maternal and Child Health
TCP: Tri-Council Policy
TR: Time ratio
U5MR: Under-five mortality rate
UHC: Universal Health Coverage
UN: United Nations
UNDP: United Nations Development Programme
UNFPA: United Nations Population Funds
UNICEF: United Nations International Children's Emergency Fund
UN-IGME: United Nations Inter-agency Group for Child Mortality Estimation
US: United States
USAID: United States Agency for International Development
VIF: Variance inflation factor
VIP: Ventilated improved pit latrine
WGS: World Geodetic System
WHO: World Health Organization
WSC: World Summit of Children

“The global child mortality curve doesn’t tell the whole story. It hides an important insight about what it will take to save the next 5 million”

Melinda Gates

Co-chair, Bill & Melinda Gates Foundation

Chapter 1

Introduction—setting the stage

Chapter 1 provides background to the study (in relation to the child survival, gender equity and social inclusion targets of the Sustainable Development Goals) and discusses the existing gaps in child healthcare in Nigeria. The chapter highlights the significance of the study, its anticipated impacts, originality, and objectives.

1.1 Background

High mortalities (5.4 million) occurring annually during the first five years of life remain major public health concerns worldwide despite the persistent national and international efforts to reduce neonatal, infant and under-five mortalities and morbidities.(1–3) Over the years, child health has been the focus of the United Nations (UN) because it is one of the basic indicators of any country's socio-economic status and quality of life of its citizenry.(4) Moreover, it gives insight to the health status of the mother, economic status of the family and maternal health seeking behavior during pregnancy and afterwards. It is on this note that 189 countries adopted the United Nations' Millennium Declaration, otherwise known as the Millennium Development Goals (MDGs) on 8th September, 2000.(5) The MDGs were eight sets of goals with specific targets aimed at combating extreme poverty, illiteracy, gender inequality, childhood mortality, maternal morbidity and mortality, HIV/AIDS, malaria and other diseases, environmental degradation, and to foster global partnerships for development. Specific to child health, the MDG-4, which was developed to reduce neonatal, infant and under-five mortality rates by two thirds between 1990 and 2015, could not be achieved in most of the resource-limited countries including sub-Saharan African and Southern Asian countries.(1,5) The MDG-4, however, generated momentum for collaborative efforts to improve child health. In September 2015, the United Nations General Assembly formulated the Sustainable Development Goals (SDGs) to replace the MDGs. The beginning of the SDG-era is a global opportunity to build on the achievements of MDGs. The SDGs are 17 integrated goals, 169 targets, and 232 indicators that emphasize social inclusion, universal health care, gender equality, sustainable ecosystem, global partnerships, eradication of extreme poverty and malnutrition, and promote well-being across all ages.[5] The child health related MDG target 4A has been superseded by the SDG target 3.2 with more ambitious targets, specifically calling for 12 neonatal deaths and 25 under-five deaths per 1,000 live births by the year 2030.[5] Achieving the child health-related SDG targets by 2030 would require greater efforts at reducing preventable deaths among children in their first five years of life. Given the intersectionality of the SDGs, the SDGs 3, 5, and 10 are firmly built on the foundation of the social determinants of health (Figure 1.1). The three goals support the strategic vision of equity in child survival (i.e., survival goals must be achieved for every child).

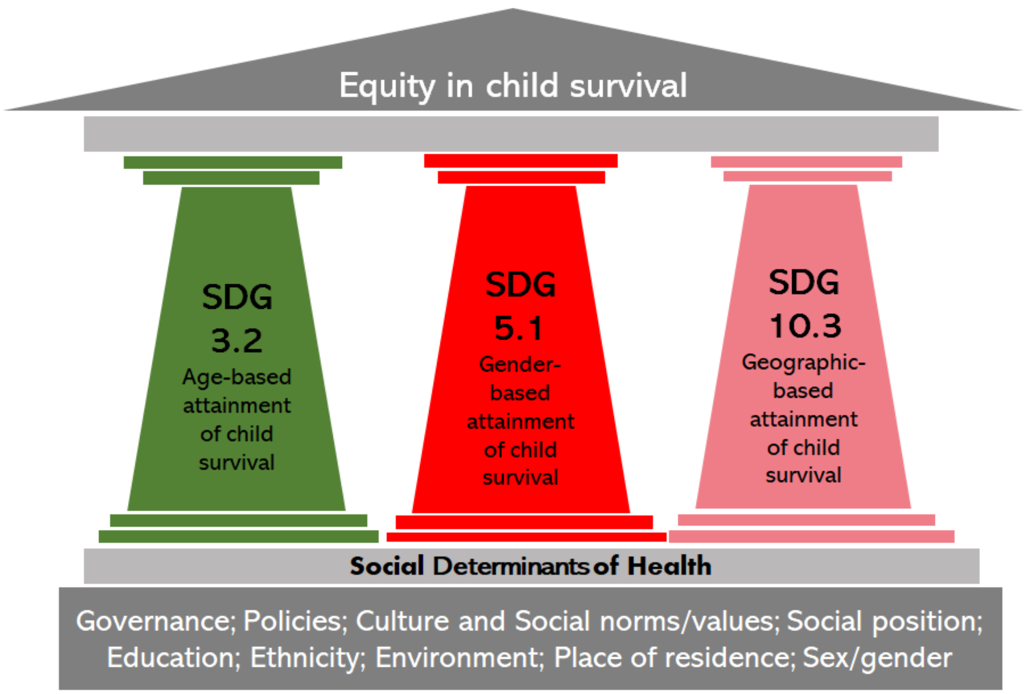

Figure 1.1: Pillars and foundation of child survival during the SDG-era (Source: author)

Notwithstanding the remarkable global progress in reducing mortalities among under-five children, huge disparities in health status were observed between regions and within countries as outlined in SDG 10 targets (Figures 1.2a and b).[1] As the core of SDGs lies in the mantra that "no individual is left behind", attention should be given to improving child health in sub-Saharan Africa, with emphasis on the creation of cost-effective and sustainable strategies to address structural and social determinants of maternal and child health.

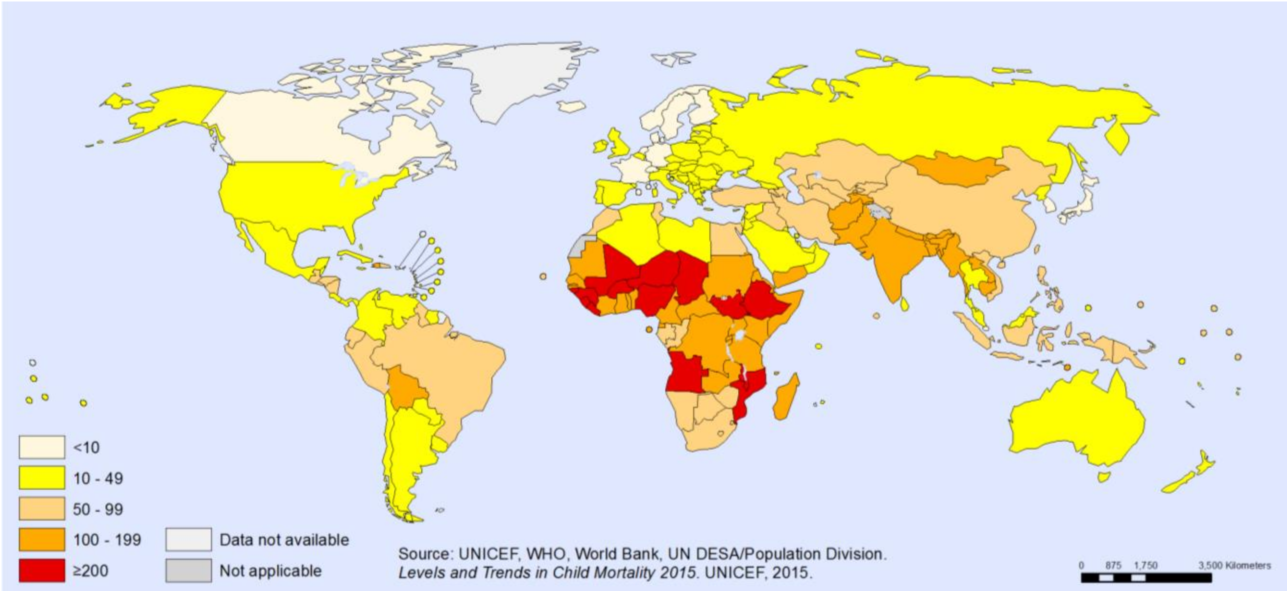

Figure 1.2a: Under-five mortality rates in 1990, by country[6]

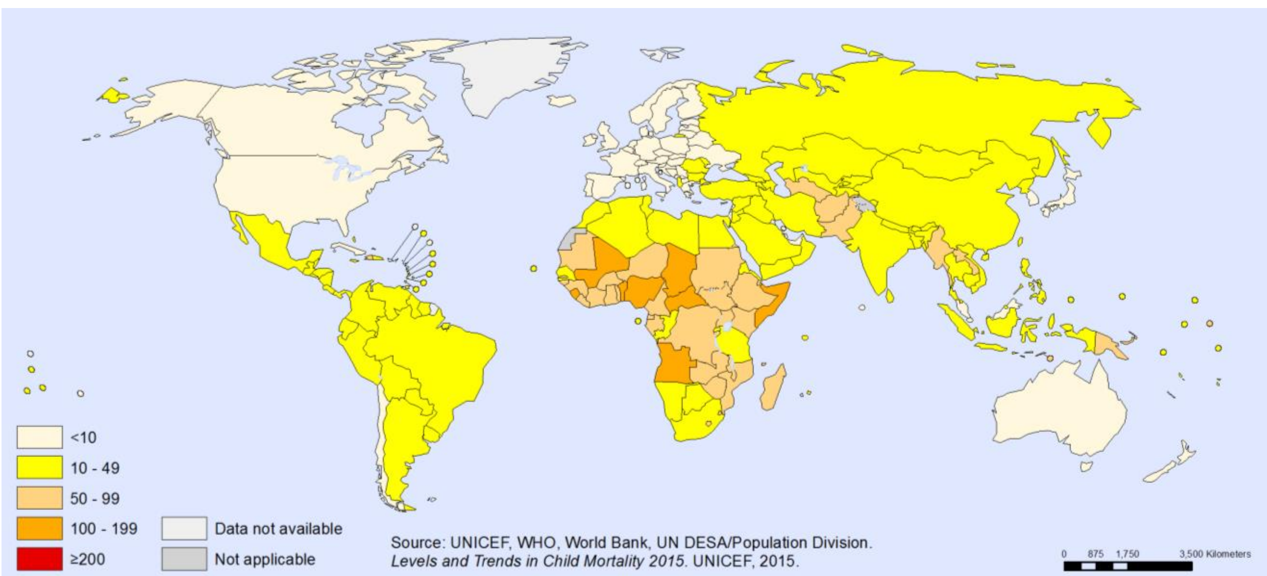

Figure 1.2b: Under-five mortality rates in 2015, by country[7]

The impact of under-five mortality is significantly felt in West African countries[8] as the sub-region accounts for nearly half of the 10 countries with the highest rates of under-five mortality.[9] Also, three West African countries have rates above 100 deaths per 1,000 live births (i.e. Sierra Leone (114), Mali (110) and Nigeria (104))[1,9–12], which emphasizes that more than 10 out of 100 children will die before reaching the age of five years in Nigeria. Also, this number is four times the 2030 United Nations SDG-3 target of one death per every 40 children. Nigeria is the second and third largest contributor to the global under-five and infant deaths,[1,13,14] respectively, and it is one of the countries making the slowest progress with mortality reduction.[10,15] In 2013, Nigeria recorded about 2,300 under-five deaths daily resulting in nearly 1 million under-five deaths annually.[16] The neonatal and infant mortality rates for Nigeria in 2015 were 34 and 69 deaths per 1,000 live births, respectively.[1] Achieving the SDG 3, 5, and 10 targets by 2030 remains a challenge in Nigeria despite the political commitment and efforts geared towards ending childhood mortality and gender discrimination in recent years.[3,17,18]

1.2 Problem statement

Keeping children alive is one of the most pressing concerns in low- and middle-income countries (LMICs) in recent years because of persistent high childhood mortalities. While it remains a challenge, there is also little local evidence to guide policymakers on appropriate social interventions to reduce the large number of children dying in Nigeria during the SDG-era. Over the years, implementation of medical and healthcare interventions in the Nigerian communities have moderately reduced childhood mortality but focusing majorly on healthcare interventions might not be enough to accelerate mortality targets during SDG-era. In addition to medical/healthcare interventions, efforts that would address a wide range of social factors affecting the disadvantaged children are needed. In highly unequal societies (as in the case of Nigeria), the poorest and most marginalized are often left out during programme design and implementation.

Research on childhood mortality in LMICs (including Nigeria) has a long tradition, and there have been accumulated evidence pointing to social determinants of health (SDH) such as socioeconomic, environmental, and cultural factors.[8,13,14,19–22] However, the roles of these multiple factors in the sequence of childhood mortality in Nigeria are complex, and are seldomly presented in epidemiological studies. It is important to understand the chains of consecutive events that are responsible for childhood mortality, with the aim of breaking the chain. As analytic techniques are evolving, there is an opportunity to test some state-of-the-art modeling techniques to advance current knowledge of childhood mortality—a social issue, through interdisciplinary research techniques. Better understanding of the sequence of social events leading to childhood mortality can guide policymakers in developing more impactful interventions. In addition, studies in Nigeria and other resource-limited settings have focused on the determinants of neonatal, infant and under-five mortalities,[8,13,14,21–26] and post-neonatal and child mortalities have not been explicitly investigated to identify the contrasting roles of socioeconomic factors across the different stages of early childhood development. Also, gender-based discrimination has resulted to unequal survival outcomes in the early phase of childhood development.[1] Despite high gender imbalance in child health,[1] there is no information on gender-based attainment of child survival outcomes during the SDG era for Nigeria.

1.3 Significance of the study and anticipated impacts

Childhood death is a tragic experience for the family and larger society that must be evaded at all costs. Saving children's lives is of fundamental importance to national development. Interventions and policies that would reduce childhood deaths hinge on a sound understanding of the complex paths through which social factors (maternal, household, and community) determine childhood deaths in Nigeria and other resource-limited countries. Also, there continues to be dialogue about factors contributing to age- and sex-specific mortalities, and their geographical variations among children in many resource-limited countries (including Nigeria). Thus, identifying the key determinants of age- and sex-specific childhood mortalities is crucial for all stakeholders in Nigeria to fast-track achievement of the SDGs-3 and 5 by 2030. Therefore, it is important to understand which social factors (i.e., maternal-, household-, and community-level factors) contribute to health inequity and the complexity of childhood mortality. More so, newer studies spanning a range of factors are needed during SDG-era for creating and mobilizing theories of change to inform policy and practice in Nigeria and similar settings. Considering that under-five mortality rate is high in sub-Saharan Africa and Southern Asia regions, this thesis offers guidance on formulation and implementation of child survival interventions, necessary to achieve SDG targets by 2030. Recognizing differing sociocultural contexts among countries, the maternal and child health strategies proposed in this thesis may be more adaptable in countries with similar socio-economic and historical contexts with Nigeria (e.g., Anglophone LMICs).

As at the time of thesis writing, there have not been studies in Nigeria that analyzed data collected after September 2015 (post-MDG implementation period) to investigate the social determinants of neonatal and under-five mortalities in the SDG-implementation era. In the same vein, the problem with implementation of child survival policies is the limited evidence on the future trajectories of childhood mortalities to potentially guide health programming in the country. On these grounds, this thesis utilized large population-based cross-sectional data from Nigeria's 2016/2017 Multiple Indicator Cluster Survey (MICS),[(27)] to provide a framework for the policymakers towards achieving SDG-3, 5 and 10 targets by 2030.

For proper planning and evaluation of child survival programmes in Nigeria, it is necessary to refine childhood mortality estimates, and generate temporal trends of mortality targets (age-, sex- and geographic). By analysing the historical data on the yearly childhood mortality rates for Nigeria, this thesis generated future long-term childhood mortality trends and expected annual reduction rates (ARR) needed to accelerate child survival for Nigeria.

This study is timely as it comes during the transition to the SDG implementation era. Through a broader understanding of complex issues relating to child survival, it opens-up new fronts of intervention, such as communities. It recommends new approaches to guide policymakers on interventions to improve child health in Nigeria and LMICs. The thesis developed appropriate models of accelerating the target of reducing childhood mortality in Nigeria. Although this thesis utilized cross-sectional and time-series studies, it addresses some of the methodological issues (discussed in chapters 5-9) in survival analysis by using novel analytic methods and advances our knowledge to exploring the influence of social determinants of health on child survival.

1.4 Originality

This thesis adds value to child health at methodological as well as theoretical and policy levels. With advancement in statistical and epidemiological methods, there are new opportunities to use emerging quantitative research methods to shed light onto the subject area of child survival in LMICs. In addition to epidemiological and demographic theories, this thesis utilized novel approaches that are hidden from the main stream public/ population health researchers to address complex research questions through interdisciplinary analytical techniques in the fields of computer science/engineering (artificial intelligence—group method of data handling (GMDH)-type artificial neural network and multilayer perceptron (MLP) artificial neural network), geography (spatial autocorrelation analysis), biostatistics/mathematics (time-series—autoregressive integrated moving average (ARIMA) and Holt-Winters exponential smoothing models; hierarchical path analysis with time-to-event outcome, and multilevel multinomial regression). The specific contributions of the analytical techniques are highlighted in their respective manuscripts (Chapters 5-9). The contributions are summarized as follows:

Methodological contributions

To date and to my knowledge, no published study has made projections of childhood mortality rates using artificial intelligence techniques such as artificial neural network. Time-series analysis and annual rate of progress provide unique approaches to determine the trajectory needed for Nigeria to achieve the child related SDG targets. To maximize predictive power of time-series models, artificial neural network was introduced to address non-linearity of childhood mortality trends in Nigeria. More importantly, long-term sex-specific mortality trends were forecasted to address gender-based attainment of SDG-3 targets in Nigeria.

Another key contribution is that a hybrid model which combined hierarchical path analysis and parametric (lognormal) survival analysis was able to offer critical pathways to childhood mortality by simultaneously analysing complex models. This thesis is further strengthened by using multilevel multinomial regression to determine factors that contribute to community variations of under-five mortality in Nigeria. The rationale for performing multinomial regression is that it provides more accurate predictions than binomial regression for dependent variables with more than two categories. With multilevel analysis, this study addresses the methodological flaws identified in some past studies by accounting for the intra-class clustering effects of the nested data and ecological fallacy. Furthermore, this thesis utilized spatial autocorrelation analysis to provide empirical evidence for geographical clustering of neonatal mortality and its social determinants with a view to improving neonatal survival at the sub-national level in Nigeria.

Theoretical contributions

Most of the studies on child survival in Nigeria have widely used National Demographic and Health Survey (NDHS) data. As far as we know, no study in Nigeria has utilized MICS data to examine the topic of child survival. This thesis potentiates the validation and triangulation of extant evidence by analyzing MICS data to advance the existing knowledge on the subject-matter.

As identified from previous studies, not all the important determinants of health inequity were addressed. This thesis revised the Mosley-Chen framework by incorporating some new variables (e.g., gestation type, maternal media exposure, death of previous children, and community infrastructural development) to generate a model of child survival during the SDG-era in Nigeria and other similar settings—using path analysis. Also, gender gap in neonatal mortalities, disaggregated by urban and rural areas in the geographical regions was sought. The multilevel multinomial analysis shows the comparative roles of social determinants of health at the different stages of early childhood development.

Policy/programmatic contributions

With the year 2030 in mind for the attainment of SDGs, there is an imperative to generate new evidence to re-strategize programmes aimed towards addressing factors affecting child health in Nigeria. This thesis gives recommendations to the stakeholders in developing structured interventions for underserved population groups, such as mothers and children in Nigeria, and other similar settings. It also highlights the need for a policy-shift towards implementing gender-responsive interventions for under-five children and neonates. As it is fundamentally important to reduce social inequities and unfairness within and across communities, states, and regions, this thesis will guide policies and programmatic actions that would potentiate sustainable and equitable decline of childhood mortality across the country during the SDG-era. Practically, the 10 major contributors to global burden of under-five mortalities in sub-Saharan African countries (i.e., Nigeria, Congo DRC, Ethiopia, Tanzania, Angola, Niger, Sudan, Mozambique, Mali, and Chad) may adapt the proposed theory of change model for implementation. As these countries continue in their efforts to prevent childhood deaths through their national child health strategic plans, there are opportunities to prioritize the implementation of the three leverage points identified in the theory of change for accelerating child survival gains before 2030.

1.5 Research purpose and objectives

The overarching goal of this thesis is to address the methodological and theoretical shortcomings identified in the previous studies conducted in Nigeria. In addition, this thesis aims to understand the complex issues relating to child survival and recommend new approaches to guide policymakers on interventions that will improve child survival in Nigeria, as well as in other similar settings during the SDG-implementation era. To achieve the overarching goals, the following specific objectives were formulated:

- **Objective 1:** (a) Compare predictive abilities of the most used conventional statistical time-series methods—ARIMA and Holt-Winters exponential smoothing models, with artificial intelligence technique such as group method of data handling (GMDH)-type artificial neural network (ANN), and (b) estimate the age- and sex-specific mortality trends in child-related SDG indicators (i.e., neonatal and under-five mortality rates) over the 1960s-2017 period, and estimate the expected annual reduction rates needed to achieve the SDG-3 targets by projecting rates from 2018 to 2030.
- **Objective 2:** (a) Identify the social determinants of age-specific childhood (0-59 months) mortalities, which are disaggregated into neonatal mortality (0-27 days), post-neonatal mortality (1-11 months) and child mortality (12-59 months), and (b) estimate the within- and between-community variations of mortality among under-five children in Nigeria.
- **Objective 3:** Identify the critical pathways through which social factors (at maternal, household, community levels) determine neonatal, infant, and under-five mortalities in Nigeria.
- **Objective 4:** (a) Determine patterns and determinants of geographical clustering of neonatal mortality at the state and regional levels in Nigeria, (b) assess gender inequity for neonatal mortality between urban and rural communities across the regions in Nigeria, and (c) measure gaps in SDG-3 target for neonatal mortality at the state and regional levels in Nigeria.

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Chapter 2

Theoretical perspective and literature review

This chapter introduces the key concepts of mortality rates, significance of measuring mortality rates among children, different measures of childhood mortality, theoretical assumptions behind the estimation methods, and methodological issues in estimating childhood mortality rates. It also discusses the theoretical frameworks and literature review.

2.1 Measurement of mortality rates for children

Mortality rates are important epidemiological measurements for researchers and policy makers to monitor quality of life and identify disadvantaged population groups. Neonatal, post-neonatal, infant, child, and under-five mortality rates have been widely used measures of child survival because the first five years of life characterize the period of greatest risk in early childhood.[1–3] These indicators have been consistently utilized for health planning, monitoring and evaluation of population health programmes and policies. It should be noted that mortality estimates depend on data quality, and assumptions behind estimation methods used. As many of the population health decisions (e.g. allocation of health resources and prioritization of disadvantaged population) are based on childhood mortality rates, accuracy of such estimates should be borne in mind. Therefore, data source, data completeness, and suitability of childhood estimation techniques should be considered before calculating mortality rates for children. Also, consistent applications of suitable estimation techniques will allow for proper monitoring and regional comparison of under-five and neonatal mortality targets during SDG-era.

Mortality rates can be calculated for a population of children with either of two different assumptions: (1) population changes: dynamic or stationary, and (2) time at risk: as either incidence rate (incidence density) or cumulative incidence (incidence proportion).[4,5] A dynamic population (also known as 'open' population) is one that considers children within a given geographical area, who have known birth dates within a given time-period, and it allows movement of children in or out of an existing geographically bound population through new births and migration from or into areas due to numerous reasons like conflicts and emergencies. A stationary population (also known as 'closed' population), in contrast, strictly considers children in each geographical area who are born on a pre-determined date and followed up for time of survival without adding new births.

Both incidence rate and cumulative incidence of mortality are calculated differently, hence producing different results. Researchers have indicated that it is challenging to estimate childhood mortality rates with cumulative incidence and incidence rate in conflict and emergency situations because of the high propensity for incorrect data manipulations and misinterpretations.[4,5] Crude age-specific mortality rate, therefore, may be a more appropriate measure to monitor the well-being of any population in emergency settings. Also, crude age-specific mortality rate is suitable for aggregated data. Crude age-specific mortality rate is often regarded as a more accurate measurement, comprising a numerator and a denominator arising from the same age-group and in the same geographic area for a specified time-period[4,6] (Figure 2.1). However, due to inadequate vital registration systems, it is challenging to accurately estimate crude age-specific mortality rates in resource-limited countries.[7] In that case, most countries in sub-Saharan Africa and international organizations heavily rely on cumulative incidence of under-five mortality (estimated as either a proportion or direct estimation using life tables,[4] that are derived from the two major sources of childhood mortality data (i.e., United Nations International Children's Emergency Fund (UNICEF)-supported MICS and United States Agency for International Development (USAID)-supported NDHS).[8] Also, most mortality studies favor the use of cumulative incidence (incidence proportion) rather than incidence density (incidence rate) because of its simplicity of calculation and interpretation,[6] as shown in Figure 2.1. On this note, UNICEF has been routinely using cumulative incidence to monitor countries' progress with respect to child survival through its report of State of the World's Children.[9] However, the incidence density is suitable to determine the rate (i.e., how rapidly) childhood deaths occur because it integrates time into the denominator. Cumulative incidence provides the probability (risk) of childhood mortality over a specified period. It is important to keep in mind that an accurate assessment of child survival relies on observing all children for the entire observation period. However, it is difficult to assume that the likelihood of mortality is evenly distributed over the time-period under observation.[6] The major limitations of cumulative incidence compared to incidence density are:[6]

- Huge loss to follow-up may over/underestimate mortality rates since the population at risk decreases over time and the outcome of interest is unknown for those population groups that are lost to follow-up; and
- It does not account for the timing of deaths.

Incidence density is preferred in measuring mortality incidence in dynamic population or in studies with fixed population with longer follow-up time.[6] Whereas cumulative incidence is more applicable for stationary populations with minimal or no loss to follow-up. This thesis utilized data from a cross-sectional cohort design[10] which assesses exposures and survival outcomes retrospectively among under-five children delivered to women of reproductive age group recruited at a single point in time. Unlike the traditional cohort study design, loss to follow up is not a threat in a cross-sectional cohort study. However, it is important to note that the mortality risks over the five year-period of observation will likely differ, depending on the estimation method used. For this reason, both cumulative incidence and incidence density were measured in this thesis.

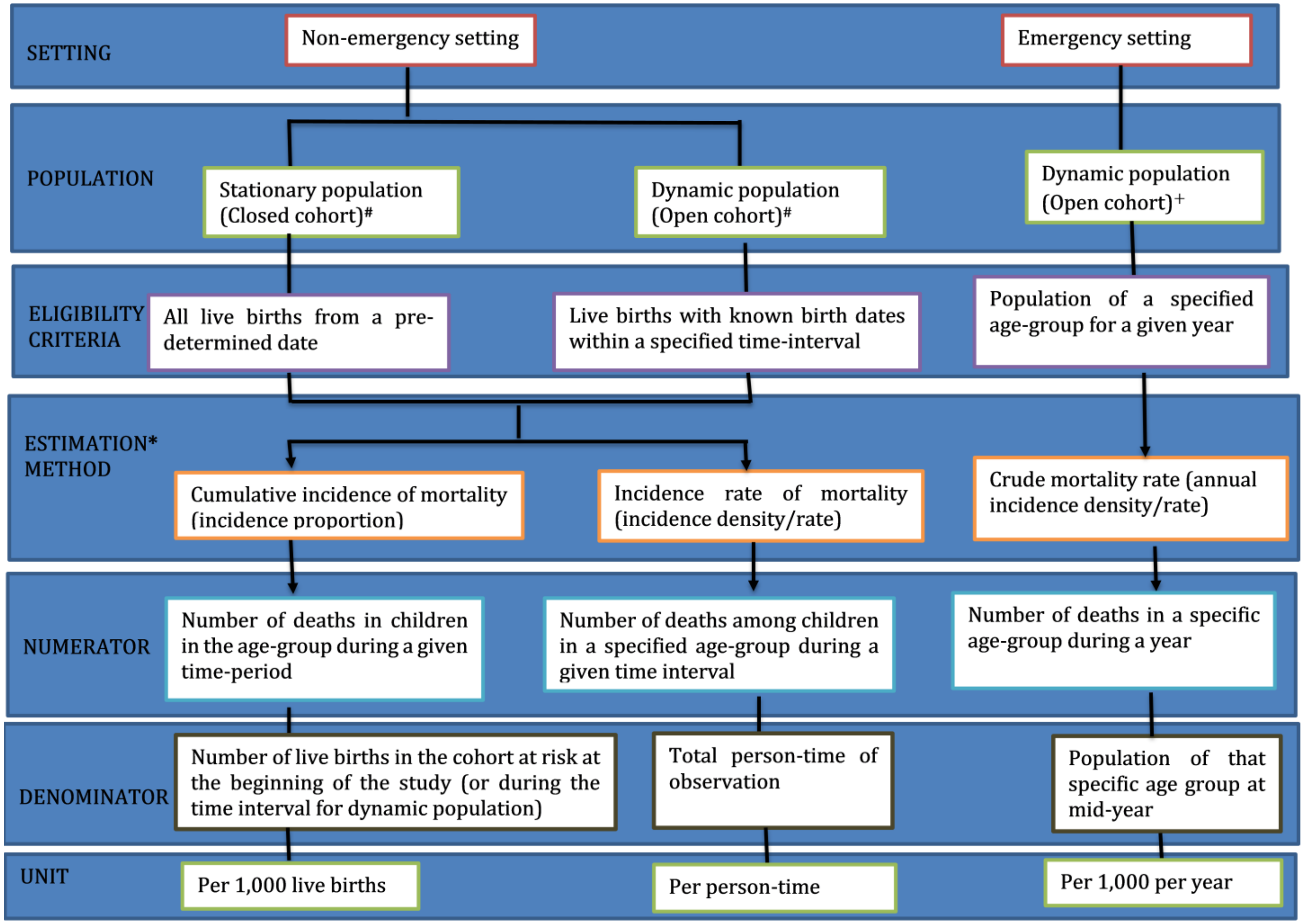

Figure 2.1: Flow chart for estimating childhood mortality rates (Source: author)

* The estimation method for closed and open populations in non-emergency settings is determined by the magnitude of the loss to follow-up. For cumulative incidence, proportion is preferred when follow-up is complete, otherwise life table is generated if follow-up is incomplete. However, risk estimates will be similar when loss to follow up is minimal for incidence density and cumulative incidence.

#Individual-level data; +aggregated (area-level) data

2.1.1 Methodological issues in estimating childhood mortality rates

Monitoring of child survival has posed myriads of challenges due to different methods of under-five mortality estimation and data reliability. Childhood mortality rates have mainly been calculated by using direct and indirect estimation methods.[7,8,11–13] There are different values for national neonatal, infant and under-five mortality estimates arising from different methodological approaches in different surveys.[8] As a result, it is difficult for policy makers and other stakeholders to assess national and subnational progress, and to initiate policy actions to curb the high childhood mortalities.

In most sub-Saharan African countries, census data were primarily used from 1960s to 1980s, but recently, greater attention has shifted to the use of more robust and national representative surveys—NDHS and MICS.[7,8,11] It is apparent that mortality estimates from censuses and vital registration systems are not accurate in resource-limited countries.[7,14] Although both NDHS and MICS surveys are comparable in their design (multi-stage, stratified cluster sampling) and large sample size (ranging from 5,000 to 30,000 households), mortality estimates from NDHS were calculated from direct method, while MICS used indirect estimation method on data of children ever-born (Brass method) until 2011.[8] In order to address the major flaws of using Brass method (see section 2.1.1.1), the MICS team switched to the direct method in the 2016/2017 national survey (MICS 5).[15] Research in Nigeria to date, has focused on the NDHS data and no known study has utilized MICS dataset to examine the contextual (community-level) factors influencing under-five mortality, perhaps due to unavailability of full birth history in the previous surveys.

2.1.1.1 Issues with childhood mortality estimation from national surveys

- **Indirect estimation of childhood mortality:** The indirect technique was originally developed by Brass[16] in 1966 and subsequently modified by Sullivan in 1972, Trussell in 1975, and Hill and Figueroa in 2001.[13,17] The indirect technique involves calculating the probability of survival from aggregated number of children ever-born and children still alive (or dead) reported by women classified by maternal age-group (i.e., summary birth histories). As outlined by Hill[12], the original Brass method followed these key postulations:

- "Population age patterns of fertility and child mortality are adequately represented by the model patterns used in developing the method
- In any time-period, mortality of children does not vary by five-year grouping of mothers
- No correlation exists between mortality risks of children and survival of mothers (by mortality or migration) in the population
- Any changes in child mortality in the recent past have been gradual and unidirectional
- Cross-sectional average numbers of children ever-born by age (or by duration of marriage or time since first birth) adequately reflect the appropriately-defined cohort patterns of childbearing."

It is clear that in most applications of the indirect method, the aforementioned assumptions are violated.(7,13) There is severe bias in assuming that for any period, mortality of children does not vary by five-year grouping of maternal age (i.e., 15-19, 20-24, 25-29, 30-34 etc.).(7,13) It is generally believed that children of young mothers between 15-19 years have the highest mortality risk.(18–21) The young mothers tend to be socio-economically disadvantaged, and their children are likely to be first births and have higher mortality risks than subsequent births.(22) In addition, data from the national surveys and censuses are subject to *selection bias* by not capturing data from certain mothers (due to migration and maternal mortality), whose children might have higher mortality risks.(23,24) Contrary to the assumptions made in the Brass method, it tends to overestimate under-five mortality rates especially in populations where fertility rapidly declines.(13,25)

In order to account for the effects of changing fertility, parity ratios and mortality risks of children born to young mothers, Hill and Figueroa extended the original Brass method by using duration of marriage or time since first birth in grouping mothers.(26) With this variant, the selection bias created by estimating childhood mortality with maternal age is minimized. However, the variant method is not completely free of errors. It has been observed that parity ratios for the survey might not accurately reflect time distribution of previous births,(26) hence wrongly inferring that more recent child births have higher mortality risks.

- **Direct estimation of childhood mortality:** Direct estimation of hazard or survival probabilities from full birth history data has been used as an alternative method to address the limitations of indirect estimation of childhood mortality.(12,27) It is derived from life-table analysis of date of birth, survival status, and (if dead) age at death (i.e., full birth history).(27) Unlike the indirect estimation, it assumes the same level of accuracy for all children reported, regardless of their survival status. In addition, it assumes that dates of birth and ages at death are reported accurately. However, it also shares the same presumption that there is no correlation or dependence between mortality risks between children and survival rates of mothers in the population.(12)

The major setbacks of direct and indirect estimations are:

- **Survival bias:** Child survival is closely tied with maternal survival. Birth histories are not available for children whose mothers had died. In circumstances where dead mothers had different patterns of fertility and childhood deaths, estimation can either be overestimated or underestimated. Beyond the mortality rate estimates, the social determinants of under-five mortalities may differ between the two groups of women.
- **Truncation bias:** This is a systematic error arising from restricting the upper eligibility age of mothers.(28) During the time of data collection for national surveys, 49 years is normally taken as the upper eligible age for recruiting mothers for interviews (as defined by the reproductive age of 15-49 years). Technically, data from women aged 44 years and below are available for analysis, considering that data are collected from women who have live births within five years preceding the survey. It implies that under-five mortality rate is being calculated at earlier time than expected from birth histories of relatively younger women. Truncation bias could lead to overestimation of mortality in earlier time-period because of the overrepresentation of first births among younger women. Contrarily, restricting maternal age has been reported to minimize **recall bias** of birth and death dates among children who died longer before the commencement of the survey.(28)

Apart from the direct and indirect methods of mortality estimation just discussed, preceding birth technique method is used for health facility data, which is discussed next.

2.1.1.2 Childhood mortality estimation from health facility data

- **Preceding birth technique method:** This is an indirect estimation of childhood mortality rates, calculated by asking the mothers about the survival status of their previous children at the time of subsequent deliveries at health facilities.[29,30] Unlike household respondents, the clinic-based respondents are more likely to accurately report stigmatizing and painful events such as childhood deaths. An advantage of this method is that it disaggregates pregnancy outcomes into live births, still births, abortions, and miscarriages.[30] This method minimizes recall bias arising from using retrospective surveys because trained health professionals collect birth history data. Also, it allows for easier collection of additional information such as detailed facility-level mortality estimates, which can be used by health authorities to plan health interventions for poor-performing catchment areas/communities and assess effectiveness of past health interventions.

The major drawbacks are as follows:

  - **Selection bias:** An apparent limitation of preceding birth technique methods is that the population attending health facilities is not randomly selected. On the standpoint that health service coverage is grossly suboptimal in resource-limited countries, it can be construed that childhood mortality will be higher among population with poor access to maternal and child health services, as depicted in the iceberg theory of health[31] i.e., only few pregnant mothers present at health facilities for deliveries, and it is difficult to quantify the number of pregnant women in the communities. Also, educated pregnant women residing in urban areas are more likely users of health facilities and in that way disenfranchising the rural populations. In addition, overestimation of mortality rates could be observed from tertiary hospitals because they are referral centres for complicated cases, which are likely to experience worse outcomes than other facility types.

Furthermore, women recruited from the facilities are not representative of all women in the reproductive age-group, since teenage mothers are less likely to be seen in the maternity centres, for fear of being stigmatized. This issue of generalizability of findings to all categories of parous mothers has been addressed in the national household surveys as mothers are recruited at random without any preference.

Table 2.1: Systematic errors in national household surveys and health facility data

Systematic errors	Mortality rate estimations from national household Surveys	Preceding birth technique method from health facility
Selection bias	Moderate	Severe
Truncation bias	Severe (especially for direct estimation)	Minimal
Survival bias	Moderate to severe	Severe
Recall bias	Minimal to moderate	Minimal to moderate
Mortality classification bias (neonatal and stillbirth)	Moderate	Minimal

2.2 Theoretical framework

The major conceptual framework guiding this thesis is the Mosley-Chen framework[32] with contributions from other four different but complementary theories/frameworks—iceberg theory of health, social ecological framework, population health framework, and life course framework. In addition, data availability, authors' programmatic experience, and evidence from literature guided the choice of variables in the framework. The foundation of this thesis closely follows the paradigm of iceberg theory of health (originally developed by John and Ryan in 1978),[31] and provides the rationale for the use of household population survey over health facility data. The theory suggests that only one-tenth of the health conditions are seen in the hospital and the other nine-tenths are dispersed within the larger community in LMICs. The adapted framework (Figure 2.2) identifies the potential determinants of child survival in resource-limited countries, ranging from child-level to community-level. The framework also theorized the interrelationships among the social factors. According to the framework, child-, maternal-, household-, and community-level factors are the independent variables and the dependent variables are neonatal, infant, and under-five mortalities. The factors are discussed in detail in the literature review (Section 2.4).

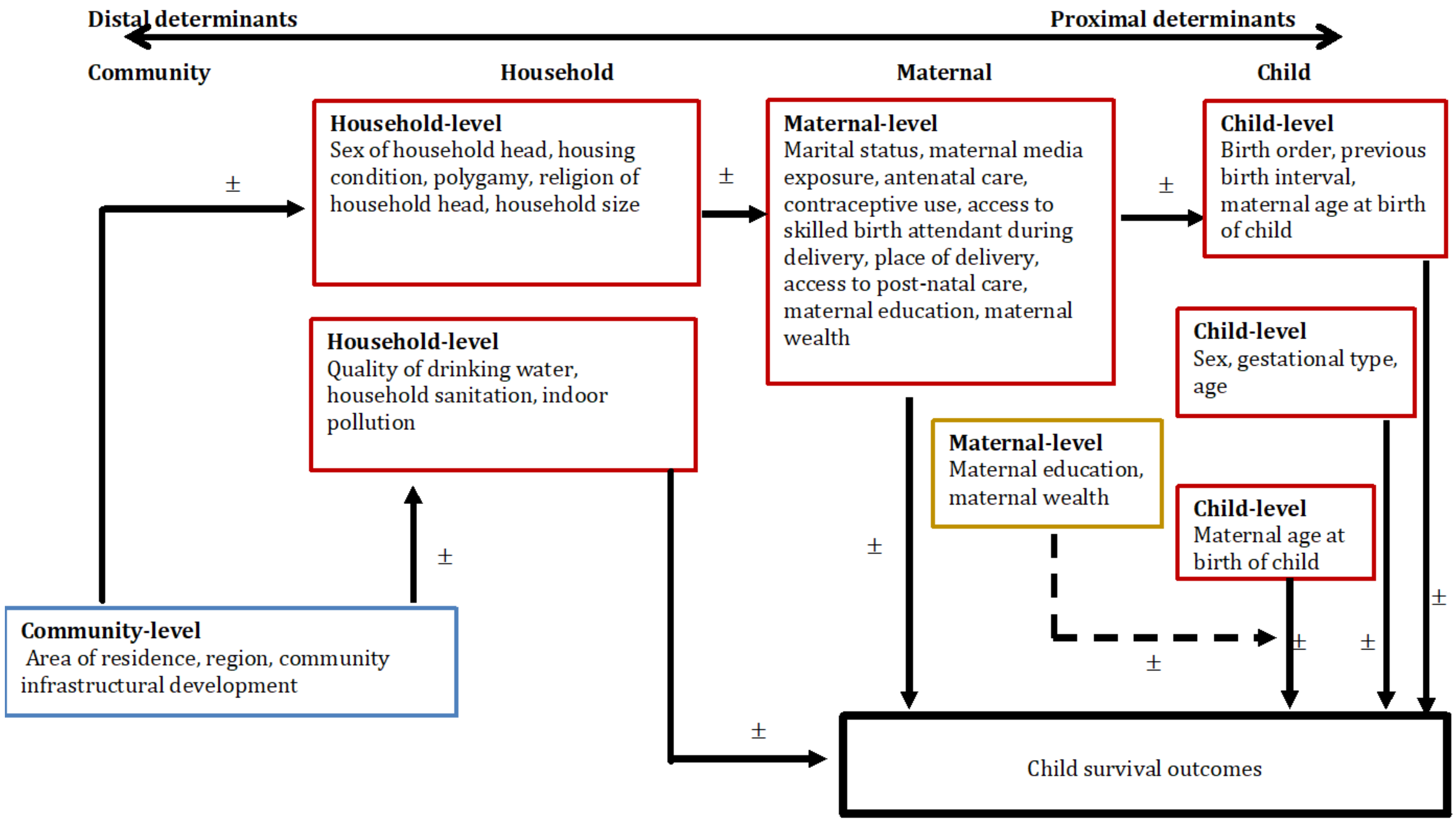

Figure 2.2: Theoretical framework of childhood mortality (adapted Mosley-Chen framework)[32]

Note: variables that could not be included in the framework (due to unavailability of data) include child nutrition, prematurity, HIV, immunization, birth weight, maternal nutritional status, prematurity, domestic violence, birth preparedness, companion at birth, distance to health facility, health literacy.

2.2.1 Mosley-Chen framework

The Mosley and Chen framework proposed in 1984 was used for this thesis because of its appropriateness for research on child survival in LMICs. Also, the framework unifies social and medical science approaches to child survival. It assumes that socio-economic status directly influences proximate determinants, which are maternal factors, environmental contamination, nutrient deficiency, injury, and personal illness control. The proximate determinants, in turn, trigger the risk factors that may lead to childhood deaths. The major limitations of this framework are: 1) its assumption of a linear pathway for disease causation and mortality; and 2) its inability to account for biological factors (such as child's sex, birth type, etc). It also fails to account for the possible inter-relationships that might occur among the factors situated at the distal and proximate levels.

Although injury was presented in the Mosley-Chen framework, this thesis could not include injury/trauma as a variable because the national household surveys do not collect data on child's exposure to injury/trauma. However, this thesis extends the original Mosley-Chen framework to accommodate new variables such as death of previous children, access to maternal and child health services (e.g., antenatal care (ANC), institutional delivery, and cultural factors (e.g., ethnic affiliation) (Figure 2.2).

Schell et al[33] presented a hierarchical structure based on the propositions from Mosley-Chen framework. The factors were categorized into proximal, intermediate, and distal determinants (Figure 2.2). The proximal determinants are conceptualized as the pathways by which health behavior contributes to childhood mortality in resource-limited countries. The proximal pathways denote shorter causal chains and easier to control than the distal determinants, except for biological factors. However, the distal determinants have increased potentials for larger scale impact and sustained change with population health interventions.

2.2.2 Social ecological framework

The social ecological framework was introduced in 1970 and has undergone several revisions since its original conceptualization. This thesis applies the Bronfenbrenner's ecological framework[34] that was modified in 2005, because it considers the entire ecological system in which a child grows. It acknowledges the complex interplay between the child's immediate physical and social environment (microsystem) and the systems within the environment (mesosystem), social, and economic conditions (exosystem), and attitudes shared by members of the society (macrosystem) (Figure 2.3). It gives a range of factors that put people at risk of diseases and death. A major limitation is that it does not fully address biological factors in the child's development and mortality.

In relation to this thesis, children (microsystem) are nested within their mothers (mesosystem). The mothers were nested within their respective households (exosystem), which, in turn, were encapsulated within the boarder communities (macrosystem).

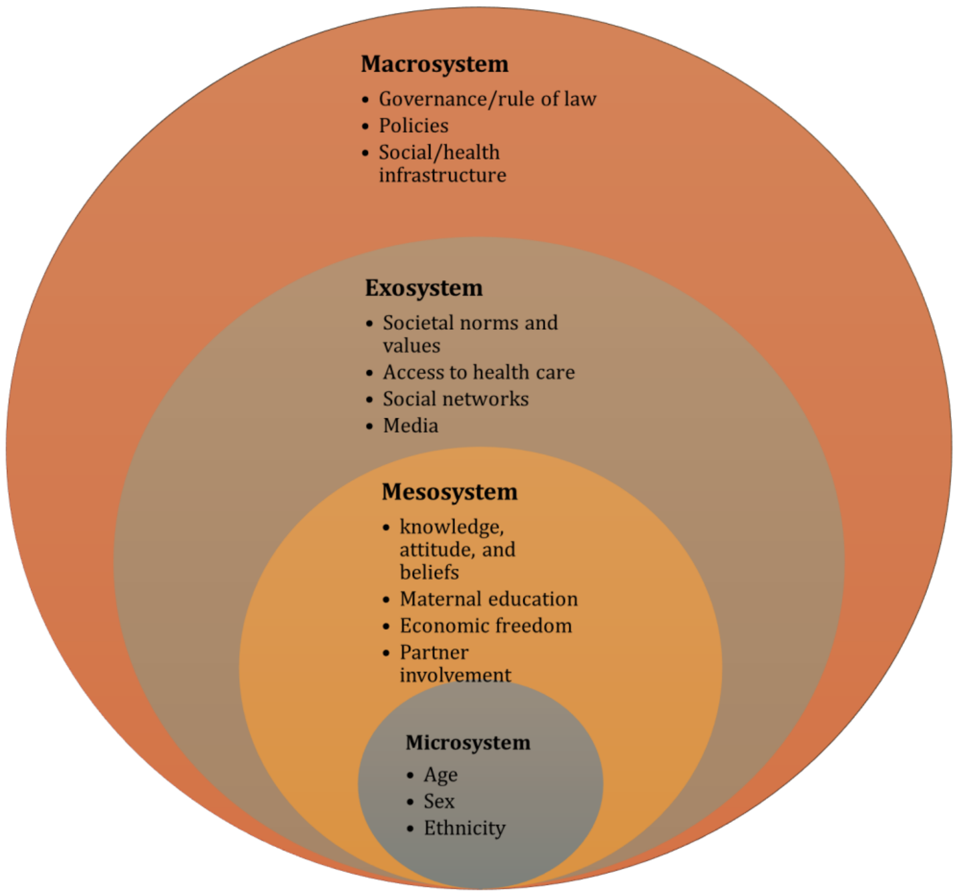

Figure 2.3: Adapted social ecological framework of child survival[34]

2.2.3 Life course framework

Drawing from the life course perspective, this thesis considers several factors that operate during fetal development, intra-partal and early childhood periods. These factors have wider implications on the health and wellbeing of children and their survival to adulthood. The framework is premised on the integration of the biological, structural, social, behavioral, and cultural factors being responsible for the maintenance of optimal functional capacity from fetal stage to adulthood. This approach perceives household as a micro social group within a macro social context of individuals who interact within ever-changing social contexts across ever increasing time and space.[35,36]

2.2.4 Population health framework

This is an elaboration of the World Health Organization's (WHO) conceptual framework for action on the social determinants of health (SDH) developed by the Population Health Agency of Canada.[37–40] This framework was used because it is appropriate for analyzing determinants of population health at multiple levels—national, regional, community, household, and individual levels. Also, it considers the interplay of different factors at these levels as they shape health. The key contribution of this framework is that it gives insights into the immediate factors, such as education, social environment, income, physical environment, biological factors, social networks and economic status, and external factors, such as political, environmental and health service delivery. In addition, as highlighted by the Public Health Agency of Canada,[38] the framework outlines population health interventions needed to reduce health disparities through:

- "Focus on the health of populations
- Address the determinants of health and their interactions
- Base decisions on evidence
- Increase upstream investments
- Apply multiple strategies
- Collaborate across sectors and levels
- Employ mechanisms for public involvement
- Demonstrate accountability for health outcomes."

2.3 Operationalization of theoretical framework

The theoretical framework in Figure 2.2, evidence from literature review, and the author's programmatic experience guided the selection of dependent and independent variables for this thesis. The independent variables were grouped to represent the hierarchical layers; child, maternal, household and community-levels.

The theoretical framework shown in Figure 2.2 propounds that child- and maternal-level characteristics directly influence child survival. However, the household- and community- level factors may indirectly influence childhood mortality through the socio-economic position of mothers, housing conditions, environmental factors, and access to health care. In addition, community infrastructural development influences health through service provision, and individual and collective agency. It is expected that maternal and paternal educational levels are related to the household income. The household socio-economic status would determine the location of residence (i.e., urban or rural), access to improved housing, sanitation and drinking water, and accessibility to health care services. Also, maternal education plays a key role in reproductive life, preferences, and agency.

2.4 Literature review

As reported by Masuy-Stroobant,(41) according to Lesaëge-Dugied in 1972, the earliest known documentation of the historical trajectory of the SDH on child survival dates to the initial epidemiological surveys conducted by Villermé during 1824-1830 in the city of Paris. The author noted an association between social deprivation and poor survival outcomes among infants. However, the concept of SDH was not fully embraced until the 20th century. The inverse relationship between the correlates of socio-economic development and mortality rates has been made repeatedly and become the guiding principle of global policies on health inequity.(42)

As reported by the UN, the global under-five mortality rates have dropped by 53% from 90 to 43 deaths per 1,000 live births between 1990 and 2015,(5,6); despite this progress, about 16,000 under-five deaths occur daily worldwide.(2,5,6) Furthermore, more than half of under-five children die from preventable diseases.(1,5,6) In 2015, the UN reported that 5.9 million under-five children died, most of which could have been prevented.[5] The major causes of under-five deaths include: preterm complications, pneumonia, intrapartum-related events, malaria, neonatal sepsis and diarrhea.[1,2,5] Likewise, children are vulnerable to malnutrition, infection and infestation, and environmental factors, such as unsafe water, sanitation, and hygiene.[1,2,5]

Projections based on the 2015 analysis of the global burden of diseases indicate that the aforementioned conditions would continue to be major contributors to childhood deaths to the year 2030 and beyond unless significantly greater efforts are made to control them.[5,7] Also, recent research suggests that there is a further problem with neonatal mortality as nearly 50% of the deaths among under-five children occur during the first 28 days of life.[1] For instance, it has been postulated that, with the current trend of progress of neonatal mortality and under-five mortality rates, more than 50 countries (mostly in sub-Saharan Africa) will not achieve SDG targets as an additional 60 million under-five children will die between 2017 and 2030.[1]

Some studies have attributed systemic challenges (such as poor governance, corruption, policy inconsistencies, insurgencies, and weak monitoring and evaluation of maternal and child health programmes)[47] to the inability of some countries (like Nigeria) to achieve the child health targets of MDGs. It is not enough knowing that these factors affect child survival as the complex system must be well-understood to create theories of change that will inform decision making.

A closer look at some epidemiologic studies has provided contradictory results. For example, Morakinyo et al.[48] observed that children from economically deprived settings such as rural areas tend to have significantly higher mortality risk than their counterparts in the urban settings. Counterintuitively, Kimani-Murage et al., and Antai et al. noted from their individual studies that children in urban settings are becoming disadvantaged.[49,50] The authors argued that the observed higher mortality risks in the urban settings were attributable to environmental-related factors such as pollutants. Furthermore, various studies have reported that maternal age, maternal education, geographic region, child's sex, birth interval, maternal weight at birth, technical competency of birth attendants during deliveries, and religious affiliations significantly influenced childhood mortality.[48–56]

In Nigeria, maternal age and education were significantly correlated with under-five mortality (Appendix B.1). The available evidence suggests that maternal age below 20 years and above 35 years were associated with increased risks of neonatal, infant and under-five mortalities.[48,52,57–60] In addition to maternal age, studies conducted in Nigeria[60] and Bangladesh[53] indicated that paternal age plays paramount role in child survival. According to Izugbara et al.,[61] unusual age difference between partners could pose countless problems such as opinion gap and lack of maternal autonomy—which critically shapes the reproductive life and health seeking behavior of women.

Several studies based on the Demographic Health Surveys in Nigeria[56,58,66,67,75,83–88] and other LMICs[50,52,53,58,68–72] have placed emphasis on maternal education. It is widely considered that maternal economic freedom is hugely dependent on maternal education. Poor maternal and household wealth indices are associated with higher mortality risks among children.[51,57,63,64,66,67,70,73] Also, high level maternal education tends to prolong birth intervals, encourage immunization, and promote positive health seeking behavior, partly due to increased maternal agency and autonomy.

While much attention has been given to investigate the effects of birth intervals on child survival, the findings are inconclusive. Different authors have reported that short and long birth intervals are associated with increased risks of adverse perinatal outcomes.[74–76] The authors[77–79] who observed increased mortality risks for children whose mothers had longer spacing between the current and previous birth, opined that competition among siblings for limited household resources disfavors the younger siblings.[77–79] Conversely, most authors suggested that short birth interval is associated with maternal nutritional exhaustion.[48,80,81] This may be partly due to depletion of maternal micronutrients, such as copper, zinc, ferritin, folate and magnesium, which are associated with adverse nutritional outcomes in mothers and their children.[51] In the past decades, studies have demonstrated that maternal survival plays a vital role in child survival.[82,83] Also, it seems plausible that short birth interval impacts negatively on breast feeding practices—a major driver of child survival.[48,80,81]

As noted by Akinyemi et al.[80] and Antai et al.,[84] adequate ANC visit is shown to reduce under-five mortality and neonatal mortality. Likewise, studies have consistently asserted that communities with higher proportion of hospital deliveries are less likely to experience under-five deaths.[48,64,81,85] However, there is emerging evidence in sub-Saharan Africa and Southern Asia that deliveries conducted by skilled health providers is associated with poor survival outcomes among neonates.[86]

There has been relatively insufficient evidence—arising from cross-sectional ecological studies—that polygamous family setting is associated with childhood mortality.[71,87] Also, there is no consensus on the influence of family size on child survival. Gebretsadik and colleagues[55] reported that family size of 4-6 increases under-five mortality risks. On the other hand, Detsa et al.[88] observed an inverse relationship between family size and under-five mortality risks. Despite the numerous studies on childhood mortality, controversy persists as little is known about the roles of biological identity (sex), and social/cultural identity (gender) in relation to child survival. However, studies have consistently demonstrated that there are generally more under-five deaths among males than females.[48,55,89] Conversely, some studies have reported gender bias in excess of female mortality due to gender discrimination, especially in terms of nutrition and healthcare seeking behavior.[90] It is apparent that household and community factors are often not considered in child survival analysis. Some authors opined that male household headship,[60,63] poor sanitation,[63,91] inadequate access to safe drinking water and use of polluting fuel for cooking,[73] and poor housing condition[60,73] are responsible for childhood mortalities.

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Chapter 3

Child and maternal health in Nigeria—a brief context setting

This chapter gave a brief background about the study area—Nigeria, and placed childhood mortality in the context of policy and healthcare system by outlining the historical transition of child health policies, programmes, and interventions in Nigeria. It also reviewed some best practises and the challenges confronting implementation of child health policies in Nigeria.

3.1 Country profile

With British influence and control over numerous independent organized kingdoms, Nigeria became a nation-state in 1914 by the amalgamation of the northern and southern protectorates. The country gained autonomy in 1960 and became a republic in 1963. After gaining independence, there were 16 years of consecutive military dictatorships and coup d'états which were marred by civil war, human rights abuse, and corruption.(1) In 1999, there was a complete peaceful transition to civilian government and, since then, the country continues to experience democratic governance.

Nigeria, often referred to as the "giant of Africa"(2), is the most populous country in Africa and the 7th most populous country in the world with approximately 197 million inhabitants(3) and an annual growth rate of 2.7%.(4) About 44% of the Nigerian population are children,(4) with 17.1% of the population below five years old.(5) Located in West Africa, Nigeria has a total land mass of approximately 923,768 km^2 and 800 km of coastline,(5) making it the world's 33rd largest country.(6) The country shares boundary with Benin in the west, Chad and Cameroon in the east, Niger in the north and the Atlantic Ocean in the south (Figure 3.1). Nigeria has great geographical diversity and tropical climate, which favor agricultural production. Nigeria has great cultural diversity with 250 ethnic groups and over 500 languages.(7) The predominant ethnic groups are the Hausa, Yoruba and Igbo, accounting for 60% of all Nigerians.(7) In addition, 46.9% are Christians, 51.6% are Muslims, with the remaining following native (traditional) beliefs.[8] Due to the culturally and religiously heterogenous population, Nigeria often experience ethnic and religious clashes (e.g., Boko Haram insurgencies) arising from struggles for political and economic sovereignty among the three major ethnic/religious groups and inadequate representation of interests of minority ethnic/religious groups.[9] Most ethnic groups exhibit patriarchal system of society where men are regarded as the head of the household. The men are responsible for making decisions and providing for their families.

Nigeria is comprised of 36 states and the Federal Capital Territory (FCT)—the administrative capital. The states are grouped into six geo-political regions (North-East, North-West, North-Central, South-East, South-West and South-South), and has 109 senatorial districts (i.e., three senatorial districts per state except FCT that has one). The senatorial districts are composed of 774 Local Government Areas (LGAs). Nigeria's population is not evenly distributed, as more people live in the rural areas (54%),[10] with limited access to basic health and social protection services.

According to the World Bank, Nigeria is classified as a lower-middle income economy.[11] As of 2015, Nigeria became the largest economy in Africa and world's 25th largest economy with nominal gross domestic product (GDP), estimated at US $300-500 billion and $1 trillion in terms of purchasing power parity (PPP).[12,13] Although the country experienced a booming economy, the country's resources have been squandered through long-standing corruption and misappropriation of public funds by the past national leaders as evident by the low GDP per capita. With a GDP per capita (PPP) of $5,900, Nigeria ranks 164 in the world.[12] The mismanagement of revenues has led to gross inequity as evident by high Gini index of 48.8,[12] low human development index of 0.532, ranking 152nd in the world,[14] unemployment rate of 12.4%,[12] and poverty rate of 54.4%.[15] Nigeria has a low literacy rate of 59.6%, with some gender disparities (male: 69.2% and female: 49.7%).[12] Table 3.1 shows the country's development indicators.

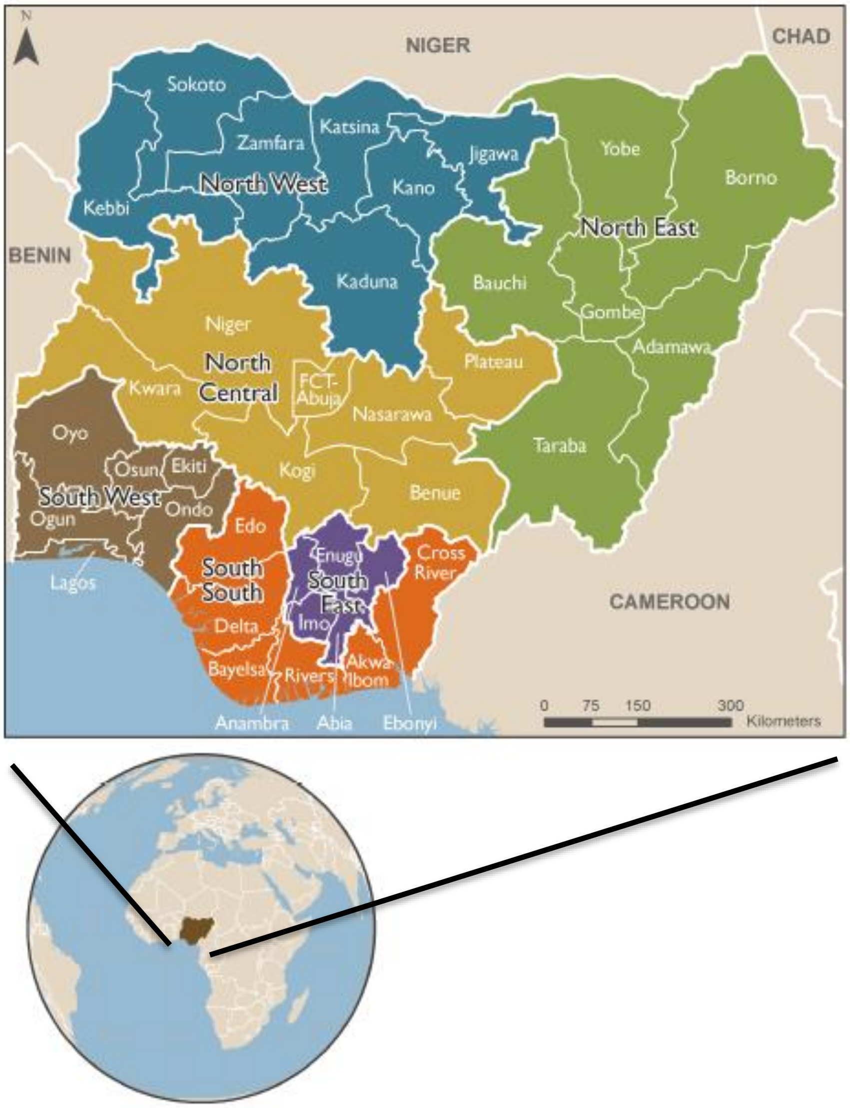

Figure 3.1: Geographic location of Nigeria with states, regions and neighboring countries[5]

Table 3.1: Development indicators, Nigeria

Neonatal mortality rate[16]	34 deaths/1,000 live births
Infant mortality rate[16]	69 deaths/1,000 live births
Under-five mortality rate[16]	104 deaths/ 1,000 live births
Maternal mortality ratio[17]	576 deaths/100,000 live births
Total fertility rate[12]	5.07 children born/woman
Mean mother's age at first birth among women aged 25-29 years[12]	20.3 years
Total birth rate[12]	36.9 births/1,000 population
Sex ratio (Total population)[12]	1.04 male/female
Contraceptive prevalence[17]	13.4%
Unmet need of contraceptive[17]	27.6%
Life expectancy (at birth)[12]	53.8 years
Health expenditure[12]	3.7% of GDP
Access to clean water[12]	68.5% of population
Improved sanitation facility access[12]	29% of population
Literacy rate[12]	59.6%
Underweight (under-five children)[17]	31.5%
Low birth weight[17]	14.8%
Health care workers per population[18]	18.3 per 10,000 population
ANC coverage (at least once by skilled health personnel)[17]	65.8%
ANC coverage (at least four times by any provider)[17]	49.1%
Complete immunization coverage[17]	23%

3.2 Overview of healthcare system in Nigeria

The healthcare delivery system in Nigeria is categorized as formal and informal. The formal healthcare system mirrors the political and administrative structures of governance in the country (i.e., primary, secondary, and tertiary healthcare). All the levels of healthcare system are designed to communicate with each other through referrals from the lowest level of healthcare—primary healthcare centres (PHC) to secondary health centres and then to the tertiary health facilities. Along similar lines, these health services are available in the public and private sectors. The public health facilities are managed by the federal, state, and local governments. In addition, there are private-for-profit health care providers, non-governmental organizations (NGOs), and community-based structures like faith-based organizations. In contrast to the formal healthcare system, a prominent concern is the ineffective service provision by the informal health service providers such as religious institutions and traditional birth attendants (TBAs). The need to strengthen the private health institutions and community institutions, such as traditional health structures, in ensuring universal health care (UHC) for mothers and their children are supported by the findings of the 2018 National Demographic Health Survey.[10] Of all deliveries in Nigeria, the majority (59%) occurred at home, while 39% occurred in health facilities—26% in public facilities vs. 13% in private facilities. It is generally believed that governments at all levels have not fully engaged the private and informal healthcare providers to provide effective maternal, newborn and child health (MNCH) services. Although private health facilities constitute about 33.1% of all healthcare services in Nigeria,(19) their activities are vestigial and require continuous training, mentoring and supervision.

In terms of delivery of basic health services, the PHC facilities are designed to provide MNCH services to the grassroots (Table 3.2). Although the National Primary Health Care Development Agency (NPHCDA), a parastatal of the Federal Ministry of Health (FMOH), is mandated to provide support to the National Health Policy for the development of Primary Health Care, the activities of PHCs have been hampered by persistent neglect by the government. There is overwhelming evidence that the current healthcare system is insufficient to meet the health needs of the population. First, Nigeria is still far from actualizing the minimum package of one PHC per 20,000 population.(20) According to the 2015 National Integrated Infrastructure Masterplan,(19) it was reported that there were 34,176 health facilities in Nigeria (out of which 88.1% were PHCs). Second, with a small health workforce (18.3 per 10,000 population),(18) Nigeria falls short of the minimum threshold of 44.5 per 10,000 population recommended by the WHO as necessary to deliver essential maternal and child health interventions required to meet the SDG targets by 2030.(21) Although healthcare services are available in both public and private health facilities across the country, people in the rural areas have limited access to quality care because most of the secondary and tertiary centres are concentrated in the urban areas. Apart from maldistribution of centres, other factors that have been documented to limit access to health care include poor health seeking behaviors, difficult topography/terrain, long distances to health centres, poverty, limited human resource for health, and weak referral systems.(22) Despite government interventions to make health care accessible to its citizenry by subsidizing care at government owned health facilities and introduction of the National Health Insurance Scheme (NHIS), incessant industrial strike actions by healthcare workers due to poor renumeration is a major practical problem that confronts the system.(23)

The public tertiary health institutions such as the teaching and specialist hospitals are funded and managed by the federal government, while the states and LGAs manage general hospitals and the

PHCs, respectively. Contrary to the Abuja declaration of allocating 15% of the government expenditure to health sector, it is clear that healthcare is completely under-funded by the government at all levels.[24,25] To bridge the current funding gap, NHIS was adopted, in addition to grants from bilateral and multinational organizations. Despite these interventions, the individual patients' out-of-pocket expenditure for health care is increasing and hampering access to quality health care.[26–28] For effective governance of the healthcare system in Nigeria, the chairman of the local government authority has the responsibility of financing health structures at the LGA level through a designated medical officer who heads the Department of Health. While the State Ministry of Health oversees health infrastructures at the state level through a political designated Honorable Commissioner for Health, the federal structures are headed by the political head who is the Honorable Minister of Health. To ensure proper coordination, there are periodic National Council on Health meetings between the Minister of Health and the State Commissioners for Health. The platform provides opportunity for discussing critical issues and reaching consensus on strategies for implementation of national policies.

Table 3.2: Categories of health care service delivery in Nigeria

	Primary Healthcare	Secondary Healthcare	Tertiary Healthcare
Number (% of total health facilities)[19]	30,098 (88.1%)	3,992(11.7%)	86 (0.3%)
Facilities	Health centres, clinics, dispensaries, and health posts	General hospitals, district hospitals	Teaching hospitals, federal medical centers (FMCs) and specialist hospitals
Services	General preventive, curative, promotive and pre-referral care to the general population	General medical and laboratory services, as well as specialized health services, such as surgery, pediatric, obstetric and gynecological care to patients	Highly specialized medical and surgical services and have special expertise and technological capacity that enable them to serve as centres of learning
Cadre of healthcare personnel	Nurses, community health officers (CHOs), community health extension workers (CHEWs), and environmental health officers (EHOs), private sector general practitioners and community pharmacists /pharmacy technicians	Medical doctors, nurses, midwives, laboratory scientists, pharmacists and community health officers	Specialist health care providers

3.3.1 Historical trajectories of child survival policies in Nigeria

Efforts in addressing early childhood mortality date back to 1978 when Nigeria became a signatory to the UN-sponsored Alma Ata Declaration of the International Conference on Primary Health Care (PHC).[29] It was declared to reduce health inequity between and within countries by improving health status of families, communities and population groups.[30] The Alma Ata Declaration firmly established the groundwork for the child survival revolution of 1982, subsequent UN Convention on the Rights of the Child (CRC)[31] and the Organization of African Unity (OAU) Charter on the Rights and Welfare of the Child in 1989,[32,33] and Declaration and Plan of Action for Children from the World Summit of Children (WSC) in 1990[34] (Figure 3.2). The Government of Nigeria swung into action by establishing the National Child Welfare Committee (NCWC) in 1990 to formulate a framework for implementing the agenda of World Summit of Children.[35] However, Nigeria was not able to domesticate the CRC until 1991.[35] Arising from these international declarations are programmes and policy reforms in Nigeria.[35,36] These include creation of "National Health Policy in 1988 (latest revision was made in 2016), National Programme of Action (NPOA) for the Survival, Protection and Development of Children in 1992, Maternal and Child Health (MCH) Policy (1994), National Immunization Policy and Standards of Practice (1996), National Acute Respiratory Infections Programme: National Policy and Plan of Actions, 1991–1995; Breastfeeding Policy (1999), Essential Drug Policy; National Nutrition Policy which was compiled in 1995 and adopted in 1998, National Reproductive Health Policy (2001), National Policy on Population and Sustainable Development, Policy on Fortification of Food with Vitamin A, National Programme of Action for the Survival, Protection, and Development of the Nigerian Child (1992); Child Rights Act (2003), National Health Act (2014) and National Policy on Women (2000)" [35], which strives to enhance the status of women, and the MCH component of the National Primary Health Care Development Programme, aimed at improving the health status of women and children. In line with global practice, most of the policy documents have been revised to accommodate newer recommendations. Also, like many countries in Africa, Nigeria ratified the SDGs in 2015, after the expiration of MDGs.

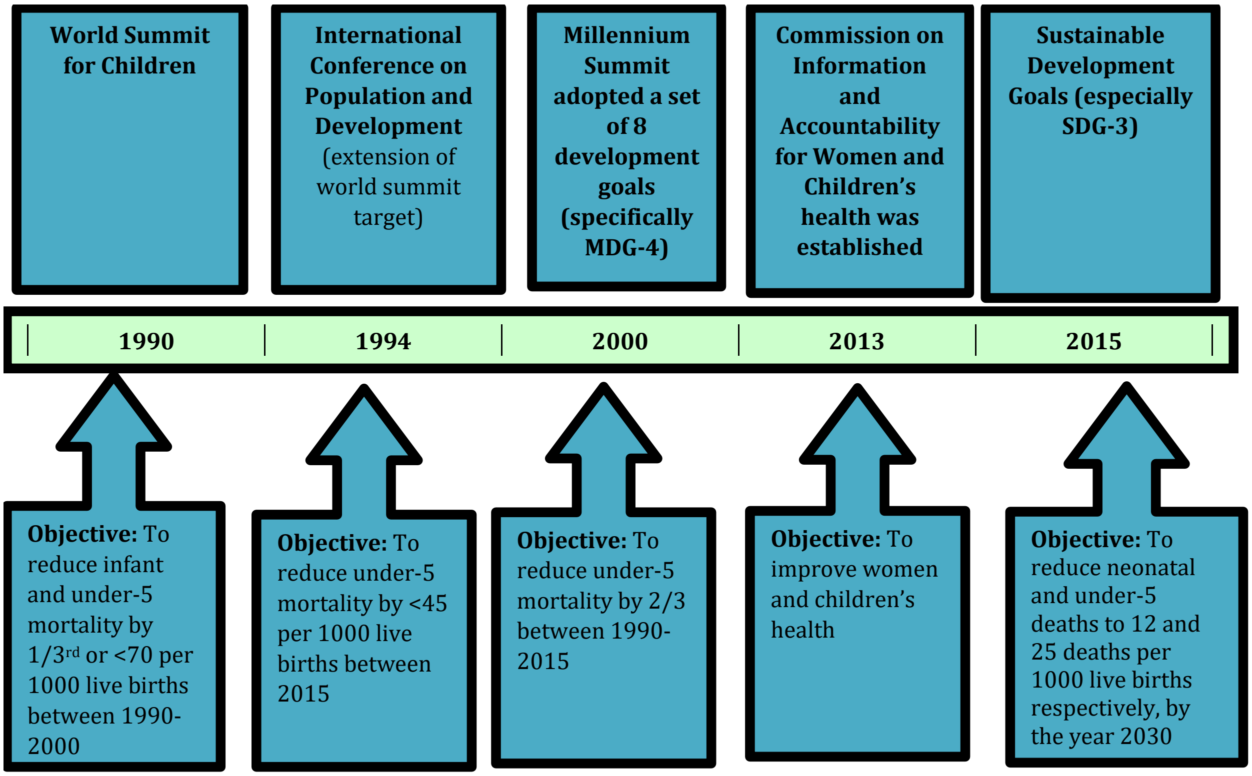

Figure 3.2: Timeline of global child health declarations (Source: author)

3.3.2 Health system approaches to addressing child mortality in Nigeria

As with other resource-limited countries, Nigeria has its own cultural, religious, and sociopolitical peculiarities impacting the inefficient healthcare system. Some of the systemic healthcare challenges that have been attributed to increased childhood deaths in the country are poor healthcare financing, lack of coordination, verticalization of child-care services, inadequate drug and supplies, poor access to care and shortage of trained healthcare workers.[35,37–39] In addressing these challenges and ensuring UHC by 2030, Nigeria has implemented key strategies which include community mobilization and advocacy, service integration, health research, capacity building, task-shifting among healthcare workers, and international and non-governmental collaborations.[40] There is increasing government's attention towards improving clinical services, and less focus on the social determinants of health (SDH)—which are important factors in accessing health care, and fundamental drivers of childhood mortalities.

In 1997, Nigeria implemented the Integrated Management of Childhood Illness (IMCI) strategy to address vertical implementation of maternal and child preventive and control programmes by integration of services, especially at the PHCs.(41) Specifically, the IMCI strategy was designed to strengthen child health service delivery by enhancing the capacity of PHC nurses to provide immunizations, nutritional services, and early childhood disease prevention and management.(42,43) However, the impact of integration of services on overall child survival remained suboptimal because its implementation remained at a lower scale.(44,45) There has also been persistent failure in accessing these cost-effective interventions in some parts of the country (especially in the hard-to-reach areas). The typical problem of poor access in hard-to-reach communities was tackled by introducing Integrated Community Case Management (ICCM) in 2013 to provide curative care for the three major childhood illnesses (i.e., pneumonia, diarrhea and malaria).(45) The coverage for universal childhood immunization, namely tuberculosis, diphtheria, whooping cough, tetanus, polio, and measles, remains low in the country. The country misses many opportunities to provide adequate immunization to under-five children. According to the 2018 NDHS report, 31% of children have received all the basic vaccinations.(10) With door-to-door immunization campaigns (especially in hard-to-reach areas), the government is gradually scaling up childhood immunization.

In line with the global initiatives, Nigeria implemented the Safe Motherhood Initiative and its related programmes—Making Pregnancy Safer, Baby-Friendly Hospital Initiative (BFHI), and Roll Back Malaria Initiative, elimination of iodine deficiency disorders, Vitamin A deficiency control, and National Programme on Immunization (NPI), with special emphasis on the eradication of poliomyelitis.(35,41) In enhancing survival of all pregnant women and under-five children, provision of emergency obstetric and newborn care (including resuscitation kits) has been prioritized at all levels of care in the country.(46) As part of the critical elements of mortality prevention among premature newborns (with low birth weight), the government has set up mechanisms for training mothers with such babies on Kangaroo Mother Care (KMC), before being discharged from clinics.(46) Facing the realities of inadequate incubators, erratic electricity, and lack of health care providers in the country, KMC is a better alternative to incubators.(47) Similarly, in recognition of the inherent problems to scaling up child survival initiatives, the country indigenously implemented biannual Maternal, Newborn and Child Health Week (MNCH

Week) as a strategy towards reducing the high maternal and childhood morbidity and mortality rates.[48] The MNCH week, which commenced in 2010, is a national one week-long event organized to deliver an integrated high impact, low-cost interventions that improve maternal and child health, and reduce mortality. These services are provided in the health facilities and as outreach to promote universal coverage. The MNCH week offers a unique opportunity for additional routine services, hence strengthening the health system.

In addition, a Healthy Beginning Initiative (HBI), otherwise known as the baby shower initiative, has been locally developed and being piloted to leverage the existing socially accepted community-based structures such as religious organizations.[49] One of the key aspects of the intervention is that it is a family centred approach that actively involves the religious leaders (as lay health advisors) to increase the uptake of HIV testing and linkage to care among pregnant women. The intervention targets the family of pregnant women with a specific focus on achieving elimination of mother to child HIV transmission and providing support to the parents to enhance child survival. The choice of religious leaders as champions is justified by the fact that they are strong influencers in the societies.[49] Also, they are instrumental in demystifying some of the misconceptions surrounding maternal and child health care services.[49] As the first step, the religious leader enlists the pregnant women together with their husbands during prayer meetings and introduce HBI to the couples. In the second step, the priest presents a “Mama Pack” to the family. This comprises of “essentials” for delivery—clean razor blade, gloves, and sterilizing agents. The Mama Pack is to reduce unhygienic delivery practices, thus lessening the intra-partum and post-partum complications/infections. To provide support, the family is followed-up from pregnancy to post-delivery period. The innovation has created opportunities for involvement of male partners which is currently inadequate in Nigeria,[50] and to ensure integration of maternal and childcare services. Nevertheless, the programme is at is nascent stage and needs to be scaled-up in the country.

As noted previously, the delivery of quality maternal and child health services are restricted by the critical shortage of health workers in Nigeria. This underscores the implementation of Midwives Service Scheme (MSS) and the Subsidy Reinvestment and Empowerment Programme for Maternal and Child Health (SURE-P MCH) that recruited midwives and village health workers which led to marginal increase in human resources for health.[51] In addition to the above interventions, the government of Nigeria inaugurated a 34-member Task Force to accelerate the reduction of maternal and child mortality,[52] implemented Saving One Million Lives (SOML) Initiative,[52] and updated the Essential Medicines and Equipment List (EML) to include neonatal commodities (including chlorhexidine gel) to prevent neonatal infections. To make chlorhexidine gel available, the Nigerian government has ensured its local production.[52]

Despite the efforts, overall child survival remains dismal in Nigeria predominantly because of the policies and programmatic failures to address the demand-side of child health interventions. Extensive interventions which have focused on the supply-side of child health intervention seemed not to be enough to tackle the issues of child health in Nigeria. More than ever before, it is highly imperative to address the salient social determinants of health operating at the child-, maternal-, household-, and community-levels that limit demand for these services, while seeking strategies that will address top-down approach to programme implementation and poor funding by the government.

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Chapter 4

Methods

This chapter highlights the two main study designs used for this thesis—time-series and cross-sectional survey of national representative samples of women aged 15-49 years in Nigeria. The data files consist of: (i) aggregated country-level neonatal and under-five mortality rates between 1960s and 2017; and (ii) child, maternal, household, and community-level factors from 2016/2017 Multiple Indicator Cluster Survey (MICS) of 30,960 weighted sample of under-five children. The second part discusses the dependent and independent variables (including data preprocessing), and data quality issues that could affect the study findings. Lastly, the different analytic methods used in this thesis were outlined. The analytic approaches include group method of data handling (GMDH)-type artificial neural network, multilayer perceptron (MLP) artificial neural network, spatial cluster analysis, autoregressive integrated moving average (ARIMA) and Holt-Winters exponential smoothing models, hierarchical path analysis with time-to-event outcome, and multilevel multinomial regression.

4.1 Study design

This is a multi-method (time-series and cross-sectional survey) analytical study of nationally representative household survey of the Multiple Indicator Cluster Survey(1) conducted in 2016/2017 in Nigeria and the consolidated childhood mortality rates from United Nations Inter-agency Group for Child Mortality Estimation (UN-IGME)(2). Given that reliable birth history data are necessary for assessing child survival, this thesis considers the aforementioned data because of their methodological rigor and credibility.(1-2) More so, these data were widely used during MDG implementation phase to track the child survival progress, in the absence of reliable civil registration data in most resource-limited countries (including Nigeria).(3)

4.2 Data sources

4.2.1 United Nations Inter-agency Group for Child Mortality Estimation (UN-IGME)

Objective 1 regarding time-series and forecasting of child-related SDG indicators (neonatal and under-five mortality rates) to 2030, relied on the analysis of aggregate national data spanning from 1964 to 2017 which are publicly available at the World Bank website.(2) These historical neonatal and under-five mortality datasets address the limitation of building accurate models from few data points. At least 50 non-missing data points are required to properly fit ARIMA time-series model.(4) The premise for the minimum observation is to account for any presence of data fluctuations. Given the necessity of refining global, regional, and national childhood mortality estimates for tracking the progress towards achieving child survival goals, the UN-IGME recalculates the annual estimates for child survival indicators from multiple data sources in consultation with the respective UN-member countries.(5) One of the toughest challenges for researchers in computing mortality rates for children is accounting for the dual effects of conflicts and HIV on child survival, which are conterminously experienced in much of sub-Saharan Africa.(6,7) The UN-IGME team offers a solution to this problem by accounting for these effects in their estimates.(6) More importantly, in a high HIV burden country with suboptimal antiretroviral therapy coverage such as Nigeria—which has the third highest HIV burden globally (1.9 million),(8) there is a tendency to underestimate childhood mortality rates. A prospective cohort study(9) in Zimbabwe which measured bias introduced by the death of mothers living with HIV found that under-five children who died from AIDS-related illnesses could not be captured partly due to death of their mothers. Besides, recent studies have indicated that child survival is closely tied to maternal survival.(10-14)

It is important to note that data quality checks were ensured by the UN-IGME team.(7) Without any viable vital registration system for Nigeria, the two nationally representative data (NDHS and MICS) were used to generate new estimates for the country.(5,7) The consolidated estimates by UN-IGME provide UN-member countries (including Nigeria) official national estimates and allows for comparability with other countries.(5)

4.2.2 Nigeria Multiple Indicator Cluster Survey (MICS)

The MICS dataset formed the basis of analysis for objectives 2-4. The MICS datasets are community-based nationally representative surveys that were conducted as face-to-face interviews between September, 2016 and January, 2017 by the National Bureau of Statistics (NBS) with technical assistance from UNICEF MICS team, New York, United States.[(15)] It has become one of the largest sources of internationally comparable data on women and children worldwide since its inception in 1990.[(1)] The 2016-2017 MICS is the fifth round of MICS, having previously conducted the survey in 1995, 1999, 2007 and 2011.[(15)] These surveys collected data on a variety of subjects relating to maternal and child health to monitor MDG indicators and continue to be vital for tracking the 2030 SDG indicators.[(1)] The MICS datasets are publicly available and can be downloaded from the UNICEF MICS website: http://mics.unicef.org/surveys.[(1)] As with all retrospective study designs, the MICS dataset is not completely free of methodological limitations such as information bias/recall bias. However, the MICS data are epidemiologically sound as the country team collaborates with global experts in the areas of household survey design and implementation.[(1)] Furthermore, national representative data are more valuable to quantify the contributions of community-level determinants of childhood mortality because social and structural factors operate at meso- and macro levels.

4.2.2.1 Sample size calculation

The sample size was calculated to generate enough data to estimate most of MICS indicators at the national, regional, state, and senatorial district level for the highly populous states in Nigeria (i.e., Lagos and Kano states). The calculation was based on the national prevalence of stunting among under-five children in Nigeria from the preceding 2011 MICS[(16)] which was estimated at 35.8%. To increase statistical power, the design effect (due to clustering) of 3.5 and relative margin of error of 18% were used. The details of sample size calculation can be seen in the 2016/2017 MICS report.[(15)]

4.2.2.2 Sampling technique

As described in the full MICS report,[(15)] the participants were 34,376 women aged 15-49 years recruited through multi-stage stratified cluster sampling technique (Figure 4.1). The first phase of the survey was to stratify the 36 states and FCT within the six geopolitical regions, and across the rural areas (36.6%) and urban areas (63.4%). The next step was systematically selecting 60 enumeration areas (EAs) from each main sampling stratum (i.e., state), except for Lagos and Kano states, where 120 EAs were sampled for each. The modification in the sampling strategy is to cater for the larger population sizes and to enable analysis at the senatorial levels for both states. Within each EA, 16 households were sampled. The sampling frame containing the EAs was the 2015 National Integrated Survey of Households (NISH round 2) masterlist,[17] gathered during the 2006 Census. The Census EA, otherwise known as the primary sampling unit (PSU), comprised of cluster of geographical and administratively distinct areas of homogenous households. In this thesis, the clusters are referred to as the "communities". Meanwhile the sampling procedure yielded 37,440 households from 2,340 EAs, however, due to insurgencies in some parts of North-East region (Borno, Yobe and Adamawa states), only 33,901 households from 2,239 EAs completed the interviews. A randomization schedule consisting of serial household lists of each EA that was prepared by the team prior to the start of the survey were utilized to randomly select an average of 16 households from each EA. Overall, the 95% response rate was achieved.

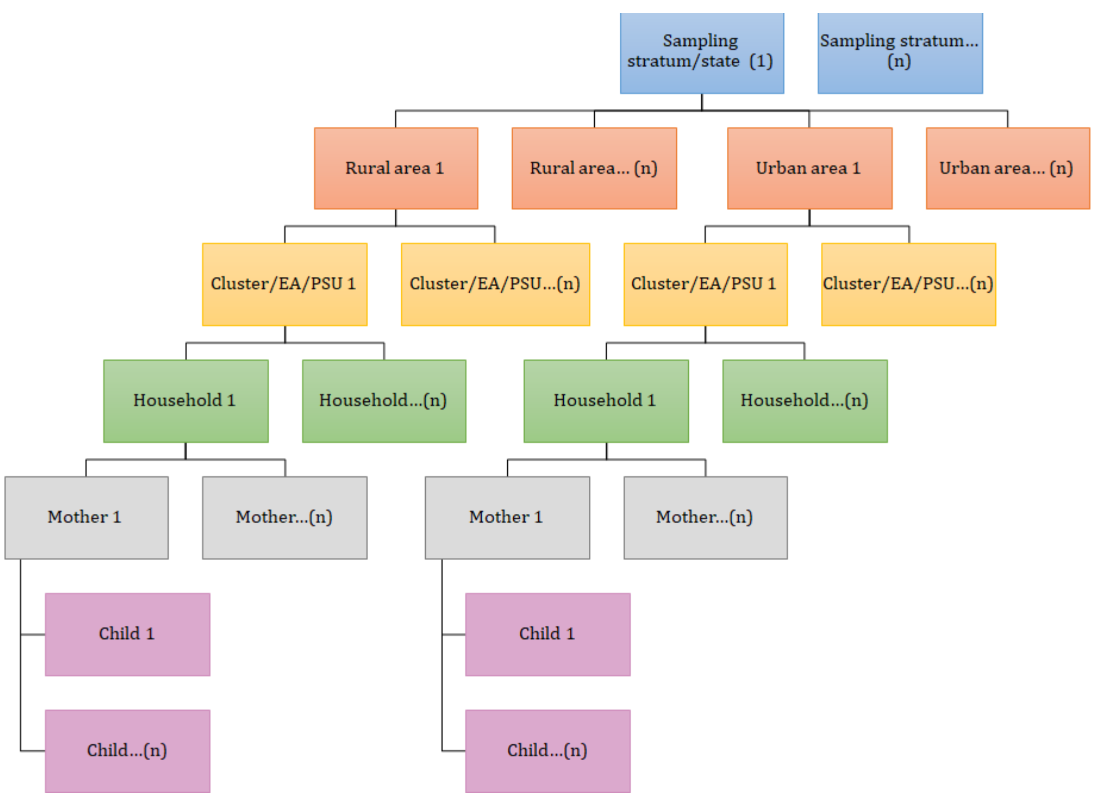

Figure 4.1: Hierarchical structure of the 2016/2017 Nigeria MICS dataset (Source: author)

4.2.2.3 Sampling weight

The sample population is not self-weighted. The MICS research team reported that due to variations in the population size across the states, weighting factors were applied to address over- and under-sampling of respondents.[15] As the initial step, the team calculated the base weights for household samples. An additional non-response adjustment for women was factored into the sampling weights for the households to generate sample weights for women. For this thesis, the sampling weights for women was used, as they were interviewed for the complete birth histories (see the 2016/2017 MICS full report for details).[15] It is important to note that no replication weight and finite population corrections were available for the sample population.

4.2.2.4 Survey questionnaires and datafiles

Four sets of questionnaires were used for data collection during the field work. These are household, women, men and under-five questionnaires. For this thesis, analyses were limited to data from the household and women questionnaires because data could be merged by common identifiers, unlike data from men and under-five questionnaires. The complete birth histories of live births were collected with women questionnaires in sequential order of childbirth (Figure 4.1). The women were asked whether births were single or multiple, sex of child, month and year of child's birth, survival status, child's current age, and age at death if the child had died. The data collected with the four sets of questionnaires were processed and archived into eight datafiles in SPSS format—*birth history (bh), women (wm), households (hh), household members (hl), mosquito nets in households (tn), female genital mutilation/ cutting (fg), mothers/ primary caretakers of children under-five (ch) and men (mn).* However, for this thesis, three datafiles *(bh, wm and hh)* were analyzed.

4.3 Ethical considerations

Prior to commencement of the secondary data analysis, an official request to use the MICS datasets for Ph.D. research thesis was sent to and approved by the UNICEF MICS team, New York (see Appendix C.1). The datasets were de-identified of the respondents' personal information hence their anonymity and confidentiality are assured. Ethical clearances were obtained earlier by the UNICEF MICS team from an appropriate Institutional Review Board (IRB) in the country.[15] The study protocol, survey instrument, and other materials were approved prior to the commencement of the survey.[15] Informed consent was obtained from all participants in the survey. Besides, an ethical exemption was sought from the University of Saskatchewan Research Ethics Committee because the study did not involve human participants as highlighted in the *Article 2.4 of the Tri-Council Policy Statement 2 (TCPS 2)*[18] *which states: "REB review is not required for research that relies exclusively on secondary use of anonymous information, or anonymous human biological materials, so long as the process of data linkage or recording or dissemination of results does not generate identifiable information."* The ethics exemption letter from ethics committee is included in the appendix (Letter C2).

4.4 Data preprocessing

4.4.1 UN-IGME

To generate reliable forecasts (objective 1), preprocessing steps for time-series were undertaken. Manuscripts 1 and 2 detail the data evaluation that preceded forecasting with time-series analysis. The critical steps included: (1) data visualization with time-plots to detect any variability of mortality rates with time (i.e., pattern/trend); (2) transformation of the series; and (3) identification of any structural breaks (i.e., stability). From the time series plots, mortality rates showed downward trends over the years; hence, violating the assumption of stationarity for ARIMA time series analysis. With non-stationarity of data, it became necessary to transform the data to stabilize the variance for the series to be stationary. After applying different transformation techniques, differencing was able to eliminate the unit roots (i.e., stochastic trend).[4] Stationarity was supported by fitting autocorrelation function (ACF) and partial autocorrelation function (PACF) plots, and Dickey-Fuller test (DF) tests with drift. From DF-tests, the order of differencing seems adequate to remove the patterns for all the mortality rates—p-value <0.05 and the absolute t-statistic was greater than the critical value at 5% level.[19] Data preprocessing for group method of data handling type artificial neural network (GMDH-type ANN) was automatically executed with an in-built solver of the GMDH Shell DS version 3.8.9.[20] A detailed description of data preprocessing is in Chapter 5.

4.4.2 Nigeria MICS— 2016/2017

4.4.2.1 Eligible sample size estimation

To address objectives 2-4, the individual birth history, women, and household datafiles were merged by key matching variables (i.e., cluster, household, women and child). Next, a subpopulation of all live deliveries by women aged 15-49 years within five years preceding the survey was analyzed. This truncated birth history approach minimized recall bias. With this inclusion criteria, the data yielded 29,830 live births. Further exclusion of 44 observations with documented mortality but missing ages at death brought the final unweighted sample size to 29,786 live births. By weighting and accounting for the nested nature of the data, the weighted sample size was 30,960 under-five children, distributed across 37 states and 2,227 communities (range: 19 to 120 communities per state). Also, the number of children per community ranged from 1 to 50, and an average of 13 children per community was observed.

4.4.2.2 Recoding and recomputing variables

Before cleaning the data, the codebook function and survey questionnaires were examined to have full information about the variables in the dataset. The variables were recoded in Stata^{TM} version 15.1 software[(21)] to avoid classification obscurities. In addition, new variables were generated from the existing variables in the datasets through data reduction techniques.

4.4.2.2.1 Dependent variables

As used in this thesis, under-five mortality is inclusive of neonatal, post-neonatal, infant and child mortalities (Figure 4.2).

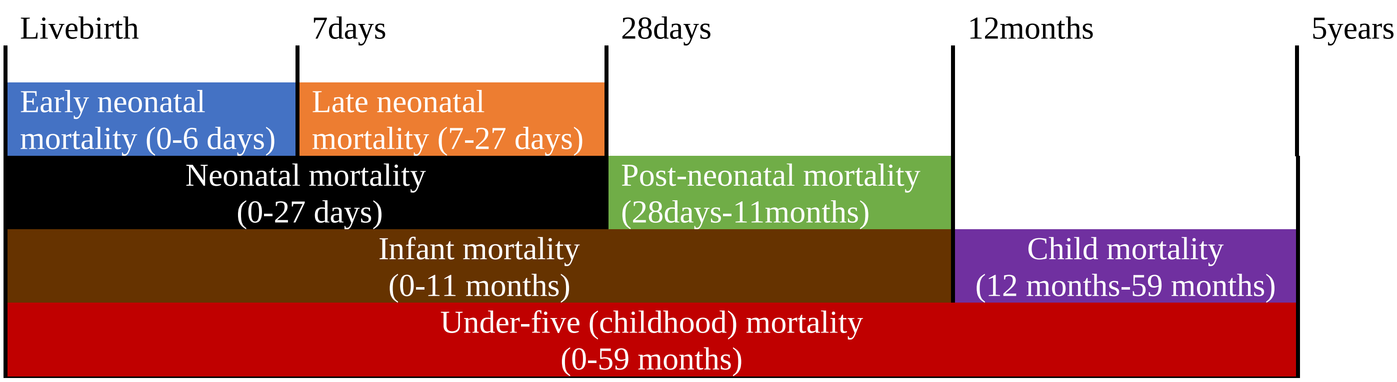

Figure 4.2: Categorization of under-five mortality (Source: author)

The primary outcomes for objective 1 (section 1.5) were the yearly neonatal (aggregated) and under-five (aggregated and sex-specific) mortality rates for Nigeria. For objective 2 (section 1.5, page 8), the main outcome (under-five survival outcome) was categorized as a multinomial variable including alive (reference), neonatal, post-neonatal, and child mortalities. For objective 3 (section 1.5), which utilized survival path analysis, the dependent variables were continuous variables—time-to-event, namely (i) time to neonatal death: defined by survival time from birth to 27 days (ii) time to infant death: defined by survival time from birth to 11 months of life; and (iii) time to under-five death: defined by survival time from birth to 59 months of life. Survival outcome was categorized as dichotomous variable; alive/right censored=0 and dead=1. The survival outcome and follow-up time were derived using MICS dataset. For each outcome variable, survival (follow-up) time was recalculated from variables on survival status, age at death and current age of living children. The main dependent variable for objective 4 (section 1.5, page 8) was neonatal survival outcome—defined as survived (coded as 0) and died (coded as 1). Neonatal death was further re-categorized into early death (death occurring within first week of life) and late death (death occurring after first week of life to 27 days).

4.4.2.2.2 Independent variables

Overall, objectives 2-4 considers 33 independent variables, which are layered at the child, maternal, household and community-levels.

- **Child-level:** Child's sex *(male=0, female=1)*, gestation type *(singleton=0, multiple=1)*, birth order *(first birth=0, 2-3=1, 4-6=2, ≥7=3)*, previous birth interval *(<2 years=0, first birth=1, ≥2 years=2)*[22], maternal age at birth *(<20 years=0, 20-34 years=1, ≥35 years=2)*
- **Maternal-level**: Maternal education *(none/primary=0, secondary/technical=1, post-secondary=2)*, death of previous children *(<3=0, 3-4=1, ≥5=2)*, maternal wealth index *(poor=0, middle=1, rich=2)*, parity *(<3=0, 3-4=1, ≥5=2)*, maternal media exposure (*high=0, medium=1, low=2, none=3*), access to ANC *(none=0, skilled*[23]*: doctors, nurses and midwives=1, unskilled=2)*, frequency of ANC visits *(none=0, 1-7=1, ≥8=2)*,[24] access to skilled birth attendant during delivery *(none=0, skilled birth attendants=1, unskilled=2)*,[23] place of delivery *(home=0, health facility=1)*, access to post-natal care (PNC), ever used any contraceptive method *(yes=0, no=1)*, marital/ union status *(currently*

married/in union=0, formerly married/in union=1, never married/in union=2), ever drank alcohol *(yes=0, no=1)*, ever smoked cigarette *(yes=0, no=1)*

- **Household-level**: Sex of household head *(male=0, female=1)*, housing condition index *(inadequate=0, adequate=1)*, polygamy *(yes=0, no=1)*, ethnic group of household head *(Hausa=0, Igbo=1, Yoruba=2, others=3)*, religion of household head *(no religion=0, Christianity/Islam/Traditional/Others=1)*, household size *(discrete)*, educational status of household head *(none/primary=0, secondary/technical=1, post-secondary=2)*, household access to safe drinking water *(unimproved source=0, improved source=1)*, household sanitation *(unimproved=0, improved=1)*, cooking fuel *(polluting fuel=0, clean fuel=1)*
- **Community-level:** Place of residence *(urban=0, rural=1)*, geopolitical region *(North-Central (NC)=0, North-East (NE)=1, North-West (NW)=2, South-East (SE)=3, South-South (SS)=4, South-West (SW)=5)*, community-level of maternal education *(low=0, medium=1, high=2)*, community infrastructural development *(low=0, high=1)*

To avoid multicollinearity issues, the maternal media exposure variable was generated by collapsing individual variables on accessibility to newspaper/magazine, radio, and television. The three variables had a four-item scale measuring the frequency of exposures to the media items—almost every day, at least once a week, less than once a week, and not at all. The items with the best exposure score were selected and recoded into four categories, where the lowest score is no exposure and the highest score is high exposure to mass media.

The new household variables generated include housing condition index, household access to drinking water, sanitation, and source of cooking fuel (proxy for indoor pollution). By applying principal components analysis (PCA),[25] housing condition index was constructed by combining three independent but related variables on quality of floor, roof, and exterior wall. Following the definitions of (un)improved roof, exterior wall and floor by the WHO,[26] the original variables were re-grouped as:

- roof (*improved*—tin/ zinc/ iron sheets/ wood/ calamine/ cement fiber/ ceramic tiles/ cement/ roofing shingles; *unimproved*—no roof/thatch/ palm leaf/ rustic mat/ palm/ bamboo/ wood planks/ cardboard/ plastic sheeting),

- exterior wall (*improved*—cement/ stone with lime/ bricks/ cement blocks/ covered adobe/ wood planks/ shingles; *unimproved*—no wall/ cane/ palm/ trunks/ thatch/ dirt/ earth/ bamboo with mud/ stone with mud/ uncovered adobe/ mud brick, plywood/ cardboard/ reused wood), and
- floor (*improved*—parquet or polished wood/ vinyl tiles/ vinyl carpet/ ceramic tiles, cement/ rug (wall to wall); *unimproved*—earth/sand/ dung/ wood planks/ palm/ bamboo).

Before running PCA, there were five assumptions that were assessed, making sure they were not violated—(i) linear relationship between variables *(correlation matrix shows r>0.3; Table 4.1)***;** (ii) suitability for data reduction *(p-value<0.001 with Bartlett's test of sphericity);* (iii) sampling adequacy *(Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy, Table 4.2)*; (iv) multiple ordinal variables; and (v) absence of outliers.

Table 4.1: Correlation matrix of housing material variables, 2016/2017 Nigeria MICS

	Roof	Wall	Floor
Roof	1.00		
Wall	0.45*	1.00	
Floor	0.47*	0.62*	1.00

**significant at p-value<0.05 (Bonferroni-adjusted significant level)*

Table 4.2: Kaiser-Meyer-Olkin measure of sampling adequacy

Variable	KMO
Roof	0.7726
Wall	0.6436
Floor	0.6384
Overall	0.6707

With KMO measures(27) ranging from 0.6 to 0.8, the three variables have commonalities, therefore were included in the PCA. Compared to other components, component one was selected to represent housing condition index because of its eigenvalue >1, and accounted for 67.7% of the total variance (Table 4.3), The first component has eigenvectors of 0.5, 0.6 and 0.6 (Table 4.4). Using median value, the new continuous variable on housing condition index variable was coded as adequate and inadequate.

Table 4.3: Principal components analysis of exterior wall, floor, and roof variables, 2016/2017 Nigeria MICS

Component	Eigenvalue	Difference	Proportion	Cumulative
1	2.03	1.44	0.68	0.68
2	0.59	0.22	0.20	0.88
3	0.38	.	0.12	1.00

Table 4.4: Eigenvectors of principal components for roof, wall, and floor, 2016/2017 Nigeria MICS

Variable	Component 1	Component 2	Component 3	Unexplained
Roof	0.53	0.85	0.03	0
Wall	0.60	-0.40	0.70	0
Floor	0.60	-0.35	-0.72	0

Also, going by the conventional WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP) classifications[(28,29)] of sanitation and drinking water, and WHO classification[(30)] of cooking fuel, the original variables were re-categorized as:

- sanitation (*improved*—flush to piped sewer system/ flush to septic tank/ flush to pit latrine/ ventilated improved pit latrine (VIP)/ pit latrine with slab/ composting toilet; *unimproved*—flush to somewhere else/ flush to unknown place/ pit latrine without slab/ open pit/ bucket/ hanging toilet/ hanging latrine/ no facility/ bush/ field);
- drinking water (*improved*—piped into dwelling/ piped into compound/ yard or plot/ piped to neighbor/ public tab/ standpipe/ tube well/ borehole/ protected well/ protected spring/ rainwater collection/ bottle water/ sachet water/ tanker-truck/ cart with small tank/ drum; *unimproved*—unprotected well/ unprotected spring/ surface water (river, stream, dam, lake, pond, canal, irrigation channel); and
- cooking fuel (*clean*— electricity/ liquefied petroleum gas (LPG) cylinder/ biogas/ no food cooked in household; *polluting*— kerosene/ coal/ lignite/ charcoal/ wood/ straw/ shrubs/ grass/ animal dung/ agricultural crop residue).

Some community-level variables were newly generated from either maternal or household-level variables. Community-level of maternal education was computed as the proportion of households in a community that reported at least maternal secondary education. The scores were aggregated into three levels based on quartile classification (i.e., 2nd quartile=50%, and 3rd quartile=75%);

(lower education <50% of overall score), moderate education 50%≤x<75% of the overall score, high education (75%≤x≤100% of overall score). Also, community infrastructural development was created from the proportion of households with electricity in various communities. The variable has two groups (low=0, high=1) based on median value.

4.5 Data evaluation

Due to the retrospective nature of this study, the MICS dataset is prone to data quality issues, such as incomplete and inconsistent responses. These data quality issues could complicate data analysis and validity of results. To assess the extent of these problems, data quality checks were performed.

4.5.1 Missing data

Missing data can reduce representativeness of study sample and further distort inferences. For the 2016/2017 MICS dataset, most variables showed high level of completeness of values. Overall, missing values ranged from 0% to 73.8%. Except for maternal access to PNC, no other variable had more than 40% of values missing, hence maternal access to PNC was excluded from the analysis so as not to lose large part of the sample. Overall, *listwise deletion* (otherwise known as complete case-wise deletion) was used in dealing with the missing data (i.e., observations with missing values were discarded from analysis). Although listwise deletion, generally results in reduction of the sample size, it was considered because it is easier to perform. With the sampling weight accommodating missing values (see section 4.2.2.3), there is minimal effect on the power to detect significant statistical association.[31]

4.5.2 Displacement of age and birth dates of mothers (age heaping)

Misreported maternal ages could affect representativeness of sample. It could also transfer vital events, such as childbirths and mortalities, leading to biased inferences. It is widely documented that interviewers sometimes deliberately push the ages of respondents outside the boundary of some questions, so as to reduce the number of questions being asked (i.e., make some questions on the survey items not applicable because of respondents' ineligibility).[32-35] Furthermore, studies have shown the propensity of female respondents to round down their ages to the nearest fives and tens, or to more culturally advantageous ages,[32-35] so as to appear younger than their real ages.[33] The implication of age heaping is the disproportionate distribution of ages ending in 0 and 5 digits in the sample.[33] In order to detect presence of age heaping, age distribution of women was visualized via a line chart (Figure 4.3).

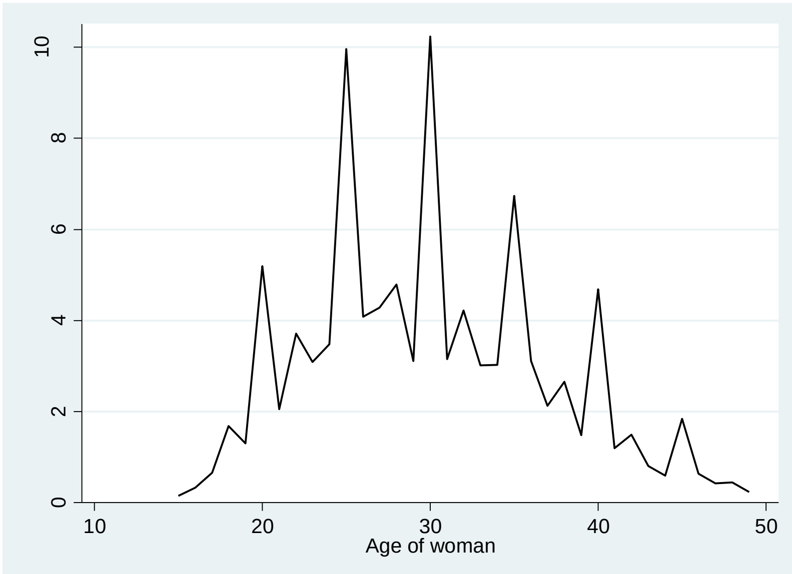

Figure 4.3: Distribution of women by single years of age, 2016/2017 Nigeria MICS

Figure 4.3 highlights the over-representation of digits ending in 0 and 5 as evident by the spikes at 20, 25, 30, 35, 40 and 45 years. To further ascertain heaping of maternal ages, explorations with *Myers' Blended Index, Whipple's Index or the United Nations Age-Sex Accuracy Index* have been recommended.[33] For this thesis, the original Whipple's index formula[32] was modified as shown in equation 4.1. The Whipple's formula assumes a linear distribution of maternal ages in each five-year age range if fertility, mortality, and migration are constant. Contrary to the cut-off of 23 and 62 years proposed by Whipple,[32] the age-range was limited to 15-49 years since it is the eligibility age of recruitment of mothers.

$$Modified\ Whipple's\ index = \frac{\Sigma(P_{15+}P_{20+\cdots+}P_{40+}\ P_{45})}{\left(1/_5\right)\Sigma(P_{15+}\ P_{16+\cdots+}\ P_{48+}P_{49})} \times 100 \quad (4.1)$$

$$Where\ P_x\ is\ the\ population\ of\ age\ x\ in\ completed\ years.$$

With a Whipple's score[36] of 202.81, translating to ≥75% deviation from perfect, there is a high degree of bias for age and digit preference for women recruited in this study. The high degree of maternal age-heaping could lead to wrong distribution of childhood mortality risks and incorrect inferences. Previous research recommends grouping of maternal age to reduce errors due to misassignment of age because age-grouping accommodates displacement of single ages within boarder intervals.[37] In order to minimize the fluctuations in maternal age and maldistribution of risks caused by using age as a discrete variable, maternal age was re-grouped into a categorical variable with three levels (i.e., <20, 20-34 and ≥35 years). Although, there is no consensus on the optimal grouping of individual ages to reduce heaping, maternal age was categorized based on the premise that young and advanced maternal age are associated with poor child survival outcomes.[38] As indicated in Figure 4.4, the maternal age distribution is closer to the true distribution of the population of mothers who are represented by this sample of mothers.

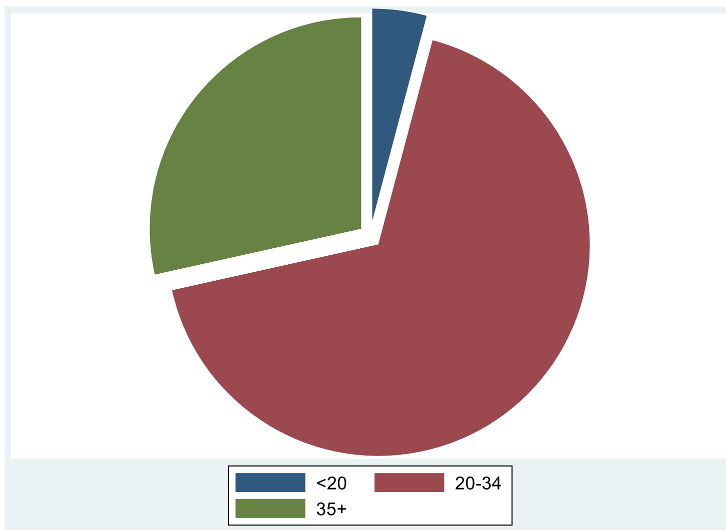

Figure 4.4: Distribution of maternal age-group, 2016/2017 Nigeria MICS

4.5.3 Demographic pattern of births

Due to high fertility rate in Nigeria, it is expected that monotonic decrease in the number of births by maternal age should result in fewer children at extremes of age.[39,40] From Table 4.5, the delivery patterns followed the expected patterns for Nigeria.

Table 4.5: Number of live births by age-group of mothers, 2016/2017 Nigeria MICS

Maternal age (years)	Number of live births (unweighted)	Number of live births (weighted)
<20	1,231	1,330
20-34	20,073	20,918
≥35	8,482	8,711
Total	29,786	30,959

4.5.4 Accuracy of birth dates for children

The degree of accuracy of child survival rests hugely on the accuracy of dates of childbirth. Due to a truncated birth history approach for this study, there is tendency to shift child's age or birthdate. Displacement of dates of childbirth has the tendency of transferring deaths across the years, hence leading to (over)underestimation of mortality.[41] As first used by Pullum and colleagues[41] in 2006, date transfers and omissions are determined by ratios of total births in a year to the next. The presence of transference and omission of births are diagnosed when there are spikes in the number of births for 2010 and drops in the number of births for 2012. From Table 4.6, it is apparent that there is no evidence to suggest strong transference and omission of births for the dataset as the ratios of number of live births at successive years are similar.

Table 4.6: Number of live births for the six years before the 2016/2017 MICS, Nigeria

Year	Number of births	Y/Y_{+1}
2010	5,742	1.03
2011	5,566	0.95
2012	5,887	0.95
2013	6,173	1.08
2014	5,735	1.00
2015	5,737	1.11
2016	5,153	-

4.5.5 Sex-ratios of reported live births

Evidence from resource-limited countries suggests cultural acceptance of male-child over female-child.[42,43] Mothers are more likely to report male births. With a global sex-ratio of 105-107 male births for every 100 female births,[44] Table 4.7 shows that the sex-ratio among the respondents is consistent with the global phenomenon. However, in 2013 and 2015, mothers reported delivering more females than males. Overall, the sex-selective reporting of births is within the normal range.

Table 4.7: Sex-ratios of reported live births, 2016/2017 Nigeria MICS

Year	Number of male live-births	Number of female live births	M:F (number of male births per 100 female births)
2010	2,928	2,813	104
2011	2,845	2,721	105
2012	3,009	2,878	105
2013	3,064	3,106	99
2014	3,005	2,730	110
2015	2,847	2,890	99
2016	2,614	2,539	103

4.5.6 Heaping of child deaths

Displacement of age at death has a propensity of under/overestimating age-specific mortality rates. The net transfer of child deaths often occurs when interviewers fail to probe for the exact timing of death. Since, the majority of under-five deaths occur within the first 28 days of life,[(45)] there is possibility to transfer some deaths that occur in earlier time to period beyond the first 28 days, hence, undercounting deaths that occurred under 28 days (i.e., underestimating neonatal mortality rates and overestimating post-neonatal mortality rates). Figure 4.5 presents distribution of childhood mortalities for 2016/2017 MICS data.

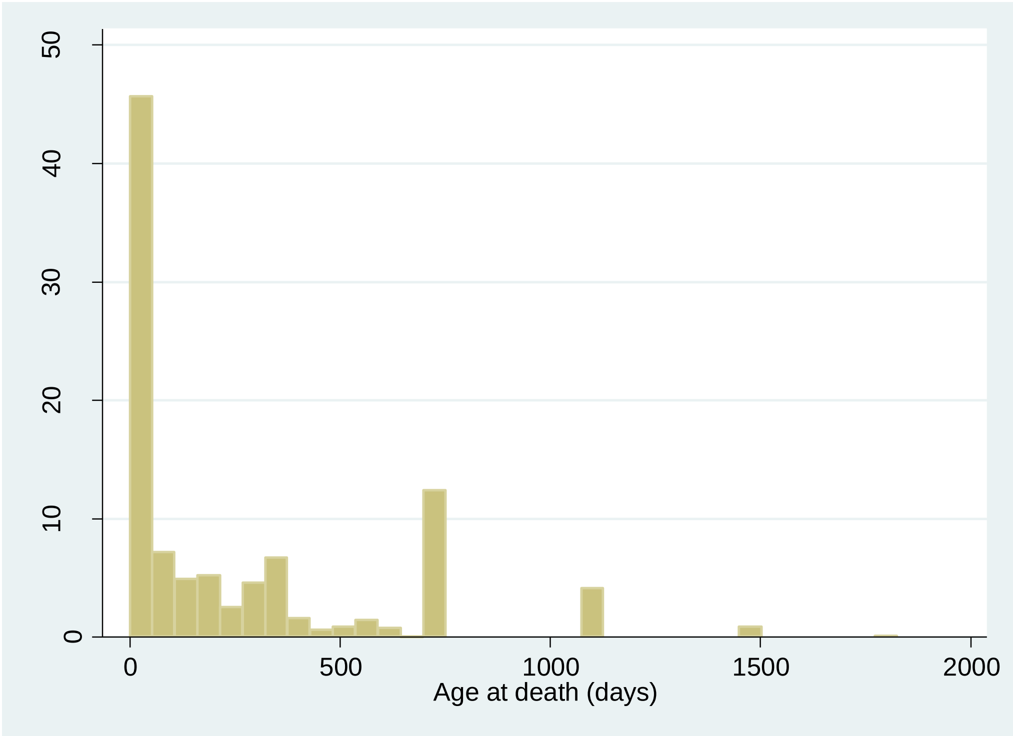

Figure 4.5: Distribution of number of deaths by age at death, 2016/2017 Nigeria MICS

To make inference about heaping of child deaths, index of heaping was calculated by determining the ratio of number of deaths at exactly 12 months and mean number of deaths at exactly 9, 10, 11, 13, 14 and 15 months, as depicted by the following formula.[46] An index score of 1.0 is suggestive of heaping of deaths at 12 months, assuming that frequency of deaths changes linearly between 9 months and 15 months.

$$Index\ of\ heaping = \frac{(6 \times D_{12})}{(D_9 + D_{10} + D_{11} + D_{13} + D_{14} + D_{15})} \quad (4.2)$$

$$Where\ D_t\ represents\ the\ number\ of\ deaths\ at\ the\ specified\ months$$

With an overall heaping index score of 8.9, there is a clear indication of heaping of death at 12 months. In practical terms, some of the reported deaths at 12 months could have occurred earlier—9, 10 and 11 months, or later—13, 14 and 15 months. In this study, heaping of death at 12 months could underestimate the unadjusted infant mortality rate.[46] Due to infeasibility to accurately redistribute age at death, no effort was made to adjust the timing of death for this study. Also, Balk asserts that adjusting age at death would not significantly change the relative age-specific mortality rates.[46]

4.5.7 Multicollinearity

It is well established that inclusion of highly correlated independent variables in a multivariate model could lead to overspecification. To check for multicollinearity, pairwise correlation matrix and collinearity diagnostics (variance inflation factor (VIF) and tolerance)[47] of all the independent variables were performed. From the pairwise correlation, the highest correlation coefficients were observed between parity and birth order ($r=0.8$). VIF and tolerance provide the amount of variability of an independent variable that is not explained by the other variables. With a small mean VIF value of 1.49 and $r<0.9$, there is no indication of possible high multicollinearity among the independent variables.

4.6 Overview of analytic approach

The neonatal, post-neonatal, infant, child and under-five mortality rates were estimated using the direct method.[48] For the descriptive analysis, frequencies and percentages were used for categorical variables. Continuous variables were described by mean and standard deviation. The survey analysis procedures in Stata™ software version 15.1[21] was used to account for the cluster sampling design (via Taylor linearization method of variance estimation) and sampling weights provided in the 2016/2017 MICS were applied in order to generate national representative estimates. The detailed analytic techniques specific to each objective are covered in the individual papers (Chapters 5-9).

4.6.1 Analysis for objective 1: Estimate the future trajectories and expected annual reduction rates needed to achieve the SDG-3 targets by 2030 for neonatal mortality rate and under-five mortality rate for Nigeria

To address objective 1, the first step to determine the appropriate time series method for forecasting mortality rates, began with comparison of two widely used traditional analytical techniques—ARIMA regression and Holt-Winters exponential smoothing with an artificial intelligence technique—group method of data handling-type artificial neural network (GMDH-type ANN). Time series analysis attempts to observe the historical patterns of observations to make future projections. As introduced by Box and Jenkins,[4] univariate non-seasonal ARIMA modeling was performed in four iterative steps: model identification, parameter estimation, diagnostic checking, and prediction. It is a combination of order of differencing, autoregressive (AR) and moving average (MA) models i.e., autoregressive term (p), differencing term (d) and moving average term (q). As in the case of Holt-Winters exponential smoothing with non-seasonal component, by controlling two parameters α and $\boldsymbol{\beta}$, it estimates the level and slope of the trend components at the current/future time points, respectively. The values of α and $\boldsymbol{\beta}$ should lie between 0 and 1, with values closer to 0 implying that the estimates at the current/future time points are based on recent observations.[49] For GMDH-type ANN, it is a feed forward, self-organizing inductive modeling and forecasting technique that mimics biological brain and its neurons.[50] It extracts important information from the data to build a model through supervised learning. Unlike ARIMA and Holt-Winters methods, GMDH ANN can fit non-linear models.[51,52] Root mean squared error (RMSE), root mean absolute error (RMAE), and modified Nash-Sutcliffe efficiency (NSE) coefficient were used to evaluate predictive accuracy of the three analytical techniques. The loss function differentials between the forecasts were statistically tested with Diebold-Mariano (DM) test and Deming regression—a variant of errors-in-variables regression. With the best forecasting modeling method (GMDH-type ANN), long-term yearly forecasts of age- and sex-specific childhood mortality rates from 2018 to 2030 were generated. Lastly, two scenarios of mortality trajectories were simulated based on: (1) annual rate of reduction (ARR) for the current (observed) trend to 2030—*status quo scenario model*; and (2) ARR needed to achieve SDG targets of 25 deaths per 1,000 live births for under-five mortality rates and 12 deaths per 1,000 live births for neonatal mortality rates by 2030—*acceleration scenario model*. Also, the relative and absolute measures of gender attainment of childhood mortality were estimated. The reliability of patterns of gender inequity in child survival was evaluated with Bland-Altman plot, Pitman's test, and Lin's concordance correlation coefficient. The ARIMA and Holt-Winters models were performed with Stata™ version 15.1 software,[(21)] and GMDH-type ANN was implemented with GMDH shell DS v. 3.8.9 software.[(53)] Chapters 5 and 6 give the full description of the analysis.

4.6.2 Analysis for objective 2: Identify the social determinants of age-specific childhood mortalities—disaggregated into neonatal, post-neonatal and child mortalities, and estimate the within- and between-community variations of mortality among under-five children in Nigeria

Given that the influence of determinants of childhood mortality (i.e., compositional and contextual factors) would vary across the different successive stages of early childhood development— neonatal (0-27 days), post-neonatal (1-11 months) and toddler/pre-school (12-59 months), and across the communities, a multilevel multinomial logistic regression was conducted in Stata version 15.1 software. The inter-clustering sampling differences and effects due to homogeneity of sampling areas due to the nested nature of the data were accounted for by the multilevel approach. For ease of analysis and parallel to previous multilevel studies, two levels of data hierarchies were considered for the random intercept model (measures of variation)—child, maternal and household data (compositional factors) were collapsed into child-level;[(54)] along with community level data (contextual). The random intercept model assumes that the residual errors at the community-level are uncorrelated.[(55)] Using *Chi-square test* for categorical variables and *one-way Analysis of Variance (ANOVA)* for continuous variables, the independent variables that were associated with the outcome variable at p-value≤0.25 were considered as candidate variables for the multivariate multinomial regression (measures of association). To achieve a parsimonious model, a backward elimination strategy was used, retaining variables with p-value <0.05 from the individual models (blocks 1-4) as candidate variables in the final model (model 5). The models were fitted as: block 0 (empty model), block 1 (child-level variables), block 2 (maternal-level variables), block 3 (household-level variables), block 4 (community-level variables) and block 5 (final model). The relative risk ratios (RRR) were estimated with their 95% confidence intervals (CI). The extent of community heterogeneity in childhood mortality was estimated by the median odds ratio (MOR) and percentage change in variance (PCV). Lastly, probability of death for each early childhood developmental stage was predicted. The multilevel multinomial logistic regression equation[56] is given by:

$$\log\left(\frac{\pi_{ij}{}^{(s)}}{\pi_{ij}{}^{(t)}}\right) = \beta_{0j}{}^{(s)} + \beta_{1j}{}^{(s)}x_{1ij} + \beta_{2j}{}^{(s)}x_{2ij} \qquad (4.3)$$

Where *s* represents separate set of intercepts for the reference (alive) and the remaining three categories (neonatal, post-neonatal and child mortality), $\beta_{0j}{}^{(s)}$ is the fixed part of the model.

4.6.3 Analysis of objective 3: Identify the critical pathways through which social factors (at community, household, maternal levels) determine neonatal, infant and under-five mortalities in Nigeria

To identify the pathways through which social factors (maternal, household, community) may affect neonatal, infant and under-five mortalities in Nigeria, hierarchical path analyses with time-to-event (survival) outcomes were performed in generalized structural equation model (gsem) in Stata™'s version 15.1 structural equation model (SEM) builder.[57] The models, which comprised of lognormal regression (parametric survival model) and binomial logit were simultaneously fitted to determine the direct and indirect effects of child, maternal, household and community-level variables in the following steps: (1) model specification via directed acyclic graphs (DAGs);[58] (2) model identification; (3) parameter estimate; and (4) model re-specification. This study introduced parametric survival modeling based on the criticism that Cox-proportional models—most common modeling method for survival analysis—as not suitable for path modeling because of its assumption of constant hazard ratios between categories over time.[59] The selection of appropriate parametric survival method—lognormal regression (accelerated failure time), was based on generalized gamma distribution from adjusted Wald test, and minimum Bayesian Information Criterion (BIC) and Akaike's Information Criterion (AIC). The details of the analysis are described in Chapter 8.

4.6.4 Analysis for objective 4: Determine patterns and determinants of geographical clustering, and to measure gaps in SDG-3 target for neonatal mortality at the state and regional levels in Nigeria

Geospatial analysis and multilayer perceptron neural network (artificial intelligence technique) were used to meet objective 4. With GeoDa software version 1.14.[60], a distance-based spatial weight matrix (based on geometric centroids and spatial arc distance of 407 km) was generated in a geographic coordinate Nigeria shapefile (WGS84: EPGS4326).[61] The appropriateness of spatial weight was assessed by the symmetry of the connectivity histogram and connectivity map, i.e., all the states were connected to each other. To determine the spatial pattern, the neonatal mortality rates were aggregated at the state-level. Global Moran's I index was used to detect spatial heterogeneity in the pattern of neonatal mortality rate, and local indicator of spatial autocorrelation (LISA) cluster maps were used to determine the locations of spatial clusters—hot- and cold-spots of neonatal mortality rates across the states. The cluster analysis follows the *Tobler's first law of geography* which states:*" Everything is related to everything else, but near things are more related than distant things"*.[62] The statistically significant hot-spots (high-high spatial autocorrelation) were determined by the grouping of states with high neonatal mortality rates, and vice-versa for cold-spots (low-low spatial autocorrelation). As highlighted in Table 4.8, Moran's I index is expected to be within +1 and -1, indicating strong positive and negative autocorrelation, respectively.

Table 4.8: Interpretation of Moran's I index

Moran I statistic	Definition	Inference
-1	Definite pattern	Perfect dispersion
0	Randomly dispersed (with no pattern)	Perfect randomness
+1	Similar values are grouped together	Perfect clustering

The global Moran's index as indicated by (I) is displayed in the following equation[63]:

$$I = \frac{N}{W}\frac{\Sigma_i \Sigma_j w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\Sigma_i (x_i - \bar{x})^2} \qquad (4.4)$$

Where N is the number of spatial units indexed by i and j, x is the neonatal mortality rate (NMR), *$\bar{x}$ is the mean of NMR; w_{ij} matrix of spatial weights; and W is the sum of w_{ij}*

The local Moran's I index is expressed with the following equation[64]:

$$I_i = \frac{n}{(n-1)S^2}(x_i - \bar{x})\sum_j w_{ij}\left(x_j - \bar{x}\right) \qquad (4.5)$$

Where x_i is the NMR in a state, x_j is the NMR at the adjacent state, $\bar{x}$ is the mean of NMR, w_{ij} is a weight that denotes the proximity between states $_i$ and $_j$, n is the number of states, and S^2 is the variance of the observed NMR.

The multilayer perceptron neural network was implemented in IBM SPSS neural networks software version 21.0[65] to predict the determinants of neonatal mortality across the regions in Nigeria. It is suitable for both linear and non-linear models.[66] The gradient descent algorithm was used to build the neural network. Finally, gaps in SDG 3 target and annual rate of reduction for neonatal mortality at the state and regional levels were calculated. The details of the statistical analysis are in Chapter 9.

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Part I

Time series modeling

- Manuscript 1—*Time series prediction of under-five mortality rates for Nigeria: comparative analysis of artificial neural networks, Holt-Winters exponential smoothing and autoregressive integrated moving average models.*
- Manuscript 2—*Changing patterns of gender inequities in childhood mortalities during the Sustainable Development Goals era in Nigeria: Findings from an artificial neural network analysis.*

Chapter 5

Manuscript 1—Time series prediction of under-five mortality rates for Nigeria: comparative analysis of artificial neural networks, Holt-Winters exponential smoothing and autoregressive integrated moving average models

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Publication status

Submitted to BMC Medical Research Methodology, and is currently under review

Contributions

Daniel A. Adeyinka conceived the study, analyzed, interpreted the data, and wrote the first draft of the paper. Prof. Nazeem Muhajarine assisted in the design, data interpretation, and reviewed the manuscript.

Notes to the reader

In this chapter, the predictive abilities of two commonly used statistical time series methods, namely, autoregressive integrated moving averages (ARIMA) and Holt-Winters exponential smoothing were compared with an artificial intelligence technique—group method of data handling technique type artificial neural network (GMDH-type ANN). This initial step is to identify a modeling technique that could contribute to better forecasting of childhood mortalities to inform policy actions in Nigeria. Predicting and long-term forecasting of country's progress towards Sustainable Development Goal (SDG) targets, especially SDG 3.2, is a daunting task because of the difficulty in addressing non-linearity of neonatal and under-five mortality rates. To address this challenge, the United Nations called for data revolution in 2014 to support researchers in employing newer technologies to improve data for sustainable development. As the use of artificial intelligence is gaining popularity because of its ability to solve more complex questions, detect hidden patterns of data variation, and ease modeling of non-linear relationships, this comparative study used historical data consisting of annual under-five mortality rates for Nigeria from 1964 to 2017.

5.1 Abstract

Background

Accurate forecasting model for under-five mortality rate (U5MR) is essential for policy actions and planning. While studies have used traditional time series modeling techniques (e.g., autoregressive integrated moving average (ARIMA) and Holt-Winters smoothing exponential methods), their appropriateness to predict noisy and non-linear data (such as childhood mortality) has been debated. The objective of this study was to model long-term U5MR with group method of data handling (GMDH)-type artificial neural network (ANN), and compare the forecasts with the commonly used conventional statistical methods—ARIMA regression and Holt-Winters exponential smoothing models.

Methods

The historical dataset of annual U5MR in Nigeria from 1964 to 2017 was obtained from the official website of World Bank. The optimal models for each forecasting method were used for forecasting mortality rates to 2030 (ending of SDG era). The predictive performances of the three methods were evaluated, based on root mean squared errors (RMSE), root mean absolute error (RMAE) and modified Nash-Sutcliffe efficiency (NSE) coefficient. Statistically significant differences in loss function between forecasts of GMDH-type ANN model compared to each of the ARIMA and Holt-Winters models were assessed with Diebold-Mariano (DM) test and Deming regression.

Results

The modified NSE coefficient was slightly lower for Holt-Winters methods (96.7%), compared to GMDH-type ANN (99.8%) and ARIMA (99.6%). The RMSE of GMDH-type ANN (0.09) was lower than ARIMA (0.23) and Holt-Winters (2.87). Similarly, RMAE was lowest for GMDH-type ANN (0.25), compared with ARIMA (0.41) and Holt-Winters (1.20). From the DM test, the mean absolute error (MAE) was significantly lower for GMDH-type ANN, compared with ARIMA (difference=0.11, p-value=0.0003), and Holt-Winters model (difference=0.62, p-value<0.001). Based on the intercepts from Deming regression, the predictions from GMDH-type ANN were more accurate ($\boldsymbol{\beta}_0$=0.004±standard error: 0.06; 95% confidence interval: -0.113 to 0.122).

Conclusions

GMDH-type neural network performed better in predicting and forecasting of under-five mortality rates for Nigeria, compared to the ARIMA and Holt-Winters models. Therefore, GMDH-type ANN might be more suitable for data with non-linear or unknown distribution, such as childhood mortality. GMDH-type ANN increases forecasting accuracy of childhood mortalities to inform policy actions in Nigeria.

Keywords: *Sustainable Development Goals; time series; under-five mortality rate; forecasting; artificial intelligence; deep learning; GMDH neural network; autoregressive integrated moving average; Holt-Winters exponential smoothing; Nigeria*

5.2 Introduction

Childhood mortality has traditionally been used as an important health indicator for assessing population well-being and consistently gained visibility in the Millennium Development Goals (MDGs) and Sustainable Development Goals (SDGs).[1] It is a major public health threat in Nigeria and other low-middle-income countries (LMICs). Despite government efforts, the high under-five mortality rate (U5MR), which was 100 deaths per 1000 live births in 2017,[2] continues to burden the economic and health system of Nigeria.

In the absence of reliable vital registration system of under-five mortalities in most of LMICs, it is difficult for stakeholders to track progress towards achieving the child survival targets of SDG-3, which is aimed at reducing U5MR to 25 deaths per 1000 live births by 2030. To adequately plan for child survival programmes in Nigeria, large investment is required. In the face of the current economic situation of Nigeria, accurate forecasts of childhood mortalities will guide effective use of the limited health resources. On this note, sound modeling approach to improve childhood mortality estimates is needed in Nigeria. Considering the applicability of the traditional time series models for forecasting U5MR, there is little evidence to guide future planning of child health programmes in Nigeria. The argument is that, it is challenging for researchers to choose appropriate time series modeling techniques that can detect non-linear patterns of mortality rates.[3–5] However, some authors have proposed artificial intelligence, such as deep learning techniques (e.g., artificial neural networks (ANN), convolution neural networks (CNN), recurrent neural networks (RNN))[5–8] and machine learning techniques (e.g., support vector machine, random regression forest)[9–11], to improve accuracy of predictive models, while other studies have failed to demonstrate their suitability.[12–14] Unlike the conventional statistical/mathematical techniques, such as Box-Jenkins approach of autoregressive integrated moving average (ARIMA) and Holt-Winters exponential smoothing method, ANN combines both linear and non-linear modeling properties.[4,5] ANN closely follows the structure and functionality of the human brain and its neurons to solve complex problems faster with minimal human interventions, hence reducing error rates.[6] As ANN is evolving with newer algorithms, few studies[9–11,15–18] have considered their applicability in population health studies. As far as we know, most of the studies in the fields of population health and medicine have used different deep learning techniques to optimize classification of health outcomes and medical data,[19,20] and disease screening/diagnosis.[21,22] However, application of a deep learning algorithm to forecast long-term childhood mortality is yet to be demonstrated in many LMICs (including Nigeria). Since childhood mortality data from resource-limited countries are often non-linear, noisy, and associated with large degree of uncertainties,[2] forecasting with conventional statistical methods is somewhat difficult.

In the fields of engineering, agriculture, finance and urban planning, Group Method of Data Handling (GMDH)-a type of artificial neural net—was observed to improve forecasting, compared with other neural networks. In a recent study, Ghazanfari *et al*[23] evaluated the performance of multilayer perceptron network (MLP)—a popular ANN algorithm, and GMDH-type ANN in predicting comprehensiveness and workability of concrete. Their study showed more accurate results with GMDH-type ANN. Also, other studies (outside of medicine and population health) have demonstrated the superiority of GMDH-type ANN compared with adaptive neuro fuzzy inference system (ANFIS) and long short-term memory (LSTM).[24,25] On this basis, our study focuses on generating accurate estimates and observing the patterns of U5MR for Nigeria during the SDG-implementation era. This study is in line with the 2014 United Nations' call for data revolution of newer technologies that would improve data for sustainable development.[26] As new approaches are needed for child health programming in resource-limited countries like Nigeria, identifying and demonstrating the use of an appropriate model will ease application of long, time series data for monitoring the attainment of global framework indicators such as SDGs.

GMDH algorithm is a self-organizing inductive modeling and forecasting technique that extracts important information from the data to build a multilayered model through supervised learning.[27] A well-known problem with all time series methods is that inadequately preprocessed input data can result in poor forecasting. Unlike the traditional statistical methods, no a priori knowledge of series stationarity and randomness is required for GMDH algorithm.[28] GMDH neural network can automatically learn from the data and uncover hidden processes not detectable by the conventional methods.[29] On the other hand, implementation of GMDH ANN turns out to be tricky because there is currently no theoretical guidelines for designing GMDH architectural layers in order to improve prediction accuracy.[7] Since, it is important to generate more accurate U5MR for Nigeria during the SDG-era, this study aimed to model long-term U5MR with GMDH-type ANN, and compare the forecasts with the most commonly used conventional statistical methods—ARIMA regression and Holt-Winters exponential smoothing models.

5.3 Methods

This study was exempted from ethical review by the University of Saskatchewan Behavioural Ethics Committee (ID# 904) as it relied on a publicly available aggregated de-identified dataset.(30) The dataset used is the historical aggregated yearly U5MRs of Nigeria for 1964-2017. The dataset was obtained from the official website of the World Bank.(31) The dataset was based on the reconciled country-level estimates from different data sources by the United Nations Inter-agency Group for Child Mortality Estimation team (UN IGME).(31)

We applied ARIMA regression, Holt-Winters exponential smoothing, and GMDH neural nets to predict annual U5MRs. The historical mortality data span from 1964 to 2017, giving a total of 54 observations, which was adequate to fit ARIMA regression (i.e., at least 50 non-missing data points).(32) Furthermore, we generated long-term forecasts to determine U5MR for Nigeria by 2030 (to coincide with attainment of SDGs). GMDH-type ANN was purposefully selected from the class of deep learning algorithms because of its robustness against incorrect, noisy, and small dataset.(33) Also, recent studies in other disciplines have demonstrated its superiority over RNN and LSTM.(24,25,34,35) P-value <0.05 and 95% confidence intervals (CI) were used to assess statistical significance.

5.3.1 Fitting ARIMA model

We utilized Stata™ version 15.1 software(36) to fit ARIMA regression model. The model construction is in four iterative steps: model identification, parameter estimation, diagnostic checking, and prediction. As the first step, data preprocessing geared towards understanding the underlying patterns in the data and data transformation was ensured. The stationarity of the aggregated U5MR was assessed by plotting line graph (Figure 5.1a). It was observed that the assumption of stationarity for time series analysis was violated as evident by the non-seasonal downward trend of the overall under-five mortality rates. After different calibrations, third-order differencing was appropriate in removing the observed trend (Figure 5.1b). Next, Dickey-Fuller (DF) test with drift was used to assess the stationarity of the differenced data (DF= -9.02, lag order= 2, p-value<0.001), and the absolute value of t-statistic was greater than the critical value at 5% level (9.02 vs. 1.68, p-value<0.001).

The autocorrelation function (ACF) and partial autocorrelation (PACF) plots were also checked to determine the structure of the correlation between time lags of the differenced data (Figures 5.1c and 5.1d). The ACF plot had a significant spike at the second lag, indicating second order moving averages (MA (2)) or ARIMA (0,3,2). Furthermore, ARIMA (0,3,2) model had the lowest Akaike's Information Criteria (AIC) and Bayesian Information Criteria (BIC), hence it was considered suitable for fitting the actual under-five mortality rates. The model with smallest possible number of parameters (principle of parsimony) was selected to represent the distribution of the data. Also, the model comparison with AIC and BIC is valid, because the candidate models fitted the same data (U5MR).(37) Following this principle, the specified ARIMA (0,3,2) model is expressed as:

$$\Delta_3 y_{t=} b_1 * \varepsilon_{t-1} + b_2 * \varepsilon_{t-2} \quad (5.1)$$

$$\Delta_3 y_t = y_t - y_{t-3} \quad (5.2)$$

y_t *and* ε_t *were the actual value and random error at time period* t*, respectively.*

b_1 and b_2 were the model parameters of moving averages at lag 1 and lag 2 (-0.35 and 0.62 respectively) with standard deviation ***δ****= 0.22.*

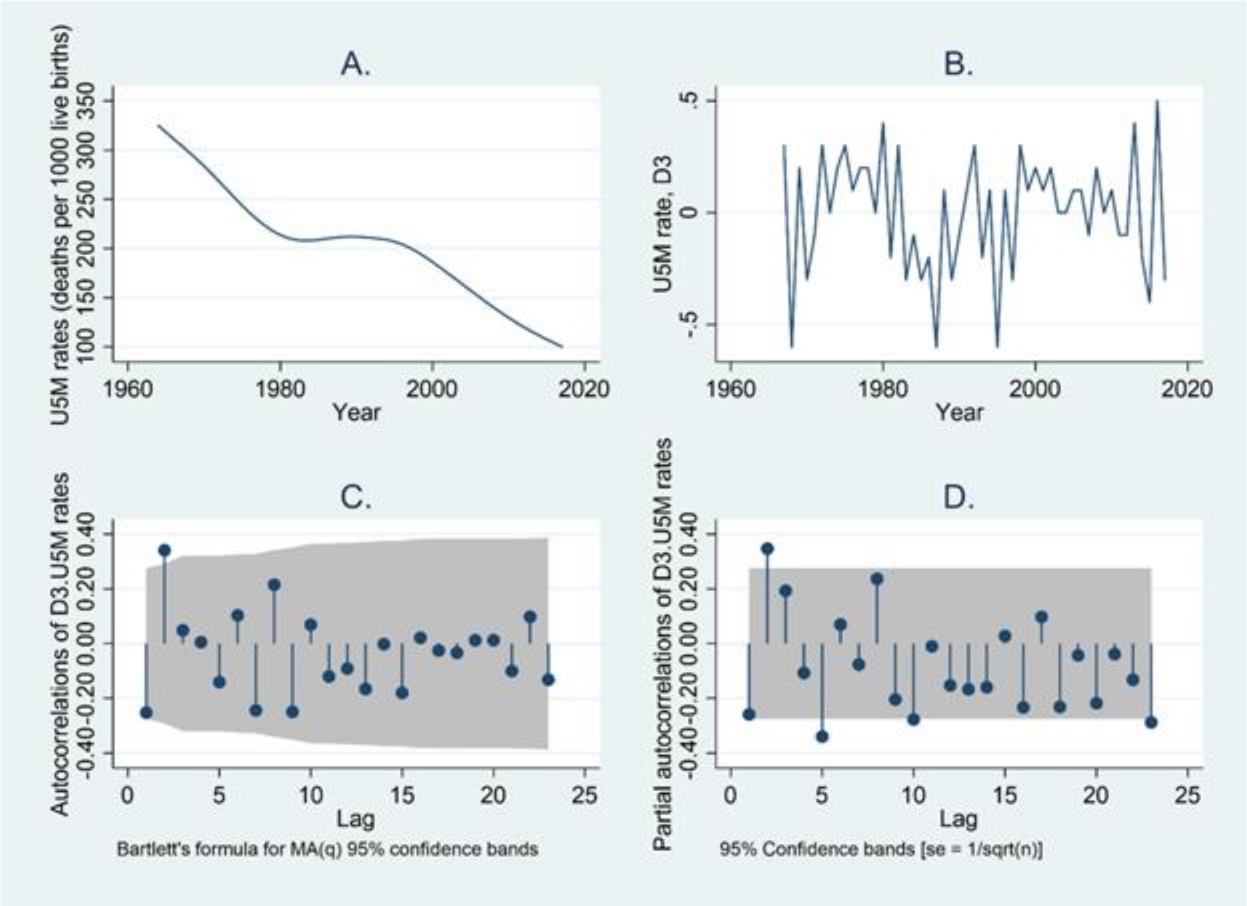

Figure 5.1: A. Time series plot of under-five mortality rates in Nigeria for ARIMA modeling, 1964-2017 B. Third order difference of yearly under-five mortality rates C. Autocorrelation function plot of third order differenced under-five mortality rates D. Partial autocorrelation function plot of third order differenced under-five mortality rates.
D3: third order differencing, U5M: under-five mortality, grey color in plots C and D: 95% Confidence Interval

The adequacy of the fitted model was determined by the randomness of the model residuals (Figure 5.2). Also, all the eigenvalues for stability of estimates were less than one and the inverse roots of MA polynomial visually indicates that the eigenvalues were within the unit circle (modulus of 0.79). This suggests that the MA parameters satisfied invertibility condition (Figure 5.2b). This was further confirmed with Portmanteau (Q) test for white noise (Q=32.3, p-value= 0.095).

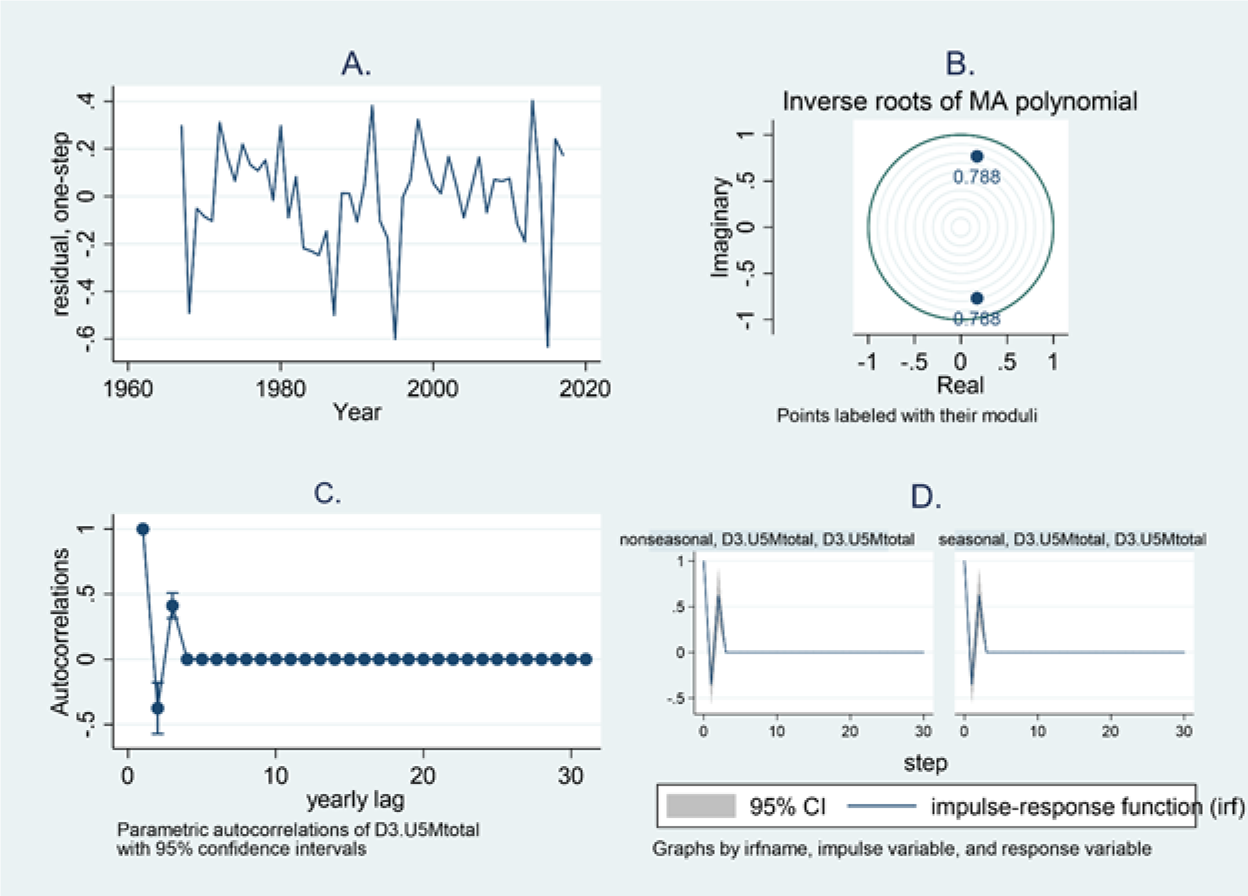

Figure 5.2: Diagnostic plots for ARIMA (0,3,2) of under-five mortality rates, Nigeria (1964-2017) A. Residual plot B. Inverse roots of MA polynomial C. Autocorrelations of differenced rates D. Impulse-response function plot

5.3.2 Fitting Holt-Winters exponential smoothing model

Holt-Winters non-seasonal smoothing (often referred to as triple exponential smoothing) was used to predict the overall under-five mortality rates. According to Chatfield,[38] it is the most advanced method in the category of smoothing methods. The smoothing parameters were automatically generated with Stata™ version 15.1 software[36] prior modeling with Holt-Winters method. The α (level) and $\boldsymbol{\beta}$ (slope) of trend should lie between 0 and 1, with values closer to 0 implying that the estimates at the current/future time points are based on recent observations.[38] The optimal smoothing weights were computed as $\boldsymbol{\alpha}$=0.91 and $\boldsymbol{\beta}$=0.51. The residual plots after fitting under-five mortality rates for Nigeria, using Holt-Winters exponential model are shown in Figure 5.3.

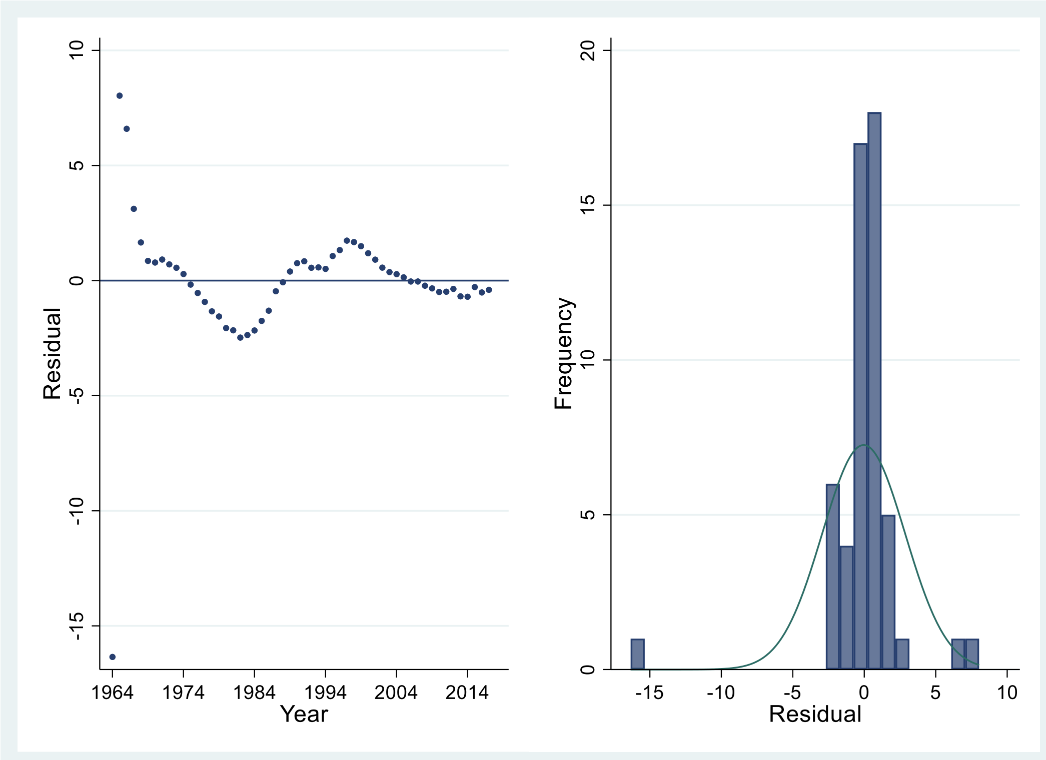

Figure 5.3: Residual plots for Holt-Winters exponential smoothing for overall under-five mortality rates, Nigeria (1964-2017)

5.3.3 Fitting GMDH-type artificial neural network model

The time series artificial neural network was implemented by the GMDH-type neural network core algorithm in GMDH Shell DS version 3.8.9 software.(39) We used the built-in time series pre-processing features of GMDH-type algorithm(40) to automatically remove the under-five mortality trend. The target variable (U5MR) was automatically transformed into cube root, with a minimum of zero lag and maximum of 6 lags. The input variables included time and lags of the transformed mortality rates. The polynomial neuron function of GMDH-type model is as follows:

$$f\left(x_i, x_j\right) = a_o + a_{1.}x_i + a_{2.}x_j + a_{3.}x_i.x_j \qquad (5.3)$$

$where\ x = (x_i, x_2 \ldots), the\ input\ variables\ vector, and\ A = (a_0, a_1, a_2, ..)\ the\ vector\ of\ weights$

To avoid under/over-fitting of U5MR arising from improper training of dataset, the network was implemented with the dataset randomly partitioned using Pareto principle(41,42)—80% was used for training and 20% was the test dataset for evaluating model accuracy. We designed an optimal neural-type time series model based on best performing hyper parametrization with polynomial neural networks of GMDH-type[43] (Figure 5.4). Following the rule of thumb that the number of hidden neurons should be less than twice the input layer size, we developed the neural architecture.[44,45] After different calibrations of neural architecture, the parameters for the network was configured with maximum number of network layers of 60 and initial neurons of 25. Similar to a method used by Banica *et al.*,[46] we stopped creating new neural layers when: (1) the new layer failed to improve the model accuracy, compared with preceding layer, (2) changes in testing error was less than 1%, and (3) configuration limit for the number of layers has been reached. Adequacy of the model was further confirmed with criterion value and residual plots (Figure 5.4). With low criterion value of 1.01e-5, the final neural architecture adequately fits the data. The parameters and coefficients of equation for GMDH-type model are given as:

$$Y_{[t]} = 5.206e^{-05} - N_{25} * 0.077 + N_2 * 1.07734 \qquad (5.4)$$

Where Y corresponds to year of forecast, and N indicates neurons 2 and 25.

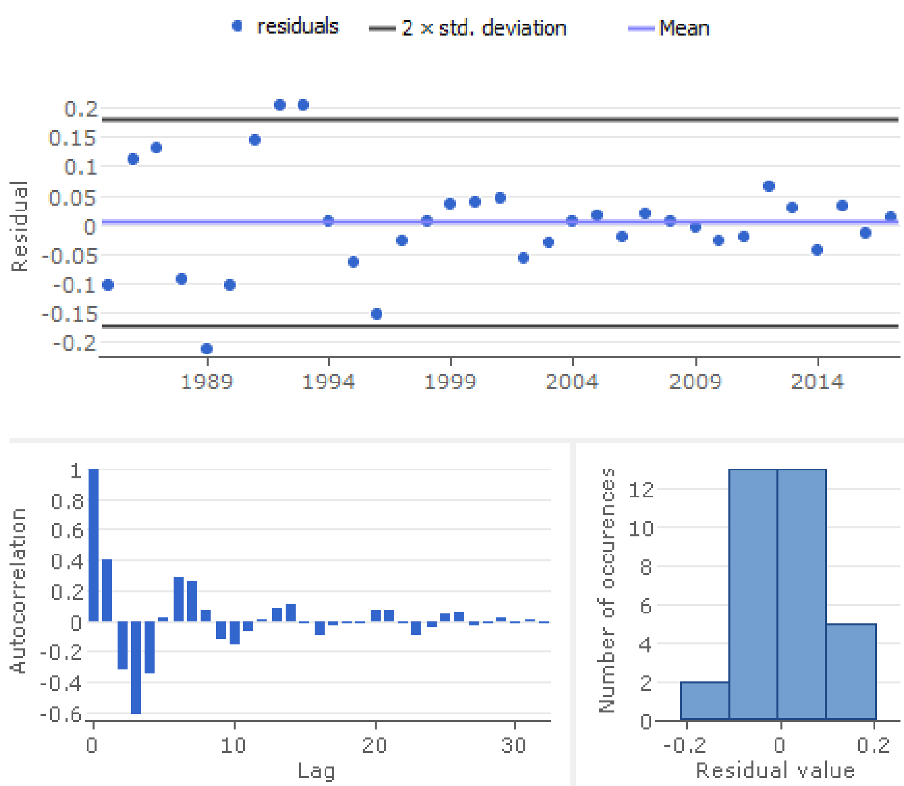

Figure 5.4: Residual plots for GMDH-type neural network for overall under-five mortality rates, Nigeria (1964-2017)

5.3.4 Model comparison

The foremost problem with measuring prediction accuracy is the identification of key performance indicators. Although mean absolute percentage error (MAPE), mean squared error (MSE) and RMSE are the commonly used accuracy metrics, they are prone to asymmetrical distribution of errors.[47] MAPE is generally not considered as a good performance indicator because of its disadvantages—(1) only accurate for ratio-scaled data, and (2) it disfavors models when the predicted values are more than the actual (historical) values.[48] On the other hand, a benefit of using RMSE is that it is more appropriate if large errors are anticipated. Even though strength of performance measurements vary, we selected root mean absolute error (RMAE) because of its robustness against outliers.[49] In addition, RMSE was chosen because it minimizes the effects of bias, and measures dispersion of prediction errors (i.e., model stability).[49] The model with the lowest RMAE and RMSE values provides good fit for U5MR in Nigeria. Furthermore, modified Nash-Sutcliffe model efficiency coefficient (NSE) was calculated to address the challenges of overestimating extreme values, arising from squared differences of actual and predicted values in original Nash-Sutcliffe efficiency equation.[50] Efficiency coefficient of ≥0.9 implies highly accurate prediction, and <0.8 implies inaccurate prediction.[51] Relative to the observed rates, statistically significant differences in loss function between forecasts of each of ARIMA and Holt-Winters models were compared to GMDH-type ANN, based on absolute value error from Diebold-Mariano (DM) test.[52] The squared error was not used because of its tendency to overestimate errors.[53] In estimating the long-run variance of the differenced series from its autocovariance function, a maximum lag order of 9 was selected by Schwert criterion and the weights of Bartlett kernel (i.e., zero autoregression).

The measurements are expressed as[54]:

$$RMAE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}|y_i - \hat{y}|} \qquad (5.5)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y_i - \hat{y})^2} \qquad (5.6)$$

$$modified\ NSE = 1 - \frac{\Sigma|y_i - \hat{y}|^j}{\Sigma|y_i - \bar{y}|^j} \quad (5.7)$$

$Where\ \hat{y} = predicted\ value\ of\ y, \bar{y} = mean\ value\ of\ y, j = 1$

To further test the equivalence of the in-sample predictions (from the individual methods) with the observed historical values, Deming regression—an extension of errors-in-variables regression was performed. Deming regression assumes that forecasting errors are caused by the methods used,[55,56] (sample size >20),[56] and the measurement error variance ratios (λ) are constant[55,57]. When λ=1, Deming regression is like orthogonal regression. An intercept ($\boldsymbol{\beta}_0$ or constant) with a confidence interval including 0 (i.e., intercept is not significantly different from zero) suggests no systematic difference/ bias between the measurements.[56] Also, slope coefficient ($\boldsymbol{\beta}_1$) with a confidence interval including 1 (i.e., slope is not significantly different from 1) indicates absence of proportional differences.[56] The Deming regression model utilized jack-knife replications to estimate the standard errors (SE) and 95%CI of the coefficients.

5.4 Results

The mean annual U5MR was 203.84 (standard deviation: 58.02) deaths per 1000 live births, ranging between 324.8 deaths per 1000 live births in 1964 and 100.2 deaths per 1000 live births in 2017. From Figure 5.5a, the in-sample prediction of U5MR for 1964-2017 from ARIMA, Holt-Winters and GMDH-type ANN were close to the observed historical rates. Also, similar out-of-sample rates were observed from 2018 to 2020 for the three models (Figure 5.5b). However, the out-of-sample forecasts from 2021 to 2030 for each model were different (Figure 5.5b). The difference is greatest for Holt-Winters model compared to GMDH-type ANN and ARIMA regression models. The forecast obtained from GMDH-type ANN model is higher than others—85.89 (95% prediction interval (PI): 85.72-86.08) deaths per 1000 live births by 2030. Holt-Winters method generated smallest mortality rate for 2030, 51.20 (95%PI: 50.66-51.73) per 1000 live births. For 2030, ARIMA model generated a rate closer to the rates for the GMDH-type ANN model—80.17 (95%PI: 79.64-80.71) deaths per 1000 live births. According to the GMDH-type model, U5MR was observed to rise from 2028 to 2030 (Figure 5.5b).

The modified NSE coefficient was slightly lower for Holt-Winters methods (96.7%), compared to GMDH-type ANN (99.8%) and ARIMA (99.6%). Further comparison between GMDH-type ANN and ARIMA with RMSE, RMAE and DM test indicated that GMDH-type ANN's performance was better (Table 5.1). The RMSE of GMDH-type ANN (0.09) was lower than ARIMA (0.23) and Holt-Winters (2.87). Similarly, RMAE was lowest for GMDH-type ANN (0.25), compared with ARIMA (0.41) and Holt-Winters (1.20). From the DM test, the mean absolute error (MAE) was significantly lower for GMDH-type ANN, compared with ARIMA (difference=0.11, p-value=0.0003), and Holt-Winters model (difference=0.62, p-value<0.001).

As shown in Table 5.2, the coefficients of slopes and intercepts suggest there were no proportional and systematic differences between the predicted rates for the three models and the observed (historical) rates. While the slopes (proportional difference) for the three methods were similar, the intercepts (systematic difference) and standard errors were different. The lowest coefficient of intercept and SE were obtained with GMDH-type ANN ($\boldsymbol{\beta}_0$=0.004±SE: 0.06; p-value=0.940)—implying that GMDH-type predictions were closest to the observed (historical) rates than ARIMA ($\boldsymbol{\beta}_0$=0.03±SE: 0.16; p-value=0.865), and Holt-Winters ($\boldsymbol{\beta}_0$=0.89±SE: 2.35; p-value=0.706).

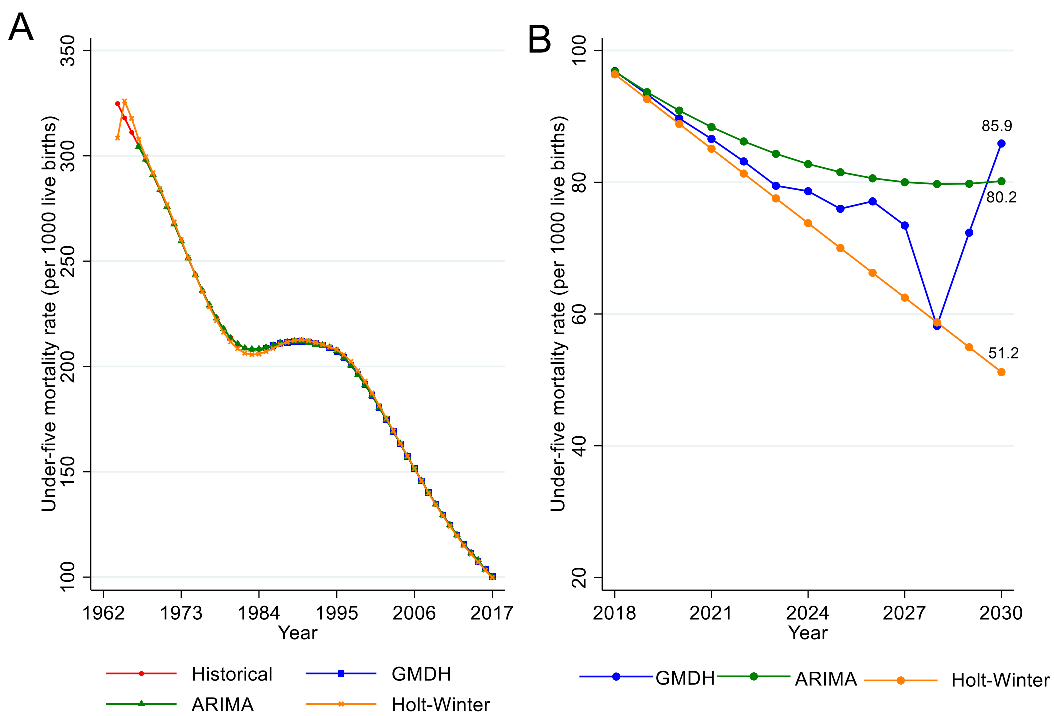

Figure 5.5: Observed (historical), predicted and forecasted under-five mortality rates by modeling techniques A. in-sample prediction (1964-2017) B. out-of-sample forecasting (2018-2030) GMDH: Group method of data handling, ARIMA: autoregressive integrated moving averages, Holt-Winters: Holt-Winters exponential smoothing method. All the lines basically overlap in Plot A

Table 5.1: Performance measures of time series techniques for under-five mortality rates in Nigeria

Model	GMDH-type ANN	ARIMA	Holt-Winters exponential smoothing
Best parameters	Training set=80%, testing set=20%	p=0, d=3, q=2	**α**=0.91, **β**=0.51
RMSE	0.09	0.23	2.87
RMAE	0.25	0.41	1.20
Modified NSE	0.998	0.996	0.967
DM test statistic	Reference	-3.608*	-4.474*

*•significant at p-value<0.05; p=number of autoregressive terms, d=number of differencing, q= number of moving average terms; RMSE: Root mean squared error; RMAE: Root mean absolute error; **α**= coefficient for the level smoothing; **β** = coefficient for the trend smoothing; modified NSE: modified Nash-Sutcliffe model efficiency coefficient; DM: Diebold-Mariano test*

Table 5.2: Deming regression for comparing GMDH-type ANN, ARIMA and Holt-Winters models

	Proportional difference (slope)			Systematic difference (intercept)		
Ref: Observed historical U5MR	$\boldsymbol{\beta}_1$ (SE)	95% LCL, UCL	P-value	$\boldsymbol{\beta}_0$(SE)	95% LCL, UCL	P-value
GMDH-type ANN	1.000 (0.0004)	0.999, 1.001	<0.001	0.004 (0.058)	-0.113, 0.122	0.940
ARIMA	1.000 (0.001)	0.998, 1.002	<0.001	0.027 (0.160)	-0.293, 0.348	0.865
Holt-Winters	1.000 (0.013)	0.969, 1.023	<0.001	0.890 (2.349)	-3.822, 5.602	0.706

LCL: Lower Confidence Limit; UCL: Upper Confidence Limit; SE: Jack-knife standard errors

5.5 Discussion

This study compared the predictive ability of artificial intelligence technique with traditional statistical methods in view of forecasting U5MR for Nigeria from 1964 to 2030. With lowest error rates of RMAE and RMSE from this comparative analysis, we demonstrated that deep learning algorithms such as GMDH-type neural nets might be more suitable for long-term forecasting of U5MR than ARIMA regression and Holt-Winters exponential smoothing methods. Similarly, Deming regression suggests more accurate prediction of U5MR with GMDH-type ANN. Using the high efficiency coefficients (>90%) and overlapping of the predicted rates as the criteria, all three models performed well with in-sample predictions of U5MR for Nigeria. For the period from 1964 to 2017 (in-sampling prediction) and out-of-sample forecasting from 2018 to 2020, all three models had similar results, however, for the longer out-of-sample forecasting period (2021-2030), the rates were significantly different. Also, Nigeria will not achieve child survival targets of SDG by 2030. Furthermore, GMDH-type ANN showed that U5MR will start increasing by 2028. Further analysis with age-specific mortality rates suggests that the surge in U5MR from 2028 to 2030 is due to increasing trend in neonatal mortality rates between 2028 and 2029, and child mortality rates from 2029 to 2030 (Figure D2-Appendix D.2).

In line with other studies,[58,59] our findings showed that ARIMA regression might not be suitable for long-term forecasting of U5MR, in this case for Nigeria. According to Koutsoyiannis,[58,59] ARIMA regression may not be ideal for data that exhibit long-range dependencies because of its slow decay of autocorrelation structure with lag time, making it less sensitive to tipping-points.

In addition, ARIMA and Holt-Winters models assume normality of time series data, whereas under-five mortality data for Nigeria showed a non-linear trend. Also, unlike the two traditional approaches, GMDH-type ANN avoids overfitting by dropping nodes with insufficient predictive power (i.e., fully automatic structural and parametric optimization).[(33)] As opposed to ARIMA and Holt-Winters methods, GMDH time series also allows for detection of recent changes in data (arising from natural behavior, policy changes and interventions), and weighs recent data more than past data during model training.[(29)] These detailed patterns might be easily missed by the conventional methods.

Given that more accurate results were obtained with the GMDH-type algorithm, projecting childhood mortality rates based on neural network would provide better evidence to guide prevention strategies to accelerate gains in child survival for Nigeria. A similar pattern of results was obtained from previous studies that predicted health outcomes with other artificial neural networks. Purwanto *et al*[(60)] and Zernikow *et al*[(61)] showed that multilayer perceptron ANN was superior to linear regression for predicting infant and preterm neonatal deaths, respectively.

More generally, this study indicates that, though U5MR in Nigeria continues to decline from 100.2 deaths per 1000 live births in 2017 to 85.9 deaths per 1000 live births in 2030, Nigeria might not achieve the SDG-3 target that aims to reduce the U5MR to 25 deaths per 1000 live births by 2030.(62) More importantly, the government of Nigeria needs policy innovations to address the observed rise in U5MR by 2028. On evidence such as indicated in this paper, the government of Nigeria should use reliable estimates to improve the design and accelerate the implementation of child health programmes in order to attain the SDG-3 targets for under-five mortality by 2030.

To our knowledge, this is the first published comparative study of ARIMA, Holt-Winters and GMDH-type neural nets on childhood mortality—in Nigeria. Also, the time series used data that covered long period of time—54 years, making the models more stable. Given the high validation accuracy (93.9%) and low RMSE (0.09) of GMDH-type ANN, there is no evidence to suggest that the observed fluctuating patterns of U5MR from 2026 to 2030 is due to overfitting. Although more datapoints are needed to generate more stable models, the forecasts from this

GMDH-ANN model seem adequate because of non-seasonality of the dataset.[63] As more datapoints are available in the future, it is necessary to fine-tune the GMDH-type ANN model. As often encountered with ANN modeling, a major gap is paucity of evidence for optimization of neurons for generating ANN architecture.[7] We relied on calibrations that could give maximum predictive power. To ensure generalizability, the GMDH-type ANN model was further tested on neonatal mortality, and sex-specific mortality data for Nigeria, obtained from World Bank.[31] There was no indication to suggest under(over-fitting) of data. The unexpected rise in U5MR from 2028 to 2030 warrants further investigation.

In conclusion, GMDH-type ANN more accurately predicted U5MR for Nigeria, compared to ARIMA and Holt-Winters smoothing models. Also, it does not require complicated assumptions needed for traditional time series models. The ARIMA regression and Holt-Winters methods might not be suitable for long-term forecasting of U5MR for Nigeria. Therefore, GMDH-type ANN might be more suitable for data with non-linear or unknown distribution, such as childhood mortality. GMDH-type ANN increases forecasting accuracy of childhood mortalities to inform policy actions in Nigeria and similar settings.

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Chapter 6

Manuscript 2—Changing patterns of gender inequities in childhood mortalities during the Sustainable Development Goals era in Nigeria: Findings from an artificial neural network analysis

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Publication status

Submitted to BMJ Open and is currently under review.

Contributions

Daniel A. Adeyinka conceived the study, analyzed, interpreted the data, and wrote the first draft of the paper; Prof. Nazeem Muhajarine contributed to the study design, edited drafts, and supervised this study. Prof. Nazeem Muhajarine, Prof. Pammla Petrucka, and Dr. Isaac Elon assisted with data interpretation, and reviewed the manuscript.

Notes to the reader

This chapter is the continuation of the previous chapter. As observed in chapter 5, GMDH-type ANN time series (artificial intelligence technique) provided the best forecasting power for modeling childhood mortality in Nigeria. In this chapter, the GMDH-type ANN time series was specifically used to forecast the neonatal mortality rate and under-five mortality rate from 2018 to 2030. In addition, this chapter examined gender inequities in under-five mortality rates in Nigeria, with a view of providing additional information on the country's progress towards gender-based attainment of child survival. Two scenarios of mortality trajectories were simulated based on the current (historical) trend—*status quo scenarios*, and the expected annual reduction rates needed to achieve the Sustainable Development Goal-3 targets by 2030 for Nigeria—*acceleration scenarios*. The findings from this study would guide policy actions and planning for child health programmes in Nigeria during the SDG era.

6.1 Abstract

Background

In line with the child survival and gender equality targets of Sustainable Development Goals (SDG) 3 and 5, we aimed to: (1) estimate the age- and sex-specific mortality trends in child-related SDG indicators (i.e., neonatal and under-five mortality rates) over the 1960s-2017 period, and (2) estimate the expected annual reduction rates needed to achieve the SDG-3 targets by projecting rates from 2018 to 2030.

Methods

This study used an artificial intelligence time-series—Group method of data handling (GMDH-type ANN) to forecast age-specific childhood mortality rates (neonatal and under-five), and sex-specific under-five mortality rates (U5MR) from 2018 to 2030. The datasets were the yearly historical mortality rates between 1960s and 2017, obtained from the official website of World Bank. Two scenarios of mortality trajectories were simulated: (1) status quo scenarios—assuming the current trend continues; and (2) acceleration scenarios—consistent with the SDG targets.

Results

At the current rates of decline of 2.0% for neonatal mortality rates (NMR) and 1.2% for U5MR, Nigeria will not achieve the child survival SDG targets by 2030. Unexpectedly, U5MR will begin to increase by 2028. To put Nigeria back on track, annual reduction rates of 7.8% for NMR and 10.7% for U5MR are required. Also, female U5MR is decreasing more slowly than male U5MR. At the end of SDG-era, female deaths will be higher than male deaths (80.9 vs. 62.6 deaths per 1000 live births).

Conclusion

Nigeria is not likely to achieve SDG targets for child survival and gender equities as female disadvantages will worsen. Stakeholders in Nigeria need to adequately plan for child health to achieve SDG targets by 2030. Addressing gender inequities in childhood mortality in Nigeria would not only require gender-sensitive policies, but also community mobilization against gender-based discrimination towards girl-child.

Keywords: *Sustainable Development Goals; gender inequity; time series; neonatal mortality rate; under-five mortality rate; artificial neural network; artificial intelligence; deep learning; group method of data handling type; Nigeria*

6.2 Introduction

In recent years, there have been substantial global improvements in child survival.[1] The success has been attributed to the intensification of international and national actions targeting improvements in the major drivers of child health (e.g., poverty, illiteracy, inadequate access to pre/post natal care, sanitation) in resource-limited countries. Despite the reduction in mortality risks among children, most childhood deaths occur in sub-Saharan Africa, where 1 in 13 children died before reaching five years of age (i.e., 76 deaths per 1000 live births) in 2017.[1] With an under-five mortality rate (U5MR) at 100 deaths per 1000 live births in 2017, Nigeria accounted for 13% of the global burden of under-five deaths, ranked second only after India.[1] The rate in Nigeria is 2.6 times the global U5MR.[1]

Previously, Nigeria did not achieve the Millennium Development Goal 4 (MDG-4), which was aimed at reducing U5MR by two-thirds between 1990 and 2015.[2] Further, given the problems that consistently threaten child survival (e.g., preterm complications, pneumonia, intrapartum-related events, malaria, neonatal sepsis and diarrhea, environmental factors and malnutrition),[1] studies have reported that most countries in sub-Saharan Africa might fall short on achieving the Sustainable Development Goal 3 (SDG-3),[3–5] which aims to reduce U5MR to 25 deaths per 1000 live births and neonatal mortality rate (NMR) to 12 deaths per 1000 live births by 2030.[6,7] However, evidence on long term trends in neonatal and under-five mortality rates for Nigeria, and whether these rates are on track to meet SDG-3 targets is scanty. Also, there are study limitations based on methods used in previous studies (e.g., conventional statistical methods used to model non-linear data).[8–10] In addition, no known published study has forecasted sex-specific under-five mortalities for Nigeria. Often, aggregation of forecasts obscures gender differences in childhood mortality; hence, it is difficult to monitor country's progress towards achieving gender equality aspirations of SDG-5 by 2030, with a focus on child survival.[11]

In a recent analysis of child mortality data from 195 countries, Iqbal et al.[12] concluded that girls were more likely to die within the first few years of life in low-and middle-income countries (LMICs). In many regions of the world, this pattern has been attributed to gender discrimination towards the girl-child.[12,13] Conversely, studies in Nigeria have reported male disadvantage in under-five mortality.[14,15] The high mortalities among males in the early childhood stage has been attributed to biological differences between boys and girls.[16] However, some authors have pointed out that there is tendency for the resource-limited countries (as in the case of Nigeria) to under-report female deaths, because families are more inclined towards reporting male deaths.[12,13]

It is imperative to implement timely policy actions in order to close the existing inequity gaps—a critical component of SDG-5 and 10 targets. In line with the expectations of the 2014 United Nations' call for data revolution that would expedite sustainable development,[17] this study aimed at using an artificial intelligence technique to: (1) estimate the age- and sex-specific mortality trends in child-related SDG indicators (i.e., neonatal and under-five mortality rates) over the 1960s-2017 period; and (2) estimate the expected annual reduction rates needed to achieve the SDG-3 targets by projecting rates from 2018 to 2030.

6.3 Methods

In this study, we used an artificial intelligence modeling technique, known as the deep learning technique of group method of data handling type (GMDH-type) artificial neural network (ANN) algorithm, to extend the previous work of the United Nations Inter-agency Group for Child Mortality Estimation (UN-IGME).[18] We analyzed age-specific historical data—yearly U5MR for 1964-2017, and NMR for 1967-2017 in Nigeria. The under-five mortality rates were disaggregated by biological attribute (sex). Unlike U5MR, we could not report sex-specific NMR because of data unavailability. The datasets were obtained from the official website of World Bank.[19] This study was exempted from ethical review by the University of Saskatchewan Behavioural Ethics Committee (ID# 904) as it relied on a publicly available aggregated de-identified dataset.[20]

Prior to long-term forecasting, the aggregated historical U5MR was first implemented with autoregressive integrated moving average (ARIMA) regression, Holt-Winters exponential smoothing model, and GMDH-type artificial neural network.[21] This initial inter-method assessment was to determine the best forecasting technique for childhood mortality data for Nigeria. Judging by the coefficient of the intercept from Deming regression, modified Nash-Sutcliffe model efficiency coefficient (NSE), root mean squared error (RMSE), root mean absolute error (RMAE), and Diebold-Mariano (DM) test, GMDH-type ANN outperformed the conventional statistical techniques (ARIMA and Holt-Winters models).[21] In this study, gender refers to a social and cultural construct, and sex connotes biological identity on child survival.

6.3.1 Model fitting

The artificial intelligence time series was implemented by the polynomial neuron function of GMDH-type neural network core algorithm in GMDH shell DS v. 3.8.9 software.[22] The GMDH-type algorithm is a family of inductive artificial neural networks with a self-organizing characteristics for modeling complex systems.[23] The theoretical advantage of GMDH-type ANN over the traditional statistical method is its ability to automatically learn the pattern of data, without a priori human knowledge, hence minimizing errors.[24] Similar to the human brain, the artificial neural network architecture (i.e., hyperparameters) is comprised of large computational units—neural layers connected via synaptic weights.[25] These hyperparameters had to be adequately specified when configuring neural network to reduce computational time and error. In order to reduce forecasting errors, the neural architectures (hyperparameters) were calibrated to closely follow the methodological approach used by Banica *et al*[26]. The stopping rules were: (1) failure of the successive neural layers to further improve the model accuracy, (2) less than 1% change in testing error, and (3) saturation of layers. In selecting the number of layers and neurons, we followed the recommendations of Berry and Linoff which suggest that the number of hidden neurons should be less than twice the input layer size.[27,28] The maximum number of network layers configured by the algorithm and initial neurons added to the layered architecture of inputs were 60 and 25, respectively.[25] With this neural architecture, in-sample predictions (1960s-2017) and out-of-sample forecasting (2018-2030), along with their 95% prediction intervals (PI) were generated for the mortality rates.

As previous studies have noted, the validity of time series lies in data stationarity, and model complexities.[29,30] However, it is generally agreed that neural network performs better when it is trained on a number of datapoints that does not over(or under)fit.[29,30] Also, in conformity with evidence that multivariable time series does not improve forecasting accuracy,[31–34] we modeled long-term trends of NMR and U5MR with univariable time series. The built-in solver of GMDH-type algorithm[22] was used for data pre-processing (removal of trend). Using Pareto principle,[35,36] the dataset was randomly partitioned into training set (80%) and testing set (20%). We augmented the validation process by using an iterative perceptron-type procedure—polynomial neural networks of GMDH-type and RMSE-balance criteria.[25] The residuals obtained from testing parts were used for model comparison. The predictive performance of the neural networks was verified with accuracy, RMSE and mean absolute error (MAE).

6.3.2 Estimation of changes in mortality rate trends

We performed Mann-Kendall and Sen's slope tests to evaluate significance changes in trend. To estimate changes in trend, annual rate of reduction (ARR) was calculated as follows[4]:

$$ARR = \left(\frac{\ln\left(\frac{MR_{t+n}}{MR_t}\right)}{n} \right) * (-100) \qquad (6.1)$$

Where MR_t is the mortality rate for baseline year and n is the number of years between the two rates.[4]

The ARR describes a constant rate of decline in the mortality rates between two time periods.[4] To generate the expected annual rate of reduction of mortality rates up to 2030 (ending of SDG-era), we built two scenarios of mortality trajectories: (1) status quo scenarios—projected estimates derived from GMDH-type ANN from 2018 to 2030, assuming the current strategies and historical trend continue; and (2) acceleration scenarios—consistent with the SDG targets of 25 deaths per 1000 live births for U5MR and 12 deaths per 1000 live births for NMR by 2030.

6.3.3 Estimation of relative and absolute gender inequity

The dimensions of gender inequity (i.e., unfair differences in U5MR between males and females) were assessed with relative inequity and absolute inequity.[37] Both relative and absolute mortality inequities were used as proxy measures for gender-bias.[12,13] The relative inequity (otherwise known as relative risk or risk ratio) was estimated as male-female sex ratio of U5MR. Sex mortality ratio is the number of male deaths per 100 female deaths in the population. The absolute inequity—an estimate of excess risk or attributable risk—was calculated as the risk difference between males and females. Sex mortality ratio (<1) or negative excess mortality risk signifies gender-bias unfavourable to females (i.e., female disadvantage and male advantage), and vice versa. In addition, we assessed the relationship between sex mortality ratios and U5MR with Spearman's rank correlation (**ρ**). As used in this study, sex refers to biological and physiological identities, while gender is a social and cultural construct.

6.3.3.1 Reliability test

To assess reliability of the changing patterns of gender inequities in child survival during SDG-era, we generated a Bland-Altman plot, and used Pitman's test and Lin's concordance correlation coefficient to statistically evaluate the agreement of the projected sex ratios (derived from GMDH-type ANN) with sex ratios derived from ARIMA regression. The motivation is to identify systematic differences and possible outliers of the relative magnitudes of male and female U5MR (in ratio scale) from both time series methods. According to McBride[38], agreement concordance coefficient was interpreted as: poor (<0.90), moderate (0.90-0.95), substantial (0.95-0.99) and excellent (0.99). The conventional statistical analyses were implemented in Stata™ version 15.1 software.[39] A two-sided p-value <0.05 and 95% confidence intervals (95%CI) were used to assess statistical significance.

6.4 Results

6.4.1 Historical trends in mortality rates from 1964 to 2017

Table 6.1 displays the historical mortality rates for neonates and under-five children in Nigeria. In 2017, the aggregated U5MR was 100.2 per 1000 live births—69.2% decrease from 324.8 deaths per 1000 live births in 1964 (p-trend<0.001). Also, NMR showed a significant decline—53.2%, from 70.3 deaths per 1000 live births in 1967 to 32.9 per 1000 live births in 2017 (p-trend<0.001). For the entire study period (1964-2017), NMR declined at a slower rate annually (ARR=1.5%) compared to U5MR (ARR=2.2%). Across the mortality indicators, rates of decline were higher between 1990-2017, compared to 1960s-1990 (Table 6.1). As shown in Figure D1, age- and sex-specific mortality rates in Nigeria showed a similar pattern of stepwise decline. The initial phase of decline was evidenced between 1960s to 1980s. While the rates mildly increased between early 1980s to late 1990s, the steepest decline (third phase) was observed between late 1990s and 2017.

Although males were observed to have higher U5MR than females (106.1 vs. 93.8 deaths per 1000 live births), there was no substantial difference in the annual rate of reduction at the end of 2017 (2.2% vs. 2.3%). It is striking that relative inequity (as determined by sex mortality ratio) progressively worsened for males from 1.09 in 1964 to 1.13 in 2017, whereas the absolute inequity improved, with an excess male under-five mortality dropping from 27.3 per 1000 live births in 1964 to 12.3 per 1000 live births in 2017. The influence of gender bias on under-five mortality is presented in Figure 6.1. There was a strong inverse correlation between relative inequities and U5MR (Spearman's ρ= -0.83, p-value<0.001). As female mortality disadvantage increases, U5MR increases.

Table 6.1: Historical age- and sex-specific mortality rates for Nigeria, 1960s-2017

Year[a]	Under-five mortality rate (per1000 live births)			Neonatal mortality rate (per 1000 live births)
	Aggregated	Male	Female	Aggregated
1964/67	324.8	338.0	310.7	70.3
1990	211.9	222.2	200.9	50.3
2017	100.2	106.1	93.8	32.9
Decline (%)				
1964/67-1990	34.8***	34.3***	35.3***	28.5***
1990-2017	52.7***	52.3***	53.3***	34.6***
1964/67-2017	69.2***	68.6***	69.8***	53.2***
Annual rate of reduction (%)				
1964/67-1990	1.6	1.6	1.7	1.5
1990-2017	2.8	2.7	2.8	1.6
1964/67-2017	2.2	2.2	2.3	1.5
Relative mortality inequity (Male:Female ratio)[b]				
1964	1.09			
1990	1.11			
2017	1.13			
Absolute mortality inequity (Male-Female difference)[c]				
1964	27.3			
1990	21.3			
2017	12.3			

[a]Study years: Under-five mortality rate (1964-2017) and Neonatal mortality rate (1967-2017)
[b]Relative inequity: Sex mortality ratio (>1) signifies gender-bias unfavourable to males
[c]Absolute inequity: Excess risk (positive value) signifies gender-bias unfavourable to males
***Significant at p-trend <0.001 (Mann-Kendall and Sen's slope tests)

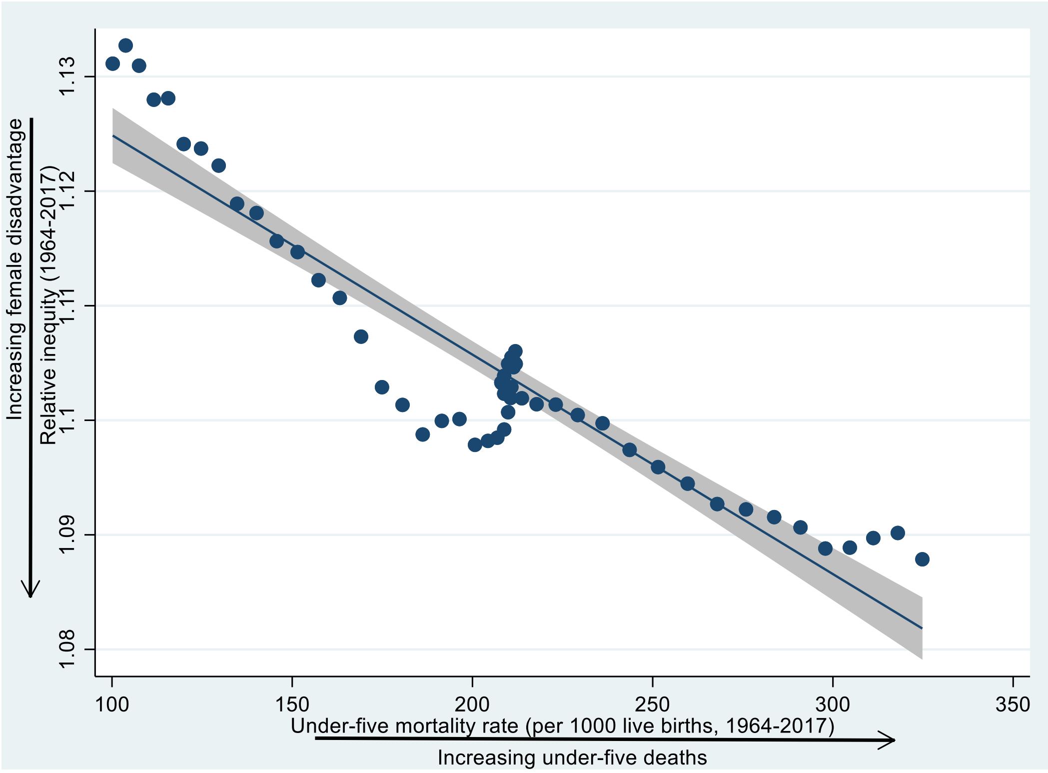

Figure 6.1: Relationship between relative inequities (sex mortality ratios) and under-five mortality rates, Nigeria 1967-2017

6.4.2 GMDH-type ANN mortality forecasts from 2018 to 2030

The forecasts from GMDH-type ANN time series have low error rates—RMSE (0.07-0.17) and MAE (0.05-0.14), and high level of accuracy (81.3%-100%) (Table D1).

6.4.2.1 Scenarios of age-specific childhood mortality

The modelled mortality rates from 2018 to 2030 for under-five and neonates are presented in Figures 6.2a and 6.2b, respectively. The corresponding numerical estimates are shown in Table D1. From the GMDH-type ANN time series, childhood mortalities in Nigeria will continue to steadily decline but the forecasted rates will not be enough to achieve the child-survival targets of SDG by 2030. With a projected annual rate of reduction of 1.19% (status-quo scenario), the U5MR will be 85.9 (95% prediction interval (PI): 85.7-86.1) deaths per 1000 live births in 2030—14.3% decline from 100.2 deaths per 1000 live births in 2017 (Figure 6.2a). Following the predicted trend of annual rate of 2.01%, NMR will be 25.3 (95%PI: 25.1-25.5) deaths per 1000 live births in 2030—23.1% decrease from 32.9 deaths per 1000 live births in 2017 (Figure 6.2b). After an initial decline between 2018 and 2027, NMR will rise steadily to peak at 30.7

deaths per 1000 live births in 2029, then it will decline to 25.3 deaths per 1000 live births by 2030. However, U5MR will decline until 2028. Surprisingly, U5MR will rise from 2028 to 2030 (Figure 6.2). Further analysis of mortality trajectories shows that the increasing U5MR between 2028 and 2029 is likely to be driven by the surge in the NMR during this period. However, the increasing U5MR between 2029 and 2030 could be due to rising child (1-4 years) mortality rates (Figure D2). Increasing annual rates of reduction (acceleration scenarios) of U5MR to 10.7% and NMR to 7.8% (i.e., 9 and 3.9 times the rates of status-quo scenario) will result in achieving the SDG-3 targets by 2030 (Figure 6.3).

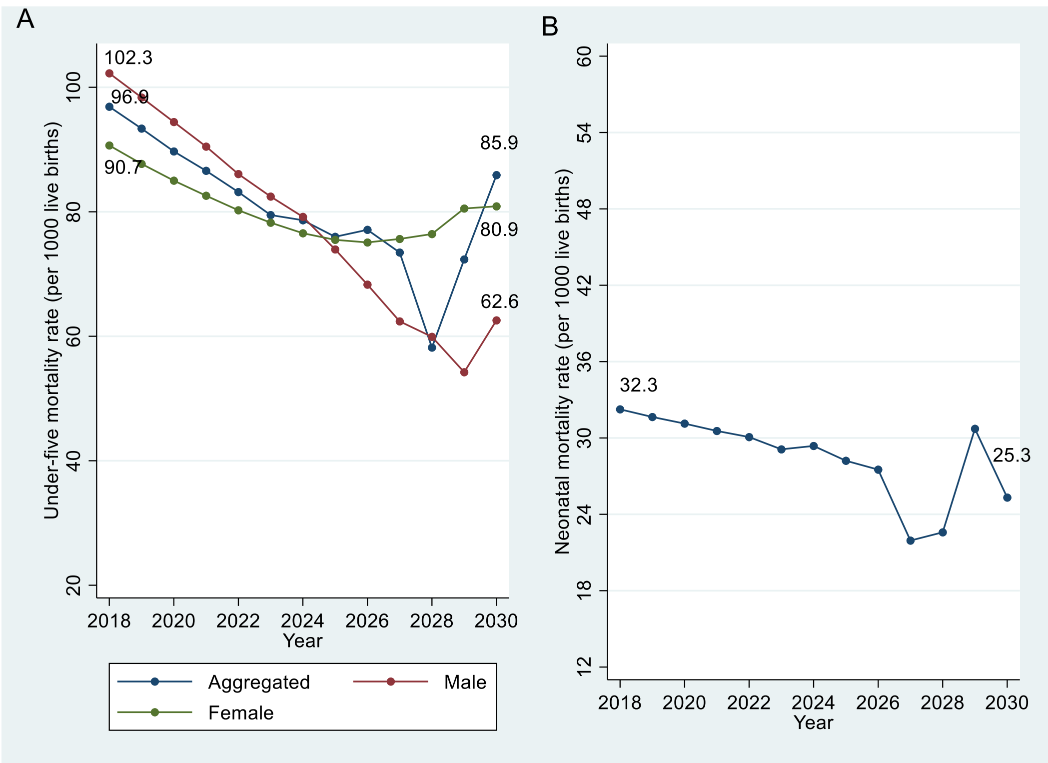

Figure 6.2: Long term forecasts of GMDH-type ANN for Nigeria, 2018-2030 A. Under-five mortality rates B. Neonatal mortality rates

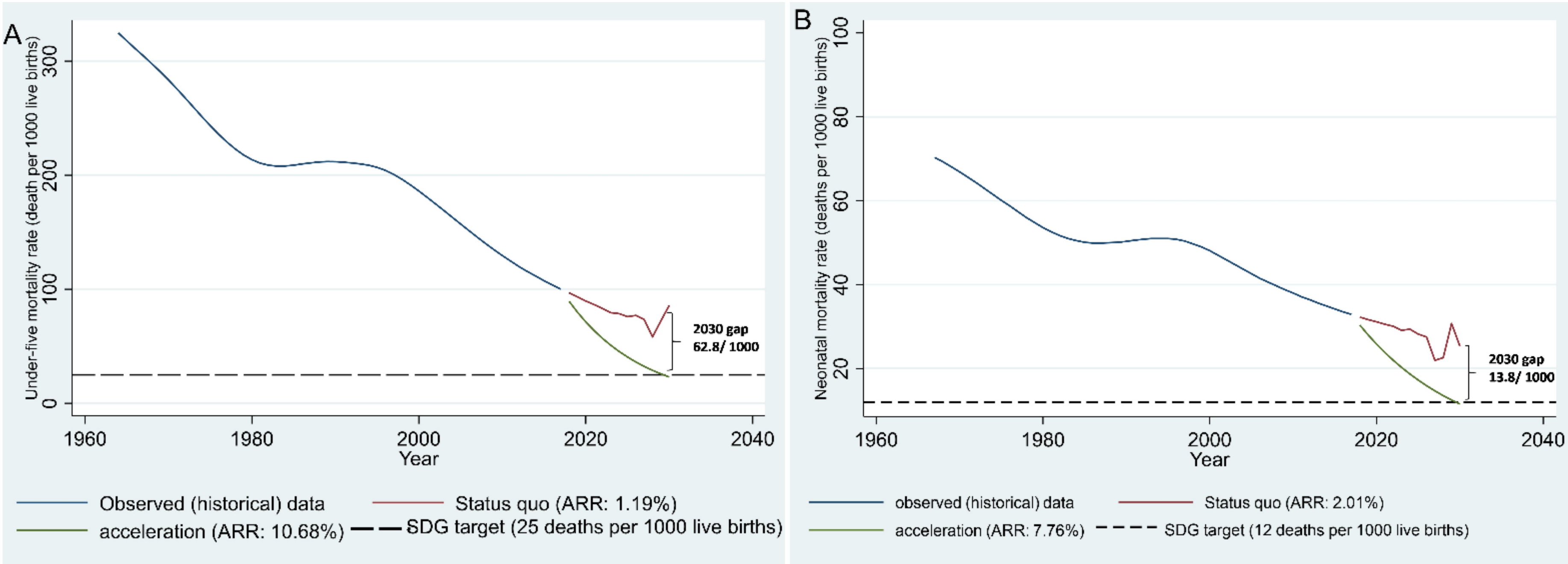

Figure 6.3: Projection scenarios for age-specific mortality rates, Nigeria, 2018-2030 A. Under-five mortality rate B. Neonatal mortality rate

Current trend and SDG trend denote status quo scenario and acceleration scenario, respectively.

ANN estimates were re-drawn with Stata v. 15.1.

6.4.2.2 Scenarios of sex-specific childhood mortality

Figure 6.2a shows the forecasting trend of U5MR, stratified by sex. Male and female mortality rates will decrease to 62.6 (95%PI: 62.2-62.9) deaths per 1000 live births, and 80.9 (95%PI: 80.7-81.0) deaths per 1000 live births, respectively, by 2030. In the status-quo scenario, we forecasted that male U5MR will reduce at a much faster rate (ARR=4.1%) than female U5MR (ARR=1.1%). The mortality rate for males will continue to be higher than the female U5MR until 2024. Remarkably, the female mortality rate will overtake male U5MR by 2025 and will steadily increase afterwards. However, male mortality rate will continue to decline till 2029, and afterwards increase. Strikingly, the unmet gap for female U5MR will be higher than male U5MR (57.6 vs. 39.7 deaths per 1000 live births) by 2030 if the current trend continues. Achieving SDG targets for both sexes will only be possible with ARR of 11.1% for males and 10.2% for females (acceleration scenario) (Figure 6.4).

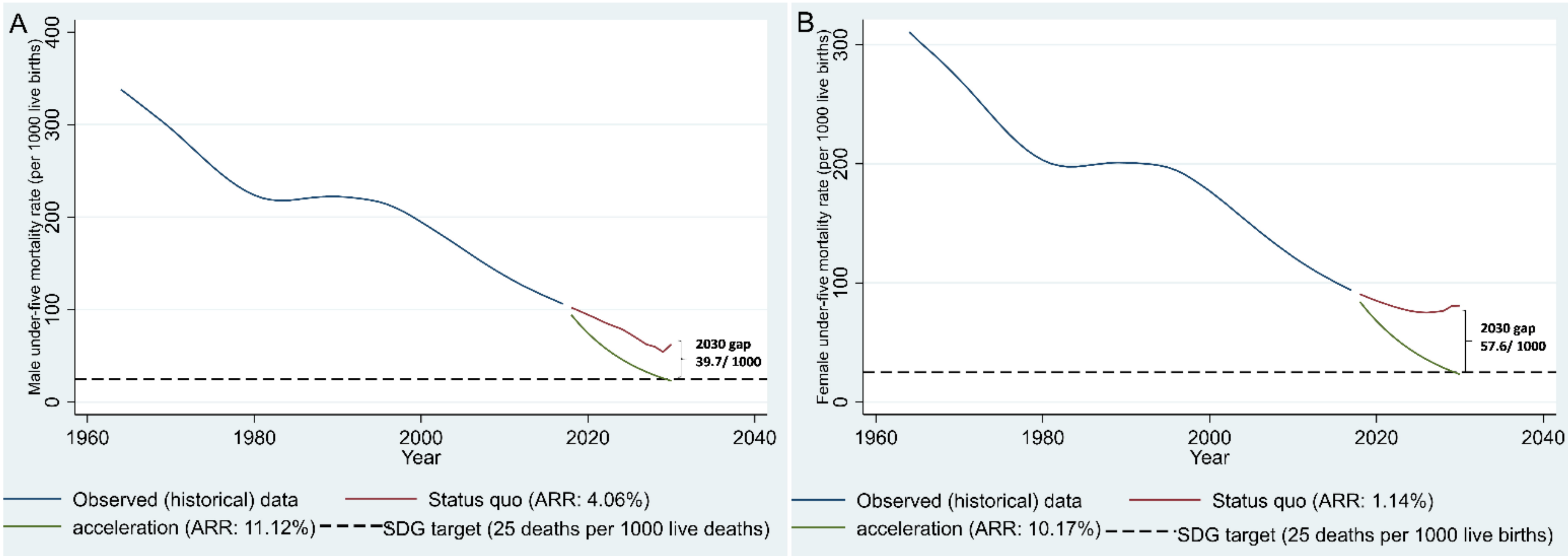

Figure 6.4: Projection scenarios for sex-specific mortality rates, Nigeria, 2018-2030 A. Male mortality rate B. Female mortality rate Current trend and SDG trend denote status quo scenario and acceleration scenario, respectively.
ANN estimates were re-drawn with Stata v. 15.1.

6.4.2.3 Future trajectories of relative and absolute gender inequities

As shown in Table D2, for the out-of-sample forecasts, the relative inequity (ratios of male to female U5MR) changed by 31.9% (1.13 in 2018 to 0.77 in 2030) and absolute inequity changed by 57.8% (11.6 in 2018 to -18.3 deaths per 1000 live births in 2030). While the relative inequity constantly rose from 1.09 in 1964, it reached its peak of male disadvantage of 1.13 during 2013-2018. The sex mortality ratios will begin to decrease (i.e., increasing female disadvantage)—from 1.11 in 2020 to 0.77 in 2030. This indicates that, by 2030, 77 male deaths will occur for every 100 female deaths, unlike 113 male deaths that occurred for every 100 female deaths in 2018. Also, there has been consistent decline in excess morality risk for males (i.e., increasing absolute inequity for females) from 27.3 in 1964 to -18.3 deaths per 1000 live births in 2030 (p-trend<0.001). This indicates that, by 2030, 18 deaths per 1000 live births among female children will be attributed to gender bias towards the girl-child. These trends predict the mortality risks that Nigeria would expect to reduce U5MR with successful interventions by 2030. In the same vein, for female deaths, 22.7% of the under-five mortality risk is attributable to gender-bias towards female-child, indicating that if gender-bias towards girl-child could be decreased, Nigeria would expect 23% fewer under-five mortalities by 2030.

6.4.2.3.1 Reliability test

From the Bland-Altman plot, Lin's concordance correlation coefficient, and Pitman's test, the projected sex mortality ratios derived from GMDH-type ANN were consistent with ratios from ARIMA (Figure D3). The concordance correlation coefficient was 0.96, suggesting substantial agreement between GMDH-type ANN and ARIMA. Furthermore, Bland-Altman plot showed 92.3% agreement. The two measurements are not statistically different as their mean difference (bias)= -0.009, standard deviation=0.04, and the limit of agreement= -0.092 to 0.075. Thus, the changing pattern of gender inequity disfavoring girl-child during the SDG-era is valid (pitman's test of difference in variance: r=0.50, p-value=0.08).

6.5 Discussion

Despite the need for better evidence in LMICs to guide healthcare planning and resource deployments, there remains paucity of studies on accurate forecast of yearly childhood mortality rates. Also, no known study as of date has forecasted sex-specific mortality rates to establish gender differences in childhood mortality in Nigeria. This study used an artificial intelligence method to forecast and offers rates of reducing age- and sex-specific childhood mortality rates for Nigeria to achieve SDG-3 and 5 targets by 2030. At the current rates of decline of 2.0% for neonatal mortality rates (NMR) and 1.2% for U5MR, Nigeria will not achieve the child survival SDG targets by 2030. Unexpectedly, U5MR will begin to increase by 2028. Although, the reasons for the upsurge in mortality rates by 2030 are not clear. The reversal in trend may be due to possible slowdown in interventions after moderate progress in reducing childhood mortality has been achieved. To put Nigeria back on track, annual reduction rates of 7.8% for NMR and 10.7% for U5MR are required. Also, female U5MR is decreasing more slowly than male U5MR. At the end of SDG-era, female deaths will be higher than male deaths (80.9 vs. 62.6 deaths per 1000 live births).

Across the child survival indicators, it is apparent that historical trends show slightly increased mortality rates from 1980s to 1990s, which declined more rapidly afterwards. We speculate that this pattern might be related to military dictatorship and structural adjustment programmes (SAPs) introduced to combat economic crises in the country during this period.[40] Nonetheless, we believe that it is well justified to attribute the modest decline in childhood mortality in the late 1990s to the restoration of democracy in the country.[41] In line with our position, several studies have correlated improvement in population health to democracy.[42–44]

This study confirms previous research findings that Nigeria will not achieve child-survival targets of SDG-3 in 2030, at the current rate of progress.[3] The U5MR and NMR will remain substantially high at 85.9 and 25.3 deaths per 1000 live births, respectively if there are no impactful policy and programmatic actions. With Lee-Carter model, Mejıa-Guevarae *et al*[3] reported a slightly lower U5MR of 73 deaths per 1000 live births for Nigeria. Along this line of research, Nigri *et al*.,[45] acknowledged superiority of neural networks (as used in this study) over the classical Lee-Carter procedure to model non-linear data such as mortality rates. The study by Mejıa-Guevarae *et al* provided no information on the yearly progress and variability in trends for Nigeria. In this study, we provided fluctuating patterns of childhood mortality rates—an important part of mortality surveillance, and whether mortality trend will be sustained by 2030.

Our results indicate downward trend in U5MR, occurring before 2028, whereas the rates are likely to increase afterwards. Likewise, there are changing patterns of sex-specific U5MR in the SDG-era. As indicated by the positive values of sex differences (absolute inequity) and sex ratios (relative inequity) greater than 1 from 2018 to 2024, there are higher male mortalities, although the trend is closing. Nevertheless, female U5MR will begin to rise steadily from 2025 to 2030—female advantage for survival disappears. These stark findings provide evidence that female mortality disadvantage is an important driver of under-five mortality during SDG-era in Nigeria. Consistent with findings from other studies,[12,46–50] this study suggests that under-five mortalities increased as female survival advantages decreased (i.e., decreasing sex ratios). While studies have reported that under similar circumstances, females have more biological advantages than males during early childhood stage, the disappearance of female advantages are more likely to be due to discrimination against girl-child.[46–49] For example, there have been concerns about the increasing cultural preference for male-child in Nigeria due to social, political, and economic reasons.[51–53] In the same context, studies have demonstrated that health needs of girls are often neglected.[54,55] Evidence from Asian and African countries[55–58] suggests societal discrimination against girl-child as evident by gender selective-abortions (due to prenatal sex determination).[55,59] According to recent reports from United Nations Human Rights Council[60] and Thomson Reuters Foundation,[61] Nigeria is ranked ninth among countries practicing female infanticide worldwide. The female infanticide in Nigeria is carried out covertly, and often denied in communities, hence its true scale is unknown.[62] However, studies have substantiated extensive practice of infanticide and male preference in Nigeria.[63–65] The reasons for gender discrimination and infanticide are deeply rooted in culture and traditions. Evidence suggests that male preference is dominant in Southern Nigeria, especially among Igbo communities.[63–65] Previous studies concluded that female infanticide was embraced in Nigeria because of the patriarchal considerations and socio-cultural prestige.[63–65]

The future prospect of Nigeria to achieve child survival targets of SDG will continue to depend on inclination to accelerate annual reduction of NMR and U5MR by 4 and 9 times the current rates, respectively. NMR is expected to decline at a relatively faster rate than U5MR (ARR: 2.0% vs. 1.2%), hence, there is an opportunity to fast-track the 12 deaths per 1000 live births target of 2030. NMR requires lesser efforts as depicted by the annual reduction rate, compared with overall U5MR (7.8% vs. 10.7%). The practical implication of this finding is that intrapartum and neonatal services must be strengthened in Nigeria. In addition, improving neonatal survival may lead to momentous decrease in the country's U5MR. As new evidence on gender-imbalance emerges from this study, the stakeholders through coordinated multidisciplinary efforts should address gender-based discrimination towards girl-child, while social and health needs of the males are not neglected.

Our study has several strengths. It is the first published study to our knowledge that utilized artificial neural network time series to forecast childhood mortality rates for Nigeria. GMDH-type ANN provides more accurate mortality estimates. Also, this is the first known study that examined gender inequities in U5MR in Nigeria, with a view of providing additional information on the country's progress towards reaching the child survival and gender equality targets of SDG-3 and 5, respectively. Given that national data were analyzed, the findings are generalizable to all the regions in Nigeria.

However, our study suffered from a few limitations. There is currently no theoretical framework guiding the optimal number of neurons for building ANN architecture.(66) The process hinged on implementing different simulations and selecting the models with highest performances. Although this study could not look for trend and project for sex-specific NMR due to unavailability of sex-disaggregated neonatal data, this is a desirable objective for future work. More so, disaggregating NMR by sex will provide insight about the increasing trend between 2028 and 2029, and the projected decline in neonatal deaths afterwards. Similarly, future research should consider forecasting sub-national childhood mortality rates with artificial neural networks. The finding of female-child disadvantage in child survival provides a good starting point for discussion and further research. Plurality of research methods, such as mixed methods study is recommended to glean insight on the complex sociocultural context influencing gender difference of U5MR.

In conclusion, our study is a further validation that Nigeria currently is not on track to achieve the SDG-3 and 5 targets for NMR and U5MR. Also, this study recognizes inequitable pace of progress for sex-specific mortality rates, worse for females. We highlight that under-five mortality rates will begin to rise by 2028. Our results provide a basis for strengthening advocacy and creating more political awareness to guarantee adequate investments in child health for accelerating progress towards child survival. Addressing gender inequities in childhood mortality in Nigeria would not only require gender-sensitive policies, but also community mobilization against gender-based discrimination towards girl-child.

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Part II

Cross sectional studies

- Manuscript 3—*Inequities in child survival in Nigerian communities during the Sustainable Development Goal era: Insights from analysis of Multiple Indicator Cluster Survey*.
- Manuscript 4—*Disentangling pathways to child survival in Nigeria during the Sustainable Development Goals era: a path analysis with accelerated failure time.*
- Manuscript 5—*Geographic inequities in neonatal survival in Nigeria: cross-sectional evidence from spatial and artificial neural network analyses.*

Chapter 7

Manuscript 3—Inequities in child survival in Nigerian communities during the Sustainable Development Goal era: Insights from analysis of Multiple Indicator Cluster Survey

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Publication status

Submitted to BMC Public Health and is currently under review.

Contributions

Daniel A. Adeyinka conceived the study, analyzed and interpreted the data, and wrote the first draft of the paper; Prof. Nazeem Muhajarine contributed to the study design, interpreted findings, reviewed the manuscript and supervised this study. Prof. Pammla Petrucka, and Dr. Isaac Elon assisted with data interpretation, and reviewed the manuscript.

Notes to the reader

Given that Nigeria is not likely to achieve Sustainable Development Goal (SDG) targets for child survival and health inequity will worsen for female (as seen in chapter 6), it is necessary to identify the social determinants of childhood mortalities in Nigeria. In view of implementing targeted child health interventions, this chapter explores the community variations in childhood mortalities. It also gives insight to the complex associations of the social determinants of health and child survival outcomes across the sequential early child developmental stages—neonatal (0-27 days), post-neonatal (1-11 months) and toddler/preschool (12-59 months).

7.1 Abstract

Background

Child survival is a major concern in Nigeria, as it contributes 13% of the global under-five mortalities. Although some studies have examined the determinants of under-five mortality in Nigeria, the comparative roles of social determinants of health at the different stages of early childhood development have not been concurrently investigated. This study, therefore, aimed to identify the social determinants of age-specific childhood (0-59 months) mortalities, which are disaggregated into neonatal mortality (0-27 days), post-neonatal mortality (1-11 months) and child mortality (12-59 months), and estimate the within-and between-community variations of mortality among under-five children in Nigeria. This study provides evidence to guide stakeholders in planning for effective child survival strategies in the Nigerian communities during the Sustainable Development Goals era.

Methods

Using the 2016/2017 Nigeria Multiple Indicator Cluster Survey, we performed multilevel multinomial logistic regression analysis on data of a nationally representative sample of 29,786 (weighted=30,960) live births delivered five years before the survey to 18,497 women aged 15-49 years and nested within 16,151 households and 2,227 communities.

Results

Determinants of under-five mortality differ across the neonatal, post-neonatal and toddler/pre-school stages in Nigeria. Unexpectedly, attendance of skilled health providers during delivery was associated with an increased neonatal mortality risk, although its effect disappeared during post-neonatal and toddler/pre-school stages. Also, our study found maternal-level factors such as maternal education, contraceptive use, maternal wealth, parity, death of previous children, and quality of perinatal care accounted for high variation (39%) in childhood mortalities across the communities. The inclusion of other compositional and contextual factors had no significant additional effect on childhood mortality risks across the communities.

Conclusion

This study reinforces the importance of maternal-level factors in reducing childhood mortality, independent of the child, household, and community-level characteristics in the Nigerian communities. To tackle childhood mortalities in the communities, government-led strategies should prioritize implementation of community-based and community-specific interventions aimed at improving socioeconomic conditions of women. Training and continuous mentoring with adequate supervision of skilled health workers must be ensured to improve the quality of perinatal care in Nigeria.

Keywords: *social determinants of health, sustainable development goals, neonatal mortality, post-neonatal mortality, child mortality, child survival, multilevel analysis, multinomial regression, Nigeria*

7.2 Introduction

As a critical element of socioeconomic and health indicators of a country, child survival has consistently been prominent in the United Nations suite of indicator frameworks.[1] The Sustainable Development Goal 3 (SDG-3) aims to reduce under-five mortality rates (U5MR) to 25 deaths per 1000 live births and neonatal mortality rates (NMR) to 12 deaths per 1000 live births by 2030.[2,3] Despite concerted global efforts in curtailing the preventable childhood deaths, progress in sub-Saharan Africa is lagging behind that of developed countries.[1] Specifically, childhood mortality remains a major social and public health problem in Nigeria, making the country the second largest contributor to under-five deaths globally.[1] Like many countries in the region, Nigeria could not achieve the childhood mortality targets of Millennium Development Goals (MDG)—aimed at reducing U5MR by two-thirds from 1990 to 2015.[1] NMR and U5MR in Nigeria are unacceptably high—32.9 deaths per 1000 live births and 100.2 deaths per 1000 live births in 2017, respectively.[1] These are 1.8 and 2.6 times higher than the global NMR and U5MR, respectively.[1]

For decades, some child survival initiatives for reducing under-five deaths have been non-specific, ineffectively addressing the varying roles of social determinants of health on mortality risks across the different stages of a child's early development i.e., neonatal (0-27 days), post-neonatal (1-11 months) and toddler/pre-school (12-59 months).[4,5] Previous studies conducted in Nigeria have identified the micro-level/compositional (i.e., child and maternal and household-level factors) associated with neonatal, infant, and under-five mortality. Generally, male child, low level of parental education, poverty, previous short birth intervals (<2 years), teenage motherhood, inadequate access to maternal healthcare services, and poor sanitation are associated with under-five mortality risk.[6,7,16–19,8–15] Despite these findings, literature remains limited regarding the effects of some individual compositional, and community contextual factors. Some of these available studies in Nigeria have provided contradictory results. For example, Ezeh et al.[17] and Morakinyo et al.[13] have linked maternal education to lower mortality risk among under-five children. Counterintuitively, Kayode et al.,[20] Yaya et al.,[21] and Akinyemi et al.[22] reported that maternal education had no significant effect on child survival. While studies[13,17,20,23] in Nigeria have shown that children in urban settings have lower mortality risks, Akinyemi et al.[22] reported no significant association between place of residence and under-five mortality in Nigeria.

Earlier epidemiologic studies have not concomitantly examined the factors influencing mortality at the different stages of early childhood development[4,5] in a single analytical model. Given the varying roles of social determinants of health (SDH) across the three different stages of early childhood development, results from multinomial modeling will be more insightful to implementing targeted and universal child survival interventions. With respect to statistical methods, standard errors are higher by fitting separate dichotomous models of early childhood mortality (as used in the past studies), compared to a single multinomial model.[24,25] Also, some of these studies in Nigeria have been hospital-based[26–29] or limited to a specific geographical region,[26–31] making generalizability of findings somewhat challenging. Despite the high post-neonatal mortality rate in Nigeria (i.e., 31 deaths per 1000 live births),[32] only a handful of studies[17,33] have been conducted. To fill these research gaps, we performed a secondary analysis of the latest (2016/2017) Multiple Indicator Cluster Survey (MICS) dataset.[34] By focusing on SDG-implementation era, this study extends the current evidence on social determinants of child survival in Nigeria, and other similar settings.

Nigeria needs to implement impactful policies/interventions towards making child-related SDG-3 targets, and the social inclusion perspective of SDG-10 targets (i.e., to reduce inequalities within and among countries) achievable by 2030. Interventions and policies that would drastically reduce childhood mortalities hinge on a sound understanding of the complex variations in the associations of the social determinants of health in the communities, and across the early child developmental stages. The objectives of this study, therefore, were to: (1) identify the social determinants of age-specific childhood (0-59 months) mortalities, which are disaggregated into neonatal mortality (0-27 days), post-neonatal mortality (1-11 months) and child mortality (12-59 months), and (2) estimate the within- and between-community variations of mortality among under-five children in Nigeria. In line with the expectations of the 2014 United Nations' call for data revolution that would expedite sustainable development,[35] this study provides evidence to guide stakeholders in planning for effective child survival strategies in the Nigerian communities during the Sustainable Development Goals era.

7.2.1 Theoretical focus

In order to identify the key socio-economic variables influencing childhood mortality in Nigeria, we adapted the Mosley-Chen framework.[36] We hypothesized that micro-level/compositional factors (i.e., child, maternal, and household-level factors) and macro-level/contextual factors (i.e., community-level factors) influence childhood mortality risk across each of the successive developmental stages and that these relationships occur at hierarchical levels. Also, siblings are likely to share the same biological and social factors, especially those who are born within five years of each other as was the case in this study. However, children residing in different communities will likely have different mortality risks. We postulated that the mortality risks will vary across communities in Nigeria because of a complex mix of compositional and contextual factors influencing them. Multilevel analysis was employed to measure the extent by which compositional and contextual factors account for variation in mortality across the early child developmental stages at the community-level.

7.3 Methods

7.3.1 Study setting and population

The data for this study were drawn from the 2016/2017 MICS[34] in Nigeria. With a population of 200 million, Nigeria—a country located in West Africa, is the most populated country in sub-Saharan Africa. It has six geo-political regions (i.e., North-West (NW), North-East (NE), North-Central (NC), South-West (SW), South-East (SE), and South-South (SS), which are further divided into 36 states and Federal Capital Territory (FCT).

7.3.2 Study design and data collection

The 2016/2017 MICS is the fifth-round of the national representative household survey, which was conducted between September 2016 and January 2017 in Nigeria. The household survey is designed by the United Nations to provide national and subnational estimates of maternal and child indicators to monitor the SDG targets. Using multi-stage stratified cluster sampling technique in all 36 states and the FCT of Nigeria, the sample size was 36,176 women aged 15-49 years (out of which 34,376 women were interviewed, 95% response rate). The sampling frame which was within the states were stratified into urban (36.6%) and rural areas (63.4%). In total, 33,901 households from 2,239 enumeration areas (i.e., primary sampling unit) were covered during fieldwork. Household is a unit consisting of family members and servants living together in a house, while community refers to the primary sampling unit (PSU), comprising of cluster of geographical and administratively distinct areas of homogenous households. The complete description of sample size calculation and sampling technique have been provided in the full 2016/2017 Nigeria MICS report.[(32)] For the purpose of this study, we merged birth history datafile with maternal and household files. To minimize recall bias, our inclusion criteria included every live birth delivered to all women aged 15-49 years in each household within five years prior to survey commencement (i.e., September 2011-September 2016). The children without documented survival outcome (i.e., alive, or dead), as well as the dates of birth and deaths were excluded from the analysis. Overall, a subpopulation of all 29,786 under-five children delivered to 18,497 women aged 15-49 years (irrespective of their marital status) was analyzed. These mothers were nested within 16,151 households and 2,227 communities. The average number of children per community was 13.4.

7.3.3 Variables

7.3.3.1 Outcome variable

We considered under-five mortality as the omnibus outcome variable. This was generated from the variables that captured survival status, age at death, and current age of living children. The outcome variable was categorized into four levels, (i.e., alive (reference), and three age- and stage-specific mortality: neonatal, post-neonatal, and child mortality). Neonatal mortality is defined as under-five death occurring from birth to 27 days of life. Post-neonatal mortality is under-five death happening between 28 days and 11 months, and child mortality is under-five death occurring between 12 months and 59 months (i.e., toddler/pre-school stages).

7.3.3.2 Explanatory variables

The selection of independent variables was guided by data availability, theoretical focus of this study—Mosely-Chen framework,[(36)] and on evidence from literature that the potential covariables are expected to influence the outcome (child survival). The explanatory variables were layered across the child, maternal, household, and community-levels (Box 7.1). From the existing data, we generated variables on maternal media exposure (accessibility to newspaper/magazine or listening to the radio or watching television), housing condition index (using principal components analysis (PCA) of three variables—quality of roof, exterior wall and floor), access to drinking water, sanitation, indoor pollution, community level of maternal education, and community infrastructural development. Concerning marital status, the variable was defined as currently married/in union, formerly married/in union, and never married/in union. Also, maternal wealth index was used as a proxy for relative socioeconomic condition of women. In MICS, there is no information about a standard measure of absolute socioeconomic status (income). For this reason, we have used wealth index. The wealth index is a composite variable that was constructed using PCA of assets owned by mothers, such as television, car, bicycle, mobile phones etc. The wealth index was categorized into low (i.e., poorest and poor), middle, and high (i.e., rich and richest) socioeconomic status. The wealth index does not give information about current maternal income and expenditure. The community-level of maternal education was calculated as the proportion of households in a community that reported at least maternal secondary education. The scores were aggregated into three levels based on quartile classification (i.e., 2nd quartile=50%, and 3rd quartile=75%); (lower education <50% of overall score), moderate education 50%≤x<75% of the overall score, high education (75%≤x≤100% of overall score). This study used proportion of households with access to electricity as a proxy for community infrastructural development. The variable has two groups based on median value. This variable was used primarily because of existing evidence that access to electricity strongly drives not only the development of social infrastructure, but also community health service delivery.[37–41] In Nigeria, electricity is mainly provided by the government, and where electricity is available, it is accessed by most of the population.[42,43] Overall, missing data ranged from 0% to 33.2%. Except for access to antenatal care (ANC), frequency of ANC visits, skilled birth attendants during delivery, and institutional delivery, no variable had missing variable above 30%.

Box 7.1: Explanatory variables

Child level: Child's sex (male=0, female=1), gestation type (singleton=0, multiple=1), birth order (first birth=0, 2-3=1, 4-6=2, ≥7=3), previous birth interval (<2 years=0, first birth=1, ≥2 years=2), and maternal age at birth (<20 years=0, 20-34 years=1, ≥35 years=2) **Maternal level:** Maternal education (none/primary=0, secondary/technical=1, post-secondary=2), maternal wealth index (poor=0, middle=1, rich=2), maternal media exposure (high=0, medium=1, low=2, none=3), death of previous children at the time of the survey (<3=0, 3-4=1, ≥5=2), parity (<3=0, 3-4=1, ≥5=2), access to antenatal care (ANC) (none=0, skilled=1, unskilled=2), frequency of ANC visits (none=0, 1-7=1, ≥8=2), skilled birth attendants during delivery (none=0, skilled birth attendants=1, unskilled/friend=2), institutional delivery (home=0, health facility=1), marital status (currently married/in union=0, formerly married/in union=1, never married/in union=2), history of contraceptive use (yes=0, no=1), ever drank alcohol (yes=0, no=1), and ever smoked cigarette (yes=0, no=1). **Household level:** Sex of household head (male=0, female=1), household head education (none/primary=0, secondary/technical=1, post-secondary=2), ethnic group (Hausa=0, Igbo=1, Yoruba=2, others=3), housing condition (inadequate=0, adequate=1), polygamy (yes=0, no=1), access to drinking water (unimproved source=0, improved source=1), sanitation (unimproved=0, improved=1), and indoor pollution (polluting fuel=0, clean fuel=1), household size (discrete). **Community level:** Place of residence (urban=0, rural=1), community infrastructural development (based on proportion of households with electricity in the community) (low=0, high=1), region (North-Central (NC)=0, North-East (NE)=1, North-West (NW)=2, South-East (SE)=3, South-South (SS)=4, South-West (SW)=5, and aggregated (community) level maternal education (based on proportion of households with women who had at least secondary education in the community) (low=0, medium=1, high=2).

7.3.4 Statistical analysis

All statistical analyses were performed using Stata™ software version 15.1.[44] Parallel to MICS methodology of mortality estimation,[32] neonatal and post-neonatal mortality rates were estimated using cumulative incidence (otherwise known as incidence proportion); and child and under-five mortality rates were derived from real sample cohorts using life tables. Given the hierarchical nature of the data and multinomial outcome, we performed multilevel multinomial logistic regression. By using survey analysis procedure (svyset cluster command in Stata™ software), bivariate analyses were conducted using Chi-square test for categorical variables and one-way analysis of variance (ANOVA) for discrete variable (household size) to select the potential covariates for multinomial regression models. To ensure representativeness of data, sample weights were applied. We used log-likelihood, Bayesian Information Criterion (BIC) and Akaike's Information Criterion (AIC) to ascertain model goodness-of-fit. Missing data were addressed with listwise deletion.

7.3.4.1 Model building

***Measures of association (Fixed-effects)*:** The association between survival outcomes, and macro-level/contextual variables (community-level) and micro-level (child, maternal and household-level) variables were examined separately. Hence, six blocks of models were fitted, reflecting intercept-only, child, maternal, household, community-level factors and parsimonious final model. In the interest of achieving a parsimonious model, we used a backward elimination strategy, retaining variables with *p-value* ≤ 0.25 from bivariate analyses as candidate variables in models 1-4. In the final model (model 5), variables with *p-value* <0.05 from models 1-4 were selected. Based on the parsimonious approach, the covariates that were entered into the final multivariate model included child's sex, gestation type, previous birth interval, maternal age at birth, maternal education, wealth index, death of previous children, parity, skilled birth attendants during delivery, contraceptive use, place of residence, and region. Exponentiating the coefficients ($\boldsymbol{\beta}$) from multilevel logistic regression, we obtained the relative risk ratios (RRR) and their 95% confidence intervals (95%CI).[(44)] We tested for interaction effects between the significant covariates in the multivariate models but found them not statistically significant; hence dropped from the analysis.

Measures of variation (Random-effects)**:** Considering that small average sample sizes (≤ 2) at hierarchical levels could bias variance estimates and effect sizes (Type-I error) in multilevel analysis, we collapsed child, maternal and household-levels into a single level (i.e., child/maternal/household).[(45)] The limited number of children at maternal-level (mean=1.6) and household-level (mean=1.8) could not allow for four-level model, with random effects at child, maternal, household and community-levels. Parallel to previous multilevel studies,[(46,47)] we had two levels of data hierarchies—child/maternal/household (micro) and community (macro) levels. With micro-and macro-levels defined as random effects, we examined whether and how much variation of child survival outcomes in the communities can be attributed to the compositional and contextual variables. The extent of the variability in mortality risks from community-to-community was estimated by median odds ratios (MOR) and percentage change in variance (PCV).[(48)] MOR is preferable to intra-cluster correlation (ICC) because it quantifies the community-level variance (unexplained contextual heterogeneity) on the odds ratio scale, making it easier to interpret.[(48)] The MOR value is always equal or greater than one. MOR of 1 implies that no variation in mortality risk across the developmental stages exist between communities. MOR was computed using the following equation:[(48)]

$$MOR = e^{0.95\sqrt{V_c}} \quad (7.1)$$

Where V_c *is the community-level variance.*

The proportional change in variance assesses the influence of compositional and contextual variables on inter-community variations of the outcome variable; we estimate this by comparing intercept-only model (model 0) with the five other models (models 1-5).

7.3.4.2 Predicted probabilities

Using estimates in the final model (model 5), we predicted the probabilities of death in each of neonatal, post-neonatal, and toddler/preschool stages by holding the final variables in the model constant at their mean values. Pairwise comparisons of predictive margins of significant correlates were also performed.(44)

7.4 Results

7.4.1 Sample characteristics

Table 7.1 shows the socio-economic and demographic distribution of the study participants. Out of the weighted sample of 30,960 live births during the interview period, 29,729 (96.0%) were reported as singletons. The male to female ratio was 1.03:1. About 1 in 7 children were delivered by teenage mothers and 17.1% by women aged ≥35 years. More than half (66.6%) were children of women with no formal or primary education. In 44.5% of the children, their mothers were poor. More children were reported to be residing in NW region (39.1%), rural area (69.9%), and from infrastructurally less-developed communities (52.4%).

7.4.2 Differentials of age-specific mortality rates

Of the weighted 30,960 live births included in this study, 2,840 died before reaching five years—121.6 deaths per 1000 live births, 95%CI: 116.8-126.5. The NMR was 37.9 deaths per 1000 live births, 95%CI: 34.9-41.1, post-neonatal mortality rate was 28.7 deaths per 1000 live births, 95%CI: 26.2-31.4, and child mortality rate was 54.3 deaths per 1000 children surviving to age one, 95%CI: 50.2-58.7. Among the children who died, 41.3% (95% confidence interval (CI): 38.8%-43.9%) occurred at neonatal stage, 30.1% (95%CI: 28.0%-32.3%) at post-neonatal stage, and 28.6% (95%CI: 26.2%-31.1%) at toddler/preschool stage. More male children died during the neonatal (57.9%) and post-neonatal (54.4%) stages, but more female deaths (51%) occurred during toddler/preschool stage (*p-value*<0.001) (Table 7.1). Uniformly across the early child developmental stages, deaths were significantly lower among women who were rich, in monogamous settings, and resided in houses deemed of adequate quality. In all the stages, mortality was higher in children whose mother had many children (grand multiparity), lived in rural communities, communities with low level of maternal education, less infrastructurally developed communities, and lived in NW region of Nigeria (Appendix E, Table E1).

Table 7.1: Characteristics of study participants according to survival status, 2016/2017 MICS, Nigeria

Variable	Sample size Mean (SD)/ n (%)	Alive Mean (SD)/ n (%)	Neonatal mortality Mean (SD)/ n (%)	Post-neonatal mortality Mean (SD)/ n (%)	Child mortality Mean (SD)/ n (%)	p-value
Child-level factors						
Child's sex (N=30959)						0.0009
Male	15725 (50.8)	14165 (50.4)	679 (57.9)	483 (54.4)	398 (49.0)	
Female	15234 (49.2)	13919 (49.6)	494 (42.1)	406 (45.6)	415 (51.0)	
Gestation type (N=30957)						<0.001
Singleton	29729 (96.0)	27135 (96.6)	1003 (85.5)	820 (92.3)	771 (94.9)	
Multiple	1228 (4.0)	974 (3.4)	171 (14.5)	69 (7.7)	41 (5.1)	
Birth order (N=30960)						<0.001
First	5436 (17.6)	4892 (17.4)	257 (21.9)	164 (18.5)	122 (15.0)	
2-3	10358 (33.5)	9617 (34.2)	287 (24.5)	240 (27.0)	213 (26.2)	
4-6	9971 (32.2)	9108 (32.4)	309 (26.3)	278 (31.3)	276 (34.0)	
≥7	5195 (16.8)	4466 (15.9)	321 (27.3)	207 (23.2)	202 (24.8)	
Previous birth interval (N=30960)						<0.001
<2 years	6601 (21.3)	5630 (20.0)	413 (35.2)	292 (32.8)	266 (32.7)	
First birth	5501 (17.8)	4942 (17.6)	270 (23.0)	166 (18.7)	123 (15.2)	
≥2 years	18858 (60.9)	17512 (62.4)	491 (41.8)	431 (48.5)	423 (52.1)	
Maternal age at birth (N=30960)						<0.001
<20 years	4320 (14.0)	3781 (13.5)	241 (20.5)	153 (17.3)	144 (17.8)	
20-34 years	21338 (68.9)	19547 (69.6)	709 (60.4)	579 (65.1)	504 (62.0)	
≥35 years	5302(17.1)	4757 (16.9)	224 (19.1)	157 (17.6)	165 (20.3)	
Maternal-level factors						
Maternal education (N=30960)						<0.001
None/primary	20609 (66.6)	18333 (65.3)	842 (71.7)	718 (80.8)	716 (88.0)	
Secondary	7981 (25.8)	7498 (26.7)	253 (21.5)	140 (15.7)	90 (11.1)	
Post-secondary	2369 (7.7)	2253 (8.0)	79 (6.7)	31 (3.47)	7 (0.9)	
Maternal wealth index (N=30960)						<0.001
Poor	13912 (44.9)	12287 (43.7)	552 (47.1)	522 (58.7)	552 (67.9)	

Middle	6068 (19.6)	5471 (19.5)	260 (22.1)	176 (19.8)	161 (19.8)	
Rich	10980 (35.5)	10326 (36.8)	362 (30.8)	191 (21.5)	101 (12.4)	
Maternal media exposure (N=30956)						<0.001
High	10047 (32.5)	9296 (33.1)	367 (31.3)	227 (25.5)	158 (19.4)	
Medium	4972 (16.1)	4588 (16.3)	158 (13.5)	118 (13.2)	107 (13.2)	
Low	3542 (11.4)	3221 (11.5)	131 (11.2)	100 (11.2)	91 (11.1)	
None	12394 (40.0)	10976 (39.1)	517 (44.1)	444 (50.0)	457 (56.3)	
Death of previous children (N=30960)						<0.001
<3	28584 (92.3)	26557 (94.6)	834 (71.1)	640 (72.0)	553 (68.0)	
3-4	1882 (6.1)	1252 (4.5)	254 (21.7)	174 (19.6)	201 (24.7)	
≥5	494 (1.6)	275 (1.0)	85 (7.3)	75 (8.4)	60 (7.3)	
Parity (N=30960)						
<3	7847 (25.3)	7293 (26.0)	262 (22.4)	168 (18.9)	123 (15.2)	<0.001
3-4	10136 (32.7)	9338 (33.3)	317 (27.0)	262 (29.5)	219 (27.0)	
≥5	12977 (41.9)	11453 (40.8)	594 (50.7)	459 (51.6)	470 (57.9)	
Access to ANC[#] (N=20775)						<0.001
None	6726 (32.4)	5972 (31.6)	267 (33.2)	266 (45.0)	221 (44.9)	
Skilled	12600 (60.7)	11667 (61.8)	457 (56.8)	257 (43.5)	220 (44.6)	
Unskilled	1449 (7.0)	1250 (6.6)	80 (9.9)	68 (11.5)	51 (10.4)	
Freq of ANC visits[#] (N=20775)						<0.001
None	6726 (32.4)	5972 (31.6)	267 (33.2)	266 (45.0)	221 (44.9)	
1-7	10416 (50.1)	9541 (50.5)	381 (47.4)	265 (44.9)	228 (46.4)	
≥8	3633 (17.5)	3375 (17.9)	155 (19.3)	59 (10.1)	43 (8.7)	
Skilled birth attendants during delivery[#] (N=20786)						<0.001
None	2646(12.7)	2318 (12.3)	113 (14.0)	97 (16.3)	118 (24.0)	
Skilled	8072 (38.8)	7540 (39.9)	310 (38.4)	135 (22.7)	88 (17.8)	
Unskilled	10068 (48.4)	9035 (47.8)	385 (47.7)	362 (61.0)	286 (58.2)	
Institutional delivery[#] (N=20783)						<0.001
Home	13358 (64.3)	11971 (63.3)	516 (64.2)	457 (77.4)	415 (84.3)	
Health facilities	7425 (35.7)	6926 (36.7)	288 (35.8)	134 (22.6)	77 (15.7)	
Marital status (N=30934)						0.5392
Currently married/in union	29748 (96.2)	26998 (96.2)	1120 (95.7)	852 (96.3)	778 (95.7)	
Formerly married/in union	803 (2.6)	717 (2.6)	32 (2.8)	25 (2.9)	29 (3.6)	
Never married/in union	382 (1.2)	351 (1.3)	18 (1.6)	8 (0.9)	6 (0.7)	
Contraceptive use (N=26807)						<0.001
Yes	1947 (7.3)	1832 (7.6)	55 (5.4)	46 (5.6)	15 (1.9)	
No	24860 (92.7)	22363 (92.4)	973 (94.6)	776 (94.4)	749 (98.1)	
Alcohol intake (N=30807)						<0.001
Yes	3649 (11.8)	3401 (12.2)	124 (10.6)	81 (9.2)	42 (5.21)	
No	27158 (88.2)	24547 (87.8)	1045 (89.4)	801 (90.8)	765 (94.8)	
Smoking experience (N=30898)						0.02
Yes	213 (0.7)	180 (0.6)	13 (1.2)	14 (1.6)	5 (0.6)	
No	30685 (99.3)	27855 (99.4)	1153 (98.8)	869 (98.4)	808 (99.4)	
Household-level factors						
Sex of household head (N=30960)						0.502
Male	29614 (95.7)	26844 (95.6)	1132 (96.4)	851 (95.7)	787 (96.8)	
Female	1346 (4.4)	1240 (4.4)	42 (3.6)	38 (4.3)	26 (3.2)	

Household head education (N=30881)						<0.001
None/primary	18114 (58.7)	16116 (57.5)	760 (65.1)	614 (69.2)	623 (77.1)	
Secondary	8320 (26.9)	7702 (27.5)	267 (22.9)	207 (23.3)	143 (17.7)	
Post-secondary	4448 (14.4)	4199 (15.0)	140 (12.0)	66 (7.5)	42 (5.2)	
Ethnic group (N=30960)						<0.001
Hausa	17484 (56.5)	15505 (55.2)	714 (60.8)	611 (68.7)	655 (80.6)	
Igbo	2409 (7.8)	2278 (8.1)	69 (5.9)	41 (4.6)	21 (2.2)	
Yoruba	2929 (9.5)	2755 (9.8)	104 (8.8)	46 (5.2)	21 (2.6)	
Others	8140 (26.3)	7546 (26.9)	287 (24.4)	191 (21.5)	116 (14.2)	
Housing condition (N=30960)						<0.001
Inadequate	13172(42.5)	11694 (41.6)	511 (43.5)	480 (54.1)	487 (59.9)	
Adequate	17788 (57.5)	16391 (58.4)	663 (56.5)	408 (45.9)	326 (40.1)	
Polygamy (N=30960)						<0.001
Yes	10880 (35.1)	9699 (34.5)	432 (36.9)	375 (42.2)	373 (45.9)	
No	20079 (64.9)	18385 (65.5)	741 (63.1)	514 (57.8)	439 (54.1)	
Household access to drinking water (N=30959)						<0.001
Unimproved	10820 (35.0)	9587 (34.1)	480 (40.9)	405 (45.6)	348 (42.8)	
Improved	20139 (65.1)	18497 (65.9)	694 (59.1)	484 (54.4)	465 (57.2)	
Household sanitation (N=30959)						<0.001
Unimproved	15926 (51.4)	14266 (50.8)	619 (52.7)	548 (61.6)	493 (60.7)	
Improved	15033 (48.6)	13817 (49.2)	555 (47.3)	341 (38.4)	320 (39.3)	
Indoor pollution (N=30960)						<0.001
Polluting fuel	29120 (94.1)	26331 (93.8)	1123 (95.7)	860 (96.7)	806 (99.1)	
Clean fuel	1840 (5.9)	1753 (6.2)	50 (4.3)	29 (3.3)	7 (0.9)	
Household size (N=30960) Mean (standard deviation)	7.8 (4.1)	7.8 (4.1)	7.2 (4.1)	7.2 (3.8)	7.6 (3.9)	<0.001
Community-level factors						
Area (N=30960)						
Urban	9327 (30.1)	8710 (31.0)	323 (27.5)	162 (18.2)	131 (16.2)	<0.001
Rural	21633 (69.9)	19374 (69.0)	850 (72.5)	727 (81.8)	681 (83.8)	
Region (N=30960)						
North-Central (NC)	5084 (16.4)	4636 (16.5)	216 (18.4)	136 (15.3)	96 (11.8)	<0.001
North-East (NE)	6517 (21.1)	5950 (21.2)	213 (18.1)	173 (19.4)	181 (22.2)	
North-West (NW)	12113 (39.1)	10651 (37.9)	534 (45.5)	453 (50.9)	475 (58.5)	
South-East (SE)	1604 (5.2)	1513 (5.4)	42 (3.6)	33 (3.7)	15 (1.9)	
South-South (SS)	2370 (7.7)	2252 (8.0)	52 (4.4)	45 (5.0)	21 (2.6)	
South-West (SW)	3272 (10.6)	3081 (11.0)	117 (9.9)	49 (5.6)	25 (3.0)	
Infrastructural development (N=30960)						<0.001
Low	16235 (52.4)	14452 (51.5)	657 (56.0)	555 (62.5)	571 (70.2)	
High	14724 (47.6)	13632 (48.5)	516 (44.0)	334 (37.5)	242 (29.8)	
Comm. Maternal education (N=30960)						<0.001
Low	16451 (53.1)	14434 (51.4)	727 (62.0)	627 (70.5)	663 (81.6)	
Medium	5842 (18.9)	5466 (19.5)	183 (15.6)	116 (13.1)	76 (9.4)	
High	8666 (28.0)	8184 (29.1)	263 (22.4)	146 (16.4)	74 (9.0)	

*One-way Anova #data available for only women with a live birth in the 2 years preceding the survey

7.4.3 Measures of variation (Random effects)

In the intercept-only model (model 0), the estimated community-level variance was 0.49 (95%CI: 0.41-0.60), implying a significant variation of mortality risks across the communities. The heterogeneity at the community-level was confirmed by MOR of 1.95. As shown in Tables 7.2-7.5, the variations in under-five mortalities across the communities were mostly explained by maternal-level variables (PCV=38.8%), followed by community-level variables (PCV=28.6%), and child-level variables contributed the least (PCV=14.3%). The combined effect of child, maternal, household and community-level variables (model 5) did not further reduce variability in the risk of under-five mortality between communities, compared to model that included only maternal-level variables (model 2). Also, in both model 2 (maternal-level variables) and model 5 (compositional and contextual variables), the community heterogeneity decreased from 1.95 to 1.68, thus, there is evidence to suggest residual variability of childhood mortality risks at the community-level.

Table 7.2: Multivariate multilevel multinomial regression of child-level factors associated with age-specific under-five mortality, 2016/217 Nigeria MICS

	Model 0	Model 1 (child-level factors) **Ref: alive (N= 30,957)**		
	Intercept-only RRR (95%CI)	Neonatal mortality (0-27 days) RRR (95%CI)	Post-neonatal mortality (28 days-11 months) RRR (95%CI)	Child mortality (12 months to 11 months) RRR (95%CI)
Fixed effects				
Child's sex				
Male		Ref.	Ref.	Ref.
Female		0.72 (0.61-0.85)***	0.84 (0.71-0.98)*	1.04 (0.85-1.27)
Gestation type				
Singleton		Ref.	Ref.	Ref.
Multiple		5.64 (4.25-7.49)***	2.76 (2.03-3.75)***	1.68 (1.09-2.58)*
Birth order				
First		Ref.	Ref.	Ref.
2-3		1.14 (0.58-2.25)	0.47 (0.10-2.17)	0.67 (0.13-3.49)
4-6		1.38 (0.68-2.80)	0.59 (0.13-2.74)	1.02 (0.19-5.43)
≥7		2.83 (1.37-5.84)**	0.88 (0.19-4.13)	1.44 (0.26-7.88)
Previous birth interval				
<2 years		Ref.	Ref.	Ref.
First birth		0.99 (0.49-2.00)	0.35 (0.08-1.66)	0.41 (0.08-2.10)
≥2 years		0.37 (0.31-0.44)***	0.47 (0.39-0.57)***	0.52 (0.43-0.63)***
Maternal age at birth				
<20 years		Ref	Ref.	Ref.
20-34 years		0.59 (0.45-0.76)***	0.71(0.54-0.93)*	0.54 (0.40-0.71)***
≥35 years		0.55 (0.39-0.78)***	0.64 (0.44-0.95)*	0.55 (0.38-0.80)**
Random effects (community-level)				
Variance (SE)	0.49 (0.05)	0.42 (0.05)		
95%CI	0.41,0.60	0.34,0.53		
PCV	Ref.	14.3%		
MOR	1.95	1.85		

***p-value<0.001 **p-value<0.01 *p-value<0.05; SE: robust standard error, RRR: relative risk ratio, CI: confidence interval, PCV: proportional change in variance, MOR: median odds ratio

Table 7.3: Multivariate multilevel multinomial regression of maternal-level factors associated with age-specific under-five mortality, 2016/2017 Nigeria MICS

	Model 0	Model 2 (maternal-level factors) **Ref: alive** **(N=18,120)**		
	Intercept-only RRR (95%CI)	Neonatal mortality (0-27 days) RRR (95%CI)	Post-neonatal mortality (28 days-11 months) RRR (95%CI)	Child mortality (12 months to 11 months) RRR (95%CI)
Fixed effects				
Maternal education		Ref.	Ref.	Ref.
None/primary		0.72 (0.53-0.99)*	0.69 (0.48-0.99)*	0.62 (0.41-0.93)*
Secondary		0.92 (0.51-1.65)	0.74 (0.39-1.41)	0.28 (0.09-0.82)*
Post-secondary				
Maternal wealth index				
Poor		Ref.	Ref.	Ref.
Middle		1.31 (0.99-1.73)	1.09 (0.80-1.49)	0.97 (0.71-1.33)
Rich		1.19 (0.87-1.62)	1.14 (0.79-1.65)	0.46 (0.31-0.69)***
Death of previous children				
<3		Ref.	Ref.	Ref.
3-4		9.40 (6.66-13.27)***	5.37 (3.83-7.55)***	6.34 (4.55-8.83)***
≥5		10.00 (5.98-16.73)***	10.70 (6.27-18.25)***	7.75 (4.75-12.63)***
Parity				
<3		Ref.	Ref.	Ref.
3-4		0.86 (0.67-1.10)	1.23 (0.90-1.67)	1.71 (1.19-2.47)**
≥5		0.57 (0.43-0.76)***	0.76 (0.54-1.06)	1.25 (0.86-1.82)
Freq of ANC visits#				
None		Ref.	Ref.	Ref.
1-7		1.04 (0.82-1.32)	0.92 (0.71-1.18)	1.19 (0.92-1.52)
≥8		1.26 (0.82-1.93)	0.65 (0.41-1.03)	1.19 (0.75-1.87)
Skilled birth attendants during delivery#				
None		Ref.	Ref.	Ref.
Skilled		1.22 (0.87-1.71)	0.73 (0.50-1.06)	0.58 (0.38-0.87)*
Unskilled		1.05 (0.79-1.40)	1.06 (0.78-1.45)	0.79 (0.60-1.04)
Contraceptive use				
Yes		Ref.	Ref.	Ref.
No		1.36 (0.91-2.03)	0.97 (0.59-1.60)	3.69 (1.40-9.75)*
Random effects (community-level)				
Variance (SE)	0.49 (0.05)	0.30 (0.05)		
95%CI	0.41,0.60	0.21,0.41		
PCV	Ref.	38.8%		
MOR	1.95	1.68		

***p-value<0.001 **p-value<0.01 *p-value<0.05; #data available for only women with a live birth in the 2 years preceding the survey; SE: robust standard error, RRR: relative risk ratio, CI: confidence interval, PCV: proportional change in variance, MOR: median odds ratio.

Table 7.4: Multivariate multilevel multinomial regression of household-level factors associated with age-specific under-five mortality, 2016/2017 Nigeria MICS

	Model 0	Model 3 (household-level factors) **Ref: alive** **(N= 30,958)**		
	Intercept-only RRR (95%CI)	Neonatal mortality (0-27 days) RRR (95%CI)	Post-neonatal mortality (28 days-11 months) RRR (95%CI)	Child mortality (12 months to 11 months) RRR (95%CI)
Fixed effects				
Housing condition				
Inadequate		Ref.	Ref.	Ref.
Adequate		1.14 (0.93-1.38)	0.82 (0.67-1.01)	0.62 (0.50-0.78)***
Polygamy				
Yes		Ref.	Ref.	Ref.
No		1.01 (0.85-1.197)	0.87 (0.73-1.04)	0.78 (0.63-0.95)*
Household access to drinking water				
Unimproved		Ref.	Ref.	Ref.
Improved		0.77 (0.62-0.95)*	0.76 (0.63-0.92)**	0.93 (0.75-1.14)
Household sanitation				
Unimproved		Ref.	Ref.	Ref.
Improved		1.02 (0.85-1.22)	0.80 (0.64-0.99)*	0.91 (0.75-1.11)
Indoor pollution				
Polluting fuel		Ref.	Ref.	Ref.
Clean fuel		0.78 (0.54-1.12)	0.79 (0.51-1.24)	0.20 (0.08-0.50)**
Random effects (community-level)				
Variance (SE)	0.49 (0.05)	0.41 (0.05)		
95%CI	0.41,0.60	0.34, 0.51		
PCV	Ref.	16.3%		
MOR	1.95	1.84		

***p-value<0.001 **p-value<0.01 *p-value<0.05; SE: robust standard error, RRR: relative risk ratio, CI: confidence interval, PCV: proportional change in variance, MOR: median odds ratio.

Table 7.5: Multivariate multilevel multinomial regression of community-level factors associated with age-specific under-five mortality, 2016/2017 Nigeria MICS

	Model 0	Model 4 (Community-level factors) **Ref: alive (N=30,960)**		
	Intercept-only RRR (95%CI)	Neonatal mortality (0-27 days) RRR (95%CI)	Post-neonatal mortality (28 days-11 months) RRR (95%CI)	Child mortality (12 months to 11 months) RRR (95%CI)
Fixed effects				
Area				
Urban		Ref.	Ref.	Ref.
Rural		1.04 (0.81-1.33)	1.48 (1.12-1.95)**	1.25 (0.84-1.88)
Region				
North-Central (NC)		Ref.	Ref.	Ref.
North-East (NE)		0.80 (0.59-1.08)	1.0 (0.73-1.36)	1.38 (0.95-2.00)
North-West (NW)		1.08 (0.86-1.35)	1.36 (1.07-1.73)*	1.83 (1.32-2.53)***
South-East (SE)		0.75 (0.52-1.07)	1.09 (0.71-1.67)	0.99 (0.57-1.72)
South-South (SS)		0.61 (0.43-0.87)**	0.98 (0.66-1.45)	0.92 (0.55-1.54)
South-West (SW)		1.02 (0.75-1.38)	0.92 (0.61-1.39)	0.79 (0.43-1.44)
Comm. Maternal education				
Low		Ref.	Ref.	Ref.
Medium		0.73 (0.55-0.97)*	0.62 (0.47-0.82)***	0.41 (0.28-0.60)***
High		0.71 (0.53-0.95)*	0.55 (0.41-0.75)***	0.31 (0.20-0.46)***
Random effects (community-level)				
Variance (SE)	0.49 (0.05)	0.35 (0.04)		
95%CI	0.41,0.60	0.28, 0.44		
PCV	Ref.	28.6%		
MOR	1.95	1.75		

***p-value<0.001 **p-value<0.01 *p-value<0.05; SE: robust standard error, RRR: relative risk ratio, CI: confidence interval, PCV: proportional change in variance, MOR: median odds ratio

7.4.4 Measures of association (Fixed effects)

The results from the bivariate analyses indicate that all the variables were significantly associated with under-five mortality, except marital status and sex of household head (Table 7.1). As shown by adjusted relative risk ratios (aRRR) in the final model (Table 7.6), the risks of dying during neonatal (0.67, 95%CI: 0.55-0.81, *p-value* <0.001) and post-neonatal stages (0.80, 95%CI: 0.65-0.98, *p-value*=0.035) were reduced for female compared to male child, but no significant reduction in the later stage, from 1-5 years of age.

Children of mothers born two or more years apart, compared to those closer together (less than two-year gap) had decreased risk of neonatal mortality (aRRR: 0.38, 95%CI: 0.30-0.49, *p-value* <0.001), post-neonatal mortality (aRRR: 0.57, 95%CI: 0.44-0.73, *p-value* <0.001), and child mortality (aRRR: 0.48, 95%CI: 0.36-0.64, *p-value* <0.001). On the contrary, first births had higher risks of post-neonatal mortality (aRRR: 1.82, 95%CI: 1.18-2.82, *p-value*=0.007) and child mortality (aRRR: 1.68, 95%CI: 1.07-2.63, *p-value*= 0.024) than births less than two years after a previous birth.
Children delivered as part of multiple births were about 6 times (aRRR: 5.77, 95%CI: 4.07-8.17, *p-value* <0.001) more likely to die during neonatal stage, and about twice (aRRR: 2.28, 95%CI: 1.52-3.44, *p-value* <0.001) the mortality risk at post-neonatal stage, compared to singletons. There were reduced neonatal, post-neonatal, and child mortality risks for children of older women, compared to teen mothers (Table 7.6).

Compared to children whose mothers were uneducated or had primary education, those with secondary education had lesser post-neonatal mortality risk (aRRR: 0.68, 95%CI: 0.47-0.97, *p-value*=0.035). Also, for children aged 1-5 years, there was reduced mortality risk among those whose mothers were rich (aRRR: 0.57, 95%CI: 0.35-0.92, *p-value*=0.02). Women with no history of contraceptive use had increased mortality risk for toddlers/preschoolers (aRRR: 3.34, 95%CI: 1.27-8.81, *p-value*=0.015). Death of previous children reduced survival of subsequent children across the three child developmental stages. The mortality risk increases as the number of deaths of previous children increases (dose-response relationship). Grand multiparous women (≥ 5 deliveries) were more likely to experience increased mortality for children in post-neonatal stage (aRR: 1.76, 95%CI: 1.06-2.93, *p-value*=0.03) and toddler/preschool stage (aRRR: 3.66, 95%CI: 2.18-6.17, *p-value*<0.001). Unexpectedly, risk of neonatal mortality was higher among women who experienced skilled birth delivery compared to women with none (aRRR: 1.39, 95%CI: 1.02-1.90, *p-value*=0.039). However, there was no statistically significant association between post-neonatal and child mortality. Further sensitivity analyses based on pairwise deletion (inclusion of missing data) showed similar associations between skilled birth delivery and neonatal mortality risk (aRRR: 1.38, 95%CI: 1.02-1.87, *p-value*=0.037). Pairwise deletion also showed that skilled birth delivery was not significantly associated with post-neonatal mortality (aRRR: 0.85, 95%CI: 0.59-1.23, *p-value*=0.387), and child mortality (aRRR: 0.70, 95%CI: 0.48-1.04, p-value=0.075).

Children residing in rural areas had 2-fold increase in post-neonatal mortality risk compared to those in the urban areas (aRRR: 1.66, 95%CI: 1.13-2.45, *p-value*=0.01), however, no statistically significant association was observed for neonatal and child mortalities. Living in SS and SE regions had protective effect on neonatal survival, while residing in NE region increased the mortality risk during toddler/pre-school stage.

7.4.5 Predicted probabilities

Given that the compositional and contextual variables are at mean values, the adjusted predicted probability of dying during the neonatal stage is 0.028 (95%CI: 0.024-0.031, *p-value* <0.001), post-neonatal stage is 0.025 (95%CI: 0.022-0.028, *p-value* <0.001), and toddler/pre-school stage is 0.015 (95%CI: 0.013-0.018, *p-value* <0.001).

Table 7.6: Multivariate multilevel multinomial regression of child, maternal, household and community-level factors associated with age-specific under-five mortality, 2016/2017 Nigeria MICS

	Model 0	Model 5 (Final model) **Ref: alive (N=18,219)**		
	Intercept-only RRR (95%CI)	Neonatal mortality (0-27 days) RRR (95%CI)	Post-neonatal mortality (28 days-11 months) RRR (95%CI)	Child mortality (12 months to 11 months) RRR (95%CI)
Child-level factors				
Child's sex				
Male		Ref.	Ref.	Ref.
Female		0.67 (0.55-0.81)***	0.80 (0.65-0.98)*	1.02 (0.80-1.30)
Gestation type				
Single		Ref.	Ref.	Ref.
Multiple		5.77 (4.07-8.17)***	2.28 (1.52-3.44)***	1.33 (0.70-2.53)
Previous birth interval				
<2 years		Ref.	Ref.	Ref.
First birth		1.26 (0.84-1.90)	1.82 (1.18-2.82)**	1.68 (1.07-2.63)*
≥2 years		0.38 (0.30-0.49)***	0.57 (0.44-0.73)***	0.48 (0.36-0.64)***
Maternal age at birth				
<20 years		Ref.	Ref.	Ref.
20-34 years		0.46 (0.33-0.62)***	0.84 (0.58-1.23)	0.66 (0.44-0.99)*
≥35 years		0.36 (0.24-0.55)***	0.71 (0.42-1.21)	0.52 (0.30-0.93)*

Maternal-level factors				
Maternal education				
None/primary		Ref.	Ref.	Ref.
Secondary		0.85 (0.62-1.17)	0.68 (0.47-0.97)*	0.77 (0.50-1.17)
Post-secondary		1.13 (0.64-2.02)	0.74 (0.39-1.43)	0.34 (0.12-1.03)
Maternal wealth index				
Poor		Ref.	Ref.	Ref.
Middle		1.30 (0.98-1.71)	1.15 (0.85-1.57)	1.07 (0.80-1.45)
Rich		1.35 (0.94-1.93)	1.37 (0.94-2.01)	0.57 (0.35-0.92)*
Death of previous children				
<3		Ref.	Ref.	Ref.
3-4		9.07 (6.48-12.68)***	5.23 (3.71-7.37)***	6.12 (4.42-8.47)***
≥5		10.01 (5.75-17.44)***	10.52 (6.21-17.82)***	7.78 (4.74-12.77)***
Parity				
<3		Ref.	Ref.	Ref.
3-4		1.77 (1.25-2.53)***	2.42 (1.57-3.73)***	3.87 (2.46-6.08)***
≥5		1.54 (0.96-2.46)	1.76 (1.06-2.93)*	3.66 (2.18-6.17)***
Skilled birth attendants during delivery#				
None		Ref.	Ref.	Ref.
Skilled		1.39 (1.02-1.90)*	0.72 (0.49-1.07)	0.75 (0.50-1.12)
Unskilled		1.08 (0.81-1.45)	1.07 (0.78-1.47)	0.87 (0.66-1.15)
Contraceptive use				
Yes		Ref.	Ref.	Ref.
No		1.22 (0.82-1.84)	0.97 (0.58-1.60)	3.34 (1.27-8.81)*
Community-level factors				
Area				
Urban		Ref.	Ref.	Ref.
Rural		1.08 (0.79-1.47)	1.66 (1.13-2.45)**	1.15 (0.74-1.79)
Region				
North-Central (NC)		Ref.	Ref.	Ref.
North-East (NE)		0.75 (0.53-1.06)	0.93 (0.64-1.34)	1.05 (0.67-1.64)
North-West (NW)		1.07 (0.82-1.40)	1.15 (0.86-1.54)	1.63 (1.09-2.41)*
South-East (SE)		0.45 (0.27-0.76)**	0.94 (0.54-1.65)	0.85 (0.40-1.80)
South-South (SS)		0.50 (0.32-0.79)**	0.99 (0.61-1.60)	0.57 (0.29-1.13)
South-West (SW)		1.28 (0.87-1.88)	1.00 (0.58-1.70)	0.96 (0.43-2.17)
Random effects (community-level)				
Variance (SE)	0.49 (0.05)	0.30 (0.05)		
95%CI	0.41,0.60	0.22, 0.42		
PCV	Ref.	38.78%		
MOR	1.95	1.68		

***p-value<0.001 **p-value<0.01 *p-value<0.05 #data available for only women with a live birth in the 2 years preceding the survey; SE: robust standard error, RRR: relative risk ratio, CI: confidence interval, PCV: proportional change in variance, MOR: median odds ratio.

7.5 Discussion

Using the recent datasets of the Multiple Indicator Cluster Survey for Nigeria, we identified the key social determinants of under-five mortality across the neonatal, post-neonatal, and toddler/preschool stages. At each stage of early childhood development, there are different factors relating to child survival, which require different interventions. Our results show that high variation (39%) of under-five mortality across the Nigerian communities is mainly accounted for by maternal-level factors such as maternal education, contraceptive use, maternal wealth, parity, death of previous children and quality of perinatal care. The inclusion of other compositional and contextual factors had no significant additional effect on the community variation of childhood mortality risks. To our surprise somewhat, attendance of skilled providers during delivery was associated (only) with an increased neonatal mortality risk. Female child and singleton had decreased mortality risk during neonatal and post-neonatal stages. Also, teenage mothers experienced increased neonatal and child mortality risks. The significant factors associated with reduced mortality risk at post-neonatal stage were maternal secondary education and urban residence. Maternal wealth and contraceptive use lowered mortality risks among toddlers/pre-schoolers. While living in South-East and South-South regions of Nigeria lowered neonatal mortality risk, residence of North-West region had increased child mortality risk.

Our analysis showed an overall under-five mortality rate of 122 deaths per 1000 live births, which is similar to a rate of 120 deaths per 1000 live births reported in the 2016/2017 MICS report.(32) Also, the neonatal, post-neonatal and child mortality rates in this study (i.e., 38 deaths per 1000 live births, 29 deaths per 1000 live births, and 54 deaths per 1000 children surviving to age one, respectively) are consistent with those reported by MICS team (i.e., 39 deaths per 1000 live births, 31 deaths per 1000 live births, and 54 deaths per 1000 children surviving to age one, respectively). As one would expect, our estimates are comparable with the rates reported in the MICS report for the socioeconomic differentials of age- and stage-specific childhood mortality rates.

Consistent with existing literature from resource-limited countries,(17,49) we found that the probability of under-five mortality was highest during neonatal stage, followed by post-neonatal stage, and lowest in the toddler/preschool stage. In terms of child's sex, our study found higher mortality risks among male children during neonatal and post-neonatal stages, and higher mortality risk among female children during toddler/pre-school stage. These findings align with reports from previous studies.[17,49–51] Many authors argued that female survival in the early childhood is physiologically related.[17,49–51] In addition, male neonates have increased risks of infections, jaundice, birth complications, congenital malformations, and more importantly pre-term births. According to Lawn et al.,[50] the high risk of male neonatal deaths could be explained, in part, by the physiological fact that males' lungs and other vital organs develop less rapidly in-utero and within first week of life, making them more susceptible to respiratory infections compared to females. In the same vein, male pre-term children are more likely to have placental problems and maternal history of hypertension (including pre-eclampsia) during their pregnancies, which might increase their risk of dying during neonatal and post-natal stages. By contrast, male-preference, inadequate care, and malnutrition among females are plausible reasons for the reversal in mortality risk among toddler/pre-schoolers.[49]

Our study also highlights that mothers with secondary education had lesser risk of post-neonatal deaths, and wealthy mothers had lesser risk of child mortality. This observation could be due to better health literacy and access to financial resources. Strikingly, we did not observe statistically significant association between post-secondary education and mortality risk across the early childhood developmental stages. Furthermore, this study explicates the need for improving perinatal care in Nigeria because of its short and long-term benefits, especially during neonatal stage. However, we speculate that the observed association between skilled birth attendants during delivery and neonatal outcomes might be due to late presentation of expectant mothers at health facilities, when complications might have occurred and/or progressed. Late arrival for skilled birth deliveries could be the result of poor health seeking behaviour or long distance to health facilities. Given the complications arising from childbirth, such newborns may die shortly after delivery. This finding may also be indicative of sub-optimal quality of perinatal services in Nigeria. More needs to be done to support assisted deliveries by skilled health professional, which is currently low in Nigeria (43%).[52] Past studies have suggested some of the contributing factors for poor performance of healthcare workers in the resource-limited countries.[53–55] These include burn-out due to shortage of skilled birth attendants, lack of motivation, inadequate supervision, weak patient-healthcare worker relationships, bad transportation system, and frequent stock-out of essential drugs.[53–55] With 18.3 skilled birth attendants per 10,000 population,[56] Nigeria still struggles to achieve the recommended United Nations' threshold of 44.5 skilled birth attendants per 10,000 population needed to achieve the maternal and child health targets of SDG-3.[57] Also, there are other potential explanations for the association between skilled birth delivery and neonatal mortality risk. There is a possibility of under-reporting under-five mortalities among mothers with no or unskilled birth deliveries at the community level. Alternatively, it could indicate a functioning referral system that sends the high-risk deliveries to health facilities to a greater extent. It is also important to note that the unique relationship could be due to misclassification of cadre of skilled health workers by uneducated mothers. Another explanation might be iatrogenic injuries or nosocomial infections, or poor quality of care overall that is posing a risk of children dying.

After controlling for other variables, our findings suggest that rural residence influences mortality in post-neonates, unlike neonates and toddlers/pre-schoolers. Past studies[17,19] in Nigeria have also reported that urban residence is a protective factor for post-natal and child mortality due to potential access to quality healthcare services. Our study further revealed that previous child death remained the strongest determinant of subsequent deaths among children (as determined with the highest relative risk ratios). In line with a study in rural Nepal, Gubhaju[58] asserts that death of previous children could lead to increased parity and shorter birth intervals, arising from early resumption of ovulation and unprotected coital exposure. However, from this study, short birth intervals have independent effect on mortality risks across the three developmental stages. Much attention has been given to the effects of birth spacing on child survival, however, the results are conflicting. Some authors argue that short and prolonged interpregnancy intervals are associated with increased risks of adverse perinatal outcomes.[59–61] Furthermore, this study identifies increased mortality risks among children of mothers born less than two years apart, part of multiple births, and had ≥ five deliveries. Some authors[61,62] have opined that the detrimental effects of short previous birth intervals on childhood mortality might be due to biological ("maternal depletion syndrome") and behavioural (competition of household resources among closely spaced siblings). Our analysis found evidence that the adverse influence of multiple births was highest for neonates and waned across the developmental stages. Taken with the findings from Bangladesh,[51] the dwindling mortality risk for children who are part of multiple births might be an indication of additional supports given to mothers by the extended family members as the children grow. Also, it has been speculated that increased mortality risk among children delivered as part of multiple gestation during neonatal and post-neonatal stages could be partly due to prematurity, twin-to-twin transfusion syndrome,[63] and vulnerability to infection due to low birth weight.[64]

The limitations of the present study include a tendency for information bias arising from maternal self-reporting of data. There might be some recall bias/poor memory leading to (over)under-reporting of childhood mortality—heaping of deaths (i.e., displacement of age at death and preference for selecting certain ages/digits over others as interviewers fail to probe the exact timing of deaths because of its cultural implications). However, recall bias is unlikely to have played a major role since we included only the live births preceding five years to the survey. Due to absence of some variables in the dataset, the data did not allow us to adjust for child nutrition, prematurity, HIV, immunization, and birth weight. However, we used maternal wealth index in-lieu of food (in)security because of its association.[65] Also, cautious interpretations are needed because of the cross-sectional nature of this study, which do not allow for causal inference. Nevertheless, we have reported associations between social determinants of health and age-specific under-five mortality in Nigeria. As far as we know, no previous published research has investigated the factors associated with neonatal, post-neonatal, and child mortality for Nigeria, using multilevel multinomial logistic regression. By simultaneously fitting with multinomial regression models, standard errors were reduced, unlike separate binary logistic regression used in past studies. Our results were further strengthened by using an analytical approach on a national representative dataset, which allows for the findings to be generalized across Nigeria and other settings with similar characteristics. Further studies are needed to establish the disappearance of urban advantage during the neonatal and toddler/pre-school stages. Also, future investigations are necessary to validate the association between quality of perinatal care and childhood mortality, and mechanisms that connect maternal-level factors with community variation of childhood mortalities in Nigeria.

In conclusion, this study provides evidence to guide policymakers in Nigeria on the appropriate interventions to make child-health related Sustainable Development Goals achievable by 2030.

The study reinforces the importance of maternal-level factors in reducing childhood mortality. As maternal-level factors majorly contributed to community variation of under-five mortality in Nigeria, the government with other stakeholders should prioritize making education accessible for girls and in reducing economic hardships for women. In addition, focusing on other social factors operating at different stages of early childhood development, such as short spacing in-between pregnancies, teenage pregnancy, contraceptive use and urbanization, offer potentials of improving child survival in Nigeria. Also, community awareness and health counseling at the health facilities should include child spacing and contraceptive use. At the health facilities, healthcare workers should be alert to the potential mortality risks among high-risk children (especially those delivered to mothers with previous history of child loss), and are advised to take detailed history to screen newborns delivered to such high-risk mothers.

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Chapter 8

Manuscript 4—Disentangling pathways to child survival in Nigeria during the Sustainable Development Goals era: a path analysis with accelerated failure time.

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Publication status

Manuscript stage

Contributions

Daniel A. Adeyinka conceived the study, analyzed, interpreted the data, and wrote the first draft of the paper. Prof. Nazeem Muhajarine assisted in the design, data interpretation, and reviewed the manuscript. Prof. Nazeem Muhajarine supervised this study.

Notes to the reader

As presented in chapter 7, there is a large variation in childhood mortality and its associated factors across communities in Nigeria. This chapter extends the previous chapter by identifying the major pathways by which social factors (at maternal, household and community levels) are associated with child survival in Nigeria. This chapter utilized a novel analytic approach to gain information on the underlying mechanisms of child survival by incorporating hierarchical modeling of path analysis with time-to-event (survival) data. The findings will guide government-led policies and interventions in improving survival outcomes of children.

8.1 Abstract

Background

Childhood mortality remains a challenge in Nigeria, with little progress towards achieving Sustainable Development Goal (SDG) 3. There has been limited evidence about the potential pathways to attaining the child survival and within country equality targets of SDG-3 and 10 that can inform policies and programmatic actions. The objective of this study was to identify the critical pathways through which social factors (at community, household, maternal levels) determine neonatal, infant and under-five mortalities in Nigeria.

Methods

This study used path analysis with time-to-event data from the 2016/2017 Nigeria Multiple Indicator Cluster Survey. It included a weighted sample of 30,960 live births within five years prior to the survey. There were three outcome variables: survival times for neonates, infants, and under-five children. The independent variables were layered factors related to child, maternal, household, and community.

Results

Women from Northern areas of Nigeria were less likely to reside in urban cities and towns than those in the Southern areas. This, in turn, limited their access to social infrastructure and acted as a barrier to maternal education. Without adequate education, women were less likely to use contraceptive methods. Women with no history of contraceptive use were more likely to have childbirths closer together (less than two-year gap), which, in turn, negatively impacted child survival.

Conclusions

This study offers comprehensive set of factors, and linked pathways, at the community, household and maternal level that are associated with child survival in Nigeria. To accelerate progress towards SDG-3 and reduce regional disparities (SDG-10) in Nigeria, stakeholders should implement more impactful policies that promote maternal education, contraceptive use and improve living conditions of women (especially in rural areas).

Keywords: *social determinants of health, path analysis, parametric survival analysis, sustainable development goals, neonatal mortality, infant mortality, under-five mortality, Nigeria*

8.2 Introduction

Child survival continues to emerge as a global priority as articulated in the Sustainable Development Goal 3 (SDG-3), which aims to reduce global and country-level neonatal and under-five mortality rates to 12 deaths and 25 deaths per 1000 live births by 2030, respectively.(1) While progress has been made in reducing under-five mortality rate by 58% from 93 deaths per 1000 live births in 1990 to 39 in 2017, about 15,000 under-five children continue to die everyday worldwide.(1) According to a recent global report, 5 million under-five deaths were recorded in 2017.(1) Based on the current trend, it was estimated that 56 million under-five children will die between 2018 and 2030.(1) Given the present high rates and slow decline of childhood mortality in sub-Saharan Africa, many countries in the region will continue to have high neonatal, infant and under-five mortalities till 2050.(2) Although, child survival has improved in Nigeria, the country ranks second globally behind India for number of neonatal and under-five mortalities.(1) As reported by United Nations, Nigeria contributes 13% to the global burden of under-five deaths—100.2 deaths per 1000 live births in 2017.(1)

In Nigeria, little progress has been made towards achieving child survival and social inclusion targets of SDG-3 and 10, respectively.(3) There is also little evidence to guide policymakers on appropriate interventions to reduce neonatal, infant and under-five mortality rates. In order to build support for policies and interventions that will improve survival of under-five children and reduce within country inequality, it is imperative to understand the pathways that involve child, maternal, household and community-level factors associated with child survival. Previous studies(4–9) in this area have recognized social factors that are associated with poor survival outcomes among under-five children, however, it remains unclear to which degree they are attributed to childhood deaths. Most of these studies, technically, have not reported results that separate associations into direct and indirect effects. Path analysis could delineate pathways of effect on child survival.(10) Cox-proportional models—most common modeling method for survival analysis—has been criticized as not suitable for path modeling because of its assumption of constant hazard ratios between categories over time.(11) Recently, path analysis that uses accelerated failure time data (parametric survival analysis) has been proposed to address these limitations. To date, studies on childhood mortality have not described potential pathways to child survival which can then inform policies and programmatic actions; therefore, we aimed to identify the critical pathways through which social factors (community, household, maternal) may affect neonatal, infant, and under-five survival in Nigeria.

8.3 Proposed path model

The analytical hierarchical framework for this study was largely adapted from Mosley-Chen framework.[12] It informed the hypothesized pathways by which child, maternal, household, and community-level factors are associated with child survival in Nigeria (Figure 8.1). Also, the framework guided the selection of variables from the MICS dataset. Through directed acyclic graphs (DAGs),[13] the framework conceptualizes that child-level factors (i.e., child's sex, birth order, gestation type—single/multiple, previous birth interval, and maternal age at birth of the child), and maternal-level factors would have direct effects on neonatal, infant, and under-five survival. Furthermore, the influence of community-level factors (i.e., region, area of residence, and social infrastructural development) on child survival are mediated via child-level, maternal-level, and household-level factors. We postulated that household-level factors (such as sanitation, drinking water source and indoor pollution) and maternal-level factors (maternal education, maternal wealth, frequency of antenatal care (ANC) visits, skilled birth attendants during delivery, and place of delivery) would have direct effects on child survival. In addition, the influence of maternal age at birth on child survival is hypothesized to be moderated by maternal education and maternal wealth index.

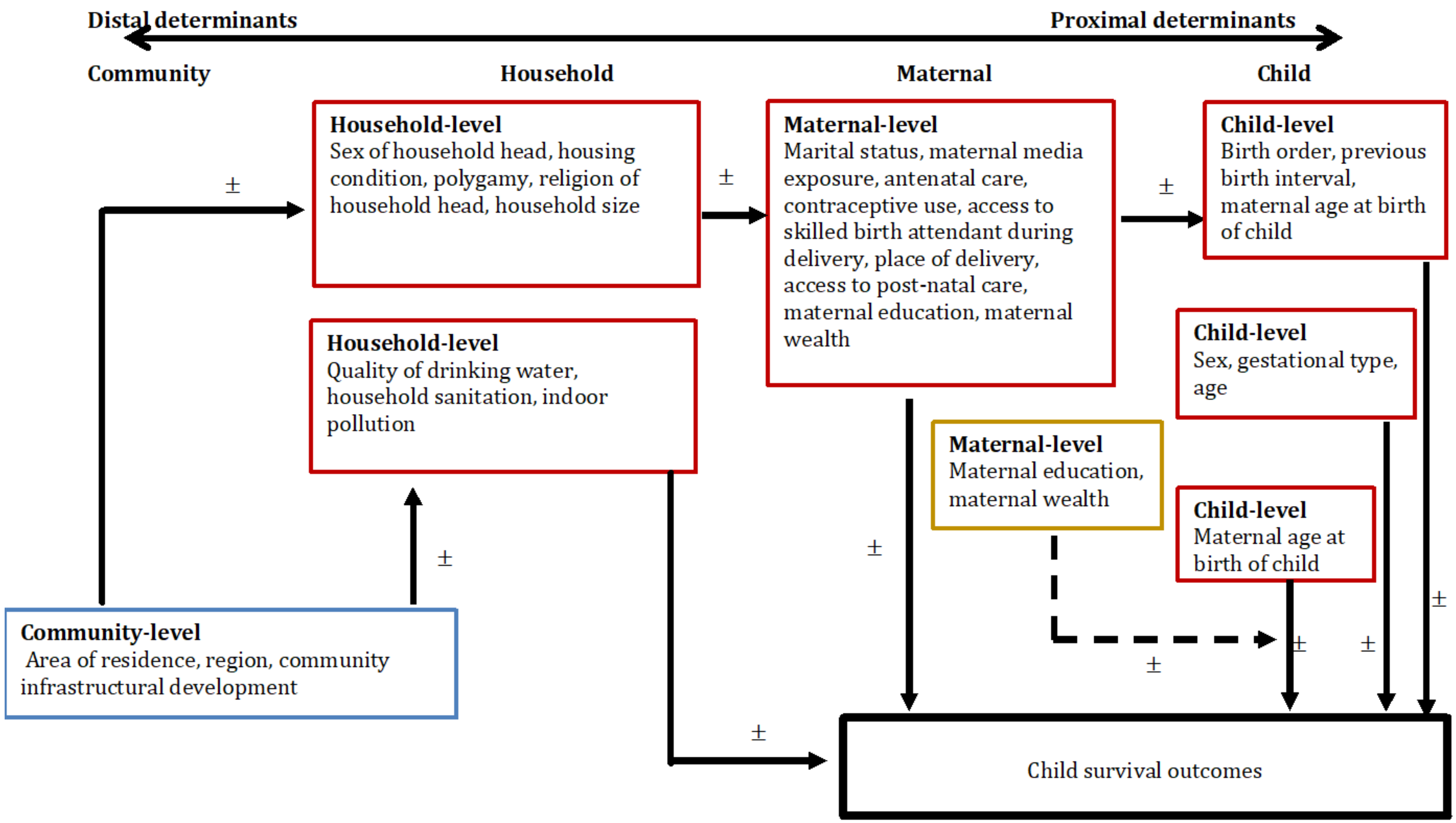

Figure 8.1: Conceptual framework of child survival outcomes
Legend: Mediators (variables in red boxes) and moderators (variables in orange box)

8.4 Methods

8.4.1 Data source

This is a cross-sectional cohort study[14] that utilized complete birth histories, as well as maternal and household datafiles from the 2016/2017 National Multiple Indicator Cluster Survey (MICS)[15]—a national representative population-based survey which was conducted in the 36 states and Federal Capital Territory (FCT), for monitoring progress towards SDG targets in Nigeria. The methodology used for MICS study has been described in the full report.[16] Data were collected from 34,376 women aged 15-49 years in 33,901 households and 2,239 enumeration areas (i.e., primary sampling unit) through multi-stage stratified cluster sampling technique. The response rate was 95%. For the purpose of this study and to minimize recall bias, our analysis included all live births (29,786) within five years prior to survey commencement (or prior to September 2016), regardless of the gestation type (single or multiple).

8.4.1.1 Outcome variables

The dependent variables are time-to-death data derived from the original variables in 2016/2017 MICS dataset. The variables on time-to-death, otherwise referred to survival time, were derived from variables on survival status, age at death, and current age of living children. The survival time are: (i) time to neonatal death-defined by survival time from birth to 27 days; (ii) time to infant death-defined by survival time from birth to one year of life; and (iii) time to under-five death-defined by survival time from birth to five years of life. Survival status was categorized as alive or right censored=0 and dead=1. Except for neonatal survival time that was reported in days, other outcome variables were reported in years.

8.4.1.2 Exposure variables

The independent variables were selected based on availability of data, Mosley-Chen framework, evidence from literature, and authors' programmatic experience. They are layered factors related to child, maternal, household, and community. The definitions are presented in Table 8.1. For ease of path analysis, the independent variables were dichotomized, except for frequency of ANC visits and household size which were discrete variables. Variables on maternal media exposure, housing condition index, and community infrastructural development were newly generated from the existing variables in the dataset. Housing condition index was extracted from the first component of a principal components analysis (PCA). It was computed from three variables—quality of roof, exterior wall and floor items; Kaiser-Meyer-Olkin measure of adequacy ranged from 0.6 to 0.8 and *p-value* (Bartlett's test of sphericity) <0.001. The first component accounted for 67.7% of the total variance of the three variables. The community infrastructural development was measured, indirectly, by calculating the proportion of households with electricity in the community. Also, multiple levels of the individual variables on cooking fuel (proxy for indoor pollution), sanitation, and source of drinking water were collapsed to generate new (separate) variables with two levels (i.e. improved/unimproved)—based on the standard classification by WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP).[(17)] Maternal media exposure variable was generated by collapsing individual variables on accessibility to newspaper/magazine, radio and television. The three variables had a four-item scale measuring the frequency of exposure to the media items—almost every day, at least once a week, less than once a week, and not at all. The item with the best exposure score was selected and recoded into four categories, where lowest score is no exposure and highest score is high exposure to mass media.

8.4.2 Statistical analysis

The unit of analysis for this study is each child. Hierarchical path analyses with accelerated failure times (parametric survival models) were performed to determine the pathways by which child, maternal, household, and community-level factors might contribute to survival of neonates, infants, and under-five children in Nigeria. By fitting three separate models, parametric survival model along binomial logit were fitted using generalized structural equation model (gsem) in Stata™'s version 15.1 structural equation model (SEM) builder.[(18)] Data were assessed for quality—multicollinearity, completeness, maternal age heaping (Whipple's index),[(19)] sex-birth ratio, and heaping of child death (displacement of age at death). Post-natal care variable was dropped because >70% of its values were missing. The following assumptions of path analysis with time-to-event outcome data were deemed to have met: no multicollinearity (mean variance inflation factor (VIF)=1.49), adequate sample size[(20)] (ratio of observation to parameter was 1238:1), and non-proportionality of hazards (i.e., collapsibility of hazard ratio).[(11)]

After preliminary analyses with all the different types of parametric survival methods, lognormal (accelerated failure time) model was observed to be appropriate in fitting the data based on minimum Bayesian Information Criterion (BIC) and Akaike's Information Criterion (AIC). We considered selected (literature- and practice-informed) moderating effects of maternal educational and maternal wealth index on maternal age at birth of child by fitting the interaction terms. However, the interaction terms were not statistically significant; hence they were dropped from the model. The path coefficients ($\boldsymbol{\beta}$) representing direct and indirect effects were obtained. The path coefficients of the direct effects were transformed exponentially into time ratios (TR),[(21)] while those of indirect effects were transformed exponentially into odds ratios (OR).[(21)] In fitting the re-specified models (final models), the complete paths (i.e., direct and indirect) with statistical significance $\boldsymbol{\alpha} \leq 5\%$ were retained. The survey analysis procedures in Stata™ software version 15.1[(18)] was used to account for the cluster sampling design (via Taylor linearization method of variance estimation) and sampling weights provided in the 2016/2017 MICS were applied.

8.5 Results

Table 8.1 describes the child, maternal, household and community-level characteristics of participants. Of the weighted sample of 30,960 live births in this study, 15,725 (50.8%) were males and 29,729 (96.0%) were singletons. More than half of the children, 21,338 (68.9%) were delivered when their mothers were 20-34 years old, and 4320 (14%) were delivered by teenage mothers. About 2 out of 3 were children of mothers who delivered at home. Most of the children were delivered by mothers who were married or in relationship as at the time of conducting the survey (96.2%). While 21,633 (69.9%) were children of women residing in rural areas, less than half of the children were of mothers who had at least secondary education (33.5%). The overall weighted time-at-risk for the study period was 75139.6 child-years.

During the neonatal period, 1174 (3.8%) of the children died, incidence rate for neonatal mortality was 1.4 (95% confidence interval (CI): 1.3-1.5) per 1000 neonate-days. Cumulatively, within one year, 2027 (6.6%) had died, translating to 75.3 (95%CI: 71.3-79.5) per 1000 infant-years for infant mortality. At fifth year, mortality rose to 2840 (9.2%), i.e., 37.8 (95%CI: 36.1-39.6) per 1000 child-years. Forty-three percent of childhood deaths occurred during the neonatal period, while 30.8% of deaths occurred during the post-natal period.

Table 8.1: Characteristics of outcome variables and child, maternal, household and community-level determinants of under-five mortality, MICS Nigeria, 2016/2017

Variable	Mean (SD)/ n (%)	Incidence rate (95%CI) Per 1000 child-years	Description
Outcome variables			
Under-5 mortality			Time to death from births to 5 years, censored/alive=0, died=1
Total time at risk (per 1000 child-years) (N=30960)	75139.6		
Failure variable (30924)			
Alive	28084 (90.8)		
Died	2840 (9.2)		
Infant mortality			Time to death from birth to 1 year of life, alive/censored=0, died=1
Total time at risk (per 1000 infant-years) (N=30960)	26938.7		
Failure variable (30924)			
Alive	28897(93.5)		
Died	2027 (6.6)		
Neonatal mortality			Time to death from birth to 27 days of life, alive/censored=0, died=1
Total time at risk (per 1000 neonate-days) (N=30960)	837768.5		
Failure variable (30924)			
Alive	29751(96.2)		
Died	1174 (3.8)		
Child-level factors			

Child's sex (N=30959)			Male=0, female=1
Male	15725 (50.8)	40.5 (38.0-43.3)	
Female	15234 (49.2)	35.0 (32.7-37.5)	
Gestation type (N=30957)			Single=0, multiple=1
Single	29729 (96.0)	35.3 (33.6-37.1)	
Multiple	1228 (4.0)	105.5 (89.4-124.7)	
Birth order (N=30960)			≤3=0, >3=1
≤3	15793 (51.0)	32.1 (30.0-34.4)	
>3	15166 (49.0)	41.3 (41.3-47.0)	
Previous birth interval (N=30960)			Duration of child spacing in years, first birth/ <2 years=0, ≥2=1
First birth/ <2 years	12101 (30.1)	50.0 (46.8-53.5)	
≥2 years	18858 (60.9)	29.6 (27.7-31.7)	
Maternal age at birth (N=30960)			Mother's age at the birth of the child, <20 / ≥35 years=0, 20-34 years=1
<20 years	4320 (14.0)	51.8 (46.4-58.0)	
20-34 years	21338 (68.9)	33.8 (31.9-35.9)	
≥35 years	5302(17.1)	42.9 (38.5-47.9)	
Maternal-level factors			
Maternal education (N=30959)			Highest educational level attained by mothers; none/primary=0; secondary/technical/post secondary=1
None/primary	20,609 (66.6)	45.2 (43.0- 47.7)	
Secondary	7981 (25.8)	24.3 (21.6-27.3)	
Post secondary	2369 (7.7)	19.1 (14.7-25.2)	
Maternal wealth index (N=30960)			Poor=0, middle/rich=1
Poor	13912 (44.9)	48.6 (45.8-51.6)	
Middle	6068 (19.6)	39.9 (35.6-44.7)	
Rich	10980 (35.5)	23.4 (21.2-26.0)	
Maternal media exposure (N=30956)			Accessibility to newspaper/magazine or listening to the Radio or watching television; no=0, yes=1
No	12394 (40.0)	47.3 (44.4-50.5)	
Yes	18561 (60.0)	31.6 (29.5-33.8)	
Number of ANC visits[#] (N=20775)			Frequency of ANC visits regardless of the personnel type; discrete
Mean (SD)	5.19 (11.2)	37.8 (36.1-39.6)	
Skilled birth attendants during delivery[#] (N=20786)			Delivery by type of personnel; none/unskilled/friend=0, skilled birth attendants=1
None/Unskilled	12714(61.2)	51.1 (47.7-54.8)	
Skilled	8072 (38.8)	32.3 (29.0-36.0)	
Institutional delivery[#] (N=20783)			Place of delivery; home=0, health facility=1
Home	13358 (64.3)	49.3 (46.1-52.9)	
Health facilities	7425 (35.7)	33.3 (29.8-37.3)	
Marital status (N=30934)			Currently married/in relationship=0, Never married/formerly married=1
Currently married/in relationship	29748 (96.2)	37.6 (35.9-39.5)	
Never married/formerly married	1186 (3.8)	40.4 (31.6-52.3)	
Contraceptive use (N=26807)			Ever used a method to avoid pregnancy; yes=0, no=1
Yes	1947 (7.3)	22.3 (17.8-28.1)	
No	24860 (92.7)	41.6 (39.6-43.8)	
Household-level factors			
Sex of household head (N=30960)			Male=0, female=1
Male	29614 (95.7)	38.2 (36.4-40.1)	
Female	1346 (4.4)	29.6 (22.7-39.2)	
Housing condition (N=30960)			Housing material type based on the quality of roof, exterior wall and floor; inadequate=0, adequate=1
Inadequate	13172(42.6)	46.4 (43.7-49.4)	
Adequate	17788 (57.5)	31.5 (29.4-33.9)	
Polygamy (N=30960)			Husband/partner has other wives; yes=0, no=1
Yes	10880 (35.1)	44.3 (41.3-47.5)	
No	20079 (64.9)	34.3 (32.2-36.5)	
Household access to drinking water (N=30959)			Household source of drinking water; unimproved source=0, improved source=1
Unimproved	10820 (35.0)	47.0 (43.7-50.6)	
Improved	20139 (65.1)	32.9 (31.0-35.0)	
Household sanitation (N=30959)			Household members using improved toilet facility; unimproved=0, improved=1
Unimproved	159256 (51.4)	42.8 (40.4-45.4)	
Improved	15033 (48.6)	32.5 (30.2-35.2)	
Indoor pollution (N=30960)			Source of cooking fuel; polluting fuel=0, clean fuel=1
Polluting fuel	29120 (94.1)	39.1 (37.2-41.0)	

Clean fuel	1840 (5.9)	18.3 (14.2-24.0)	
Household size (N=30960)			
Mean (standard deviation)	7.8 (4.1)	37.8 (36.1-39.6)	Number of household members (Discrete)
Religion of household head (N=30960)			Household head religion affiliation; no religion=0, any religion (Christianity, Islam, traditional/others)=1
No religion	14 (0.04)	15.4	
Religious	30946 (99.7)	37.8 (39.6)	
Community-level factors			
Area (N=30960)			Urban=0, rural=1
Urban	9327 (30.1)	25.8 (22.9-29.2)	
Rural	21633 (69.9)	43.1 (41.0-45.4)	
Region (N=30960)			Geopolitical region where mothers reside; northern part (NC/ NE/ NW) =0, Southern part= (SE/ SS/ SW) =1
North-Central (NC)	5084 (16.4)	35.0 (31.3-39.2)	
North-East (NE)	6517 (21.1)	35.3 (31.1-40.2)	
North-West (NW)	12113 (39.1)	50.8 (47.7-54.2)	
South-East (SE)	1604 (5.2)	21.5 (17.8-26.1)	
South-South (SS)	2370 (7.7)	19.0 (15.8-22.9)	
South-West (SW)	3272 (10.6)	23.0 (19.4-27.5)	
Infrastructural development (N=30960)			Proportion of households with electricity in the community; low=0, high=1
Low	16235 (52.4)	45.3 (42.8-47.9)	
High	14724 (47.6)	29.7 (27.4-32.2)	

#data available for only women with a live birth in the 2 years prior to survey

8.5.1 Indirect effects

The final (re-specified) models of indirect effects of independent variables on neonatal, infant, and under-five survival are presented in Figures 8.2 and 8.3. Compared to Northern Nigeria, mother-child dyads in Southern Nigeria were less likely to reside in rural areas (OR: 0.30, 95%CI: 0.24-0.39, *p-value*<0.001). As expected, those living in rural areas were less likely to access better social infrastructure in their communities (OR: 0.08, 95%CI: 0.06-0.11, *p-value*<0.001). Mothers who had access to better infrastructure were 5.5 times more likely to have post-primary education (95%CI: 4.65-6.41, *p-value*<0.001). Sequentially, mothers with post-primary education were less likely not to have used contraceptives (OR: 0.29, 95%CI: 0.24-0.34, *p-value*<0.001). As anticipated, women with no history of contraceptive use were 25% less likely to have longer spacing between the current and previous birth (OR: 0.75, 95%CI: 0.64-0.87, *p-value*<0.001). Supplementary Figures F1-F3 (Appendix F) outline the other (less impactful) chains of indirect effects.

8.5.2 Direct effects

8.5.2.1 Neonatal survival

The results from bivariate analysis are presented in Table F1 (Appendix F). The direct association from re-specified path diagram shows that previous birth interval ≥2 years had the highest positive effect ($\boldsymbol{\beta}$=2.78), while multiple births had the highest negative effect ($\boldsymbol{\beta}$=-5.06) (Figure F1—Appendix F.2). As shown in Supplementary Table F4, the survival time for neonates of mothers who had a previous birth interval ≥2 years was 16 times the survival time of first-born or with birth interval <2 years, 95%CI: 9.90-26.42, *p-value*<0.001. The survival time for neonates in multiple births decreased by 99% compared to singleton births, TR=0.01 (95%CI: 0.003-0.02), *p-value*<0.001. In addition, the survival time for females increased by 2.57, compared to males, 95%CI: 1.57-4.23, *p-value*<0.001. Survival time increased for neonates whose mothers were 20-34 years, TR=2.74 (95%CI: 1.67-4.50, *p-value*<0.001) and decreased with neonates born late in the birth order (>3rd birth order), TR=0.32 (95%CI: 0.19-0.55, *p-value*=0.007). The complete pathway (both direct and indirect effects) with the greatest impact has $\boldsymbol{\beta}$=4.97, as notated below in Figure 8.2. The other significant less impactful pathways are shown in re-specified path diagram (Figure F1, Appendix F).

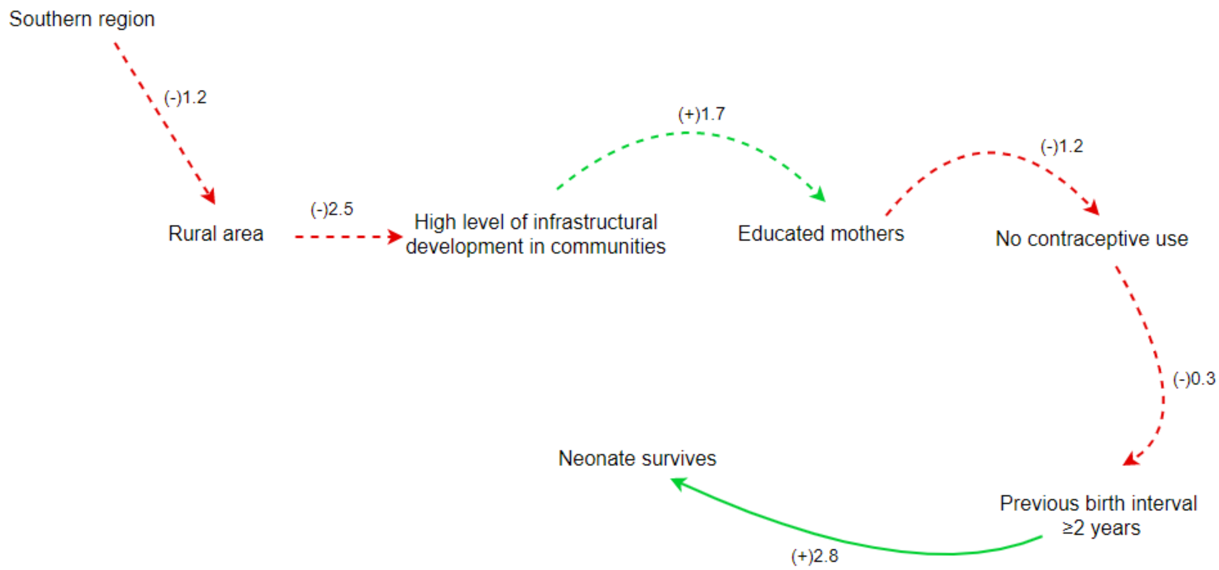

Figure 8.2: A simplified path diagram with path coefficients of the mechanism of neonatal survival in Nigeria (from re-specified path diagram). Color code: red—inverse relationship, and green—positive relationship. Broken lines: indirect effects, and unbroken line: direct effect.

8.5.2.2 Infant survival

Figure F2 (Appendix F.2) presents the final (re-specified) path diagram and Figure 8.3 highlights the most impactful pathway that has the highest path coefficient (***β***=6.63) for infant survival. Infants of mothers who had longer spacing between the current and previous birth (birth interval ≥2 years) had longer survival time, compared to children whose mothers had shorter interval between births (birth interval <2 years), TR=20.37 (95%CI: 12.77-32.49, *p-value*<0.001) (Supplementary Table F4). Also, children delivered as part of multiple births were less likely to survive during infancy, compared to singletons, TR=0.01 (95%CI: 0.002-0.01, *p-value*<0.001*)*. Considering maternal age, infants delivered by women whose age was 20-34 years had longer survival time, TR=2.24, (95%CI: 1.38-3.65, *p-value*=0.001). Also, the survival time increased for female infants, (TR=2.61, 95%CI: 1.69-4.03, *p-value*<0.001), and infants whose mothers had post-primary education (TR=3.84, 95%CI: 2.29-6.43, *p-value*<0.001). However, infants born late in the birth order (fourth-born and above), were less likely to survive (TR=0.33, 95%CI: 0.20-0.55, *p-value*<0.001).

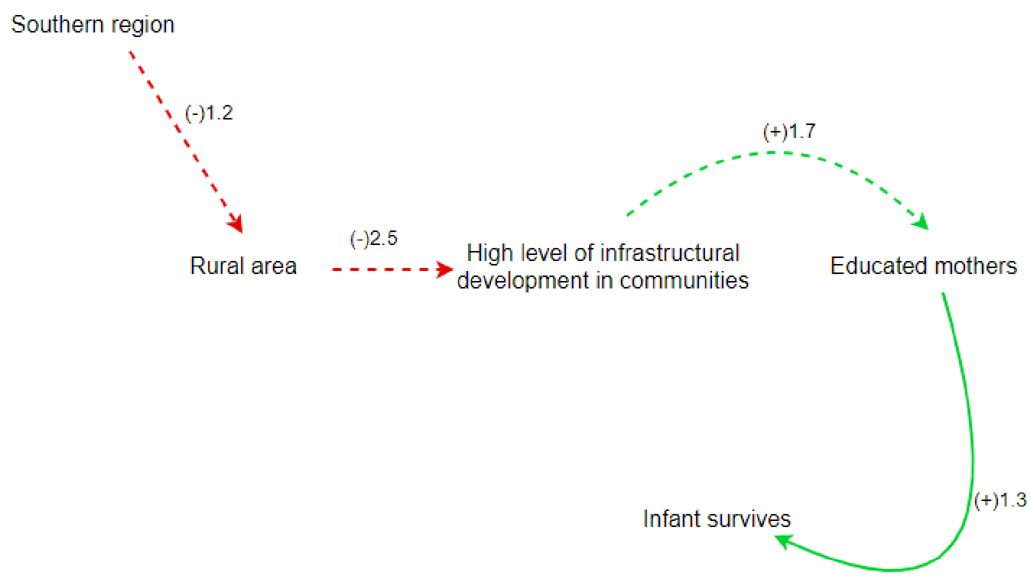

Figure 8.3: A simplified path diagram with path coefficients of the mechanism of infant survival in Nigeria (from re-specified path diagram). Color code: red—inverse relationship, and green—positive relationship. Broken lines: indirect effects, and unbroken line: direct effect.

8.5.2.3 Under-five survival

From Supplementary Table F4, children of mothers born more than two years apart survived longer (TR=13.43, 95%CI: 9.19-19.61, *p-value*<0.001). Also, children delivered as part of multiple birth had shorter survival time, compared to single births, TR=0.01 (95%CI: 0.005-0.02, *p-value*<0.001). The survival time increased for female children (TR=1.94, 95%CI: 1.34-2.81, *p-value*<0.001), children delivered by women aged 20-34 years (TR=2.10, 95%CI: 1.42-3.09, *p-value*<0.001), and children whose mothers had post-primary education (TR=6.32, 95%CI: 4.01-9.97, *p-value*<0.001). However, children born late in the birth order (fourth-born and above) were less likely to survive (TR: 0.34, 95%CI: 0.23-0.52, *p-value*<0.001).

The pathway in Figure 8.4 shows the highest path coefficient for under-five survival ($\boldsymbol{\beta}$=9.18).

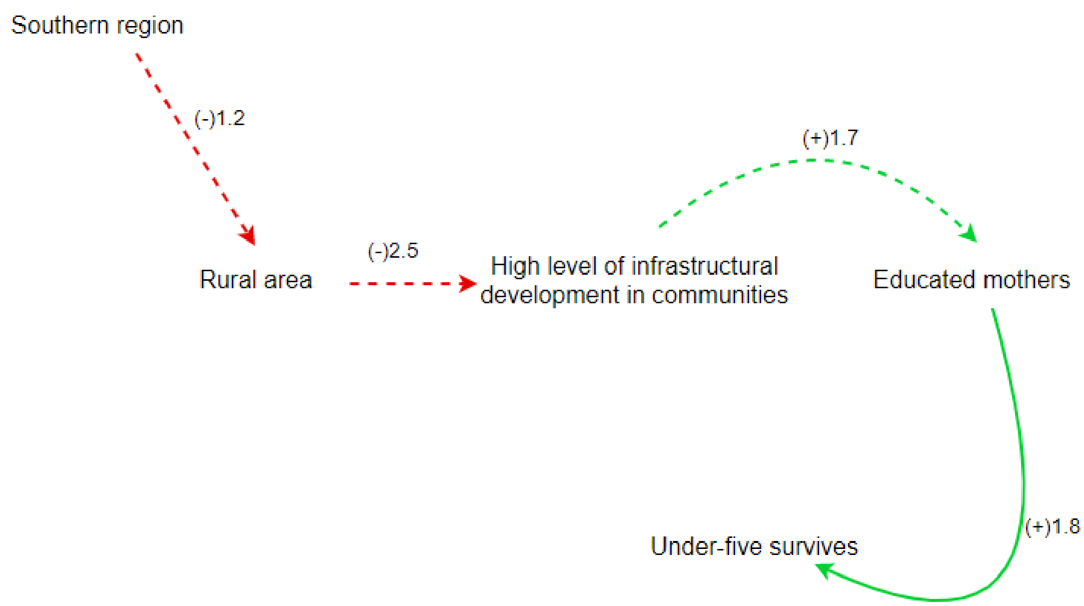

Figure 8.4: A simplified path diagram with path coefficients of the mechanism of under-five survival in Nigeria (from re-specified path diagram). Color code: red—inverse relationship, and green—positive relationship. Broken lines: indirect effects, and unbroken line: direct effect.

8.6 Discussion

We have taken hierarchical path analyses with accelerated failure time approach to studying the pathways of influence for child, maternal, household, and community-level factors associated with neonatal, infant and under-five survival in Nigeria. Female children, those whose mothers delivered at least two years apart, and maternal age 20-34 years had longer neonatal, infant, and under-five survival times. Unlike neonatal period, children whose mothers had post-primary education were more likely to survive during infancy and within first five years of life. During the first years of life, children delivered as part of multiple births, and those born late in the birth order, were less likely to survive. In addition, factors such as region and area of residence, infrastructure development, maternal education, contraceptive use, previous birth interval, marital status, and maternal age at birth were found to operate indirectly on the neonatal, infant and under-five survival.

This study offers comprehensive set of factors at the community, household and maternal level that are associated with child survival in Nigeria. The path analysis reveals that in the neonatal, infant and under-five models, women from the Northern areas of Nigeria were less likely to reside in urban cities and towns than those in the Southern areas. This, in turn, limited their access to social infrastructure and acted as a barrier to maternal education. Without adequate education, women were less likely to use contraceptive methods. Women with no history of contraceptive use were less likely to have adequate spacing (≥2 years) between children, which, in turn, negatively impacted child survival. This is consistent with what has been observed previously.(22,23) With respect to birth interval, inadequate child spacing depletes maternal micronutrients (e.g., copper, zinc, ferritin, folate and magnesium) which are critical to child survival.(24)

As observed from this study, the direct relationship between high maternal education level, and infant and under-five survival could be due to better health literacy and heath seeking behaviours for themselves and their children.(7,23–28) Similarly, empirical evidence from literature suggests that health prevention measures against childhood diseases (such as immunization)(29) and prompt care of sick children are vital elements for child survival.(12,27,28) Furthermore, through an alternative pathway, the indirect effects of maternal education on neonatal, infant, and under-five survival were mediated by maternal age at birth. The association between maternal educational and maternal age at birth raises concerns about reverse causality. On this basis, Asante *et al.*, reported that uneducated female youths might have earlier sexual debut,(30) whereas, numerous studies have noted the temporal relationship between teenage pregnancy and risk of dropping out of school.(31–33) Physiologic immaturity, low birth weight, prematurity, and infections may be considered as important aetiological factors for childhood mortality among teenage mothers,[34] however, Adeyinka *et al.*, opined that it is an indication of the lack of critical and supportive care needed by teenage mothers in low-resource settings.[35] To a lesser extent, marital status exerted indirect effects on neonatal, infant and under-five survival through previous birth interval. This study provides evidence to support that children delivered to never or formerly married women were less likely to use contraceptives, which in turn is associated with short birth spacing after a previous delivery.

Contrary to the findings from previous studies,[23,24] we did not find association between the frequency of ANC visits and skilled birth attendants during delivery, and child survival. It is possible that this observation could have been masked by inability to account for high-risk pregnancies, and quality of care received during pregnancy and labour. Similarly, this study could not ascertain the timing of those interventions. These assumptions should be tested in future studies.

We recognize that path analysis provides plausibility of theoretical model, and not for making prediction/ causal inferences.[10] From this perspective, our findings should be regarded as associations, and not causations. In addition, maternal recall bias/poor memory arising from self-report could not be completely overlooked. However, we expect that limiting our analysis to five years prior to the survey might have minimized its effect. As generalized structural equation modeling is at its nascent stage during the time of our analysis, goodness-of-fit tests were not available in Stata™ software.[21]pg2 Hence, we could not assess model-fit. Despite these limitations, this study has some strengths. To our knowledge, this is the first study that combined survival analysis with path analysis to explain the pathways of effects of social determinants of health on child survival. Also, the study relied on a large dataset which comprised of representative national sample and high response rate; hence, findings are generalizable to under-five children in Nigeria and other settings with similar contexts. Path analysis with time-to-event outcome constitutes a relatively new area of research which is still evolving. This study adds to the few papers that utilized path analysis in population health research.

In conclusion, our findings indicate child survival inequity in Nigeria, which might be independently due to multiple gestation, previous birth intervals, maternal education, birth order, child's sex, and maternal age at birth. Also, this study has highlighted the key pathways by which region, area of residence, infrastructural development, contraceptive use, and marital status influence neonatal, infant and under-five survival. In order to accelerate progress towards child survival targets of SDG-3 and reduce regional disparities (SDG-10) in Nigeria, stakeholders should implement more impactful policies that promote maternal education, contraceptive use and improve living conditions of women in rural areas. Also, our findings indicate the need for community and facility-based interventions for neonates of teenage mothers.

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Chapter 9

Manuscript 5—Geographic inequities in neonatal survival in Nigeria: cross-sectional evidence from spatial and artificial neural network analyses.

Authors

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Publication status

Manuscript stage

Contributions

Daniel A. Adeyinka conceived the study, analyzed, interpreted the data, and wrote the first draft of the paper. Prof. Nazeem Muhajarine assisted in the design, data interpretation, and reviewed the manuscript. Prof. Nazeem Muhajarine supervised this study.

Notes to the reader

This chapter discusses the last manuscript of the five series of papers prepared for this thesis. It delves deeper into the spatial patterns and determinants of neonatal mortality rates across the states and regions of Nigeria. As demonstrated in the previous chapters, Nigeria has high neonatal mortality rate, and most of the childhood mortalities occurred during the neonatal period. From chapter 6, there is evidence of gender inequity in childhood mortality in Nigeria—worsening for females. It is also apparent from the preceding chapter (Chapter 8) that non-availability of basic social amenities for women indirectly influenced mortality risks for children, which is worse in Northern Nigeria. To understand the gender inequity gaps in neonatal mortality, equiplot was generated. The equiplot shows disaggregation of gaps by urban/rural areas across the geographical regions. Also, using spatial autocorrelation, this chapter identifies the high-risk and low-risk clusters of neonatal mortality. Furthermore, multilayer perceptron neural network analysis—an artificial intelligence modeling technique was used to determine the important contributors to neonatal mortality across the states and regions. Lastly, subnational annual reduction rates were estimated to give insight to what pace is needed to meet SDG target for neonatal mortality by 2030 across the states and regions of Nigeria.

9.1 Abstract

Background

Neonatal mortality is a major concern in Nigeria as it contributes 10.5% to the global neonatal deaths. Due to limited evidence of geographic variations in neonatal deaths, it is challenging to implement strategies that would guarantee equitable decline in neonatal mortality across the states and regions of Nigeria, as the country seeks to meet the child-survival Sustainable Development Goal 3 (SDG-3) targets. This study was therefore conducted to provide empirical evidence of geographical variations of neonatal mortality and its social determinants with a view of improving neonatal survival at the sub-national level in Nigeria.

Methods

With a combination of spatial analysis and artificial intelligence technique, this study analyzed data from the 2016/2017 Nigeria Multiple Indicator Cluster Survey. Data from a weighted national representative sample of 30,924 live births delivered within five years before the survey were analysed. Global Moran's I index, and local indicator of spatial autocorrelation cluster maps were used to determine hot- and cold-spots. The gender inequity gaps in neonatal mortality rate (NMR), disaggregated by urban/rural residence across the 6 geographical regions were visualized with equiplot. Multilayer perceptron neural network was used to identify the key determinants of neonatal mortality across the states and regions in Nigeria. The annual rate of reduction (ARR) needed to meet the SDG-3 neonatal targets were estimated at the subnational level.

Results

The overall neonatal mortality rate was 38 deaths per 1000 live births. There was significant clustering of neonatal deaths across Nigeria (Moran's I index=0.1, p-value=0.02). North-West and North-Central regions were identified as hot-spots for neonatal deaths (i.e. clustering of states with higher rates). Gender inequity was worse in the rural areas of Northern Nigeria, while it was worse in the urban areas of Southern Nigeria. NMR was disproportionately higher among females in urban areas (except North-West and South-West regions). Conversely, male neonates had higher mortality risks in the rural areas for all regions. Multilayer perceptron neural network indicates that determinants of neonatal mortality varied across the six geographical regions. Overall, multiple births, previous birth interval, birth order, and maternal age at birth were the top contributors to neonatal mortality in Nigeria. The ARR needed to achieve SDG target for neonatal mortality rate ranged from 4% (South-South region) to 9% (North-West and North-Central regions).

Conclusions

This study offers evidence indicating wide geographic clustering of neonatal mortality across Nigeria, majorly driven by poor maternal access to media, short birth interval, increasing birth order, and young maternal age at birth. This study highlights the need for policy-shift towards implementing state and region-specific strategies in Nigeria. Gender-sensitive, cultural, and regional appropriate reproductive, maternal and child health targeted interventions may address geographical inequity in neonatal survival.

Keywords: *health inequity; social determinants of health; neonatal mortality; sustainable development goals; spatial analysis; multilayer perceptron neural network; Nigeria*

9.2 Introduction

Despite progress made in reducing global under-five mortality rate by 58% from 93 deaths per 1000 live births in 1990 to 39 deaths per 1000 live births in 2017, millions of children continue to die yearly.(1) Among the 5.4 million under-five deaths recorded in 2017, 46.3% (2.5 million deaths) occurred during the neonatal period (first 28 days of life), making neonatal period, a time of highest mortality risk for children.(1) With 27 deaths per 1000 live births, neonatal mortality rates (NMR) remain highest in the region of sub-Saharan Africa.(1) Moreover, the inter-country disparity in neonatal mortality is more profound for Nigeria, as it ranks second after India in the global neonatal mortality burden.(1) Also, 1 in 28 babies delivered in Nigeria did not survive during the first 28 days of life, making an estimated 266,000 neonatal deaths, and accounted for 10.5% of the global burden of neonatal deaths in 2017.(1) The risk of dying for a neonate in Nigeria is twice the global NMR of 18 deaths per 1000 live births.(1)

Although recent reviews(2–4) of health indicators in Nigeria suggest moderate improvement in survival of under-five children, NMR has stagnated in recent years. A further concern is the masking of heath inequities at the subnational level by aggregating the country's performance of neonatal survival. Drawing on the conclusions of World Health Organization (WHO) Commission of Social Determinants of Health (SDH), gender and spatial dimensions are important determinants of population health.(5)

With respect to the roles of gender (a social and cultural construct) and sex (biological identity) on child survival, epidemiologic studies have provided contradictory findings. While some studies have linked worse survival outcomes among male children to biological disadvantages,(2,6,7) others have reported gender bias in excess of female mortality due to gender discrimination, especially in terms of selective termination of female fetuses and newborns, and neglect of nutrition and health care for the girl-child.(8) Also, evidence suggests that population residing in socio-economically disadvantaged areas such as rural residence experience worse health outcomes because of high levels of poverty, inaccessibility to quality health care, and inadequate social infrastructure.(2,9) In contrast, some studies have noted urban area disadvantage for under-five mortalities due to air pollution, overpopulation, and waste disposal crisis.(10–12) In order to achieve the desired Sustainable Development Goal 3 (SDG-3) target of reducing NMR to 12 deaths per 1000 live births by 2030,[13,14] it is fundamental that policy makers be cognizant of and address the gender bias and rural-urban disparity in child survival, and social determinants of neonatal mortality across the states and regions in Nigeria.

Understanding the geographical patterns of mortality during neonatal period—the most crucial period of early child's development,[15,16] is useful for micro-level planning and allocation of resources to areas where they are needed most (underserved population) for driving progress towards SDG-3 at the subnational level. Although some researchers have attempted to examine the social determinants of neonatal mortality,[2,3,17,18] no known published study has examined the spatial patterns of neonatal mortality in Nigeria. Also, there is dearth of information on gender differences in NMR across urban-rural areas and geographical regions. This study was therefore conducted to provide empirical region-specific evidence of variations in neonatal mortality and its social determinants with a view of improving neonatal survival at the sub-national level in Nigeria. The primary objective of this study was to determine patterns and determinants of geographical clustering of neonatal mortality at the state and regional levels in Nigeria. The secondary objectives were to: assess gender inequity for neonatal mortality between urban and rural communities across the regions, and to measure gaps in SDG-3 target for neonatal mortality at the state and regional levels in Nigeria.

9.3 Methods

9.3.1 Study area

Nigeria, the most populated country in sub-Saharan Africa, is located in West Africa. It comprises of six geo-political regions (i.e., North-West (NW), North-East (NE), North-Central (NC), South-West (SW), South-East (SE), and South-South (SS), which are further divided into 36 states and Federal Capital Territory (FCT). There are more than 250 ethnic groups, which are divided into three major ethnic groups. Predominantly, there are Yoruba in the SW, Igbo in the SE, and Hausa in the Northern Nigeria.

9.3.2 Study design and data sources

This is a cross-sectional study that utilized full birth history, along with maternal and household datafiles, obtained from the 2016/2017 Nigeria Multiple Indicator Cluster Survey (MICS).[(20)] The MICS is a national population-based survey conducted by trained interviewers in Nigeria, with support from UNICEF Headquarters, New York to provide estimates of maternal and child health indices for the country.[(21)] The detailed explanation of the methodology used for MICS has been described in the full report.[(21)] With a complex, multi-stage stratified cluster sampling technique, data were collected from 36,176 women aged 15-49 years between September 2016 and January 2017 in the 36 states and FCT of Nigeria.[(21)] The 37 states (including FCT) in the six geo-political regions corresponded to the sampling strata. The strata were then sorted into rural and urban areas. Overall, 33,901 households from 2239 enumeration areas, otherwise referred to as primary sampling units (PSU) were covered during fieldwork. The PSU, which was used as a proxy for community, was defined as administrative/ enumeration area with homogenous population characteristics. Of the women interviewed, the response rate was 95%. To minimize recall bias, the present study was limited to 29,756 children delivered in the last five years preceding the survey commencement.

9.3.3 Theoretical framework

This study utilized Mosley-Chen framework[(22)] to identify the relevant social determinants of neonatal deaths in Nigeria. The framework underscores that childhood mortality in the resource-limited countries results from the complex inter-relationships of multiple biological and social factors at the child, maternal, household, and community-levels. For this study, we hypothesized that there would be substantial variations in neonatal mortality across the rural/urban communities, states, and regions of Nigeria. The geographical inequities in neonatal mortalities would vary by the degree of impact of social determinants of health on the child-mother dyads.

9.3.4 Variables

Dependent variable: The outcome variable—neonatal survival status was generated from information on child survival outcome, age at death and current age of living children divided into two categories: alive (coded as 0) and dead (coded as 1).

Independent variables: The independent variables considered were informed by Mosley-Chen framework, programmatic experience of authors, evidence from literature, and availability of variables in MICS dataset. The variables are layered across child, maternal, household, and community-level (Table 9.1). Besides the variables collected in the MICS dataset, we generated housing condition index by applying a principal components analysis (PCA) to reduce variables on quality of roof, exterior wall and floor; overall Kaiser-Meyer-Olkin measure of adequacy was 0.7, and *p-value* (Bartlett's test of sphericity) <0.001. The first component was considered because it had eigenvalue of 2.03 and accounted for 67.7% of the total variance. With median value as the cut-off point, housing condition index variable was coded as adequate and inadequate. Also, maternal media exposure (accessibility to newspaper/magazine or listening to the radio or watching television), access to drinking water, sanitation, indoor pollution, community level of maternal education, and community infrastructural development were generated. Household sanitation, sources of drinking water, and cooking fuel (proxy for indoor pollution) were re-categorized into improved and unimproved, as defined by the WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP).[(23)]

9.3.5 Statistical analyses

This study employed artificial intelligence technique—backpropagation feedforward multilayer perceptron (MLP) neural network,[(24)] and geospatial analyses. We first generated descriptive statistics for all the variables using Stata™ version 15.1 software (College Station, Texas).[(25)] The statistical differences in the proportions between the surviving and deceased children (univariate analyses) were assessed with Chi-square test. The significance level was set at *p-value* <0.05. The complex survey design commands in Stata™ software and sampling weights were applied to account for the hierarchical sampling, and unequal selection probabilities of samples. We also computed early NMR (risk of death from birth to 6 days of life), and late NMR (risk of death from 7 days to 27 days after birth). Furthermore, strip plots were used to visualize the state and regional distributions of early and late mortality rates. According to the following equation,[(26)] we predicted the state- and regional-levels annual reduction rates (ARR) required to achieve the desired SDG-3 targets for NMR from 2016.

$$ARR = \left(\frac{ln\left(\frac{SDG\ target}{NMR}\right)}{n} \right) * (-100) \qquad (9.1)$$

Where SDG target is 12 deaths per 1000 live births, NMR is the estimated neonatal mortality rate from 2016/2017 MICS, and n is 14 years.

The gender inequity gaps in NMR, disaggregated by urban/rural residence across the 6 geographical regions were visualized with equiplot.[27]

9.3.5.1 Geospatial analysis

Based on geometric centroids and spatial (arc) distance of 407 km in a Nigeria shapefile (WGS84 geographic coordinate system), obtained from the United Nations Office,[28] we generated a distance-based weight matrix, to ensure that all the states were interconnected—a condition for spatial analysis.[29] The symmetry of connectivity histogram and connectivity map were used to assess the suitability of the spatial weights. The units of spatial analysis were states. In determining spatial patterns, the NMR was first estimated for each state. As proposed by Anselin,[29] we performed univariate global spatial autocorrelation, and assessed the degree of similarity (spatial clustering) of NMR across the states in Nigeria. A global Moran's I index of a positive value indicates non-dispersion (i.e., spatial clustering).[29] We also generated univariate local indicator spatial autocorrelation (LISA) cluster and significance maps to identify the states with high NMR as denoted by hot-spots, and the states with low NMR (cold-spots). The statistically significant hot-spots were determined by the grouping of states with high NMRs, and vice-versa for cold-spots. The spatial effects of the identified independent variables on neonatal mortality from the MLP neural network (as demonstrated by ≥50% normalized importance) were further assessed with bivariate LISA cluster maps. Thereafter, we used PCA to reduce the variables that were spatially autocorrelated with NMR (i.e., proportion of children with previous birth interval <2 years, birth order >3, young maternal age at birth (<20 years) and no maternal exposure to mass-media)—otherwise referred to as social determinants of child health index. Low index of social determinants of child health indicates low inequity among neonates. With singular value decomposition (SVD) method and z-score transformation (i.e., mean of zero and variance of one), the first component explained 74.9% of the total variance and its eigenvalue was 3.0. The most important advantage of SVD is its robustness against outliers.[30] As a result, the combined spatial effect of the variables that constituted the first principal component on

NMR was visualized with a multivariate cluster map. The statistical significance of spatial autocorrelations was tested by running 999 Monte Carlo simulations with a *p-value*<0.05. The spatial analysis was implemented in GeoDa software version 1.14.[31]

9.3.5.2 Artificial neural network

With a view of identifying the salient determinants of neonatal mortality at regional and national levels, backpropagation feedforward MLP neural networks were implemented in the IBM SPSS neural network software version 21.0.[32] Much like the human brain, the architecture of MLP is a collection of several artificial neurons that are connected by their weights and assembled into an input layer, at least a hidden layer, and an output layer.[33] The input layer receives the inputs and performs the calculations via the neurons before on-ward transmission to the hidden layer. The hidden layer is the "black-box" connecting the input and output layers. The output layer receives information from the hidden layer to produce the final results.[33] In addition to the linear activation function of MLP, it can also account for nonlinear relationship between the inputs and outputs, hence producing more accurate results, compared to the traditional statistical methods.[33]

Data preprocessing: The unit of analysis for neural network was every child delivered by women in each household. Figure 9.1 shows the flow chart of data preprocessing for MLP neural network. With the dataset randomly partitioned into training (70%), testing (20%), and holdout (10%) sets, the MLP learning algorithm (gradient descent algorithm) used the training set to learn the inherent pattern of the dataset. The testing and holdout sets were used for model validation. This model building process used two hidden layers. The input layer factors were the independent variables selected for this study, excluding region (since the analyses were stratified by regions). The output layer consisted of one factor—neonatal survival status (dependent variable). After eliminating the bias units, input layer had 74 units, while output layer had 2 units. The number of units in hidden layers were automatically computed. The number of units in the hidden layer 1 and hidden layer 2 were 13 and 10, respectively. This initial process generated weighted sum and bias of input and hidden layers. The weighted sum and bias were activated through the hyperbolic tangent (tanh) activation function and softmax activation function.[33] The computational efficiency of the models was optimized at learning rate (η) of 0.4, and momentum (μ) of 0.8. The gradient descent allows for weight correction (i.e., tuning) through backpropagation of errors across the networks by using iterative process.[33] The number of epochs (***ρ***) that allowed convergence of input data was 100. Each epoch involves complete iteration over a batch of training set to adjust the weights and minimize errors of the network with an error rate (δ) of 0.00001. The MLP neural networks were validated based on values of error function (cross entropy), area under receiver operating characteristic curve (ROC) and accuracy rate from holdout samples.[33]

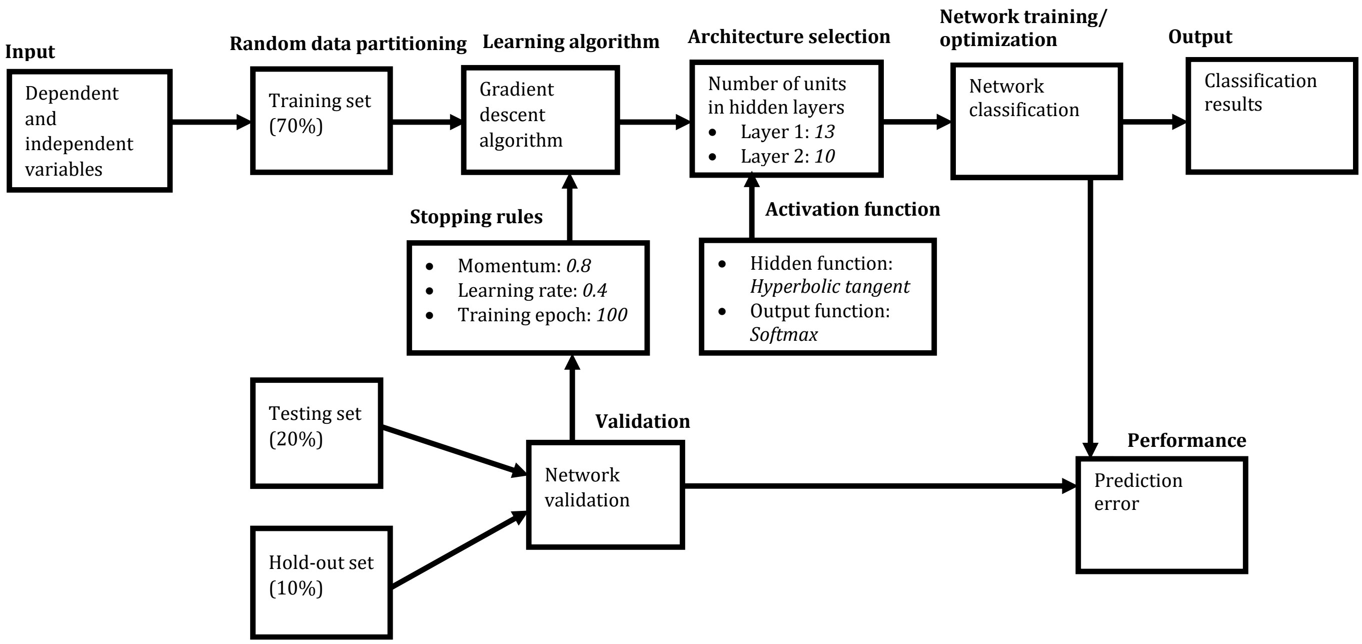


Figure 9.1: Flow chart of multilayer perceptron neural network modeling (Source: author)

9.4 Results

Table 9.1 shows the sociodemographic characteristics of the study participants. Of the weighted sample of 30,924 under-five children included in the study, 50.8% were males, 96.0% were single births, and 60.9% were children whose mothers had preceding birth interval ≥2 years.

The NMR was 37.9 deaths per 1000 live births. Most of the neonatal deaths (85.9%) occurred within the first seven days of life, translating to 32.3 deaths per 1000 live births (early NMR), and declined to 5.7 deaths per 1000 live births during late neonatal period (7-27 days). Although not statistically significant, the NMR was slightly higher in rural areas (39.3 deaths per 1000 live births) than urban areas (34.7 deaths per 1000 live births); *p-value*=0.262. Higher neonatal mortality risk was observed for males (43.2 deaths per 1000 live births), compared to females (32.5 deaths per 1000 live births); *p-value*=0.0004.

Table 9.1: Socio-demographic characteristics of study participants, 2016/2017 MICS, Nigeria

Variable	Sample size n (%)	Alive n (%)	Neonatal mortality n (%)	p-value	Description
Child-level factors					
Child's sex (N=30924)				0.0004	male=0, female=1
Male	15704 (50.8)	15024 (50.5)	679 (57.9)		
Female	15220 (49.2)	14726 (49.5)	494 (42.1)		
Gestation type (N=30922)					singleton=0, multiple=1
Single	29694 (96.0)	28691 (96.4)	1003 (85.5)	<0.001	
Multiple	1228 (4.0)	1058 (3.6)	171 (14.5)		
Birth order (N=30924)				<0.001	first birth=0, 2-3=1, 4-6=2, ≥7=3
First	5426 (17.5)	5170 (17.4)	257 (21.9)		
2-3	10342 (33.4)	10055 (33.8)	287 (24.5)		
4-6	9962 (32.2)	9653 (32.4)	309 (26.3)		
≥7	5194 (16.8)	4873 (16.4)	321 (27.3)		
Previous birth interval (N=30924)				<0.001	<2 years=0, first birth=1, ≥2 years=2
<2 years	6591 (21.3)	6178 (20.8)	413 (35.2)		
First birth	5492 (17.8)	5222 (17.6)	270 (23.0)		
≥2 years	18842 (60.9)	18350 (61.7)	491 (41.8)		
Maternal age at birth (N=30924)				<0.001	<20 years=0, 20-34 years=1, ≥35 years=2
<20 years	4315 (14.0)	4074 (13.7)	241 (20.5)		
20-34 years	21311 (68.9)	20602 (69.3)	709 (60.4)		
≥35 years	5298 (17.1)	5074 (17.1)	224 (19.1)		
Maternal-level factors					
Maternal education (N=30924)				0.016	none/primary=0, secondary/technical=1, post-secondary=2
None/primary	20590 (66.6)	19749 (66.4)	842 (71.7)		
Secondary	7969 (25.8)	7716 (25.9)	253 (21.5)		
Post-secondary	2365 (7.7)	2286 (7.7)	79 (6.7)		
Maternal wealth index (N=30924)				0.053	poor=0, middle=1, rich=2
Poor	13905 (45.0)	13353 (44.9)	552 (47.1)		
Middle	6058 (19.6)	5798 (19.5)	260 (22.1)		
Rich	10962 (35.4)	10600 (35.6)	362 (30.8)		
Maternal media exposure (N=30921)				0.135	accessibility to newspaper/magazine or listening to the radio or watching television. (high=0, medium=1, low=2, none=3)
High	10032 (32.4)	9665 (32.5)	367 (31.3)		
Medium	4966 (16.1)	4808 (16.2)	158 (13.5)		
Low	3542 (11.5)	3410 (11.5)	131 (11.2)		
None	12381 (40.0)	11864 (39.9)	517 (44.1)		
Parity (N=30924)					<3=0, 3-4=1, ≥5=2
<3	7841 (25.4)	7578 (25.5)	262 (22.4)	<0.001	
3-4	10115 (32.7)	9798 (32.9)	317 (27.0)		
≥5	12969 (41.9)	12375 (41.6)	594 (50.7)		
Access to ANC[#] (N=20761)				0.02	none=0, skilled=1, unskilled=2
None	6724 (32.4)	6457 (32.4)	267 (33.2)		

Skilled	12589 (60.6)	12132 (60.8)	457 (56.8)		
Unskilled	1449 (7.0)	1369 (6.9)	80 (9.9)		
Freq of ANC visits# (N=20761)				0.457	none=0, 1-7=1, ≥8=2
None	6724 (32.4)	6457 (32.4)	267 (33.2)		
1-7	10404 (50.1)	10023 (50.2)	381 (47.4)		
≥8	3633 (17.5)	3477 (17.4)	155 (19.3)		
Skilled birth attendants during delivery# (N=20772)				0.705	none=0, skilled birth attendants=1, unskilled/friend=2
None	2646(12.7)	2533 (12.7)	113 (14.0)		
Skilled	8065 (38.8)	7755 (38.8)	310 (38.4)		
Unskilled	10061 (48.4)	9676 (48.5)	385 (47.7)		
Place of delivery# (N=20769)				0.965	home=0, health facility=1
Home	13350 (64.3)	12834 (64.3)	516 (64.2)		
Health facilities	7418 (35.7)	7131 (35.7)	288 (35.8)		
Marital status (N=30898)				0.6621	currently married/in union=0, formerly married/in union=1, never married/ in union=2
Currently married/in union	29714 (96.2)	28594 (96.2)	1120 (95.7)		
Formerly married/in union	802 (2.6)	770 (2.6)	32 (2.8)		
Never married/ in union	382 (1.2)	364 (1.2)	18 (1.6)		
Contraceptive use (N=26778)				0.05	yes=0, no=1
Yes	1943 (7.3)	1888 (7.3)	55 (5.4)		
No	24834 (92.7)	23862 (92.7)	973 (94.6)		
Alcohol intake (N=30772)				0.269	yes=0, no=1
Yes	3645 (11.8)	3521 (11.9)	124 (10.6)		
No	27127 (88.2)	26082 (88.1)	1045 (89.4)		
Smoking experience (N=30863)				0.081	yes=0, no=1
Yes	212 (0.7)	198 (0.7)	13 (1.2)		
No	30651 (99.3)	29498 (99.3)	1153 (98.8)		
Household-level factors					
Sex of household head (N=30924)				0.279	male=0, female=1
Male	29581 (95.7)	28450 (95.6)	1132 (96.4)		
Female	1343 (4.3)	1301 (4.4)	42 (3.6)		
Household head education (N=30846)				0.0035	none/primary=0, secondary/technical=1, post-secondary=2
None/primary	18097 (58.7)	17336 (58.4)	760 (65.1)		
Secondary	8308 (26.9)	8041 (27.1)	267 (22.9)		
Post-secondary	4441 (14.4)	4300 (14.5)	140 (12.0)		
Ethnic group (N=30924)				0.081	Hausa=0, Igbo=1, Yoruba=2, others=3
Hausa	17465 (56.5)	16751 (56.3)	714 (60.8)		
Igbo	2404 (7.8)	2335 (7.9)	69 (5.9)		
Yoruba	2922 (9.5)	2818 (9.5)	104 (8.8)		
Others	8134 (26.3)	7847 (26.4)	287 (24.4)		
Housing condition (N=30924)				0.644	inadequate=0, adequate=1
Inadequate	13162 (42.6)	12651 (42.5)	511 (43.5)		
Adequate	17762 (57.4)	17099 (57.5)	663 (56.5)		
Polygamy (N=30924)				0.369	yes=0, no=1

Yes	10873 (35.2)	10441 (35.1)	432 (36.9)		
No	20051 (64.8)	19310 (64.9)	741 (63.1)		
Household access to drinking water (N=30924)				0.002	unimproved source=0, improved source=1
Unimproved	10811 (35.0)	10331 (34.7)	480 (40.9)		
Improved	20113 (65.0)	19419 (65.3)	694 (59.1)		
Household sanitation (N=30923)				0.549	unimproved=0, improved=1
Unimproved	15917 (51.5)	15298 (51.4)	619 (52.7)		
Improved	15007 (48.5)	14452 (48.6)	555 (47.3)		
Indoor pollution (N=30924)				0.037	polluting fuel=0, clean fuel=1
Polluting fuel	29088 (94.1)	27965 (94.0)	1123 (95.7)		
Clean fuel	1837 (5.9)	1786 (6.0)	50 (4.3)		
Community-level factors					
Area (N=30924)					
Urban	9308 (30.1)	8985 (30.2)	323 (27.5)	0.2624	urban=0, rural=1
Rural	21616 (69.9)	20766 (69.8)	850 (72.5)		
Region (N=30924)					
North-Central (NC)	5079 (16.4)	4863 (16.3)	216 (18.4)	0.0007	North-Central (NC)=0, North-East (NE)=1, North-West (NW)=2, South-East (SE)=3, South-South (SS)=4, South-West (SW)=5
North-East (NE)	6514 (21.1)	6301 (21.2)	213 (18.1)		
North-West (NW)	12101 (39.1)	11567 (38.9)	534 (45.5)		
South-East (SE)	1599 (5.2)	1557 (5.2)	42 (3.6)		
South-South (SS)	2364 (7.6)	2312 (7.8)	52 (4.4)		
South-West (SW)	3268 (10.6)	3151 (10.6)	117 (9.9)		
Infrastructural development (N=30924)				0.072	based on proportion of households with electricity in the community—low=0, high=1
Low	16223 (52.5)	15566 (52.3)	657 (56.0)		
High	14701 (47.5)	14185 (47.7)	516 (44.0)		
Comm. Maternal education (N=30924)				0.0008	based on proportion of households with women who had at least secondary education in the community—low=0, medium=1, high=2
Low	16436 (53.2)	15709 (52.8)	727 (62.0)		
Medium	5839 (18.9)	5656 (19.0)	183 (15.6)		
High	8649 (28.0)	8386 (28.2)	263 (22.4)		

[#]data available for only women with a live birth in the 2 years prior to survey, ANC: antenatal care

9.4.1 Geographical variations of neonatal mortality rates

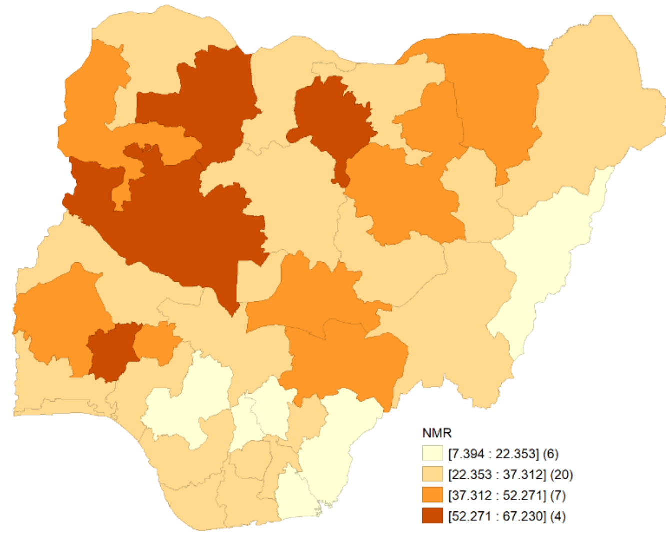
Figures 9.2 and 9.3 indicate that there were wide variations in NMR across the states and regions in Nigeria. NMR was highest in the NW region (44.1 deaths per 1000 live births), and lowest in SS region (22.1 deaths per 1000 live births). Specifically, Kano state had the highest NMR (67.4 deaths per 1000 live births), followed by Niger state (58.2 deaths per 1000 live births). The lowest NMR was observed in Edo state (7.9 deaths per 1000 live births). Regarding early and late NMR, they were highest in NC region (36.3 deaths per 1000 live births and 9.1 deaths per 1000 live births, respectively). While early NMR was lowest in SS region of Nigeria (20.0 deaths per 1000 live births), late NMR was lowest in SW region (1.5 deaths per 1000 live births). With the current deficit in national SDG target of 68.4%, Nigeria needs to reduce NMR at an annual rate of 8.2% to achieve SDG target by 2030 (Table 9.2 and Figure G1-Appendix G). As depicted in Table 9.2, the annual reduction rate for NMR ranged from 4% (SS region) to 9% (NW and NC regions). The state-level deficit in SDG-3 targets and required annual rate of reduction for NMR are displayed in Figure G1-Appendix G).

As shown in Figure 9.2b, significant clustering of NMR was observed across the states in Nigeria; global Moran's I index=0.1, *p-value*=0.02. The univariate LISA cluster map for NMR further revealed that the states with higher NMR (13.5%)—as determined by the high-high clusters (hot-spots), were located majorly in NW region (Jigawa, Katsina, Kano, and Zamfara states), and to a lesser extent in NC region (Niger state). The high-high clusters depict the states with statistical significantly higher NMR than the national average. Contrarily, low-low clusters (cold-spots) were the states with statistical significantly lower NMR than the national average. The cold-spots (24.3%) were concentrated in SS region (Akwa Ibom, Bayelsa, Cross River, Delta, and Rivers states), and SE region (Abia, Anambra, Ebonyi and Enugu states). However, there were some outliers—high-low and low-high clusters. The high-low clusters were formed by significant clustering of two states (5.4%), where NMRs were high and adjacent to states with low NMRs. The high-low clusters were formed by Benue state (NC region), and Imo state (SE region). Two states (5.4%) were identified as low-high clusters in NW region (Kaduna and Sokoto states)—states with low NMRs and were neighbors to states with high NMRs. The spatial correlogram (Appendix G-Figure G2) shows the changes in spatial autocorrelation of NMR with distance. Between 0 to 172.5km, the spatial autocorrelation of NMR was 0.16 (i.e., spatial clustering). The spatial autocorrelation of NMR dropped to 0.12 between 172.5 to 345km. Beyond 345km, NMRs were spatially dispersed, ranging from to -0.18 to -0.01. The spatial autocorrelation was zero at 409.8km (i.e., absence of systematic spatial variation in NMR).

There was no significant spatial dependence of early NMR, global Moran's I index=0.02, *p-value*=0.173, but statistically significant moderate global spatial clustering of late NMR was observed, Moran's I index=0.3, *p-value*=0.001 (Appendix G-Figures G3 and G4, respectively).

A.

B.



C.

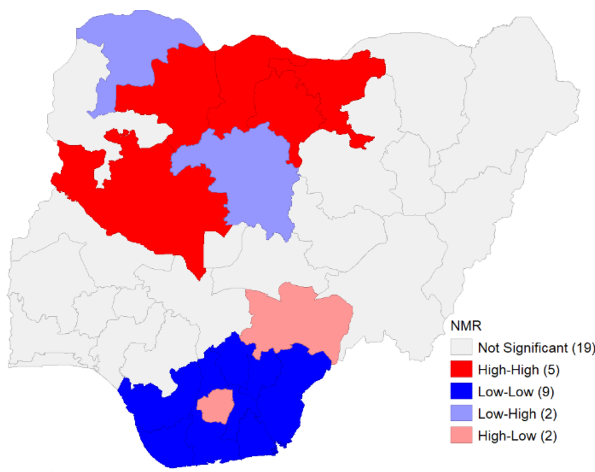
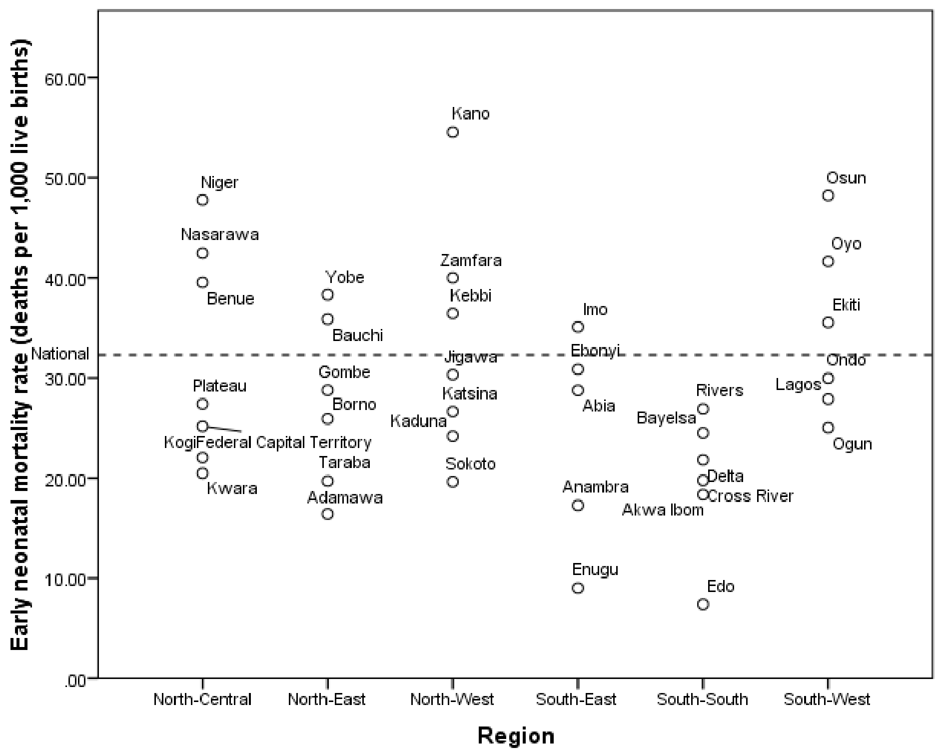


Figure 9.2: A. States and regions in Nigeria[19] B. Spatial distribution of NMR, 2016/2017 Nigeria MICS C. Univariate LISA cluster map for NMR, 2016/2017 Nigeria MICS.

A.



B.

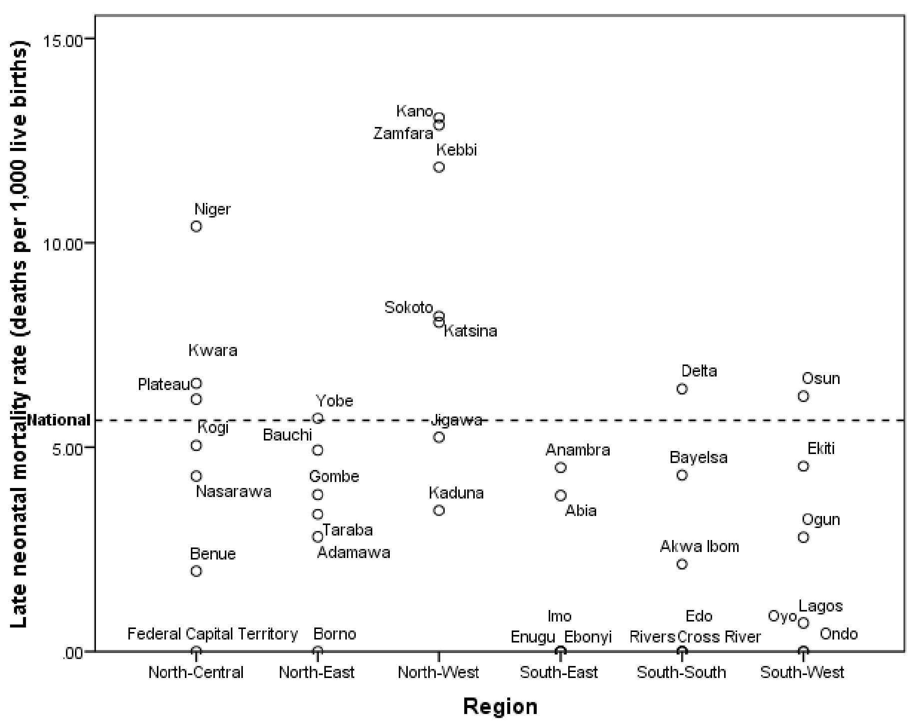


Figure 9.3: State-level A. Early neonatal mortality rates, 2016/2017 Nigeria MICS B. Late neonatal mortality rates, 2016/2017 Nigeria MICS.

9.4.2 Magnitude of gender inequity in neonatal mortality rate across urban/rural residence

Mortality rate was highest among male neonates residing in rural NW region (54.2 deaths per 1000 live births) and lowest among male neonates in urban SS region (10.8 deaths per 1000 live births). Figure 9.4 shows the absolute inequity (i.e., risk difference) between males and females disaggregated by urban/rural residence across the geographical regions. The absolute difference was largest in urban SS region (-19.9) and lowest in urban NC (-0.4). Overall, the gender differences in NMR tended to be larger in the rural North, however, urban South was observed to have large differences. Except for NW and SW regions, female NMR was higher in urban areas. However, male NMR was generally higher in urban areas in all regions. The urban SS had the worst absolute gender difference (-19.9). Compared to other regions, SE region had lower absolute gender inequities.

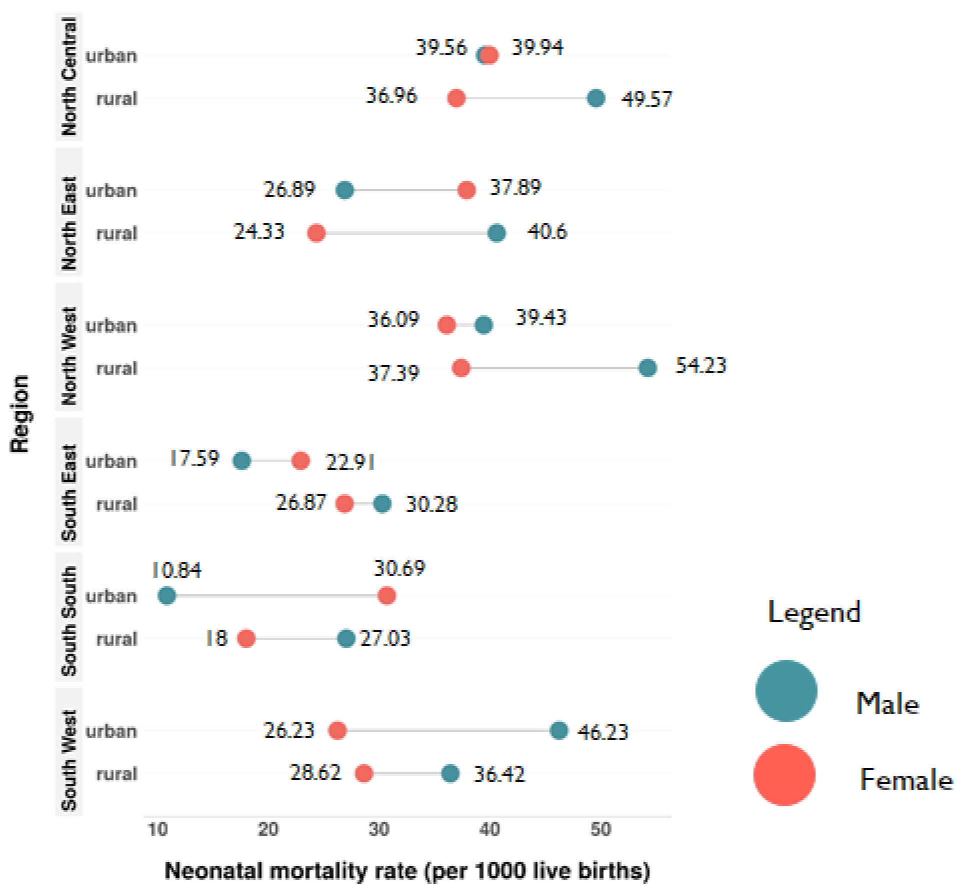


Figure 9.4: Absolute gender inequity in neonatal mortality rate across urban/rural residence of geographical regions, 2016/2017 Nigeria MICS

9.4.3 Determinants of neonatal mortality across the regions

From the predictive MLP neural nets, there were different determinants of neonatal mortality across the regions in Nigeria (Table 9.2). Overall, based on the normalized importance values, multiple births (100%), previous birth interval (53.9%), and birth order (51.3%) were identified as the major contributors to neonatal mortality in Nigeria. The regional-level analysis also found similar evidence that these three factors were common contributors across all the regions. Except for NW region, maternal age at birth appeared consistently across the regions (Table 9.2). Also, we observed that maternal mass-media exposure is a social determinant of neonatal mortality in the Southern part of the country (Table 9.2)

To establish the direction of association and spatial autocorrelation of the most important variables—multiple births, previous birth interval, birth order, maternal age at birth, and maternal access to mass-media—identified from MLP, bivariable LISA cluster maps were generated (Figure 9.5 and Figure G5). There was no statistically significant spatial association between multiple births and NMR in Nigeria, Moran's I index= -0.1, *p-value*=0.05 (Figure G5, Appendix G). However, births closer together (less than two years gap) and increasing birth order (>3) were significantly associated with the spatial patterns of NMR; Moran's I index=0.1, *p-value*=0.01, and Moran's I index=0.2, *p-value*=0.003, respectively. The Moran's I index for NMR and deliveries by adolescent mothers indicates significant clustering (I=0.21, *p-value*=0.001), and no maternal exposure to mass-media (I=0.1, *p-value*=0.008). Figure 9.4a suggests that there were 5(13.5%) high-high clusters, implying clustering of states with high NMR and high percentage of children of mothers born less than two years apart. The high-high clusters were in NE region (Bauchi and Yobe states), and NW region (Jigawa, Kano, and Katsina states). Also, SE region (Abia and Anambra states), SS region (Bayelsa, Delta, and Edo states), NC region (Kogi and Kwara states), and SW region (Lagos, Ogun and Ondo states) clearly indicate clustering of states with significantly low NMRs and low percentage of children of mothers born less than two years apart (low-low clusters). Figures 9.4b-d display the bivariate LISA cluster maps for the associations between NMR, and increasing birth order (>3), deliveries by adolescent mother and no maternal exposure to mass media. The multivariate cluster map also shows evidence of significant positive spatial autocorrelation (I=0.2, *p-value*=0.002) between increasing birth order, births closer together, young maternal age at birth, no maternal access to mass-media, and NMR in Nigeria (Figure 9.6). In the multivariate map, high NMR was spatially correlated with high child health index (hot-spots) in NE (Bauchi and Yobe), NW (Jigawa, Kano, Katsina, Kebbi and Zamfara), and NC (Plateau). The SE (Abia, Anambra, Ebonyi, Enugu), SS (Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Rivers), NC (Kogi, Kwara), and SW (Lagos, Ogun, Ondo) were identified as the cold-spots—low NMR was spatially correlated with low social determinants of child health index. The high-low clusters were found in NC (Benue), SW (Ekiti, Osun, Oyo), and SE (Imo). The high-low cluster were the states with significant spatial correlation between high NMR and low social determinants of child health index. However, the low-high clusters indicated states with significant low NMR and high social determinants of child health index. The low-high clusters were formed by NE (Adamawa, Borno, Gombe), and NW (Kaduna and Sokoto).

9.4.4 Model assessment

The neural network models produced ROC values ranging from 0.69 to 0.95 (Table 9.2). The ROC for the overall (national) model was 0.71, translating to an accuracy rate of 96.0%. With similar cross-entropy errors and accuracy rates across the training, testing and holdout samples, there is evidence to suggest that the neural networks were not over trained.

Table 9.2: Regional comparison of NMR, progress towards SDG targets, key contributors to mortality rates and model performance

Region	Neonatal mortality rate (deaths per 1000 live births	[a]Current deficit in SDG-3 target (%)	Expected annual rate of reduction (%)	[b]Normalized importance (≥50%) (from MLP neural network)	[c]Model Accuracy (%)	ROC
North-Central	42.5	-71.8	9.03	Previous birth interval (100%), multiple births (92.9%), birth order (90.3%), household head education (78.9%), sanitation (73.0%), ANC access (72.8%), skilled birth attendance (69.6%), maternal age at birth (65.7%), household ethnicity (65.3%), maternal education (61.2%), maternal poverty (58.0%), housing condition (58.0%), community level of maternal education (55.4%), parity (53.8%), community development (51.9%), frequency of ANC visits (50.4%)	96.2	0.771

North-East	32.7	-63.3	7.2	Birth order (100%), frequency of ANC visits (71.2%), sanitation (70.8%), multiple births (68.5%), place of delivery (66.5%), birth interval (56.3%), maternal age at birth (54.0%)	97.2	0.694
North-West	44.1	-72.8	9.3	Multiple births (100%), birth order (59.9%), birth interval (56.7%)	94.3	0.719
South-East	26.3	-57.4	5.6	Multiple births (100%), maternal mass media exposure (92.2%), maternal educational level, frequency of ANC visits (60.6%), contraceptive use (59.6%), birth order (51.4%), maternal age at birth (50.2%)	99.0	0.945
South-South	22.1	-45.7	4.4	Polygamy (100%), sex of household head (74.4%), parity (73.2%), ANC access (70.9%), maternal wealth index (70.7%), community level of maternal education (63.0%), ethnicity of household head (61.6%), previous birth interval (60%), alcohol intake (59.6%), birth order (55.9%), maternal mass media exposure (53.5%), household head education (53.4%), multiple births (50.1%)	97.5	0.737
South-West	35.7	-66.4	7.8	Maternal mass media (100%), birth order (97.4%), skilled birth attendance (84.9%), maternal education (82%), community level of maternal education (73.8%), maternal age at birth (68.7%), alcohol intake (66.3%), household head education (61%), multiple births (60.2%), house condition (57.6%), household ethnicity (55.4%), frequency of ANC visits (52.8%), parity (51.7%), contraceptive use (51.6%), previous birth interval (50.1%)	93.3	0.795
National	38.0	-68.4	8.2	Multiple births (100%), previous birth interval (53.9%), birth order (51.3%)	96.0	0.705

[a]Current deficit in SDG-3 target (%): difference, in percentage, the SDG target and the estimated rate for NMR as at 2016/2017

[b]Normalized importance: equivalent to regression coefficient. This is the neural network classification of independent variables based on their strength of associations with the outcome variable.

[c]Model accuracy: the predictive performance of the trained neural network on previously unseen datasets (i.e., validation data sets).

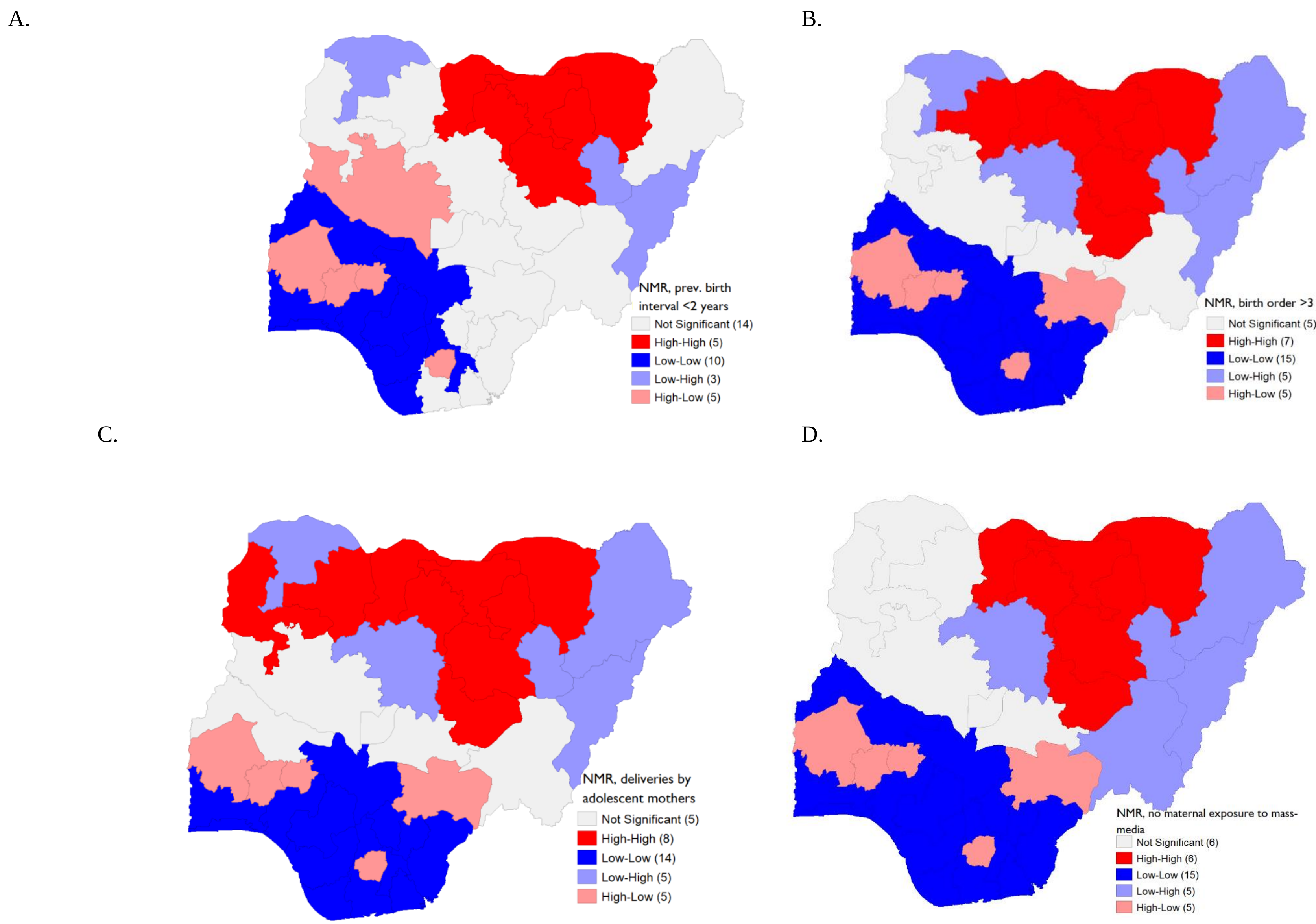


Figure 9.5: Bivariate LISA cluster maps of neonatal mortality rate, and A. previous birth interval <2 years. B. birth order >3. C. deliveries by adolescent mothers D. no maternal exposure to mass-media

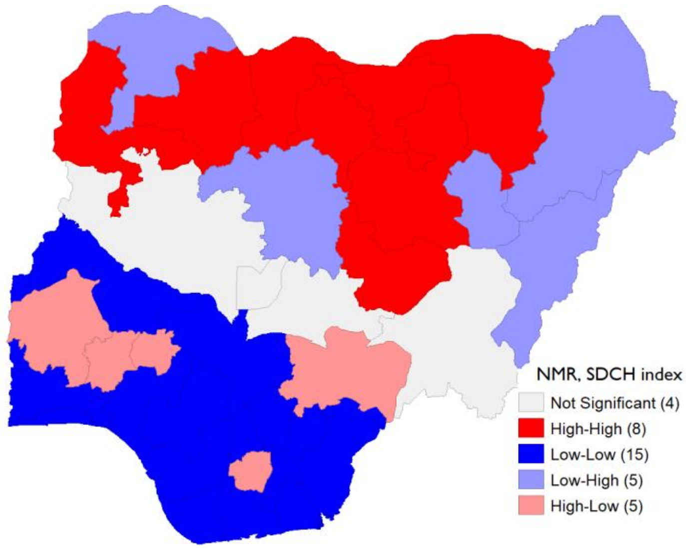


Figure 9.6: Multivariate (PCA) LISA cluster maps of neonatal mortality rate, and social determinants of child health index (previous birth interval <2 years, birth order >3, deliveries by adolescent mothers, no maternal exposure to mass-media)

NMR: Neonatal mortality rate, SDCH: Social determinants of child health, PCA: Principal components analysis

9.5 Discussion

In this study, we estimated NMR of 37.9 deaths per 1000 live births for Nigeria, and most of the deaths (85%) occurred within the first week of life. This is an indication of missed opportunity for improving child survival in the early phase of child's development in Nigeria. Among the regions and states, NC (Benue, Nasarawa and Niger), NE (Bauchi and Yobe), NW (Kano, Kebbi and Zamfara), and SW (Ekiti, Osun and Oyo) were observed to have higher NMRs than the national rate. More importantly, Kano state contributed 15.5% to all neonatal deaths in the country. Also, our findings show that children delivered as part of a multiple birth, and those with high social determinants of child health index (i.e., delivered later in birth order (>3), born within two years after preceding births, delivered to adolescent mothers, and those without access to mass-media) had higher risk of neonatal death in Nigeria. However, there was no clear evidence of spatial dependence of multiple births on the geographic pattern of NMR. Also, we observed inter-regional disparities in the absolute sex-specific NMR between urban/rural areas. Our analysis clearly shows the need to implement targeted interventions to reduce gender gap between urban and rural residences across the geographical regions. Gender inequity was worse in the rural areas of Northern Nigeria, while it was worse in the urban areas of Southern Nigeria.

NMR was disproportionately higher among females in urban areas (except NW and SW regions). Conversely, male neonates had higher mortality risks in the rural areas for all the regions. The region with the most equitable NMR was urban NC region (-0.4), followed by urban NW (3.3) and rural SE (3.4).

The geospatial analyses suggest that there was huge disparity in neonatal mortality within Nigeria. The states in the NW and NC regions had higher NMR, and clustered to form hot-spots of neonatal mortality. However, a distinct pattern of downward trend of NMR was observed towards the Southern part (i.e., SS and SE)—cold-spots. The finding that NW and NC had higher NMR is consistent with the pattern reported in the 2016/2017 Nigeria MICS report.(19) Previous surveys conducted before Boko Haram insurgency started in Nigeria (i.e., 2009) showed that NMR was worst in the NE region.(34,35) It is important to reinforce the consequences of conflicts on maternal and child health in the affected region.(36,37) In line with the on-going insurgencies in the NE region,(38) it can be inferred that the hot-spots formed in the NW and NC regions might be in part due to neglect of the internally displaced people from NE region (especially vulnerable women), as they fled to the neighboring states in the NW and NC regions. We recommend that the Government of Nigeria should prioritize maternal and child health services among the internally displaced populations and develop innovations that would improve child health outcomes in the NE, NW and NC regions.

In the Southern part of the Nigeria, maternal mass-media exposure was observed to be a social determinant of neonatal survival. Our findings at least hint that mass-media exposure among women contributed to reduction of NMR in Southern Nigeria. This implies that more policies should be shifted towards implementing context-specific strategies in the states and regions. We believe that culturally appropriate reproductive, maternal and child health messages targeted to women in the hot-spots (Northern Nigeria) via mass-media campaigns will increase maternal demands for quality preventive and curative services for children. In the same manner, the states that reported better exposure to mass-media by women were found to have lower percentages of children whose mother had a previous birth within two years. Notably, previous birth interval and birth order were observed to be consistent across the regions. Although recent evidence indicates that short previous birth interval is a major driver of childhood mortality, the

conclusions have been mixed.[39–41] However, most studies emphasize “maternal depletion hypothesis” for the elevated childhood mortality risks arising from short preceding birth intervals.[41,42] In line with the idea of strong competitions among siblings, this study shows that children born later in birth order were likely to experience neonatal mortality. The impact of young maternal age at birth on neonatal mortality differed across the regions. In 21.6% of the states, mortalities were markedly elevated among states with high percentage of neonates delivered by adolescent mothers. The states were in the Northern Nigeria—Bauchi, Jigawa, Kano, Katsina, Kebbi, Plateau, Yobe and Zamfara. Further analysis revealed that in these 8 states that formed clusters of high adolescent mothers and high NMR, neonatal deaths were highest (83.9%) among women who were first married or in union during adolescence stage. Contrarily, NMR was low in 37.8% of the states with low percentage of neonates delivered by adolescent mothers—located in Southern Nigeria—Abia, Akwa Ibom, Anambra, Bayelsa, Cross-River, Delta, Ebonyi, Edo, Enugu, Kogi, Lagos, Ogun, Ondo and Rivers. In light of the reported findings of the Population Reference Bureau,[43] globally, there are about 58 million adolescent girls who have been married and experiencing health, and socio-economic crises. Often, this subpopulation is omitted in government policies and programmes.[43] According to UNICEF, child marriage is prevalent (44%) in the NW and NC regions of Nigeria—ranking 11th globally.[44,45] Evidence suggests that the key drivers of child marriages in Nigeria include inadequate girl-child education, political/economic ties, gender norms, poverty and violence against girls.[44] Our findings highlight the need for stakeholders to sensitize the communities in Nigeria on the 2003 Child Right’s Acts[46] which prohibits forced and child marriages.
What is more striking from this study is that the determinants of neonatal mortality were not uniform across the six geographical regions. Across the regions, the most important contributor to NMR were previous birth interval (NC), birth order (NE), multiple births (NW and SE), polygamy family (SS), and maternal exposure to mass-media (SW). This finding indicates that both broad and targeted strategies may be necessary to alleviate the NMR in Nigeria.

From our result, Nigeria requires impactful policy actions to address the social determinants of neonatal mortality because of the gender, urban-rural, state, and regional differences in the patterns of neonatal mortalities. To achieve this overarching goal will require engagement of the community members, decision and policy makers, and research institutions. More prominently, the states and regions are at different levels of progress towards achieving the SDG targets. It is crucial to set short-term and medium-term targets for reducing NMR at the national and subnational levels.

To our knowledge, this is the first known published literature that utilized spatial analysis and artificial neural network to cast new light to the urban-rural, state, and regional variations of social determinants of neonatal mortality in Nigeria. This study is in line with the aspirations of SDG-3—good health and wellbeing of children, SDG-5—promote gender equality, SDG-10—reduce inter(intra)-country inequality, and SDG-17—increase the availability of high-quality, timely and reliable data disaggregated by social determinants of health.[13] Despite the strengths, some limitations exist. Owing to the cross-sectional design of this study, causal arguments should not be made. Rather, the findings should be considered within the context of associations. Another major source of limitation is recall bias/ poor memory which could be due to self-reporting by women. This is not likely to markedly affect our observations because data were limited to live births five years prior to the survey commencement.

Overall, this study found considerable geographic variations in neonatal mortality and its determinants across the states and regions in Nigeria (majorly driven by young maternal age at birth, short birth interval, low maternal exposure to mass-media, and increasing birth order). This highlights the need for the country to develop and implement state and region-specific child survival initiatives to address the high rates of neonatal mortality, especially in the Northern Nigeria (i.e., hot-spot zones). Further studies are needed to explain why some states were in clusters of outliers (high-low and low-high), and reasons for varying patterns of gender inequity across the rural and urban areas.

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Chapter 10

Discussion and Conclusions

The purpose of this chapter is to summarize the main findings and describe their policy implications for maternal, newborn and child health programmes in Nigeria and other similar settings. The chapter draws from the theoretical and methodological underpinnings to guide interpretation of the research findings. This chapter concludes by identifying the potential areas of future research and proposes a knowledge translation plan.

10.1 Summary of findings and policy implications

The overview of the study objectives and key findings are summarized in Figure 10.1. The significant pathways of influence of social determinants of child survival are displayed in Figure 10.2. The policy implications/recommendations are summarized as an action-oriented framework—theory of change (Figure 10.3). The framework has strategic interventions for improving child survival in Nigeria (based on the findings of this thesis), while making assumptions and considering risks. The theory of change addresses the three pillars of SDG (i.e., age, gender, and geographic-based attainment of child survival) outlined in Figure 1.1. The interventions are to strengthen community-based structures to provide maternal and child health services (SDG-3), reduce discrimination against girl-child (SDG-5), and empower women across the communities, states and regions to demand healthcare services (SDG-10).

Through five inter-related but distinct studies, this thesis generated policy-relevant evidence to guide stakeholders in Nigeria and other similar settings on the appropriate interventions to make child-related SDG targets achievable by 2030. Driven primarily by the Mosley-Chen framework,[1] this thesis examined the current trend and progress of child survival, gender equality, and social inclusiveness—SDG targets 3, 5, and 10 for Nigeria, respectively. The key social determinants of mortalities across the early childhood stages (i.e., neonatal, post-neonatal and toddler/pre-school), and their contributions to the variation in childhood mortalities at the community level in Nigeria were assessed. Furthermore, this thesis examined the critical pathways through which social factors (at maternal, household and community levels) determine neonatal, infant and under-five mortalities in Nigeria. As the first 28 days of life is the most crucial period of early child's development,[2] this thesis focused on the patterns and determinants of geographical clustering of neonatal mortality at the state and regional levels in Nigeria, urban-rural disparity of sex-specific neonatal morality rates, and measured the gaps in SDG-3 target for neonatal mortality at the state and regional levels in Nigeria. For the first two studies, time series analyses of historical dataset[3] of annual under-five and neonatal mortality rates in Nigeria from 1960s to 2017 were performed. For the remaining three studies, the latest 2016/17 national representative data from Nigeria Multiple Indicator Cluster Survey[4] were analyzed.

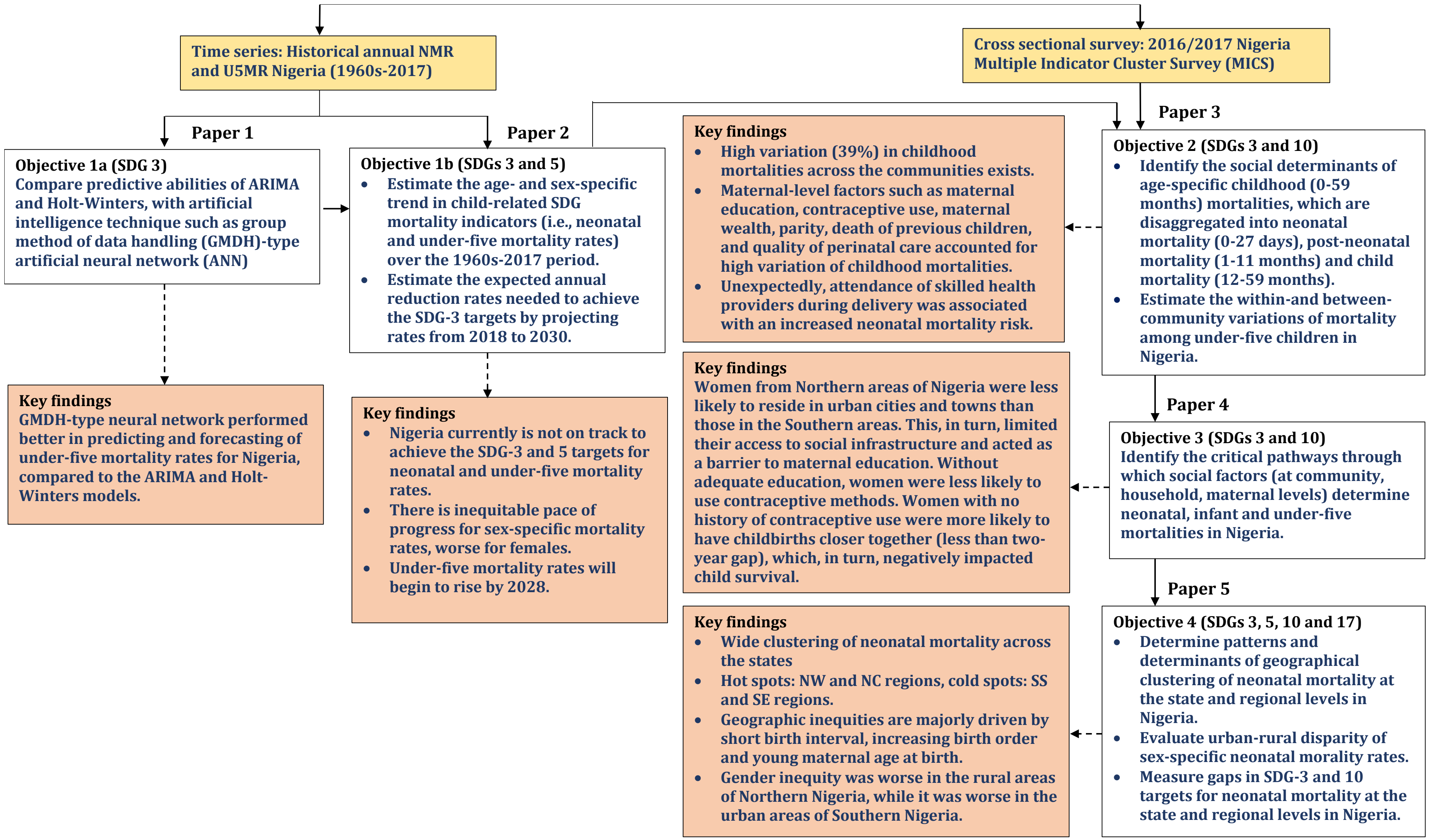

Figure 10.1: Summary and inter-connection of thesis papers (1-5), childhood mortality in Nigeria

The tragic loss of a child has huge emotional and economic costs for individual households and communities at large. Also, child survival is widely recognized as one of the key pillars of economic development and social equities. As an important element of surveillance, inaccurate mortality estimates have profound negative implications on healthcare planning, and subsequent monitoring and evaluation of newborn and child health programmes. Given the importance of creating sustainable future for the children, 44 out of the 232 (19%) global SDG indicators are directly related to children.[5]

Predictive abilities of time series methods

The resolutions of the Statistical Commission of General Assembly stressed the importance of continuous monitoring of countries' progress towards achieving sustainable developments by 2030.[6] In line with this resolution, this thesis began by evaluating different time series methods in order to identify the technique that could generate reliable childhood mortality estimates for Nigeria. Paper 1 (i.e., comparative analysis of the traditional statistical methods and artificial intelligence techniques—objective 1a) found evidence that artificial intelligence times series such as GMDH-type ANN provides more accurate forecasts of childhood mortality rates for Nigeria, because of its ability to reduce loss function, and fit non-linear data. The conventional statistical methods such as ARIMA and Holt-Winters exponential smoothing models, might not be suitable for modeling long term mortality trends because of the slow decay of autocorrelation process.[7,8]

Progress towards achieving child survival SDG targets in Nigeria

Based on the findings of paper 1, the second paper (objective 1b) used GMDH-type ANN to forecast age- and sex-specific mortality rates from 2018 to 2030. Paper 2 provides evidence for stakeholders to strengthen interventions/programmes for under-five and female children in Nigeria, to meet the child-related SDG targets by 2030. Considering the current annual rates of change in childhood mortalities, age- and sex-specific mortality rates will continue to decrease, although at slower rates. However, the rates will remain high by 2030. In 2030, the NMR and U5MR are forecasted to be 25.3 deaths per 1000 live births and 85.9 deaths per 1000 live births, respectively. The unmet gaps will be 13.3 deaths per 1000 live births for NMR, and 60.9 deaths per 1000 live births for U5MR. If the current age- and sex-specific mortality trends for under-five children continue, U5MR will start to increase by 2028. Also, female U5MR is decreasing at a slower rate than male U5MR. In 2030, the male and female mortality rates are forecasted to be 62.6 deaths per 1000 live births and 80.9 deaths per 1000 live births, respectively. Consistent with other studies,[(9,10)] this study supports gender equity for attainment of child survival targets. Addressing gender inequities in Nigeria entails providing supportive environments for girl-child education, reduce the rate at which girl-child drop out from school, improve health literacy, women's reproductive health, financial freedom, and autonomy. It is therefore necessary for the stakeholders to engage with the community leaders to promote gender equity in the Nigerian societies through active community mobilization and involvement.

Social determinants of childhood mortality in Nigeria

To understand the key social determinants of childhood mortalities and their varying roles at the different phases of early child's development, paper 3 (objective 2) took a deeper look into the compositional and contextual factors of community variations in child survival. Paper 3 shows evidence of community inequities in childhood mortalities, which can be attributed to socioeconomic disparities among women. The paper specifically indicated that 39% of variance in childhood mortalities were due to maternal-level factors such as maternal education, maternal wealth, contraceptive use, parity, death of previous children and quality of perinatal care. On the contrary, child-level factors had little effect on the heterogeneity of under-five mortalities across the Nigerian communities. This indicates that the risk of childhood mortality can be reduced by improving maternal living conditions and providing high-quality perinatal care. Contrary to the theoretical underpinning of this study, attendance of skilled health providers during delivery was associated with an increased neonatal mortality risk. This finding was unexpected given the clinical and public health importance of skilled health providers during deliveries. However, newer evidence in sub-Saharan Africa shows that deliveries by skilled health providers are associated with higher neonatal mortality risks.[(11)] This particular finding could be due to inability to control for the quality of services rendered by skilled birth attendants during deliveries, because MICS did not collect variables on quality of maternal and child care. Also, there is a possibility of under-reporting under-five mortalities by women who had no or unskilled birth attendants during delivery. Other plausible explanations are functioning referral systems that send the high-risk deliveries to health facilities to a greater extent, iatrogenic injuries, nosocomial infections, or poor quality of care overall that is posing a risk of children dying. This might be an indication that governments at all levels need to invest in human resources for maternal and child health services in order to reduce the vulnerability of newborns. Some authors have argued that many women in Africa and Asia—especially those with no/little education and poor income—have limited access to health facilities, making access to supervised deliveries by skilled personnel challenging.[(11–17)] Furthermore, many healthcare workers are not adequately trained to manage complicated labour (arising from delayed presentation of pregnant women for supervised deliveries at health facilities).[(11,12)] Other factors challenging the healthcare system are maldistribution of health facilities, insufficient manpower, inadequate neonatal resuscitation kits/incubators, and poor referral system.[(18–21)] Training and continuous mentoring with adequate supervision of skilled health workers and investing in health infrastructure should be ensured to improve the quality of perinatal care in Nigeria.

Of note, death of a previous child appears to be the strongest determinant of mortality across the three developmental stages. Also, short child spacing (i.e., children born closer together (<2 years gap)) seems to be a shared determinant of neonatal, post-neonatal and child (toddler/pre-schooler) mortalities. Based on this evidence, healthcare workers should maintain high index of suspicion for mortality risks in newborns delivered to mothers with death of a previous child and short birth interval. Screening of high-risk mothers should entail detailed history taking for previous deaths of under-five children. Also, through culturally appropriate messages, raising community awareness about child spacing is recommended. Considering that social determinants of mortality among under-five children were different across the neonatal, post-neonatal, and toddler/pre-school stages, targeted inventions are required.

Intervening in the pathways to childhood mortality in Nigeria

For programmatic purpose, paper 4 (objective 3) identified the specific chain of events that are responsible for high mortality rates among neonates, infants, and under-five children, with the hope of breaking the chain. The same pattern was observed for the three groups of children. Revisiting the theoretical framework for this thesis (Figure 2.2), the paths that are supported empirically are presented in Figure 10.2. The most prominent pathway is the one interlinking region with survival time for neonates, infants, and under-five children (as differentiated in

Figure 10.2). There is evidence to suggest that women from Northern region of Nigeria were more likely to reside in rural cities and towns than those in the Southern region. This, in turn, limited their access to social infrastructure and acted as a barrier to maternal education. Without adequate education, women were less likely to use contraceptive methods. Women with no history of contraceptive use were more likely to have childbirths closer together (less than two-year gap), which, in turn, negatively impacted child survival. The finding from this thesis is a further validation that mortality risk in under-five children is due to interplay of multilayered factors. Thus, it is important to implement targeted interventions, focusing on uneducated women (with no history of contraceptive use and child spacing <2 years) living in rural areas of Northern Nigeria. Also, given that the effect of maternal education on neonatal survival is mediated through maternal age at birth, special care should be given to neonates of teenage mothers. Importantly, intensified efforts are needed to reduce teenage pregnancies. As shown in Figure 10.2, children of never married or formerly married women were observed to have higher mortality risk through the mediating effects of none usage of contraceptives and short child spacing. Also, child-level factors such as birth order, child's sex, multiple gestation, and maternal age at birth are directly associated with child survival (see Figure 10.2). However, contrary to the theoretical underpinnings, the final model did not support association between child survival and maternal wealth index, frequency of ANC visits, delivery at health facilities, household water source, sanitation, indoor pollution, and skilled birth attendants during delivery.

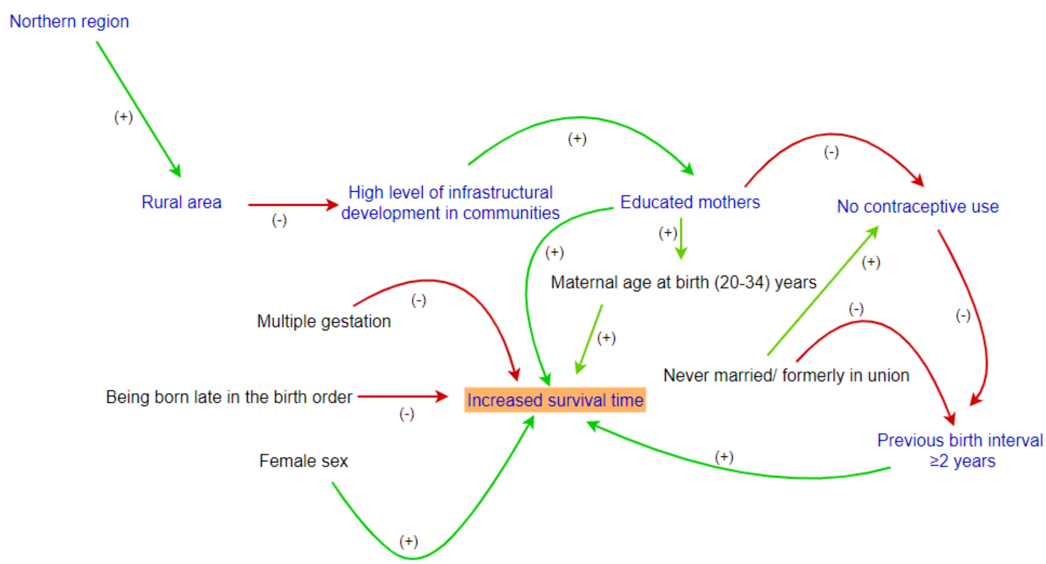

Figure 10.2: Pathways to child survival in Nigeria (Source: author)

Reducing regional inequities in neonatal mortality in Nigeria

The observed disparity in childhood mortality between Northern and Southern regions from paper 4 warranted further investigation to identify the states and regions that constitute the hot-spots and cold-spots. The unique addition of paper 5 (objective 4) is its focus on the social determinants of neonatal mortality across the regions. Also, gender inequity gaps in NMR, disaggregated by urban/rural residence across the 6 geographical regions were evaluated. The geospatial analysis indicates regional variations in neonatal morality. At a spatial distance of 407 km, five states (13.5%), mostly in NW region (Jigawa, Katsina, Kano, and Zamfara states), and to a lesser extent in NC region (Niger state) formed clusters of higher NMR—hotspots. Also, there are 2 states with higher NMR, adjacent to the states with lower NMR (high-low spatial outliers)—Benue state (NC region), and Imo state (SE region). It is also clear that gender inequity was worse in the rural areas of Northern Nigeria, while it was worse in the urban areas of Southern Nigeria. NMR was disproportionately higher among females in urban areas (except North-West and South-West regions). Conversely, male neonates had higher mortality risks in the rural areas for all the regions. From the multilayer perceptron neural networks, there were different drivers of the observed clustering across the regions. However, as noted in paper 5, children who were part of multiple gestation, born less than 2 years apart, young maternal age at birth, and delivered late in the birth order (fourth-born and above) were the top contributors of neonatal morality across the regions. To reduce geographical inequities, adequate monitoring of these high-risk neonates must be ensured.

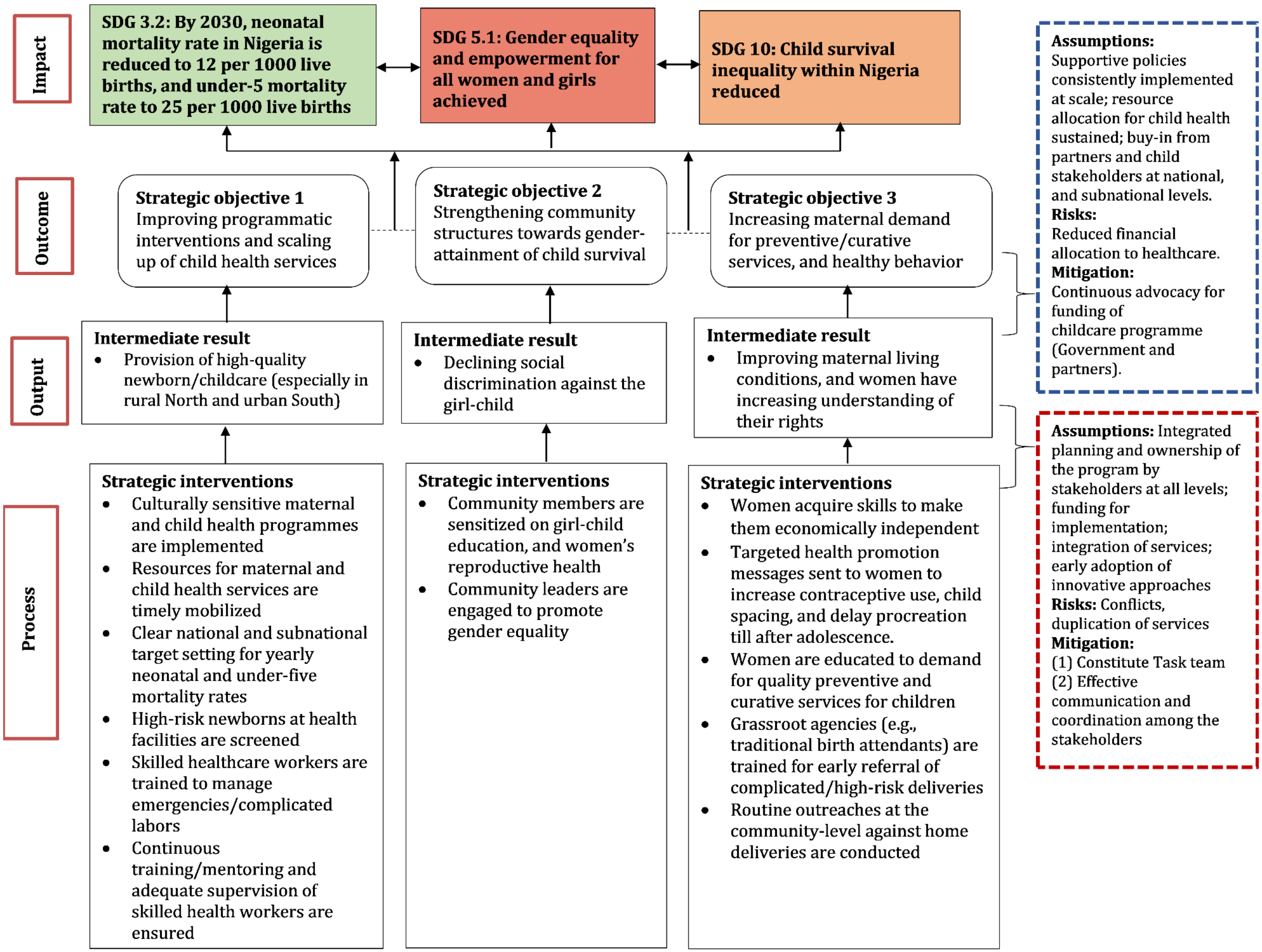

Figure 10.3: Theory of change (from papers 1-5) for child survival in Nigeria (Source: author)

10.2 Theoretical and methodological considerations

The strengths and limitations of the theoretical and methodological procedures of each paper have been discussed in their respective chapters. Here, the implications of the study design and analytical designs on the findings are summarized.

10.2.1 Internal validity

10.2.1.1 Study design

(i) **Dataset:** The two datasets analyzed (IGME and MICS) are robust. The datasets are generated through rigorous epidemiological processes which involved multidisciplinary collaboration of credible organizations—United Nations agencies and global experts.(2,22) With lack of reliable vital registration in most LMICs, these databases provide high quality data to monitor the country's performances on SDG indicators. To ensure cross-country comparison of MICS, quality control measures were undertaken.(22) It entails standardizing the research protocols, training of field workers, and pre-testing of survey questionnaires in 8 states that are distributed across the regions of Nigeria (i.e., Cross River, Enugu, Gombe, Lagos, Kaduna, Kano, Nasarawa and Oyo states). Also, data were captured through computer assisted interviewing platform (CASPI) and transmitted electronically to a central server with CSPro CAPI application version 5.0. Compared to the traditional data collection methods like paper-based questionnaires, CASPI minimized omission and skipping errors (i.e., instrument bias). Introduction of measurement error could have potentially affected all respondents within the survey and underestimated true exposure effects (i.e., non-differential misclassification), but it is not anticipated in this thesis.

(ii) **Statistical power/strength of association:** Inadequate statistical power could lead to failure to reject a null hypothesis in favor of a true alternative hypothesis (i.e., Type-I error). As noted in literature, statistical power could be extremely affected by low sample size, low incidence of outcome, strength of association between variables, and significance level.(23,24) Before data collection, MICS team ensured that the sample size is adequate to allow for sub-national analysis. Although the statistical power for MICS was not reported, statistical power is adequate to detect true association because of the observed narrow width of 95% confidence intervals. In addition, the strengths of association are strong.

(iii) **Temporality:** In reference to Bradford Hill's criteria of causality, temporality is an important point for inferring causality.[25] However, the limitations of the cross-sectional studies naturally include inability to establish temporality. The temporal sequence of events could not be established in this thesis because the outcomes (childhood mortalities) and the maternal/household-level factors were measured at the same time. It is therefore important to interpret the findings from this thesis as associations rather than causal relationships. As described in chapter 8, the possibility for reverse causality should be careful considered in the relationship between maternal age at birth and maternal education on child survival outcomes. For instance, no/low level of maternal education could be responsible for teen pregnancies and its associated poor survival outcomes because of their poor health seeking behavior. On the other hand, schooling is halted when teenagers become pregnant. However, the use of a theoretically-sound framework (i.e., Mosley-Chen framework), the author's programmatic knowledge and evidence from literature, in no doubt has partially addressed reverse causality through logical sequence of events. Overall, the path analysis underscores the influential roles of maternal education and adolescent sexual behaviors in reducing childhood mortalities. Further studies could consider longitudinal cohort studies to establish temporality.

(iv) **Information (measurement) bias**: A prominent limitation of cross-sectional study is recall bias, arising from self-reporting of deaths among under-five children. Mothers might not accurately report age at death. The somewhat transfer of deaths might be reflective of recall bias or poor memory. Another plausible explanation is that death of children is a sad event that most women may wish not to report as the culture forbids bringing back such hapless experience.[26] Hence, there is a tendency to underestimate the effect size if less age-specific mortalities are reported. To reduce the effects of recall bias/ poor memory, analyses were limited to live births preceding five years before the survey commencement. Furthermore, misclassification of skilled healthcare workers might have existed, given that a huge proportion (67%) of respondents had either no or little education. In line with a previous study in Kenya, Blanc et al[27] found that women with low level of education could hardly recall the cadre of healthcare workers that assisted them during delivery. From this perspective, one could argue that the unexpected positive association between the skilled health worker and neonatal mortality risks could be partly due to misclassification of cadre of healthcare workers. Given that the observed association fits with emerging evidence in LMICs and that the MICS field workers were trained to minimize such information bias, it did not appear that differential misclassification of cadres could have affected the biological plausibility of neonatal mortality risks.

(v) **Classification bias:** Household surveys are generally prone to misclassification between stillbirths and neonatal deaths because neonatal deaths are self-reported by mothers. Newborns that are alive shortly before delivery, otherwise known as term stillbirth (i.e., fetal death occurring between ≥37 weeks) are often misclassified as neonatal deaths. Misclassification errors could lead to overestimation of neonatal deaths. For this thesis, misclassification errors could not be established because MICS did not capture data on stillbirths. However, the extent of misclassification of neonatal death could not determined in this thesis.

10.2.1.2 Analytic design

(i) **Confounding:** In epidemiological research, confounding refers to the distortion of association between dependent and independent variables due to the influence of a third variable on both. The independent variables were treated as potential confounders. The selection of potential confounders was based on the available variables in the 2016/17 MICS dataset. The potential confounders were dealt with through stratification of age and gender (papers 1 and 2); geographical location (paper 5); and multivariate regression analyses (papers 3-5). Due to the secondary nature of the analysis, some potential confounders such as pregnancy complications, immunization history,[28,29] prematurity, birth weight,[30] HIV,[31] and food (in)security[32] were completely absent from the original dataset; hence, they could not be adjusted. Instead, the maternal wealth index was considered a reasonable proxy because these potential confounders are closely related with maternal education and wealth.[28–32] There could be residual confounding because of these possible confounders that were not collected and adjusted. Also, the variable on maternal access to post-natal care services was not selected in the 2016/2017 MICS dataset because more than 70% of its data were missing.

(ii) **Statistical rigor:** Statistical rigor is sometimes hard to achieve in epidemiological research.[33] While failure to achieve statistical rigor could lead to spurious associations that might be due to chance, it is important to minimize such errors through rigorous study design and analytic procedures. In this thesis, state-of-the-art quantitative research methods were applied to minimize statistical errors that could lead to formulation of ineffective child health policies during SDG-era in Nigeria. One limitation of aggregated data is ecological fallacy—erroneous deduction of inferences for individuals from group-level data. Due to the multilevel nature of MICS dataset, multilevel analysis was employed to prevent ecological fallacy. Besides, the multinomial regression approach is believed to reduce statistical error that could have occurred with binomial regression.

10.2.2 External validity

(i) Selection bias: One of the major strengths of this thesis is the use of large nationally representative sample size (29,786 under-five children) with high response rate (95%) and appropriate sampling weight, thus reducing non-response bias. Also, ascertainment bias and sampling bias were minimized because the survey was community-based and multi-stage stratified cluster sampling was used. With the study design, the distribution of the socioeconomic characteristics of the respondents is representative of the general population of women and children in the 37 states of Nigeria, hence making the findings generalizable to all communities in Nigeria. However, considering the persistent insurgencies in some states in the northeastern part of the country (i.e., Borno, Yobe and Adamawa), some communities were inaccessible for data collection.[22] Furthermore, exclusion of mothers who were younger than 15 years and older than 49 years during data collection is a potential source of selection bias because it is generally agreed that childhood mortality occurs more frequently at the extreme ages. However, it is unlikely that this would have affected both the effect size and degree of association as the population of mothers with under-five children in the two groups is negligible.

(ii) Survival bias: This study suffers from the same limitation of survival bias associated with survey data. Since, surviving mothers were interviewed for complete birth histories and lacked data from deceased mothers, the analysis might not be truly representative of mortality experience of children of deceased mothers if the socioeconomic characteristics differ in this group.

10.3 Conclusion and future research directions

This thesis demonstrates the application of interdisciplinary research methods and theories to advance current understanding of the social determinants of child survival in population health research. A clear message arising from this thesis is that Nigeria is currently not making progress towards achieving the child survival target of SDG-3, gender inequality target of SDG-5 and social inclusion target of SDG-10 by 2030. This thesis offers evidence that maternal level factors (such as maternal education, contraceptive use, maternal wealth, parity, death of previous children and quality of perinatal care) accounted for community variation in under-five mortalities, whereas state/regional clustering of neonatal mortality was majorly driven by young maternal age at birth, inaccessibility to mass-media, short birth interval and increasing birth order. This thesis provides evidence to guide policymakers in Nigeria on the appropriate interventions to make child-health related Sustainable Development Goals achievable by 2030. In addition, this thesis supports the social inclusion perspective and universal coverage of health services for all children (regardless of location and socioeconomic status of mothers) as emphasized in the SDGs, to tackle the barriers operating throughout different child's developmental stages.

Given the versality of artificial intelligence, future research should consider forecasting age- and sex-specific mortality rates for Nigeria with hybrid artificial neural networks. Due to lack of historical data on sex-disaggregated NMR, this thesis could not forecast long term NMR for male and female neonates, future studies should identify the trends and project sex-specific NMR. Also, it is important for future studies to examine the association between the cadre of skilled healthcare during delivery and neonatal mortality risk in Nigeria with community trials or qualitative research methods. Regarding the observed gender differences between urban and rural residences across the geographical regions, plurality of research methods is needed to give more insights into the complex sociocultural factors.

10.4 Knowledge translation

This study utilized end-of-project knowledge translation (KT) approach to disseminate the study findings. The goal is to inform decision makers in the field of maternal and child health by sharing the findings from this thesis to guide health policies and practices geared towards improving child survival in Nigeria and other resource-limited countries. The plan entails traditional methods like publishing in impactful peer-reviewed journals, and conference presentations. Also, the plan will include innovative translational activities such as developing tool kits for screening for social determinants of child survival and learning curricula/modules on child survival for resource-limited countries. The study findings have been presented in the following conferences: 3rd Annual People Around the World Conference, Saskatoon in February 6-7, 2020; 19th Annual Fall Symposium, Saskatchewan Epidemiology Association (SEA), Regina in October 8, 2019 and 60th Anniversary Celebration of Department of Community Health and Epidemiology, University of Saskatchewan, Saskatoon in October 25, 2019. The first three papers are currently undergoing external peer-reviewing in BMC Medical Research Methodology, BMJ Open, and BMC Public Health, respectively. Also, a white paper will be sent to the Nigerian government through the UNICEF MICS team. In collaboration with the National Task Force on Maternal and Child Health in Nigeria, knowledge translation will occur through capacity-building workshops and seminars for researchers, stakeholders, and community-based organizations. In addition, the key findings will be published in *"The Conversation"* and leading Nigerian newspapers. The findings will also be summarized inform of infographics to increase public awareness of the social determinants of child survival in Nigeria. The proposed strategies will be shared with the stakeholders to identify their preferences and ensure their active involvement. As a crucial step to ensuring active community participation, gatekeepers (e.g., women leaders, religious leaders, traditional leaders, etc.) will be consulted to set the stage for knowledge translation in the communities.

10.5 References

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Appendix

Appendix A: Overview of the manuscripts

Manuscript	Title	Objective	Dataset	Study design	Outcome	Statistical method	Unit of analysis	Dissemination
1	Time series prediction of under-five mortality rates for Nigeria: comparative analysis of artificial neural networks, Holt-Winters exponential smoothing and autoregressive integrated moving average models	Compare predictive abilities of ARIMA and Holt-Winters, with artificial intelligence technique such as group method of data handling (GMDH)-type artificial neural network (ANN)	Historical data of yearly under-five mortality rates for 1964-2017	Time-series	Under-five mortality rates	ARIMA regression, Holt-Winters exponential smoothing and GMDH-type neural nets	Country	
2	Changing patterns of gender inequities in childhood mortalities during the Sustainable Development Goals era in Nigeria: Findings from an artificial neural network analysis	(1) Estimate the age- and sex-specific mortality trends in child-related SDG indicators (i.e., neonatal and under-five mortality rates) over the 1960s-2017 period, and (2) estimate the expected annual reduction rates needed to achieve the SDG-3 targets	Historical data of yearly age-specific childhood mortality rates (neonatal and under-five), and sex-specific under-five mortality rates	Time-series	Neonatal mortality and under-five mortality rates	Group method of data handling type (GMDH-type) artificial neural network (ANN)	Country	1) Oral presentation: a. 3rd Annual People Around the World Conference, Saskatoon. Feb. 6-7, 2020 2) Poster presentation: a. 19th Annual Fall Symposium, Saskatchewan Epidemiology Association (SEA), Regina. Oct 8, 2019. b. 60th Anniversary Celebration of Department of Community Health and Epidemiology, University of Saskatchewan, Saskatoon. Oct 25, 2019.

		by projecting rates from 2018 to 2030						
3	Inequities in child survival in Nigerian communities during the Sustainable Development Goal era: Insights from analysis of 2016/2017 Multiple Indicator Cluster Survey	Identify the social determinants of age-specific childhood mortalities, which are disaggregated into neonatal mortality, post-neonatal mortality, and child mortality, and estimate the within- and between-community variations of mortality among under-five children in Nigeria	Nigeria Multiple Indicator Cluster Survey, 2016/2017	Cross-sectional	Neonatal, post-neonatal and child mortalities	Multilevel multinomial logistic regression	Child and community	1.) Oral presentation: a. 3rd Annual People Around the World Conference, Saskatoon. Feb. 6-7, 2020 2.) Poster presentation: a. 19th Annual Fall Symposium, Saskatchewan Epidemiology Association (SEA), Regina. Oct 8, 2019. b. 60th Anniversary Celebration of Department of Community Health and Epidemiology, University of Saskatchewan. Saskatoon. Oct 25, 2019. c. Canadian Association for Health Services and Policy Research (CAHSPR) Annual Conference, Saskatoon. May 26-29, 2020
4	Disentangling pathways to child survival in Nigeria during the Sustainable Development Goals era: a path analysis with accelerated failure time.	Identify the critical pathways through which social factors (at community, household, maternal levels) determine neonatal, infant and under-five mortalities in Nigeria	Nigeria Multiple Indicator Cluster Survey, 2016/2017	Cross-sectional	Neonatal, infant and under-five mortalities	Hierarchical path analysis with accelerated failure time (lognormal)	Child	1.) Oral presentation: a. 3rd Annual People Around the World Conference, Saskatoon. Feb. 6-7, 2020 2.) Poster presentation: a. 19th Annual Fall Symposium, Saskatchewan Epidemiology Association (SEA), Regina. Oct 8, 2019. b. 60th Anniversary Celebration of Department of Community Health and Epidemiology, University of Saskatchewan. Saskatoon. Oct 25, 2019.

								c. Canadian Association for Health Services and Policy Research (CAHSPR) Annual Conference, Saskatoon. May 26-29, 2020
5	Geographic inequities in neonatal survival in Nigeria: a cross-sectional evidence from spatial and artificial neural network analyses	Determine patterns and determinants of geographical clustering, urban-rural disparity of sex-specific neonatal morality rates, and measure gaps in SDG-3 target for neonatal mortality at the state and regional levels in Nigeria	Nigeria Multiple Indicator Cluster Survey, 2016/2017	Cross-sectional	Neonatal mortality	Multilayer perceptron (MLP) neural network, spatial analysis	Child, state, region	1) Oral presentation: a. 3rd Annual People Around the World Conference, Saskatoon. Feb. 6-7, 2020 2) Poster presentation: a. 19th Annual Fall Symposium, Saskatchewan Epidemiology Association (SEA), Regina. Oct 8, 2019. b. 60th Anniversary Celebration of Department of Community Health and Epidemiology, University of Saskatchewan, Saskatoon. Oct 25, 2019. c. Canadian Association for Health Services and Policy Research (CAHSPR) Annual Conference, Saskatoon. May 26-29, 2020

Appendix B: Supplementary material for chapter 2

Appendix B.1: Appraisal of literature in child survival

Table B1: Appraisal of selected studies in Nigeria (2008-2018)

Author (Year of publication)	Country	Data source (Study period)	Study design and analysis	Sample size	Level of analysis	Focus	Findings	Gaps
Adetoro (2014)	Nigeria (national)	Demographic and Health Survey (DHS) 2008	Cross-sectional Binary logistic regression models	16,065 women who delivered at least a live birth within 5 years before the survey	Child-level	Predictors of under-5 mortality	Maternal illiteracy, professional occupation, high mothers' wealth index, not having first child at age 19 years and urban residence significantly reduced the odds of child mortality	Key child, maternal, household and community level factors were not considered. No consideration for hierarchical study design and sampling weight Selection bias by redistricting analysis to currently married women, making generalization challenging
Abu (2015)	Benue state (sub-national)	Community survey	Mixed methods (cross sectional, focus group discussion and key informant interview	1,500 ever married women aged 15 to 49 who had at	Individual level	Prevalence, the socioeconomic and demographic determinants of	Rural residence is a significant factor for	Not representative of Nigerian population No consideration for child and community level factors

			Probit regression model	least 1 delivery within 5 years before survey		under-five mortality	under-5 mortality	
Akinwande (2016)	Zaria (sub-national)	Retrospective hospital data (2000-2010)	Cross-sectional Regression and correlation	24078 deliveries	Not stated	Relationship between Infant and under-5 mortality, and delivery rates	Under-5 mortality correlated with delivery rates	Samples were not representative (i.e. from tertiary hospital) Limited focused on relationship between infant and under-5 mortality, and delivery rates, no determinants were examined
Chukwu (2015)	Nigeria (national)	DHS (2008)	Cross sectional Cox Proportional hazard model and Cox Frailty model	Not stated	Individual level	Demographic characteristics responsible for under-five mortality	Mothers aged <20 years and no maternal educational status had higher hazard ratio	Community level determinants were not considered No adjustment for the nested nature of data
Dahiru (2018)	Zaria (sub-national)	Community based study (2014)	Indirect estimation (Brass)	638 women who had previous live births, regardless child survival status	State-level	Under-5 estimates	Under-5 mortality estimates were high	Violation of Brass' assumptions Determinants were not examined
Ezeh (2015)	Nigeria (National)	Pooled DHS data for 2003, 2008, 2013	Cross-sectional Cox-regression models (accounted for cluster sampling survey and applied sampling weight)	63,844 singleton live-births of the most recent birth within 5	Adjusted for individual-level, household-level and	Factors associated with post-natal, infant, child and under-5 mortality	Maternal illiteracy, rural residence and poor household	Restricted analysis to singleton and most recent live births (selection bias). Only household wealth index was considered as household factor

				years before survey	community level factors with complex cluster sample survey commands		wealth index were associated with mortality across the 4 age groups.	and major community level factors were not considered.
Adewuyi (2017)	Nigeria (national)	DHS 2013	Cross-sectional Multivariate logistic regression with complex survey commands	30,384 singleton live-births of 23,127 women within 5 years before survey	Not specified	Rural–urban differences in infant mortality rates (IMRs) and the associated risk factors	Rural residence is a predictor of infant mortality	The study sample is not representative because it was limited to women aged 20-35 years. Restricted the scope of the study to individual factors (socioeconomic, biodemographic and heath behavioral patterns). No household and community level factors were considered.
Gayawan (2015)	Nigeria (national)	DHS 2008	Spatial analysis of mortality index geographically weighted regression	104,808 live births of 23,751 women aged 15-49 years, within 5 years before survey date	State (district)-level	Spatially varying relationships of determinants of child mortality	maternal education, household headship, household wealth index, and toilet facilities were significant determinants of child mortality	Child- and community level factors were not included. Child mortality was not defined

Uthman (2012)	Nigeria (national)	DHS 2008	Life table Control chart Spatial analysis (spatial autocorrelation)	28,647 live births within 5 years before survey	State-level	Variation in under-5 mortality	Wide variation of under-5 mortality	Determinants of under-5 mortality were not examined
Adeolu (2016)	Nigeria (national)	DHS 2013	Chi-square Logistic regression	20,192 currently married women aged 15-49 years, who had live births within 5 years before survey start date	Maternal level	Household's environmental, socio-economic characteristics, maternal demographic and their effect on child mortality	No maternal education and unimproved toilet were significantly associated with high under-5 mortality	Selection bias arising from restricting analysis to currently married women. Intra-clustering effect due to the hierarchical study design was not accounted for. Child-related and community level factors were not examined.
Antai (2010)	Nigeria (national)	DHS 2003	Cross sectional Multilevel logistic regression	2118 live births of 1350 women within 5 years prior to survey, and living in urban areas	Individual and community level	Impact of urban population growth and socioeconomic disadvantage on under-5 mortality	Under-5 mortality was associated with urban area disadvantage	Findings could not be generalized because analysis was restricted to urban areas Key household and community level factors were not considered
Adebowale (2017)	Nigeria (national)	DHS 2013	Cross sectional Chi square Cox-proportional hazard Brass mortality estimation	Most recent delivery of 18,516 women of reproductive age who had given birth in the past 5 years prior the survey	Individual-level	Relationship between housing materials and under-5 mortality	Significant determinants were inadequate and moderate housing materials, male gender, low birth	No adjustment was made for the nested nature of data

							weight, rural residence	
Izugbara (2015)	Nigeria (national)	DHS 2008	Cross sectional Logistic regression	104,808 live births of 33,385 women aged 15-49 years, within 5 years before survey date	individual level	Relationship between spousal age-related factors for neonatal mortality	Spousal age difference greater than 15 years was associated with higher neonatal mortality	Although, multilevel was stated in the title, there was no indication that hierarchical study design and sampling weights were considered. Major child, maternal, household and community level factors were not considered.
Izugbara (2015)	Nigeria (national)	DHS 2008	Cross sectional Multivariate multilevel logistic regression	104,808 live births of 33,385 women aged 15-49 years, within 5 years before survey date	Individual, household and community-level	Association between household-level variables and under-5 mortality	The significant determinants of under-5 mortality were: male gender, no parental education, male household headship and older adults, living in houses built from earth/ sand, rural residence, low wealth index,	Although the study examined child, maternal, household and community predictors, key household level factors such as access to clean water, improved sanitation and cooking fuel were not considered.
Morakinyo (2017)	Nigeria (national)	DHS (2003-2013)	Cross sectional Life table Pearson Chi-square	66,158 live births within	Child-level	Trends and drivers	Significant predictors	Although sampling weights were applied, it was not clear

			Probit regression	5 years before the survey.		of neonatal mortality rate, infant mortality rate, and under-5 mortality rate	were maternal age, mothers' education, place of residence, child's sex, birth interval, weight at birth, skill of birth attendant, delivery by caesarean section	whether hierarchical study design was accounted for. Community level factors were not considered
Adedini (2014)	Nigeria (national)	DHS 2008	Cross sectional Multilevel Cox proportional hazard regression	28,647 live births of 18,028 women aged 15-49 years, within 5 years before survey date	Community and individual levels	Regional variations in infant and child (1-4 years) mortality effects of individual- and community-level characteristics on infant/child mortality	Mothers residing in communities with higher proportion of hospital deliveries and at least secondary education experienced lower infant/child mortality	Household level factors were not considered
Antai (2009)	Nigeria	DHS 2003	Cross sectional Cox proportional hazard regression	6029 live births of 7620 women aged 15-49 years, within 5	Individual	Role of religion in under-five	Maternal affiliation to traditional indigenous religion is significantly	Limited focused on religion Nested nature was not considered

				years before survey date			associated with increased under-five mortality	

Table B2: Appraisal of selected studies in multi-country (2008-2018)

Author (Year of publication)	**Country**	**Data source (Study period)**	**Study design and analysis**	**Sample size**	**Level of analysis**	**Focus**	**Findings**	**Gaps**
Costa (2017)	20 LMICs (including Nigeria)	60 DHS (2005-2014)	Cross sectional B-spline regression ANOVA	Not stated	Country-level	Determined excess female under-five mortality	Varying excess female under-5 mortality rate was observed	Ecological fallacy
Beatriz (2018)	30 sub-Saharan Countries (including Nigeria)	Latest DHS and World Bank Data; 2010-2015	Ecological study Multilevel logistic regression models	339,028 live births of 411,054 women in the 5 years before the survey	Individual and country-level	Urban-rural disparity in under-5 mortality	At country level, rapid urban population growth and slow economic growth had significant impact on under-5 mortality between urban and rural	Varying definition of urban in countries which could lead to misclassification of the dichotomous variable. Limited focus (urban-rural disparities) Key child, maternal, household and community level factors were not considered. Ecological fallacy
Harttgen (2015)	25 sub-Saharan Countries	62 DHS (1990-2011)	Cross-sectional study with multistage cluster sampling	315,721 live births of women	Country- and region level	Relationship between child	Household's economic well-being, mother's education	Ecological fallacy Key child, maternal, household and community level

	(including Nigeria)		Multilevel structured additive regression within Bayesian Framework	aged 15-49 within 5 years before the survey.		mortality and undernutrition	and age, geographical regions strongly influence child mortality risk	factors were not considered.
Finlay (2011)	55 low- and middle-income countries (including Nigeria)	118 Demographic and Health Surveys (1990-2008)	Cross-sectional study Modified Poisson regression model	176,583 first live births of women aged 12-35 years, within 12-60 months prior to survey	Country-level	Association between maternal age at first birth and infant mortality, stunting, underweight, wasting, diarrhea and anemia	The first-born children of adolescent mothers were most vulnerable to infant mortality compared to other age groups	Regression models were not weighted Most child, maternal, household and community level factors were not considered Findings could not be extended to women aged >35 years Underestimation of effect size by restricting analysis to first live births Ecological fallacy
Van de Poel (2009)	6 francophone Central and West African countries	6 DHS (1995-2004)	Cross sectional Probit regression	Not stated	Household and community-level	Differences in the distributions of factors that determine infant mortality	Urban residence, safe drinking water, electricity and improved housing condition significantly reduced infant mortality	Although not clearly stated, it was assumed that it was a multilevel analysis Child-level factors were not considered Not generalizable to English-speaking African countries such as Nigeria
Sartorius (2014)	192 countries (including Nigeria)	World Bank Development Indicator database (1990-2011)	Ecological analysis Spatial clustering Robust generalized linear negative	Not stated	Country-level	Predictors of infant mortality	High clustering of infant mortality in sub-Saharan Africa and Asia Maternal mortality, lack of improved water and sanitation	Key determinants were not considered. Ecological fallacy

			binomial regression model				and female illiteracy were significantly attributed to high infant mortality	
Doku (2017)	57 LMICs (including Nigeria)	Pooled DHS (2005-2015)	Cross sectional Cox proportional hazards multivariable regression models meta-regression analysis	464,728 live births of women aged 15-49 years within 3 years preceding the survey	Country-level	Association between attendance for ANC and survival of neonates	Countries with lower neonatal mortality had increased ANC visits	Limited focus on ANC visits Ecological fallacy
Kipp (2016)	46 African Countries (including Nigeria)	World Bank data and DHS (2000 and 2013)	Ecological study	Not stated	Country-level	Association between health, economic/ social factors and reduction of under-five mortality	increasing health expenditure relative to gross domestic product, decreasing maternal mortality ratio, increasing coverage of treatment for acute respiratory infection were associated with rapid reduction of under-5 mortality	Key child, maternal, household and community level factors were not considered. Ecological fallacy

Table B3: Appraisal of selected studies from other studies (2008-2018)

Author (Year of publication)	Country	Data source (Study period)	Study design and analysis	Sample size	Level of analysis	Focus	Findings	Gaps
Mugo (2018)	South Sudan	MICS (2010)	Cross sectional logistic regression generalized linear latent and mixed models with the logit link and binomial family that adjusted for cluster and survey weights	8125 singleton live births of mothers aged 15-49 years, within 5 years prior survey	Adjusted for individual-level, household-level and community level factors	Determinants of neonatal, infant and under-five mortality in a war-affected country	Previous death of child, urban residence and unimproved water source were associated with increased neonatal, infant and under-5 mortality	Restricted analysis to war-torn country, singleton and ever-married mothers, hence making generalization challenging
Gebretsadi (2016)	High mortality regions of Ethiopia	DHS (2011)	cross sectional multivariable Cox proportional regression models	2097 live births of 16,515 mothers aged 15-49 years, within 5 years prior survey	Individual level	Major risk demographic, socioeconomic, and environmental factors of under-five mortality	Preceding birth interval of ≥2 years, breastfed children were associated with lower under-5 mortality risk	Selection bias (high mortality regions) Hierarchical study design was not accounted for
Bhowmik (2016)	Bangladesh	DHS (2007)	Cross-sectional Logistic regression and multiple classification (to rank the predictors)	2,132 under 5 deaths after live births that were 20 years preceding the survey date	Individual-level	Socio-demographic determinants of childhood mortality at neonatal, post-neonatal, and post-infant period	Neonatal and child mortality: biological factors of children were ranked first as the significant groups of predictors, regional settings were ranked second, and parents' socio-economic status were 3rd.	Selection bias by limiting analysis to ever-married women and only dead children High propensity for recall bias Hierarchical study design was not accounted for. The study did not address the key household and there

							Post-neonatal mortality: Mother's education and household's environment were the significant predictors.	were no community-level factors
Khan (2017)	Bangladesh	Pooled DHS (2007, 2011, 2014)	Cross sectional Cox's proportional hazards models with community and mother level random effects (or frailty models)	Sample size was not stated, mothers were ever-married women at reproductive ages	Maternal and community levels	To identify the socioeconomic and demographic factors associated with mortality in children aged less than 5 years	male gender, children from mothers aged <25 years, father aged <26, no maternal education, birth interval of ≤24 months, unemployed mothers were significantly associated with under-5 mortality	Key household and community level factors (i.e. infrastructural development, sanitation, clean water, access to maternal care) were not considered. Selective bias by limiting analysis to ever-married women
Kusneniwar (2013)	Rural Andhra Pradesh (India)	REACH project (longitudinal data) and SHARE INDIA project (cross-sectional survey-2008-09)	Multimethod (longitudinal and cross-sectional) Longitudinal (Pearson correlation and trend analysis) Cross-sectional (univariate and multivariate logistic regression)	Not clearly stated	Individual-level	Determinants of infant mortality	Significant determinants of infant mortality were education, household economic status, access to safe drinking water and sanitation facility and use of clean cooking fuel emerged as significant	Study findings were not generalizable The sample size was not clearly stated Eligibility criteria were unknown Influence of community level factors were not determined
Helova (2017)	Pakistan	DHS (2012-2013)	Cross-sectional multistage cluster sampling	7399 live births of women (most recent)	Individual and community level	Association between individual and community	Lower odds observed for 24 months pregnancy	Underestimation of effect size by restricting analysis to most recent births.

			Multivariate, multilevel logistic regression	aged 15-49 years in the last 5 years		factors, and neonatal, infant and under-5 mortality	interval, higher household wealth Increased odds: Employed mothers, consanguineous marriages (for infant and under-5), poor, rural, low education	key household level factors such as access to clean water, improved sanitation and cooking fuel were not considered.
Kassar (2013)	Maceió, (Brazil)	Cases (all infants who died before 28 days of life) were selected from Mortality Information System Control (survivors during the same period) were selected from Information System on Live Births	Case-control Logistic regression	136 cases and 272 controls. Controls were randomly selected	Individual-level (child)	Determinants of neonatal death with emphasis on health care during pregnancy, childbirth and reproductive history	Significant predictors of neonatal mortality were: maternal history of previous infant deaths, hospitalization during pregnancy, inadequate prenatal care, lack of ultrasound examination during prenatal care, transfer of the newborn to another unit after birth, admittance of the newborn at the intensive care unit (ICU), and low birth weight, small family size and not having children younger than five years	No household and community level factors were examined Generalizability is challenging.
Kavitha (2015)	India	National Family Health	Cross sectional Logistic regression	Sample size was not stated but	Child-level	Effect of young maternal age on size of the baby	infant mortality was higher among	Hierarchical study design and sampling

		Survey (NFHS)-3		analyzed women aged 15-29 years who had live births within 5 years before survey dates		at birth and infant loss by place of residence	adolescents than adult women in urban areas	weights were not considered. Adequacy of sample size was unknown. Cannot be generalized to women >29 years. Child, household and community-level factors were not considered.
Abir (2015)	Bangladesh	Pooled DHS (2004-2011)	Cross sectional Multilevel regression (the type regression was not specified)	most recent 16722 singleton live births of women aged 15-49 years who had deliveries within 3 years before survey	Not clear	To determine factors associated with mortality neonatal, postnatal, infant, child mortality	Contraceptive use, having children aged ≥ 3 years, mothers not having previous death of a siblings were associated with lower early child mortality.	Community-level factors were not considered Selection bias (restricted analysis to ever-married women, singleton children, and most recent birth)
Naz (2017)	Pakistan	DHS (2013)	Cross sectional Multilevel logistic regression	11,507 singleton live-births of 13,558 eligible women of reproductive age of 15–49 years	Not clear	Association between housing air pollution and under-five mortality	Polluting fuel and not breasting were associated with neonatal, post neonatal and under-5 mortality	Focus was on breast feeding and indoor pollution

Appendix C: Supplementary material for chapter 4

Appendix C.1: Ethical approval certificates

Letter C1: UNICEF permission to use MICS dataset

REPLY REPLY ALL FORWARD ...

noreply.unicef.mics@gmail.com
Mon 12/02/2018 13:28

Mark as unread

To: Adeyinka, Daniel;

• You forwarded this message on 16/02/2018 13:50.

Action Items

DEAR DANIEL,

Thank you for requesting to use the MICS dataset(s). You have been granted access.

The data may not be used for purposes other than those expressed in the application form and may not be redistributed or passed on to others in any form.

Please log into the MICS website using the email and password you provided during registration and download the dataset(s) on survey page.

We would appreciate if you would share your research findings with us – please email us at mics@unicef.org.

Best regards,

UNICEF MICS Team

Letter C2: Certificate of exemption

UNIVERSITY OF SASKATCHEWAN

To:	Nazeem Muhajarine, Community Health and Epidemiology
Student:	Daniel Adedayo Adeyinka, Community Health and Epidemiology
Date:	February 26, 2019
RE:	Behavioural Ethics Application ID 904

Thank you for submitting your project entitled: "Revisiting the Barriers to Child Survival: Progress, Challenges, and Opportunities for Achieving Sustainable Development Goal 3 in Nigeria". This project meets the requirements for exemption status as per **Article 2.2 of the Tri-Council Policy Statement (TCPS): Ethical Conduct for Research Involving Humans, December 2014**, which states *"Research that relies exclusively on publicly available information does not require REB review when:*

(a) the information is legally accessible to the public and appropriately protected by law; or

(b) the information is publicly accessible and there is no reasonable expectation of privacy."

It should be noted that though your project is exempt of ethics review, your project should be conducted in an ethical manner (i.e. in accordance with the information that you submitted). It should also be noted that any deviation from the original methodology and/or research question should be brought to the attention of the Behavioural Research Ethics Board for further review.

Digitally Approved by Vivian Ramsden, Acting Chair
Behavioural Research Ethics Board
University of Saskatchewan

Appendix D: Supplementary material for chapter 6

Appendix D.1: Supplementary Tables

Table D1: Projected under-five and neonatal mortality rates for Nigeria, 2018-2030 (obtained using GMDH-type Artificial Neural Network analysis)

	Under-five mortality rate (per 1000 live births) (95% prediction interval)			Neonatal mortality rate (per 1000 live births) (95% prediction interval)
Year	Overall	Male	Female	Overall
2018	96.9 (96.7-97.1)	102.3 (101.9-102.6)	90.7 (90.5-90.8)	32.3 (32.1-32.4)
2019	93.4 (93.2-93.6)	98.4 (98.0-98.7)	87.7 (87.6-87.9)	31.7 (31.5-31.8)
2020	89.7 (89.5-89.9)	94.4 (94.1-94.6)	85.0 (84.9-85.2)	31.1 (31.0-31.3)
2021	86.6 (86.4-86.8)	90.5 (90.1-90.8)	82.6 (82.4-82.7)	30.6 (30.4-30.7)
2022	83.2 (83.0-83.4)	86.1 (85.7-86.4)	80.2 (80.1-80.4)	30.1 (29.9-30.3)
2023	79.5 (79.3-79.7)	82.5 (82.1-82.8)	78.3 (78.1-78.4)	29.1 (28.9-29.3)
2024	78.7 (78.5-78.2)	79.2 (78.8-79.5)	76.6 (76.4-76.7)	29.4 (29.2-29.6)
2025	76.0 (75.8-76.2)	74.0 (73.6-74.3)	75.5 (75.4-75.6)	28.2 (28.0-28.4)
2026	77.1 (76.9-77.3)	68.3 (68.0-68.7)	75.1 (74.9-75.2)	27.5 (27.3-27.7)
2027	73.5 (73.3-73.6)	62.4 (62.1-62.8)	75.6 (75.5-75.8)	21.9 (21.8-221)
2028	58.2 (58.0-58.4)	59.9 (59.6.4-60.3)	76.4 (76.3-76.6)	22.6 (22.4-22.8)
2029	72.4 (72.2-72.5)	54.2 (53.9-54.6)	80.5 (80.4-80.7)	30.7 (30.5-30.9)
2030	85.9 (85.7-86.1)	62.6 (62.2-62.9)	80.9 (80.7-81.0)	25.3 (25.1-25.5)
RMSE	0.09	0.17	0.07	0.09
MAE	0.06	0.14	0.05	0.07
Accuracy	93.9%	81.3%	93.8%	100%

RMSE: root mean squared errors, MAE: mean absolute errors

Table D2: Projected relative and absolute gender inequities of under-five mortality rates, Nigeria

Year	Relative inequity (Male: Female)	Absolute inequity (Male-Female)
2018	1.13	11.59
2019	1.12	10.67
2020	1.11	9.42
2021	1.10	7.89
2022	1.07	5.82
2023	1.05	4.20
2024	1.03	2.63
2025	0.98	-1.54
2026	0.91	-6.77
2027	0.83	-13.24
2028	0.78	-16.52
2029	0.67	-26.30
2030	0.77	-18.32

Appendix D.2: Supplementary Figures

Figure D1: Historical under-five mortality rates (U5MR) (1964-2017) and neonatal mortality rate (NMR) (1967-2017), Nigeria

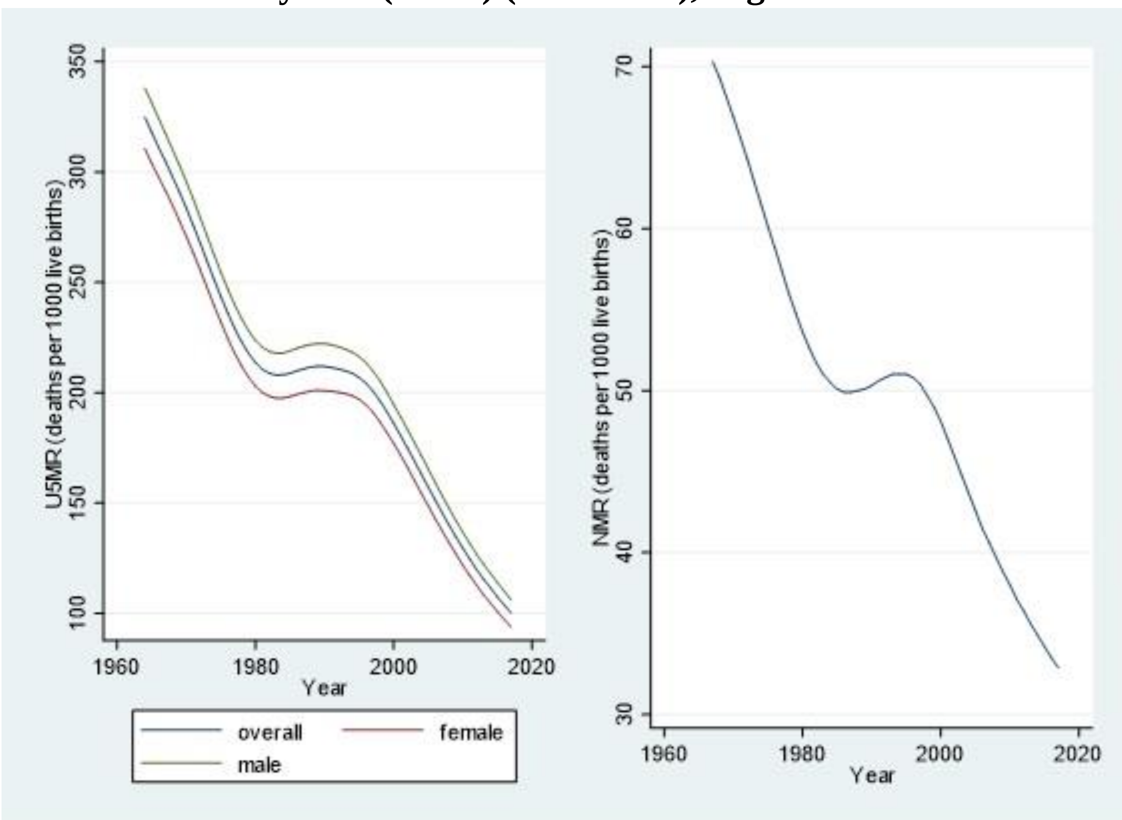
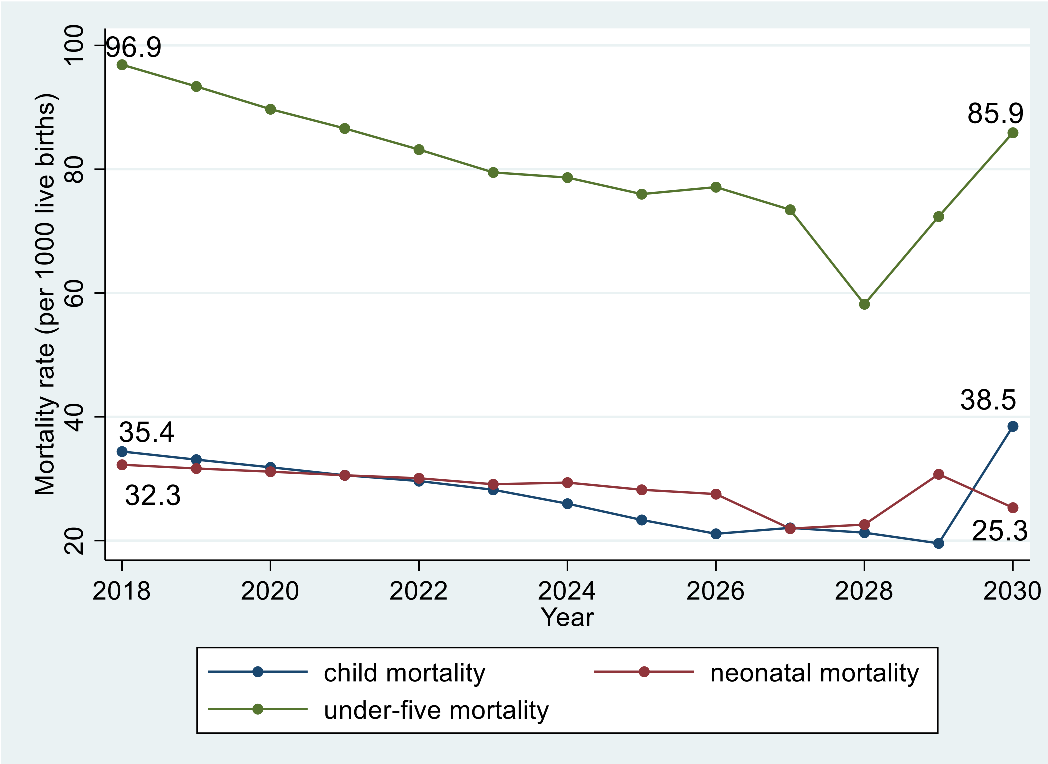
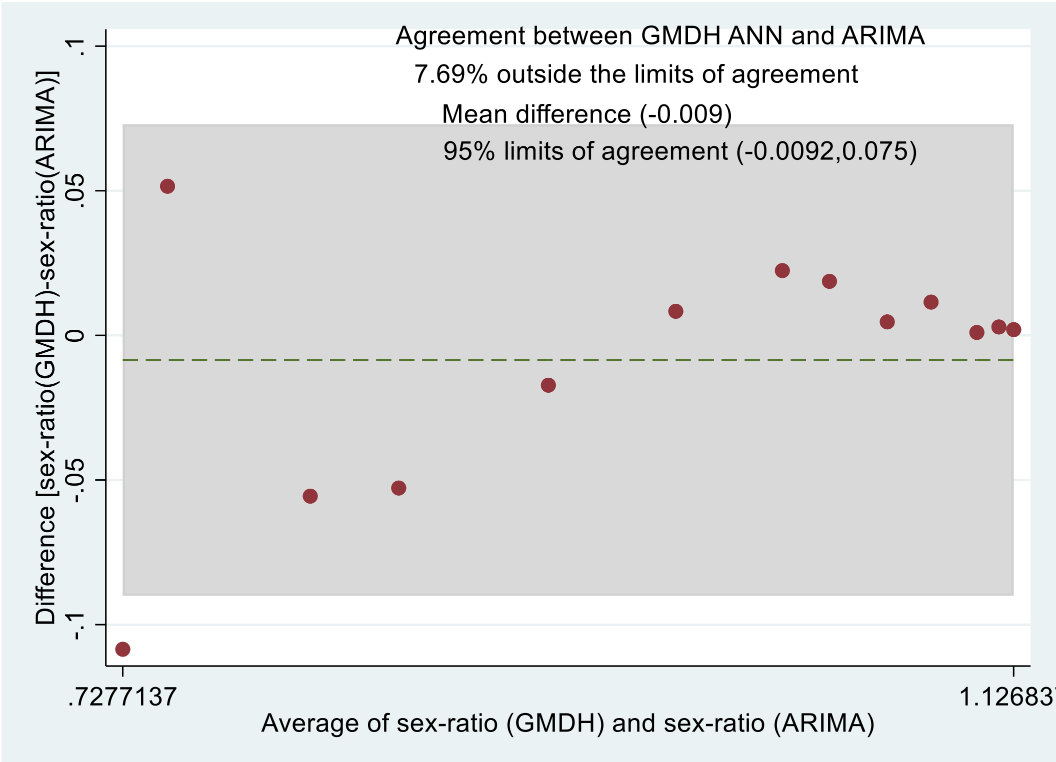


Figure D2: Out-of-sample GMDH-type ANN mortality forecasting for Nigeria, 2018-2030



Neonatal (0-27 days), child (1-4 years), and under-five (0-4 years)

Figure D3: Agreement between projected sex-ratios of GMDH-type ANN and ARIMA



With wide 95% limits of agreement and 7.69% outside limits of agreement, there is evidence of low proportional bias.

Appendix E: Supplementary material for chapter 7

Appendix E.1: Supplementary Tables

Table E1: Differentials of age-specific childhood mortality rates, 2016/2017 MICS, Nigeria

variable	Neonatal mortality rate (per 1000 live births)	Post-neonatal mortality rate (per 1000 live births)	Child mortality rate (per 1000 children surviving to age 1)
Child-level			
Child’s sex			
Male	43.2	30.7	49.7
Female	32.4	26.6	59.1
Gestation type			
Singleton	33.7	27.6	52.9
Multiple	139.0	56.0	93.1
Maternal age at birth			
<20 years	55.8	35.5	74.9
20-34 years	33.2	27.1	49.9
≥35 years	42.2	29.6	57.1
Birth order			
First born	47.2	30.2	45.9
2-3	27.7	23.2	43.3
4-6	31.0	27.9	58.7
≥7	61.7	39.8	80.8
Previous birth interval			
<2 years	62.5	44.2	83.2
First birth	49.0	30.2	45.9
≥2 years	26.0	22.9	46.4
Maternal level			
Maternal education			
None/primary	40.8	34.9	73.5
Secondary	31.7	17.5	21.4
Post-secondary	33.4	13.0	10.2
Maternal wealth index			
Poor	39.7	37.5	81.2
Middle	42.8	29.0	54.0
Rich	32.9	17.4	19.4
Mat. Media exposure			
High	36.5	22.6	33.6
Medium	31.8	23.7	33.9
Low	37.1	28.1	43.6
None	41.7	35.8	78.7
Death of previous children			
<3	29.2	22.4	40.0
3-4	135.0	92.6	233.4
≥5	172.0	151	344.0
Parity			

<3	33.4	21.4	40.6
3-4	31.3	25.8	43.6
≥5	45.8	35.4	69.8
Access to ANC			
None	39.7	39.5	81.2
Skilled	36.3	20.4	47.6
Unskilled	55.0	46.9	86.4
Freq. of ANC visits			
None	39.7	39.5	81.2
1-7	36.6	25.4	58.5
≥8	42.8	16.4	34.0
Skilled birth attendants during delivery			
None	42.6	36.5	94.5
Skilled	38.4	16.7	76.9
Unskilled	38.2	35.9	31.4
Institutional delivery			
Home	38.6	34.2	80.0
Health Facilities	38.8	18.0	29.7
Contraceptive use			
Yes	28.2	23.5	18.8
No	39.1	31.2	63.1
Marital status			
Currently married	37.6	28.6	54.1
Formerly married	40.3	31.5	65.1
Never married	47.4	20.3	46.2
Alcohol intake			
Yes	34.1	22.2	26.2
No	38.5	29.5	59.2
Smoking experience			
Yes	63.0	67.8	53.4
No	37.6	28.3	54.4
Household-level			
Sex of household head			
Male	38.2	28.7	55.5
female	31.3	28.2	34.7
Housing material index			
Inadequate	38.8	36.5	79.8
Adequate	37.3	23.0	34.7
Polygamy			
Yes	39.8	34.5	72.4
No	36.9	25.6	45.0
Educational status of household			
head	42.0	33.9	72.0
None/primary	32.1	24.9	34.6
Secondary	31.6	14.9	20.6
Post-secondary			
Ethnic group of household head			
Hausa	40.8	34.9	82.6
Igbo	28.8	16.9	21.3
Yoruba	35.5	15.8	16.0
Others	35.3	23.5	32.1
Household access to drinking			
water	44.3	37.5	66.4
Unimproved	34.5	24.0	47.6
Improved			

Household sanitation			
Unimproved	38.9	34.4	62.0
Improved	36.9	22.7	45.1
Indoor pollution			
Polluting fuel	38.6	29.5	57.2
Clean	27.4	16.0	8.1
Community-level			
Area			
Urban	34.7	17.4	22.3
rural	39.3	33.6	65.6
Region			
NC	42.5	26.8	33.1
NE	32.7	26.5	69.9
NW	44.1	37.4	86.2
SE	26.2	20.7	23.5
SS	22.0	18.9	23.7
SW	35.6	15.1	16.3
Infrastructural development			
Low	40.5	34.2	70.4
High	35.1	22.7	34.8
Comm. Maternal education			
Low	44.2	38.1	84.7
Medium	31.4	19.9	33.5
High	30.3	16.8	19.8

Appendix F: Supplementary material for chapter 8

Appendix F.1: Supplementary Tables

Table F1: Direct effects of child, maternal and household-level factors on neonatal survival in Nigeria

	Bivariate		Multivariate	
Neonatal survival	**Crude time ratio (95%CI)**	**p-value**	**Adjusted time ratio (95%CI)**	**p-value**
Child-level factors				
Child's sex (ref: male)				
Female	2.58 (1.55-4.29)	<0.001	2.72 (1.62-4.58)	<0.001
Maternal age at birth (ref: <20 and ≥35 years)				
20-34 years	3.39 (2.01-5.72)	<0.001	2.80 (1.57-4.99)	<0.001
Gestational type (ref: single)				
Multiple	0.01 (0.002-0.02)	<0.001	0.004 (0.001-0.01)	<0.001
Birth order (ref: first to 3rd birth)				
>3rd order birth	0.55 (0.33-0.91)	0.021	0.41 (0.22-0.78)	0.007
Prev. birth interval (ref: first birth and <2 years)				
≥2 years	11.73 (7.42-18.55)	<0.001	18.93 (10.06-35.65)	<0.001
Maternal-level factors				
Maternal education (ref: none/ prim)				
Post-primary	1.97 (1.19-3.27)	0.009	1.80 (0.84-3.87)	0.134
Maternal wealth index (ref: poor)				
Middle/ rich	1.18 (0.69-2.03)	0.554	0.70 (0.33-1.51)	0.363
Freq of ANC visits (Discrete)	0.98 (0.96-1.00)	0.068	0.98 (0.97-1.00)	0.056
Birth attendants (ref: none/ unskilled)				
Skilled	0.93 (0.53-1.64)	0.802	0.77 (0.29-2.01)	0.592
Place of delivery (ref: home)				
Health facilities	0.90 (0.50-1.61)	0.724	0.79 (0.28-2.19)	0.645
Household-level factors				
Sanitation (ref: unimproved)				
Improved	1.08 (0.64-1.84)	0.772	1.20 (0.62-2.30)	0.589
Cooking fuel (ref: polluting fuel)				
Clean fuel	2.53 (0.91-7.02)	0.075	1.42 (0.37-5.50)	0.603
Drinking water (ref: unimproved)				
Improved	2.08 (1.23-3.52)	0.006	1.59 (0.79-3.21)	0.193

Table F2: Direct effects of child, maternal and household-level factors on infant survival in Nigeria

	Bivariate		Multivariate	
Infant survival	**Crude time ratio (95%CI)**	**p-value**	**Adjusted time ratio (95%CI)**	**p-value**
Child-level factors				
Child's sex (ref: male)				
Female	2.54 (1.63-3.96)	<0.001	2.79 (1.74-4.48)	<0.001
Maternal age at birth (ref: <20 and ≥35 years)				
20-34 years	3.48 (2.12-5.71)	<0.001	2.45 (1.41-4.25)	0.001
Gestational type (ref: single)				
Multiple	0.01 (0.002-0.01)	<0.001	0.003 (0.001-0.1)	<0.001
Birth order (ref: first to 3rd birth)				
>3rd order birth	0.43 (0.27-0.69)	<0.001	0.47 (0.26-0.84)	0.011
Prev. birth interval (ref: first birth and <2 years)				
≥2 years	13.79 (8.90-21.27)	<0.001	19.72 (11.23-34.63)	<0.001
Maternal-level factors				
Maternal education (ref: none/ prim)				
Post-primary	4.90 (2.94-8.16)	<0.001	2.71 (1.29-5.69)	0.008
Maternal wealth index (ref: poor)				
Middle/ rich	2.72 (1.62-4.57)	<0.001	0.75 (0.38-1.50)	0.418
Freq of ANC visits (Discrete)	1.00 (0.97-1.02)	0.682	0.99 (0.97-1.01)	0.173
Birth attendants (ref: none/ unskilled)				
Skilled	2.54 (1.46-4.42)	0.001	1.72 (0.67-4.41)	0.256
Place of delivery (ref: home)				
Health facilities	2.09 (1.19-3.67)	0.011	0.74 (0.27-2.02)	0.560
Household-level factors				
Sanitation (ref: unimproved)				
Improved	2.06 (1.23-3.46)	0.006	1.57 (0.88-2.82)	0.127
Cooking fuel (ref: polluting fuel)				
Clean fuel	4.93 (1.86-13.07)	0.001	1.21 (0.35-4.16)	0.767
Drinking water (ref: unimproved)				
Improved	3.52 (2.16-5.73)	<0.001	1.58 (0.87-2.88)	0.132

Table F3: Direct effects of child, maternal and household-level factors on under-five survival in Nigeria

	Bivariate		Multivariate	
Under-five survival	**Crude time ratio (95%CI)**	**p-value**	**Adjusted time ratio (95%CI)**	**p-value**
Child-level factors				
Child's sex (ref: male)				
Female	1.89 (1.30-2.77)	0.001	2.08 (1.39-3.10)	<0.001
Maternal age at birth (ref: <20 and ≥35 years)				
20-34 years	3.36 (2.27-4.97)	<0.001	2.29 (1.49-3.51)	0.001
Gestational type (ref: single)				
Multiple	0.01 (0.004-0.03)	<0.001	0.01 (0.002-0.02)	<0.001
Birth order (ref: first to 3rd birth)				
>3rd order birth	0.37 (0.26-0.54)	<0.001	0.43 (0.27-0.69)	<0.001
Prev. birth interval (ref: first birth and <2 years)				
≥2 years	9.13 (6.35-13.12)	<0.001	12.87 (8.07-20.52)	<0.001
Maternal-level factors				
Maternal education (ref: none/ prim)				
Post-primary	8.22 (5.26-12.84)	<0.001	3.16 (1.70-5.87)	<0.001
Maternal wealth index (ref: poor)				
Middle/ rich	4.60 (3.06-6.91)	<0.001	1.19 (0.67-2.10)	0.549
Freq of ANC visits (Discrete)	1.00 (0.98-1.02)	0.918	0.99 (0.97-1.00)	0.078
Birth attendants (ref: none/ unskilled)				
Skilled	3.92 (2.47-6.23)	<0.001	1.90 (0.84-4.31)	0.125
Place of delivery (ref: home)				
Health facilities	3.34 (2.08-5.36)	<0.001	0.85 (0.36-2.05)	0.724
Household-level factors				
Sanitation (ref: unimproved)				
Improved	2.32 (1.56-3.44)	<0.001	1.37 (0.85-2.21)	0.196
Cooking fuel (ref: polluting fuel)				
Clean fuel	9.43 (3.88-22.94)	<0.001	1.34 (0.43--4.19)	0.616
Drinking water (ref: unimproved)				
Improved	3.37 (2.22-5.14)	<0.001	1.33 (0.82-2.16)	0.246

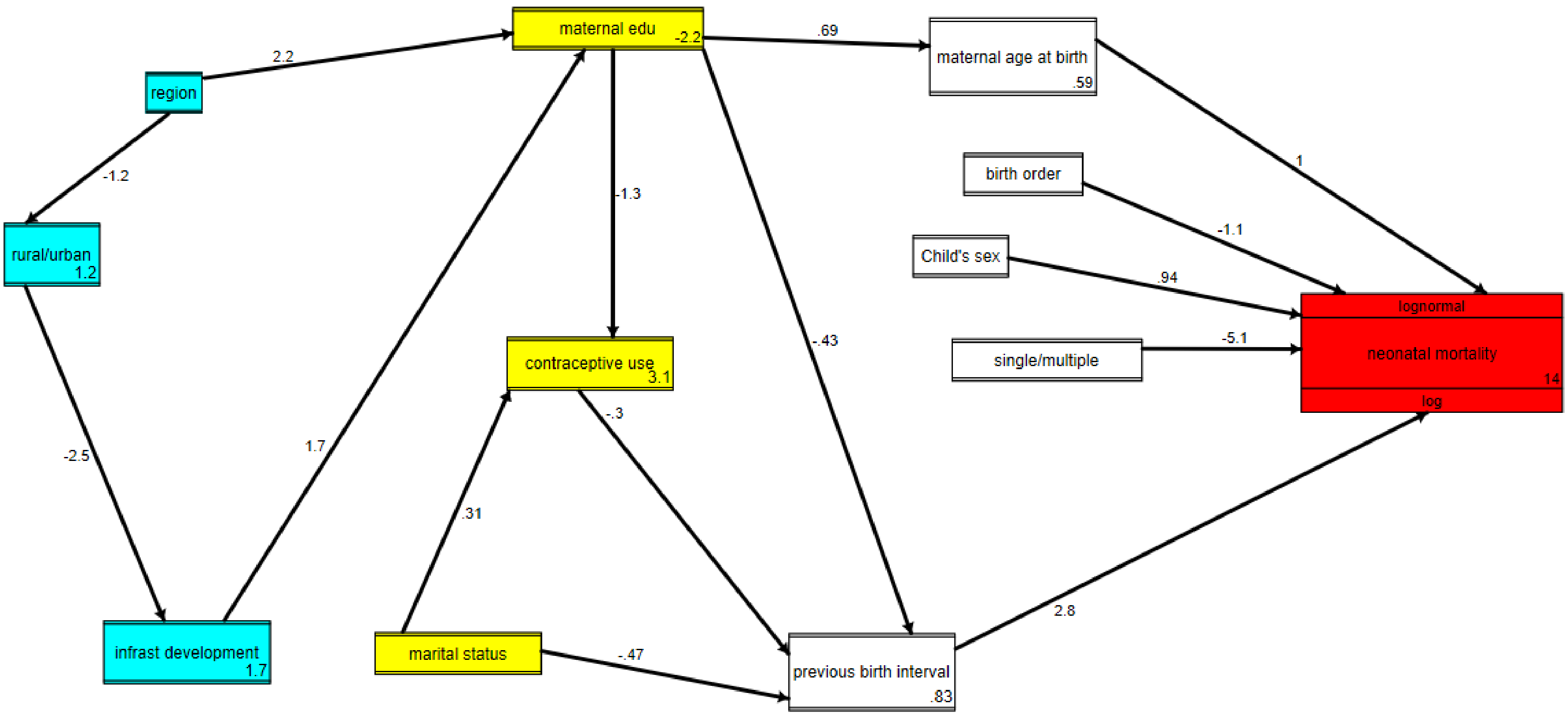
Table F4: Final models (re-specified) of direct and indirect effects of social determinants on neonatal, infant and under-five survival times in Nigeria, Nigeria MICS, 2016/2017

Dependent variable	Independent variable	Exp ($\boldsymbol{\beta}$) 95%CI
Direct effect		**Time ratio (95%CI)**
	Child's sex (*Ref: Male*)	-
	Female	2.57 (1.57-4.23)
	Maternal age at birth *(Ref: <20/≥35 years)*	-
	20-34 years	2.74 (1.67-4.50)
	Gestation type *(Ref: Single)*	-
Neonatal survival	Multiple	0.01 (0.003-0.02)
	Birth order *(Ref: ≤3)*	-
	>3	0.32 (0.19-0.55)
	Previous birth interval *(Ref: First birth/<2 years)*	-
	≥2 years	16.17 (9.90-26.42)
	Child's sex (*Ref: Male*)	-
	Female	2.61 (1.69-4.03)
	Maternal age at birth *(Ref: <20/≥35 years)*	-
	20-34 years	2.24 (1.38-3.65)
	Gestation type *(Ref: Single)*	-
	Multiple	0.01 (0.002-0.01)
Infant survival	Birth order *(Ref: ≤3)*	-
	>3	0.33 (0.20-0.55)
	Previous birth interval *(Ref: First birth/<2 years)*	-
	≥2 years	20.37 (12.77-32.49)
	Maternal education *(Ref: None/ primary)*	-
	More than primary	3.84 (2.29-6.43)
	Child's sex (*Ref: Male*)	-
	Female	1.94 (1.34-2.81)
	Maternal age at birth *(Ref: <20/≥35 years)*	-
	20-34 years	2.10 (1.42-3.09)
	Gestation type *(Ref: Single)*	-
	Multiple	0.01 (0.005-0.02)
Under-five survival	Birth order *(Ref: ≤3)*	-
	>3	0.34 (0.23-0.52)
	Previous birth interval *(Ref: First birth/<2 years)*	-
	≥2 years	13.43 (9.19-19.61)
	Maternal education *(Ref: None/ primary)*	-
	More than primary	6.32 (4.01-9.97)
Indirect effect		**Odds ratio (OR) 95%CI**
Area of residence *(Ref: Urban)*	Region *(Ref: Northern)*	-
Rural	Southern	0.30 (0.24-0.39)
Maternal education *(Ref: None/primary)*	Region *(Ref: Northern)*	-
Post-primary	*Southern*	8.76 (7.55-10.15)
Maternal education *(Ref: None/ primary)*	Comm. Development *(Ref: Low)*	-
More than primary	High	5.46 (4.65-6.41)
Comm. Development *(Ref: Low)*	Area of residence *(Ref: Urban)*	-
High	Rural	0.08 (0.06-0.11)
Prev. birth interval (*Ref: First birth/<2 years)*	Marital status *(Ref: currently married*	-

≥2 years	never/formerly married	0.63 (0.52-0.75)
Prev. birth interval (*Ref: First birth/<2 years)*	Contraceptive use *(Ref: Yes)*	-
≥2 years	No	0.74 (0.64-0.86)
Contraceptive use *(Ref: Yes)*	Maternal education *(Ref: None/primary)*	-
No	More than primary	0.28 (0.24-0.34)
Contraceptive use *(Ref: Yes)*	Marital status *(Ref: currently married*	-
No	never/formerly married	1.37 (1.01-1.85)
Maternal age at birth *(Ref: <20/≥35 years)*	Maternal education *(Ref: None/primary)*	-
20-34 years	More than primary	1.98 (1.78-2.21)

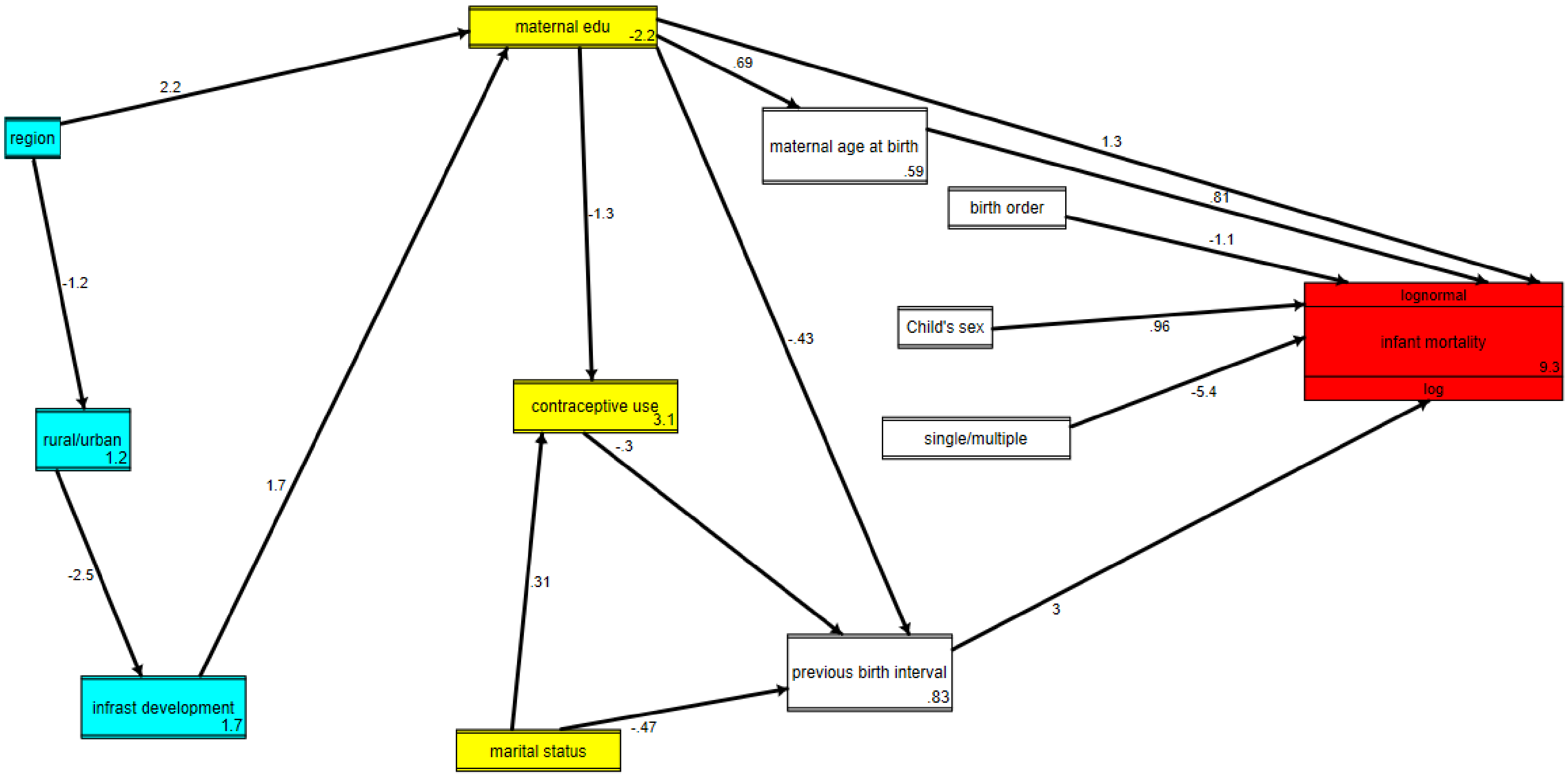
Appendix F.2: Supplementary Figures

Figure F1: Hierarchical path diagram (re-specified final model) showing path coefficients of social determinants of neonatal mortality in Nigeria, MICS 2016/2017



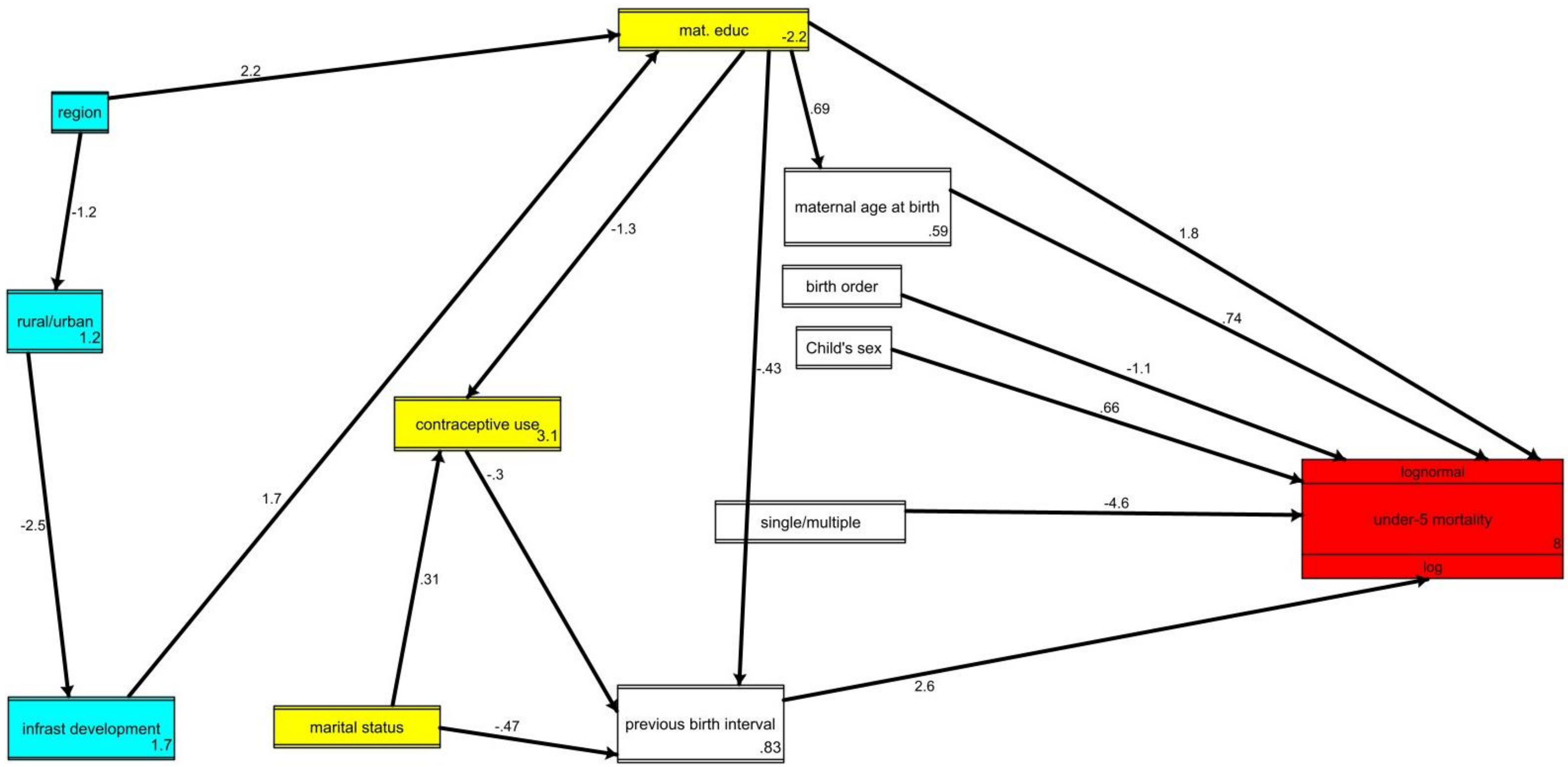
Color coding: Outcome variable (red), community-level factors (green), maternal-level factors (yellow), child-level factors (white)
Boxes with double-line borders belong to Bernoulli family and have logit link.

Figure F2: Hierarchical path diagram (re-specified) with parameter estimates of social determinants of infant mortality in Nigeria, MICS 2016/2017



Color coding: Outcome variable (red), community-level factors (green), maternal-level factors (yellow), child-level factors (white)
Boxes with double-line borders belong to Bernoulli family and have logit link.

Figure F3: Hierarchical path diagram (re-specified) with parameter estimates of social determinants of under-five mortality in Nigeria, MICS 2016/2017

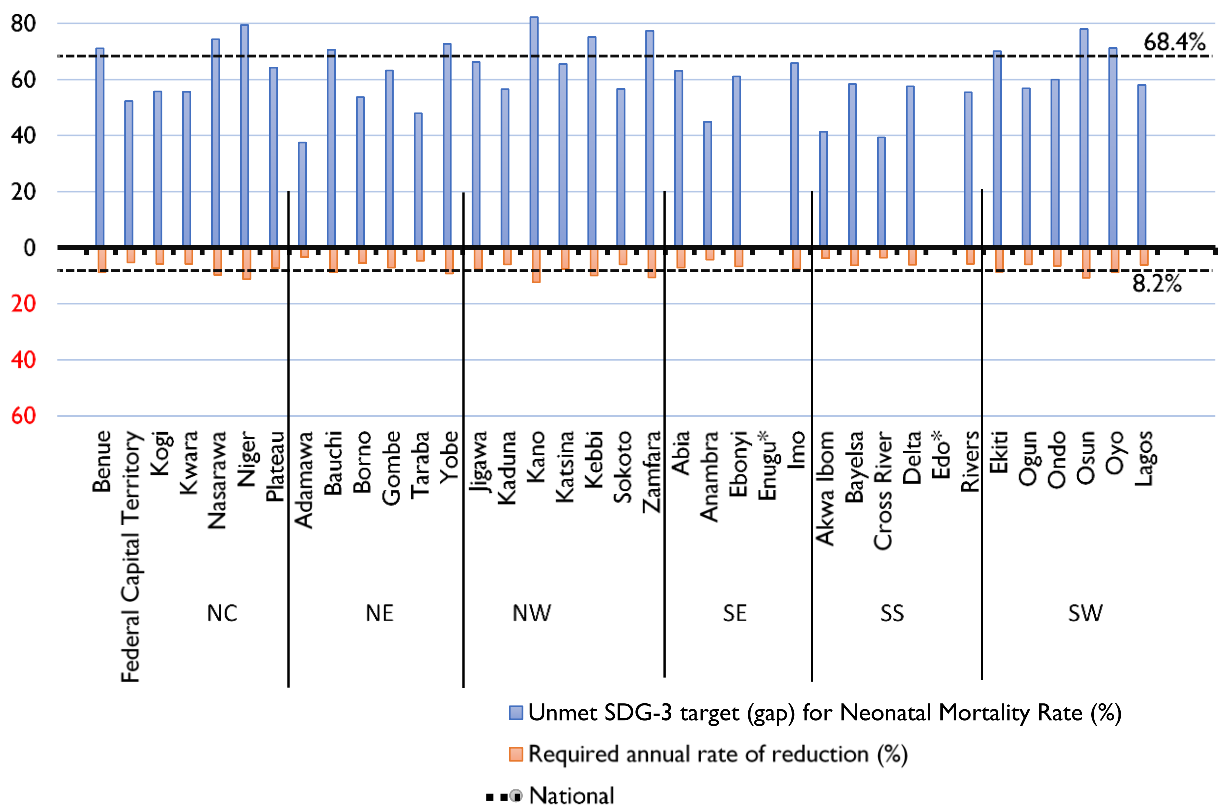


Color coding: Outcome variable (red), community-level factors (green), maternal-level factors (yellow), child-level factors (white)
Boxes with double-line borders belong to Bernoulli family and have logit link

Appendix G: Supplementary material for chapter 9

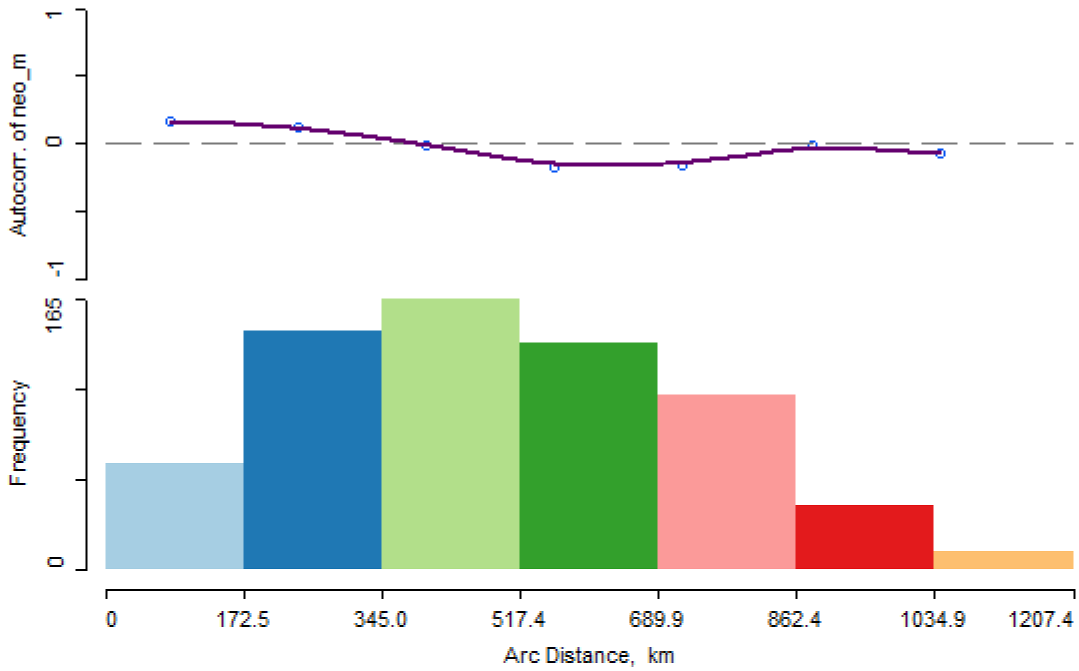
Appendix G.1: Supplementary Figures

Figure G1: State-level deficit in SDG-3 targets and required annual rate of reduction for neonatal mortality rates, Nigeria MICS, 2016/2017



*Enugu and Edo states had NMRs lower than SDG-3 target.

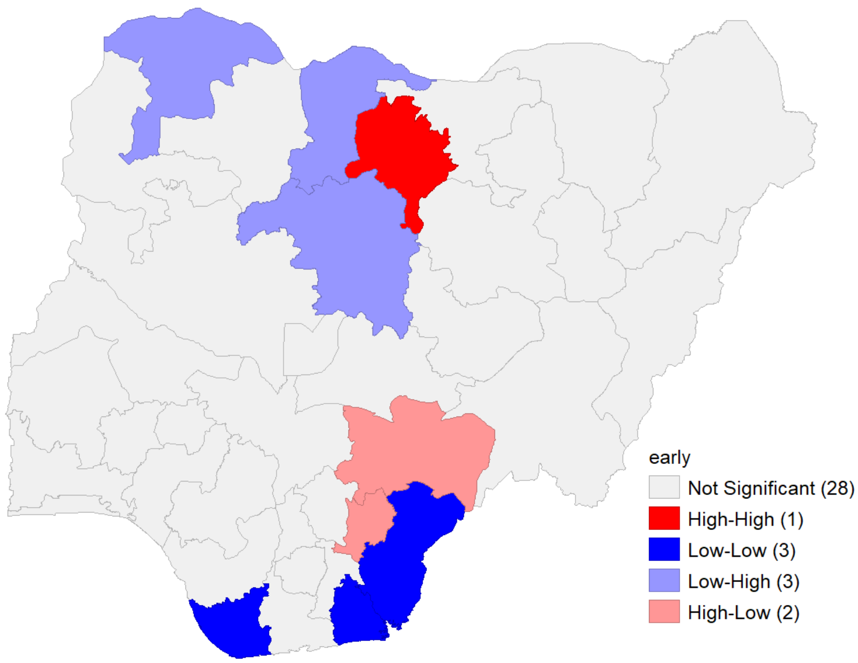
Figure G2: Spatial correlogram of neonatal mortality rate, 2016/2017 Nigeria MICS



Autocorr.	0.163	0.122	-0.017	-0.180	-0.169	-0.011	-0.076
Min	0	172.480	344.960	517.441	689.921	862.401	1034.881
Max	172.480	344.960	517.441	689.921	862.401	1034.881	1207.361
# Pairs	64	145	165	137	106	39	10

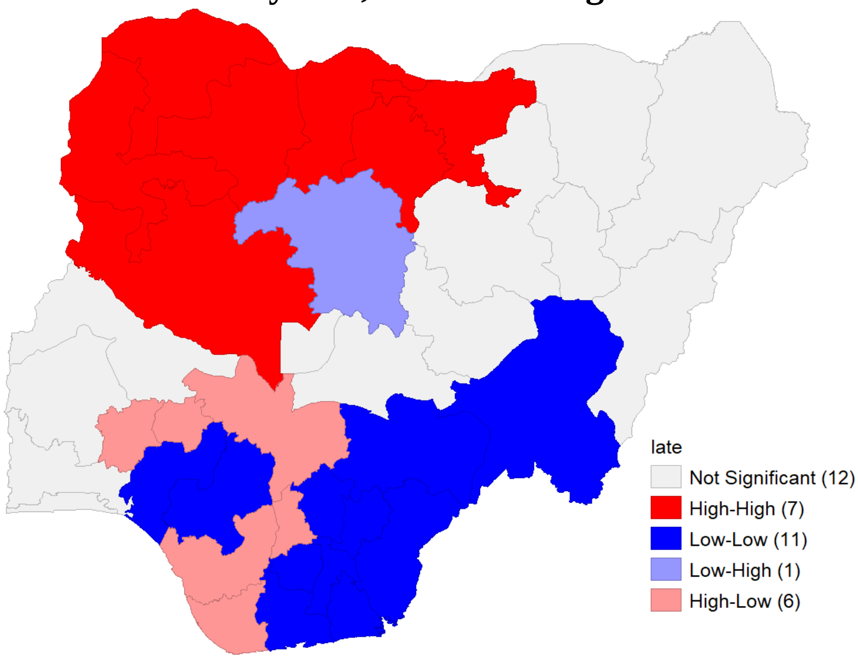
min: 0, max: 1207.361, total # pairs: 666, Autocorr. = 0 at 409.810 in range: [344.960, 517.441]

Figure G3: Univariate Local Indicator Spatial Autocorrelation (LISA) cluster map of early neonatal mortality rate, 2016/2017 Nigeria MICS



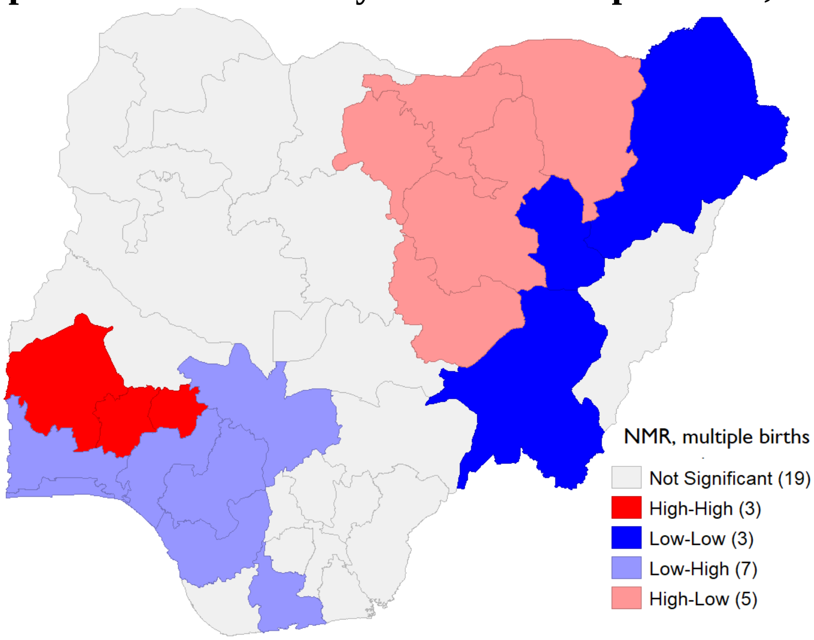
Global Moran's I index=0.02, p-value=0.173

Figure G4: Univariate Local Indicator Spatial Autocorrelation (LISA) cluster map of late neonatal mortality rate, 2016/2017 Nigeria MICS



Global Moran's I index=0.3, p-value=0.001

Figure G5: Bivariate Local Indicator Spatial Autocorrelation (LISA) cluster map of neonatal mortality rate and multiple births, 2016/2017 Nigeria MICS



Global Moran's I index= -0.1, p-value=0.05