Evaluating the quality of routine data in primary health facilities for monitoring maternal and newborn care in Gombe State, northeastern Nigeria

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Declaration by Candidate

I, Antoinette Alas Bhattacharya, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

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Abstract

Background. Accurate data are essential for monitoring progress and course correction. Good quality facility-based routine data can be used at the facility, district, national, and global levels to improve quality of care and care policies. However, poor routine data quality has been an ongoing challenge. This thesis aimed to evaluate the quality of routine data for monitoring maternal and newborn care in primary health facilities in Gombe State, Nigeria.

Methods. To examine the quality of routine monitoring data, in Study 1 we assessed facility-reported data in the District Health Information Software, version 2 (DHIS 2) according to three routine data quality dimensions: completeness and timeliness, internal consistency, and external consistency. Using direct observations as a gold standard, in Study 2 we assessed the validity of data in facility registers as well as women's recall of childbirth events. For 21 months (April 2017-December 2018), we implemented a data quality intervention, working with all 11 local government area (district-equivalent) monitoring and evaluation officers and maternal and child health program coordinators of Gombe State which oversee 492 primary health facilities. The intervention included regular self-assessment of data quality, learning workshops, and planning for improvement. In Study 3, we quantified the changes in data quality using before-and-after analyses, comparing the intervention period to the 21-month pre-intervention period (July 2015-March 2017).

Results. Twelve of 14 priority facility-based indicators were available in Gombe's health information system to monitor maternal and newborn care. However, the facility data were incomplete and showed inconsistencies over time, between related indicators, between internal and external data sources. Contact indicators had higher data quality than indicators reflecting the content of care. Though there were challenges with the quality of facility-reported data, the validity study demonstrated that health workers were able to record valid information for some aspects of maternal and newborn care. When compared to childbirth observations, health workers documented accurately in maternity registers for the following indicators: the cadre of main birth attendant; maternal background characteristics, and newborn outcomes. Lastly, the data quality intervention was associated with improved completeness, timeliness, consistency between related data, and accuracy of facility reporting.

Conclusion. Facility-based routine data in Gombe State can monitor priority service provision indicators for mothers and newborns. To realize the potential of these data, opportunities to improve data quality include: expanding data quality assessments beyond completeness and accuracy; maximizing the reporting and specificity of existing data; refining supervision feedback on the data quality metrics; and optimizing the digitization of facility data in information systems such as DHIS 2. Further research opportunities include: deepening our understanding of how health workers directly engage with facility documentation to perform clinical care tasks; and developing a composite score to summarize the multi-dimensionality of routine data as a measure for continuous data quality monitoring and as an outcome for data quality interventions.

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For Gaurav

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Chapter 7 (as cited in the manuscript)

Table of Abbreviations

AIDS	acquired immunodeficiency syndrome
ANC	antenatal care
AMTSL	active management of the third stage of labor
AUC	area under receiver operating characteristic curve
BCG	Bacillus Calmette-Guérin vaccine
CHEW	community health extension worker
CI	confidence interval
DHIS2, DHIS 2	District Health Information System version 2, District Health Information Software version 2
DHS	Demographic and Health Survey
DQA	data quality assessment, data quality assurance
DQLW	data quality learning workshop
DQR	data quality review
DTP	diphtheria-tetanus-pertussis
EBF	exclusive breastfeeding
ENAP	Every Newborn Action Plan
ENC	essential newborn care
EPMM	Ending Preventable Maternal Mortality
HCW	health care worker
HIS	health information system
HIV	human immunodeficiency virus
HMIS	health management information system
ICC	intraclass correlation coefficient
IF	inflation factor
IPT	intermittent preventive therapy for malaria
GSPHCDA, the Agency	Gombe State Primary Health Care Development Agency
IDEAS	Informed Decisions for Actions in Maternal and Newborn Health
L&D	labor and delivery
LBW	low birthweight
LGA	local government area (district-level equivalent)
LSHTM	London School of Hygiene & Tropical Medicine
M&E	monitoring and evaluation
MICS	Multiple Indicator Cluster Survey
MNCH	maternal, newborn, and child health
MNH	maternal and newborn health
PHCDA	Primary Health Care Development Agency
PNC	postnatal care
PPC	postpartum care
PRISM	Performance of Routine Information Systems Management
RHIS	routine health information system
SBA	skilled birth attendant
SD	standard deviation
TT	tetanus toxoid
USAID	United States Agency for International Development
WHO	World Health Organization

Chapter 1: Introduction

1.1 Overview of thesis

This thesis aims to evaluate the quality of routine data in primary health facilities for monitoring maternal and newborn care in Gombe State, northeastern Nigeria. The research presented has drawn from facility- and population-level datasets to quantify metrics which reflect the data quality dimensions of health facility data for completeness and timelines, internal consistency, external consistency, and validity.

This thesis contains eight chapters with four appendices and is presented in a research-paper style. Chapter 1 provides the background and context in which the research took place: quality of care for mothers and newborns, routine health information systems, and a setting description for Nigeria and Gombe State in northeastern Nigeria. In chapter 2, I present a literature review of data quality dimensions and metrics, the interventions implemented with the intention of improving the quality of routine data, and the factors identified as affecting data quality. In chapter 3, I present the thesis aim and objectives. Chapter 4 describes the overall thesis methodology and data sources.

Results are presented in three manuscripts. Chapters 5 and 6 present published manuscripts examining the quality of routine data in Gombe State, Nigeria, the setting for this thesis. Study 1 (chapter 5) assessed the quality of routine data *reported by facilities* in the District Health Information Software version 2 (DHIS 2) to monitor priority maternal and newborn health (MNH) indicators. Study 2 (chapter 6) examined the validity of data sources, including routine data *documented by facilities*, to reflect maternal and newborn care during childbirth. This thesis distinguishes between the data *documented by facilities* during service delivery and the aggregate data *reported by facilities*.

Chapter 7 presents a submitted manuscript currently under editorial review. Study 3 (chapter 7) examines the quality of routine data before and after a data quality intervention was implemented in Gombe State.

The discussion chapter, chapter 8, brings together the findings from the research as well as the strengths and limitations of the thesis. This chapter concludes with the implications of the thesis for policy, practice, and research.

A note on references

References cited in the narrative sections of this thesis and in the submitted manuscript (Study 3, chapter 7) are located at the end of the thesis, starting on page 175. References cited in the published manuscripts are located within the respective chapters, starting on page 100 in chapter 5 (Study 1) and on page 119 in chapter 6 (Study 2).

1.2 Quality of care for women and newborns

Data quality and measurement challenges prevent critical MNH issues from being fully understood. These critical issues include which mother-baby pairs access health facility care, what services are provided to mothers and newborns, and how many and why mothers and babies experience complications or die. Global initiatives such as the Ending Preventable Maternal Mortality, Every Newborn Action Plan, and the United Nation's Global Strategy for Women's, Children's, and Adolescents' Health have included strategic priorities to improve the use of data for monitoring, including strengthening the data sources and measurement of the content and quality of care received in facilities.[1-3]

Emphasis on the health and survival of women and children has contributed to a 38% reduction in maternal mortality[†] and 49% reduction in under-5 mortality since 2000. While these have been remarkable achievements for the Millennium Development Goals and early Sustainable Development Goals, preventable deaths remained high worldwide with an estimated 295,000 maternal deaths in 2017 and 5.3 million child deaths in 2018.[4 5] These are the latest data available, as of June 2020.

Within child deaths, neonatal mortality, defined as deaths occurring within the first 28 days of life, has declined at a slower rate and has contributed to 47% of under-five mortality in 2018.[5] Approximately 2.5 million newborns died in 2018. It is estimated that nearly one-third of neonatal deaths occurred on the first day of life and about three-quarters of the deaths occurred in the first seven days.[6 7] With the majority of neonatal deaths happening around the time of childbirth, the survival of a newborn and the optimal interventions to improve survival are linked to strengthening maternal health care as well.[6 8]

[†] Maternal deaths are defined as deaths from any cause, except unintentional or incidental deaths, while pregnant or within 42 days from the termination of pregnancy. [Source: Trends in maternal mortality 2000 to 2017: estimates by WHO, UNICEF, UNFPA, World Bank Group and the United Nations Population Division. Geneva: World Health Organization; 2019].

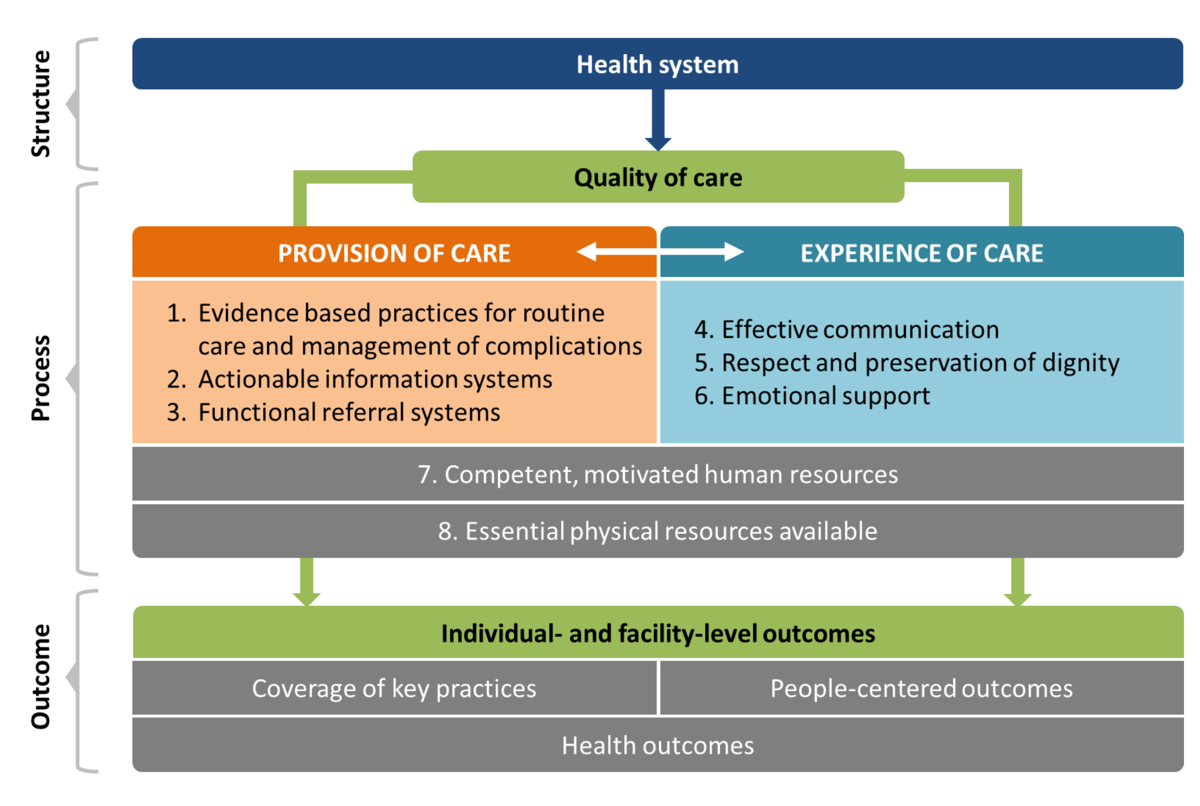
Improvements in the health and survival of women and newborns have not been uniform. The vast majority of maternal and neonatal deaths have occurred in low- and middle-income countries. However, even within high-income countries, inequities exist. Across all settings, disparities in health outcomes and service delivery have persisted by multiple measures of disaggregation, such as geographical location, socioeconomic status, religion, and race.[9-12]

Global MNH achievements included increased access and uptake of antenatal care services and deliveries in health care facilities.[13] Thus, more opportunities should have existed to identify health care needs to prevent deaths in women and their newborns. However, increases in facility-based services have not improved survival as expected, suggesting that contact with the health system may be insufficient to improve health outcomes. Improved health and survival also are affected by the quality and content of care received during the facility visits.[14-18]

Lessons from the Millennium Development Goals and early Sustainable Development Goals have moved quality of care more prominently into the conversation. The rapidly expanding body of evidence on facility-based quality of care point to suboptimal care and missed opportunities to ensure the survival and to avoid unnecessary morbidity for women and their newborns, particularly around the time of childbirth.[17-21] For facility-based births, improving quality of care especially during the intrapartum period is considered one of the most effective strategies for reducing maternal and neonatal mortality and morbidity.[13 22-25]

In 2016, the World Health Organization (WHO) identified eight domains (Figure 1.1) for improving the quality of care in health facilities, including "actionable information systems" (domain 2 in Figure 1.1) to promote the use of data for timely and high quality of care for women and their newborns. Specifically, a robust information system would promote client management and facility management such that: (i) "Every woman and newborn has a complete, accurate, standardized medical record during labor, childbirth, and the early postnatal period"; and (ii) "Every health facility has a mechanism for data collection, analysis, and feedback as part of its activities for monitoring and improving performance around the time of childbirth."[13]

Figure 1.1 WHO framework: eight domains for improving the quality of maternal and newborn care



Source: World Health Organization, 2016.[13]

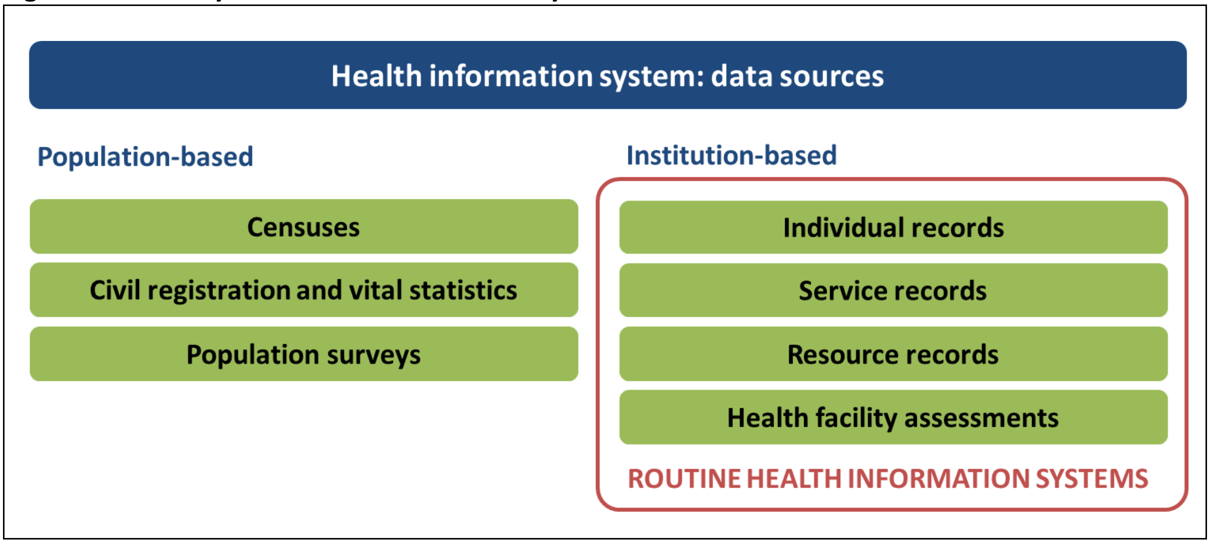
1.3 Routine health information systems

A health information system is a collective effort to capture, report, process, and use health information at each level of the health system.[26 27] A robust information system is considered an essential building block of the health system, contributing to improved access, coverage, quality, and safety of services. This would then lead to improved health outcomes and health equity.[28] Data generated through health information systems also inform decision making for the other building blocks of the health system, such as service delivery, health workforce, financing, leadership and governance, and commodities and technologies.[27] Thus, a working information system would not be an end in itself, but rather a means to generate data needed by users at different levels of the health system to take action.[26 29]

Assumptions underly the usefulness of the information system. First, if quality data are available, they would be used to make decisions and take action. Second, decisions based on quality data would make efficient use of resources and improve processes and policies. Third, increased efficiency and appropriate use of resources would result in improved health outcomes through more effective health management and service delivery.[29 30]

Health information system data sources are typically categorized as population-based and institution-based data, as shown in Figure 1.2.[31] Population-based data sources comprise national censuses, population surveys, and civil registration vital statistics systems. A common feature is that these sources provide representative information on the general population, helpful for data on geographic areas or subpopulations.[32] Institution-based data sources comprise both facility- and community-related sources such as individual and service records, health facility assessments, and resource records on the workforce, infrastructure, logistics, and finances. A common feature for these sources is that the data are usually collected by staff during day-to-day activities to describe an event, procedure, or resource associated with a given health institution.[29 32]

Figure 1.2 Country-level health information system data sources

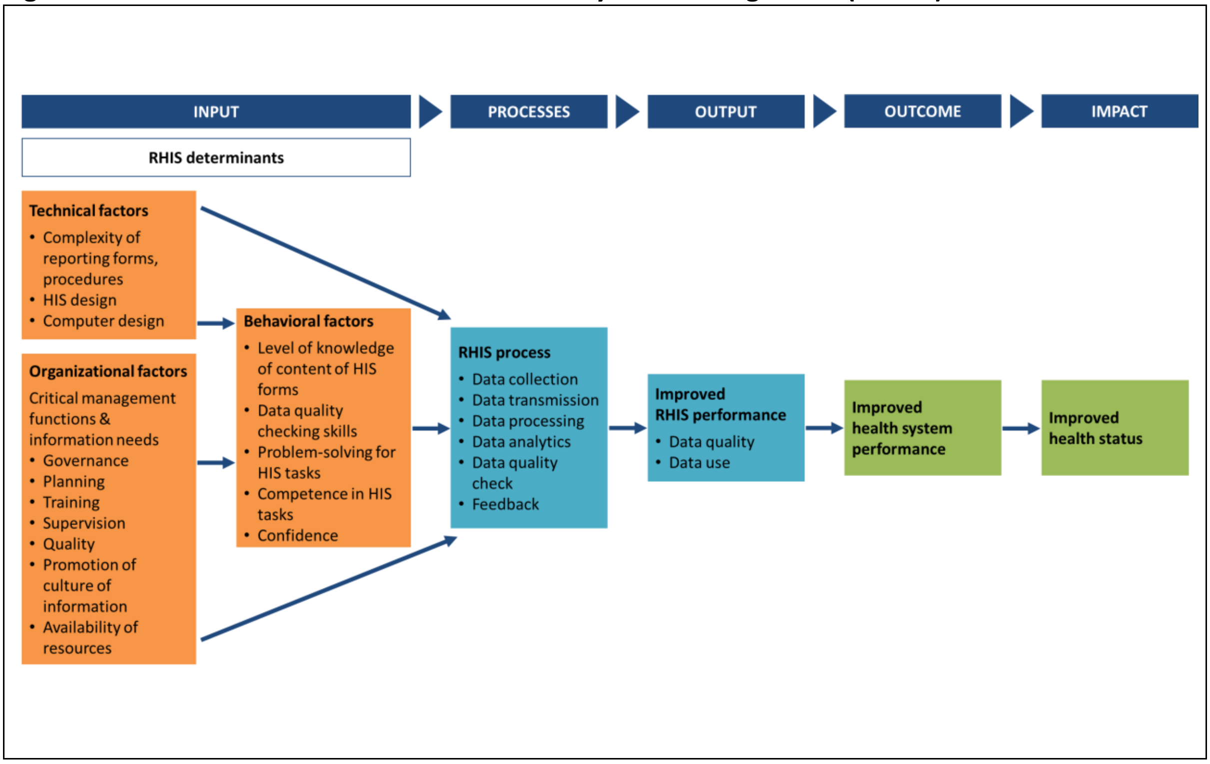


Sources: World Health Organization and Health Metrics Network, 2008[31]; MEASURE Evaluation, 2017[33]

A routine health information system (RHIS) is a subset of a health information system primarily integrating institution-based data sources. In settings where most health services are delivered through public programs, RHIS provide essential data for monitoring and performance management.[27 30 34] RHIS have the potential to provide frequent disaggregated information for understanding disparities and inequities in the provision of services and health outcomes, an important consideration to achieve universal health coverage.[27 35-38]

According to the Performance of Routine Information Systems Management (PRISM) framework (Figure 1.3), the performance of a robust RHIS relies on technical, organizational, and behavioral factors to promote the sound execution of RHIS processes such as data collection, data transmission, and data quality checking. In turn, these RHIS processes would facilitate the availability of quality data and the use of data for decision making at all levels of the health system to improve performance and the quality of services delivered in health facilities.[39]

Figure 1.3 Performance of Routine Information System Management (PRISM) framework



Source: Aqil A, Lippeveld T, and Hozumi D, 2009.[39]

Routine health information systems within learning health systems

The Institute of Medicine envisioned a learning health system "designed to generate and apply the best evidence for the collaborative health care choices of each patient and provider; to drive the process of discovery as a natural outgrowth of patient care; and to ensure innovation, quality, safety, and value in health care." Embracing a concept that data are a public good to improve health and health care, high-functioning learning health systems rely, in part, on robust RHIS processes (see Figure 1.3 above, PRISM Framework).[40] For learning health systems, routine data does not reflect data submitted at regular intervals for reporting[39]; rather routine data reflects the data collected about a patient during clinical care.[40]

Electronic health records, digital documentation of a patient's health care, are considered the model health records for the learning health system. Electronic health records help make information available in real-time for client management, identification of clinical and programmatic needs for quality improvement, and for evaluation of implemented solutions.[41] If designed effectively, electronic health records could reduce the documentation workload of health care workers, allowing the data for each clinic event or observation to be documented once, but used and reused for any clinical, programmatic, research, or management purpose.[42]

Most RHIS in low- and middle-income countries use a mix of paper- and electronic-based tools and devices to capture and manage routine data. At the service delivery level, paper-based individual records are the predominant data collection tools used.[43,44] Nevertheless, electronic medical records are increasingly being implemented across all facility types, but particularly in larger facilities through vertical health programs such as HIV/AIDS.[45]

The infrastructure necessary for wide adoption of individual-based electronic health records in low- and middle-income countries is not yet available. The District Health Information Software is an open source information system used in low- and middle-income countries to support the management of aggregate routine data, including monthly facility-based data.[46] This software undergoes continuous refinement and the District Health Information Software version 2 (DHIS 2) is used in over 70 low- and middle-income countries. DHIS 2 is considered an innovation for transmitting and aggregating data faster than completely paper-based information systems and for improving data quality by limiting errors in how data are transmitted and aggregated from the facility to higher levels of the health system. Further, DHIS 2 has the potential to promote program monitoring because its digital platform increases the accessibility of data for health managers and stakeholders at the district-, state-, and national levels. [37,47,48]

1.4 Study setting: Gombe State, northeastern Nigeria

Nigeria and its commitment to primary health care

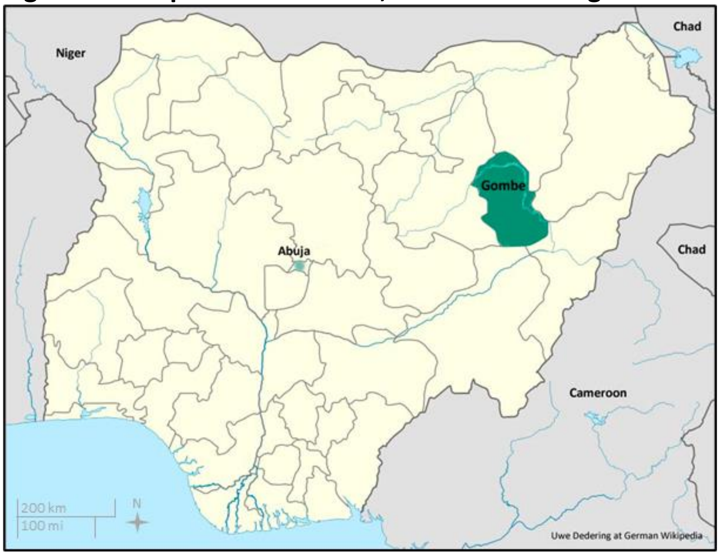
Nigeria, situated in western Africa, is the most populous country on the continent with an estimated population of 196 million and a life expectancy at birth of 54 years.[49] According to the 2019 Demographic and Health Survey, an estimated 65% of women and 78% of men, aged 15-49 years, have a primary education or higher.[50] Nigeria spent 3.7% of its gross domestic product on health in 2016, aligned with the lower-middle income countries average spend of 4.0%.[51]

Nigeria bears a large burden of maternal and newborn mortality. Of the estimated deaths worldwide, 67,000 (23%) of maternal deaths in 2017 and 267,000 (11%) of newborn deaths in 2018 occurred in Nigeria. The maternal mortality ratio was 917 [658-1320] per 100,000 live births in 2017 and the neonatal mortality rate was 36 [28-47] per 1,000 live births in 2018.[4 5 52] From the last available Demographic and Health Survey, published in 2019, approximately 39% of women delivered in a health facility, rising slowly from the estimate of 32% in 1990. During their last pregnancy, 67% of women reported making at least one visit for antenatal care and 57% of women have reported at least four antenatal care visits.[50]

In 2011, Nigeria enacted the *Primary Health Care under One Roof* policy through a national health bill to strengthen primary health care services and consolidate its management under one authority at the national- and state-levels: the Primary Health Care Development Agency. *Primary Health Care under One Roof* was based on a district-level service delivery model and integrated the following services, at a minimum: maternal, newborn, and child health services; family planning; immunizations, community outreach and education, nutrition, essential drugs, and common illnesses. The *Primary Health Care Under One Roof* policy underscored the commitment to ensuring access to essential health services closer to the population.[53 54] Given the high burden of deaths, there has been an emphasis on maternal and neonatal services within primary health facilities.[55-57]

Gombe State, northeastern Nigeria

Figure 1.4 Map of Gombe state, northeastern Nigeria



Source: Profoss (derivative) and Uwe Dedering (original), CC BY-SA 3.0.[58]

The studies within this thesis focus on Gombe State (Figure 1.4), one of six states in northeastern Nigeria. Since 2011, the population of northeastern Nigeria has been affected by persistent conflict and violence.[59-64] While estimates for maternal mortality are unreliable for Gombe State, the 2015 estimate of the maternal mortality ratio in northeastern Nigeria was considerably higher than the rest of the country at 1,549[‡] maternal deaths per 100,000 live births.[65 66] The 2017 Multiple Indicator Cluster Survey estimated the neonatal mortality rate for Gombe State at 35[‡] per 1,000 live births, aligned with the national estimate of 36 [28-47] per 1,000 live births.[5 67] The following are estimates for Gombe State for 2018, the final year of the thesis study period: Gombe had an estimated population of 2.9 million and was predominantly rural.[68] Nearly 35% of the women reported some primary school education. During their last pregnancy, 46% of women reported at least one antenatal care visit with a doctor, nurse, or nurse-midwife and 28% gave birth in a health facility.[50] Over 70% of facility deliveries took place in rural public primary health facilities.[69]

‡ No confidence intervals were available for the above-cited maternal mortality ratio of northeastern Nigeria and neonatal mortality rate for Gombe State.

For the principal study periods covering this thesis, June 2015-December 2018, Gombe State had 11 local government areas (LGAs, district-equivalent) with 114 administrative wards (sub-district equivalent), which was 10-11 wards per LGA.[68] There were 587 primary health facilities and 28 referral facilities distributed throughout Gombe State.[70]

In 2016, the Gombe State Primary Health Care Development Agency, responsible for implementing *Primary Health Care under One Roof* , spearheaded an initiative to improve MNH outcomes by increasing outreach and education to communities; strengthening the capacity of facilities to deliver quality antenatal-postnatal care, labor and delivery, and neonatal care; and promoting measurement, learning, and evaluation to track program progress and improve accountability.[65] One goal for this initiative was to build capacity and appoint one "priority" primary health care facility within each of the 114 wards. By the end of 2018, capacity building was ongoing and 57 facilities (50% of the 114 wards; 10% of total primary health care facilities in Gombe State) had been designated as a "priority" primary health facility.[71] The London School of Hygiene & Tropical Medicine (LSHTM), through the Informed Decisions for Actions in Maternal and Newborn Health (IDEAS) Phase 2 Project, supported the Gombe State Primary Health Care Development Agency to track program progress for the MNH initiative by conducting extensive data collection activities. Later in this chapter, I will describe the IDEAS Phase 2 Project (page 26), as this thesis has drawn from the project's facility-level and population-level datasets.

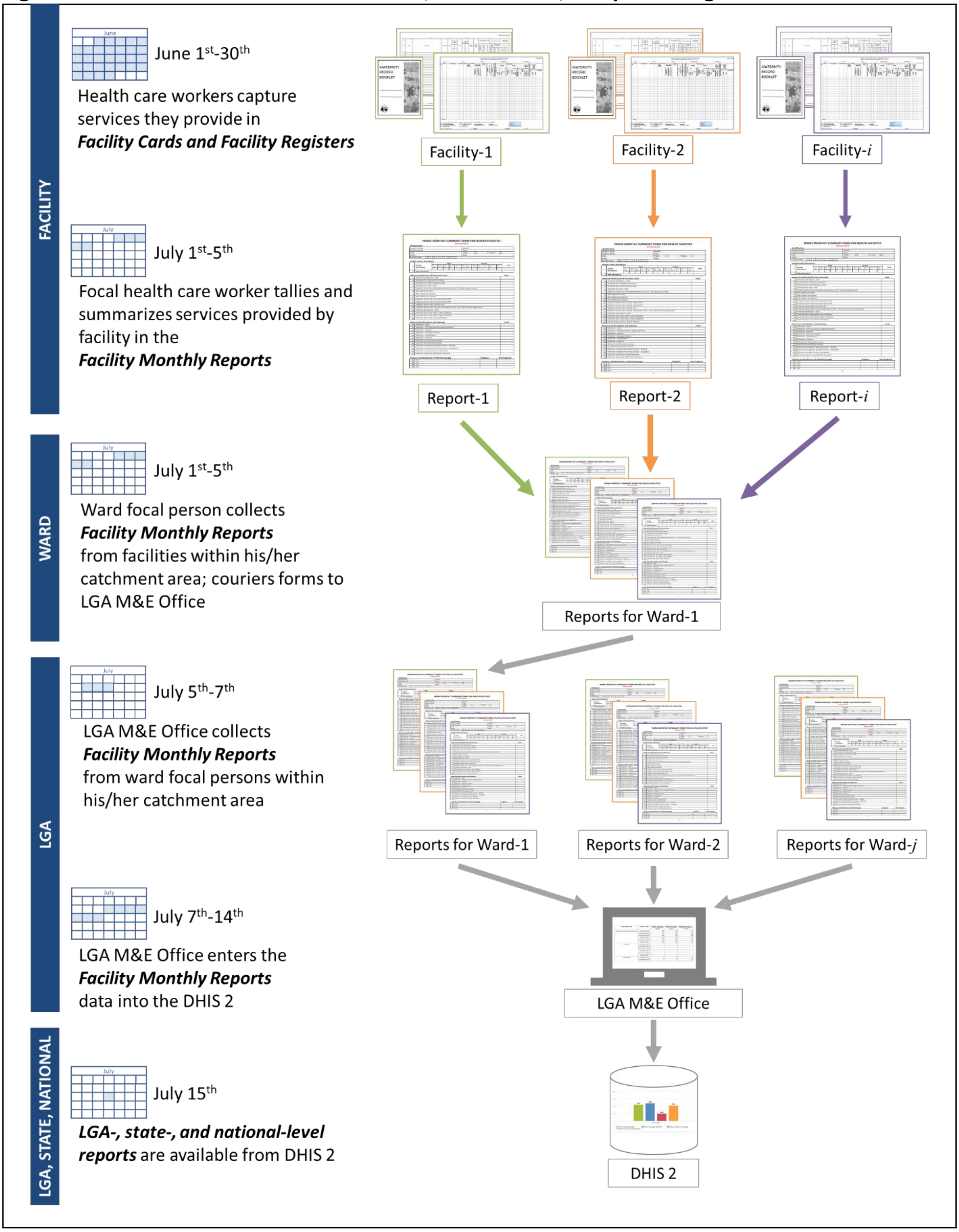
Routine health information system for Nigeria and Gombe State

In 2013, Nigeria expanded beyond paper-based RHIS and adopted DHIS 2 to support data collection, transmission, and processing of community and facility data to the district-, state-, and national-levels. The overall RHIS functioning in Gombe State has been similar to other states in Nigeria.[72] During the study period of this thesis, Gombe State's monitoring and evaluation (M&E) Office within the Gombe State Primary Health Care Development Agency's Directorate of Planning, Research, and Statistics had the primary responsibility to ensure the smooth functioning of the RHIS. The State

M&E office was tasked with setting standards, procedures, and timelines for the capture, collection, validation, and reporting of data from the communities through to the state office. Each district had an LGA M&E officer responsible for ensuring that these standards, procedures, and timelines were upheld for their respective facilities and communities.[72]

As noted below in Figure 1.5, Gombe's RHIS included paper-based and electronic forms for data collection, reporting, and transmission. Facilities used paper-based records and registers for individual-level data. Facilities then tallied a subset of these data into a standardized paper-based monthly report. At the end of each month, these paper-based monthly reports were submitted to appointed focal persons at the ward-level. These ward focal persons then collected the monthly reports for their catchment facilities and couriered them to the LGA M&E officer. The LGA M&E officer was then responsible for entering these paper-based monthly reports into an electronic version in DHIS 2. At each step, it was expected that the quality of data would be inspected before submission to the following level.

Figure 1.5 Gombe state RHIS data collection, transmission, and processing



Notes:

LGA=local government area; M&E=monitoring and evaluation; DHIS 2 = District Health Information Software, version 2.

1.5 IDEAS Phase 2 data quality intervention

This thesis evaluates the quality of routine data in primary health facilities to monitor MNH in Gombe State, Nigeria. In Study 3 (chapter 7), I examined any changes in the metrics of routine data before and after a district-focused data quality intervention, which took place from April 2017-December 2018. The data quality intervention was implemented within the IDEAS Phase 2 Project at LSHTM (introduced earlier as the Informed Decisions for Actions in Newborn and Maternal Health Phase 2 Project at the London School of Hygiene & Tropical Medicine). In this section, I provide background information on the IDEAS Phase 2 Project and the intervention.

IDEAS Phase 2 Project

The IDEAS Phase 2 Project was a four-year measurement, learning, and evaluation project covering 2016-2020 and funded by the Bill & Melinda Gates Foundation to support the Gombe State Primary Health Care Development Agency's initiative to improve MNH outcomes within primary health care.[73] In Gombe State, IDEAS worked with government and implementing partners to improve measurement and accountability in MNH. IDEAS engaged in extensive quantitative and qualitative data collection at the facility and household levels. This included bi-yearly facility-level surveys to assess service availability and readiness, bi-yearly direct clinical observations of labor and delivery events, and annual household-level surveys to understand access to and content of MNH care. The relevant data collection activities are described in more detail in chapter 4, where I present the data sources used in this thesis.

In late 2016, the Gombe State Primary Health Care Development Agency requested support from the IDEAS team to improve local decision making within Gombe. The IDEAS team proposed an intervention that would emphasize working with LGA-level staff to improve the quality of MNH data documented at the facility-level.

IDEAS Phase 2 data quality Intervention

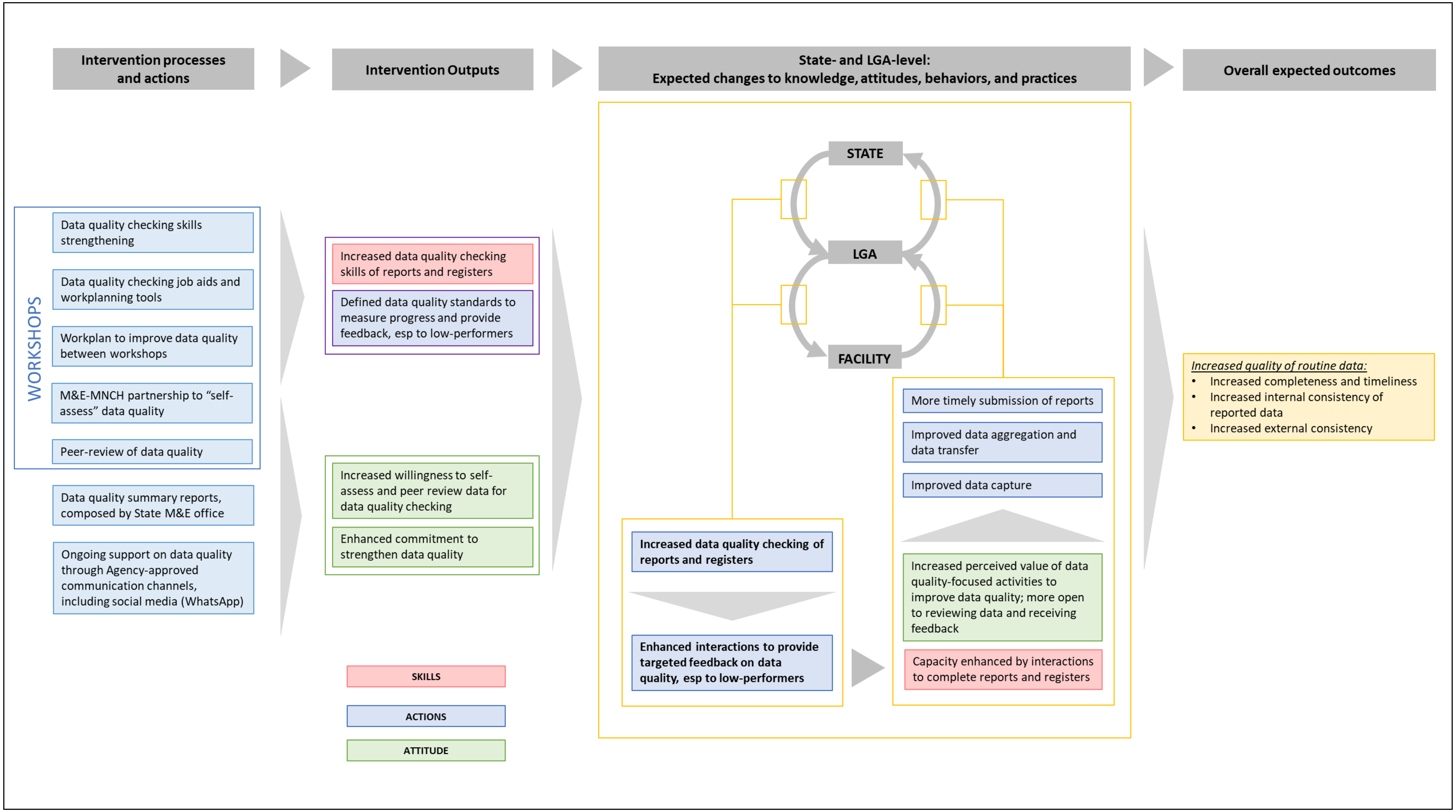
Supported by the preliminary results of the literature review described in chapter 2 and based on an understanding of Gombe's RHIS, I developed a theory of change and designed an intervention to improve the quality of routine MNH data in primary health facilities. Figure 1.6 illustrates the intervention's theory of change.

The data quality intervention description that follows overlaps with the intervention description in Study 3 (chapter 7). I have kept the overlapping descriptions to ensure this chapter can provide a comprehensive, stand-alone introduction to the thesis.

The intervention focused on strengthening the data quality checking skills of the existing LGA (district-level) staff. It was designed to optimize the existing LGA-level supervision responsibilities, adding job aids and defining feedback standards to provide structure to their current data quality checking duties and to target their feedback to facilities based on performance. By presenting this intervention as a facilitative layer for existing responsibilities and by leveraging scheduling for current activities to minimize cost, this intervention intended to maximize the chances of sustainability if expected outcomes were to occur.

There was an emphasis on the partnership between the LGA M&E officer and the LGA maternal, newborn, and child health (MNCH) coordinator to underscore the link between the quality and use of routine data for program monitoring and decision making.[74] The intervention included the following activities: (i) data quality learning workshops to present data quality self-assessment findings and develop workplans for improvement; (ii) defining data quality performance standards and milestones for completeness, timeliness, and consistency; (iii) introduction of job aids for self-assessment of data quality; (iv) monthly data quality summary reports; (v) deliberate practice of constructive feedback to peers and low-performing facilities to promote a positive culture of data use; and (vi) ongoing engagement on data quality issues through government-approved communication channels, including social media applications.

Figure 1.6 Theory of change: IDEAS Phase 2 Project intervention to improve the quality of routine MNH data in Gombe State, northeastern Nigeria



Four workshops took place, one every six to nine months over the 21-month intervention period, April 2017-December 2018. Approximately one day of the workshop was devoted to self-assessment and to strengthening data quality checking skills using data that the M&E officers and MNCH coordinators brought from their facilities. Based on the WHO data quality review toolkit for facility data[75], job aids were developed to facilitate understanding and practice of key data quality checking concepts. Another day was devoted to sharing their self-assessment findings for feedback and to developing workplans to improve routine data quality within their own LGA in-between workshops.

To promote a positive culture of information use, the LGA teams were given training and expected to deliberately practice providing constructive feedback to peers throughout the workshops.[76] The teams were expected to provide encouraging feedback, in addition to feedback on poor performance.

Ongoing peer communication in-between workshops was a pre-planned activity for the intervention. As an output from the first workshop's session to develop a plan for improving data quality, the attendees decided to revive a dormant communication channel in the instant messaging application, WhatsApp Messenger (WhatsApp Incorporated, Mountain View, California, USA), to continue data quality-related discussions in-between workshops and promote information-sharing.

Twenty-eight individuals participated in the workshops and ongoing communication in-between workshops. These included the M&E officer and MNCH coordinator from each of the 11 LGAs. At the state-level, four officials participated: the director of the State's planning, research, and statistics department, the State's M&E officer, the State's health management information systems officer, and the State's MNCH coordinator. From the IDEAS Phase 2 Project, I co-facilitated the workshops with the IDEAS Nigeria Country Coordinator, Dr. Nasir Umar.

Monthly data quality summary reports were also disseminated, allowing LGAs to see their progress over time. These involved tabulations and visualizations of data completeness, timeliness, and internal consistency. While the IDEAS team anticipated taking on this role in the beginning to build capacity within the Gombe State Primary Health Care Development Agency team, the State M&E officer immediately took on this responsibility from the first workshop, based on the job aids provided.

Chapter 2: Literature review: quality of routine health facility data

2.1 Introduction

Quality routine data, when aligned with the information needs of the users, can inform decision making to optimize the quality of care provided to mothers and newborns in health facilities.

In this chapter, I present a literature review on the quality of routine health facility data. I begin with the literature review questions and methods. Based on the review, I provide a definition for data quality and then describe its dimensions and metrics. In the last two sections, I present evidence on the interventions intended to improve data quality and the identified factors associated with data quality.

2.2 Literature review questions

Given the wide-ranging discourse and relevance of data quality in technical areas within and outside public health, the literature review focused on public RHIS in resource-limited settings. The literature review aimed to answer the following questions:

1. How has data quality been defined?
2. How has the quality of routine facility data been measured?
3. What factors are associated with the quality of routine facility data?
4. What interventions have been implemented to strengthen the quality of routine facility data?

2.3 Literature search strategy

I conducted a narrative review of the published literature on the quality of routine health facility data. The literature search focused on three concepts integral to the review questions: (i) data quality, (ii) routine data, and (iii) health care facilities. Subject headings and key words, including proximity search terms, were used to make the search more inclusive. Concepts and search terms used are in Table 2.1.

Table 2.1 Literature search concepts and search terms

Concept 1: data quality		**Concept 2: routine data**
data quality	*proximity searching*[§]*:*	routine data
data accuracy	data *adj3* quality	medical record
data validity	data *adj3* accuracy	electronic medical record
data reliability	data *adj3* validity	electronic adj1 record
data availability	data *adj3* reliability	EHR
data completeness	data *adj3* availability	EMR
data timeliness	data *adj3* completeness	administrative data
data consistency	data *adj3* timeliness	monthly report
data concordance	data *adj3* consistency	monthly summary
data missing	data *adj3* concordance	health statistics
data error	data *adj3* missing	service statistics
data precision	data *adj3* error	routine health information system
data integrity	data *adj3* precision	routine information system
data confidentiality	data *adj3* integrity	district health information system
data comparability	data *adj3* confidentiality	district health information software
data relevance	data *adj3* comparability	DHIS
data quality improvement	data *adj3* relevance	DHIS2 OR DHIS?2
		health management information system
data quality intervention		HMIS
		health information system
		logistics management information system
Concept 3: health care facilities		LMIS
facility OR facilities		eLMIS
clinic OR clinics		eHMIS
primary health		medical record system
primary health center		
primary health centre		
primary health facility		
PHC		
health center		
health centre		
hospital		

[§] Proximity searching: The *adj* operator was used to specify how close search term words must be. For example, “data *adj3* quality” specified that “data” and “quality” can be up to three words apart. Thus, the search would find “data quality”, “quality data”, and “quality of the data”.

The literature review period did not have a time limit and it included any health program (i.e., MNH, malaria, immunization). To refine the literature review search, I included studies that satisfied the following criteria:

1. The study included a qualitative or quantitative assessment of routine data quality at the facility-level.
2. The study occurred in a low- or middle-income country as categorized by the World Bank.[77]
3. The study was published in English.

After consulting with a LSHTM librarian and the IDEAS Phase 2 Project literature review specialist, I searched four databases: MEDLINE, EMBASE, Global Health, and Web of Science. Duplicates were removed through EndNote X8.2 (Clarivate Analytics, Philadelphia, Pennsylvania, USA) followed by a manual search for duplicates. Following this, abstracts and titles were screened according to the three criteria described above. For the remaining abstracts, the full texts were assessed for eligibility. The reference lists of the articles meeting the above criteria were searched to identify other relevant studies.

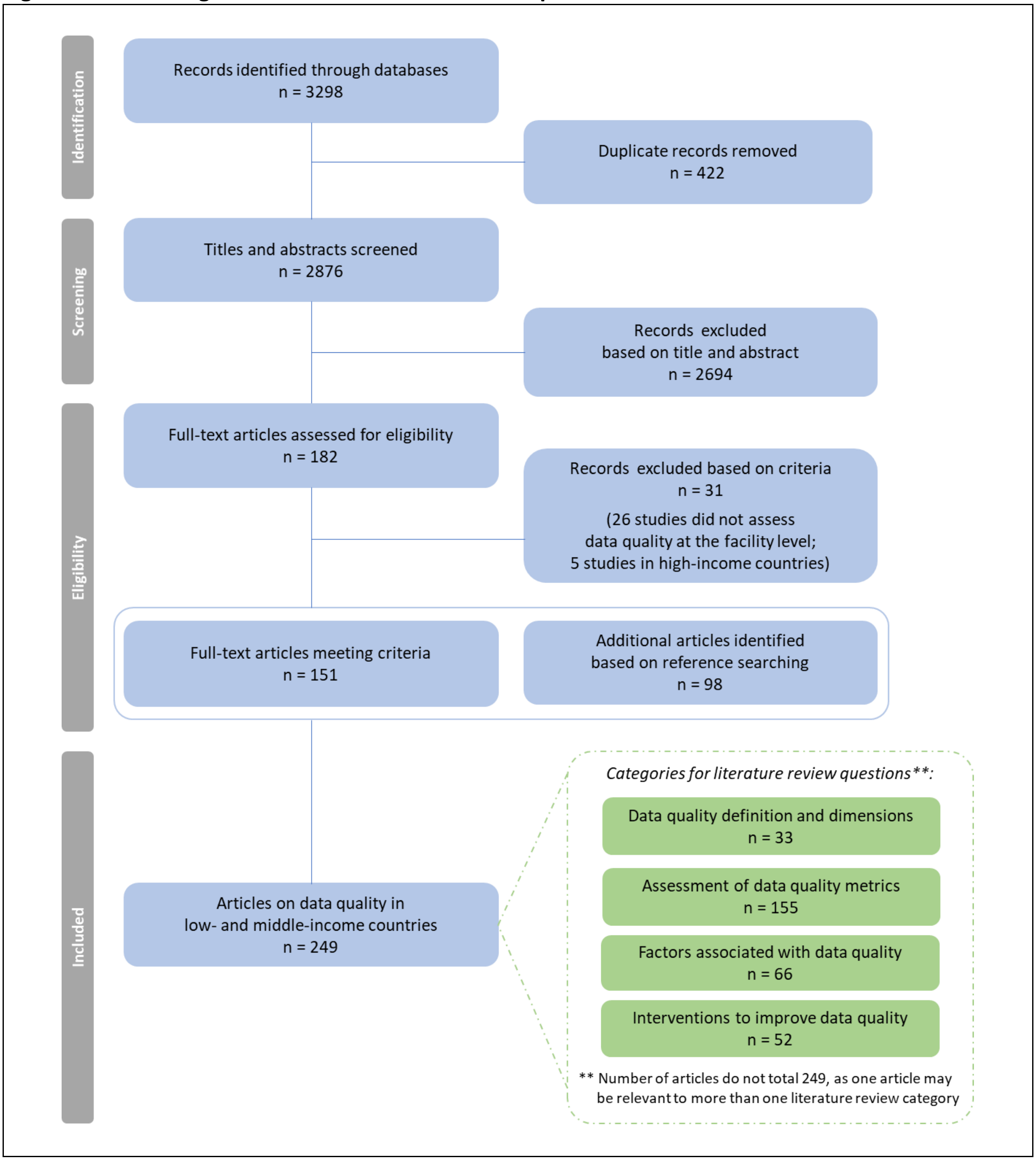
The articles were categorized to align with the literature search question(s) the study would best contribute to: defining data quality and the data quality dimensions; studies which assessed at least one data quality metric; studies which described an intervention intended to improve data quality; and qualitative or quantitative studies which assessed factors associated with data quality. An article may be placed in multiple categories.

The data extraction form included study type, country and setting (urban/rural), health program, facility type, sample size and selection, the data quality intervention (if any), the tools used to assess data quality, data quality metrics assessed and their results, and factors associated with data quality.

2.4 Literature search results

A flow diagram of the literature search process is presented in Figure 2.1.

Figure 2.1 Flow diagram of literature review search process



Through the database search, 2,876 articles were identified once the concepts were combined and duplicates were removed. A further 2,694 were excluded based on a review of the titles and abstracts. The main reason for excluding abstracts was due to health coverage estimates being the main outcome of interest; though the abstract mentioned data quality, data quality metrics were neither assessed nor quantified. Other reasons for exclusion were that the study did not assess facility-level data, did not take place in a low- or middle-income country, or did not have the full article available in English.

Thirty-three (33) documents were identified to define data quality and its dimensions: eight theoretical discussions of data quality [29 39 78-83]; 10 documents which reviewed the literature on data quality or presented a review of tools available to assess data quality [84-93]; 15 tools to assess data quality in low- and middle-income countries [33 75 94-106]. I prioritized these documents as definitions for data quality and its dimensions would have been the natural starting point for literature reviews and tools intended to examine and measure data quality.

A total of 155 studies were identified that examined at least one data quality dimension. These studies were further categorized according to the following data quality dimensions: completeness and timeliness (95 articles); internal consistency (97 articles); external consistency (23 articles); and validity (17 articles). Appendix 1 presents a table for the 155 studies by data quality metric and a complete reference list. An article that assessed more than one dimension was placed in more than one category. The rationale for categorizing the articles into these data quality dimensions are described in the upcoming section “Data quality dimensions used for this thesis”.

To complete the literature review, 66 studies were identified which examined factors associated with data quality and 52 studies were identified which described an intervention aimed at improving data quality.

2.5 Defining data quality and its dimensions

A general, working definition of data quality across peer-reviewed and grey literature is related to its "fitness for purpose" to reflect the suitability of data according to need and context.[33 75 81 82 88] Adapting a definition from the International Organization for Standardization, a literature review by Arts, de Keizer, and Scheffer (2002) offered a user-focused definition to describe data quality as "the totality of features and characteristics of data, that bear on its ability to satisfy the needs that result from the intended use of the data".[82 84]

Within the PRISM framework presented in chapter 1 (see Figure 1.3, page 19), data quality has been portrayed as an outcome that reflects how these inherent characteristics are preserved throughout the data collection, data transmission, data processing activities.[99] Data collection is the process of capturing data for clinical and administrative actions taken by health system actors. Data transmission, which can be vertical or horizontal, refers to how data moves among interdependent entities to ensure that administrative, management, and political decisions are based on the same information. Data processing is the cleaning and arrangement of information for analyses and with minimal errors to reduce bias in decision making.[29 99]

Most often, data quality has been described as a multi-dimensional concept, with each dimension referring to a unique feature of data.[39 75 78 79 81 83 84 86 88-90 94 97 103 104] In a literature review by Chen et al (2014), the authors found 49 "attributes" to describe data quality in public health information systems, underscoring its multi-dimensional nature.[86]

Accuracy, completeness, and timeliness have endured as key dimensions for describing data quality.[39 75 78 83 84 86 88 94 97 103] Accuracy, as a proposed data quality dimension, has reflected the extent to which data truly represent the event, situation, resource availability, or outcome. Completeness has reflected the extent to which data are present to portray the event, situation, resource availability, or outcome. Timeliness has reflected the extent to which expected data are recorded or reported by a given timeline.

In addition to accuracy, completeness, and timeliness, other dimensions have been suggested by researchers and from expert consultations within global health: reliability and consistency[31 78 83 90 94 97 100], relevance[29 31 83 87 89 90 94], confidentiality[31 90 97 100], precision[83 97 100], accessibility[31 90 94], integrity[31 97 100], and legibility[94].

To translate the data quality dimension into practice, metrics are used to quantify and interpret the achievement of the given dimension.[92] Global health initiatives, such as Gavi the Vaccine Alliance and the Global Fund, proposed data quality metrics to ensure that management and resource allocation for programming were based on complete, timely, and accurate data.[95 97] Among the first data quality assessment tools was developed by the WHO for Gavi-supported immunization programs.[95 96] Later, this tool was adapted by the USAID-supported MEASURE Evaluation project and the Global Fund to assess the data generated within HIV/AIDS, malaria, and tuberculosis programs.[97 100 103] In these tools, three data quality metrics were used to quantify the dimensions of completeness and timeliness: completeness of facility reporting, completeness of data, and timeliness of facility reporting. To quantify the dimension of accuracy, a metric referred to as the "verification factor" was proposed. Determining the verification factor involved a field-based exercise in which the aggregate data reported by a facility was compared to a fresh re-count of the facility's source documents to examine the level of agreement.

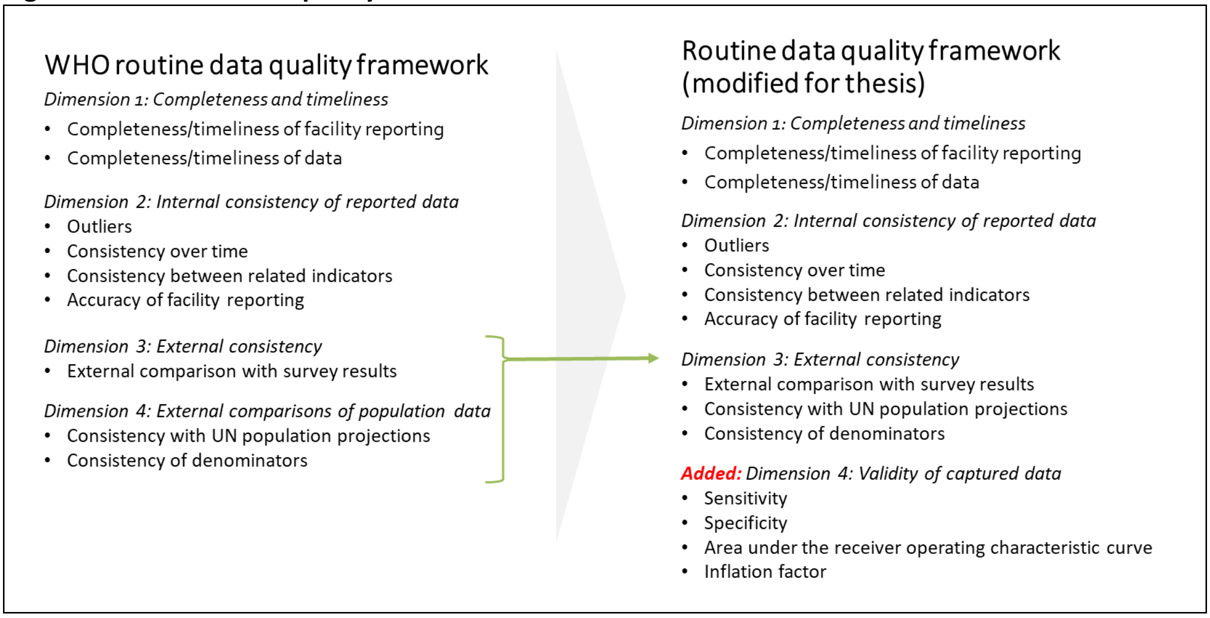
In early 2017, a global consultation bringing together experts from WHO, USAID/MEASURE Evaluation, the Global Fund, Gavi the Vaccine Alliance and other partners, published a reorganization of the data quality dimensions within the context of RHIS facility-based data. This built on the collective experiences of the institutions involved, including experience gained from applying the WHO Guide to health facility data quality report card.[101] The facility-focused data quality framework proposed four broad, descriptive dimensions: completeness and timeliness; internal consistency of reported data; external consistency; and external comparisons of population data. MEASURE Evaluation led the multi-partner publication of a curriculum, *Routine health* *information systems: a curriculum on basic concepts and practice*, which utilized this data quality framework within the overall context of RHIS.[33] WHO led the multi-partner publication of a toolkit, *Data quality review: a toolkit for facility data quality assessment*, which guided the quantification of each data quality dimension's metrics through two assessment exercises: (i) a desk review exercise of available reported data and (ii) a field-based data verification exercise of reported data.[75] While the metrics proposed to calculate the fulfillment of each dimension were not novel, the collection of metrics differed from other frameworks by acknowledging the RHIS context, including the relevance of quantifying the agreement between routine data and external sources.

2.6 Data quality dimensions used in this thesis

This thesis aims to evaluate the quality of routine data in primary health facilities for monitoring maternal and newborn care in Gombe State, northeastern Nigeria. For this thesis, it seemed sensible to work from the data quality framework presented in the 2017 WHO data quality review toolkit[75], which represented the latest consensus by global experts and institutions on the quality of facility data within the RHIS context.

I have adapted the data quality framework with a few modifications, as shown in Figure 2.2.

Figure 2.2 Routine data quality: dimensions and metrics used for this thesis



Source for WHO routine data quality framework (left-side of figure): World Health Organization; 2017.[75]

First, I have added validity as a data quality dimension to capture the inherent characteristic of the data 'truthfully' reflecting the event or situation intended to be documented. This dimension aligns most with accuracy and assumes the existence of a gold standard or knowledge of what the truth is for a given event, situation, or outcome. As I will describe in the methodology chapter, chapter 4, this thesis uses data from direct clinical observations of service delivery which could serve as the gold standard. Because it is a resource-intensive exercise and requires specialized training to observe and document processes, events, and outcomes in service delivery, having access to this dataset presented a unique opportunity to measure validity for routine data.

Second, I have combined the data quality dimensions ‘external comparisons of population data’ and ‘external consistency’ into one dimension: external consistency. The metrics of ‘external comparisons of population data’ reflect specific instances of external consistency and use more stringent criteria for agreement between data sources than the ‘external comparison with survey results’ metric. For ‘external comparisons of population data’, we compare population denominators of interest which could be used to calculate coverage based on routine data, including the comparison with external sources such as the United Nations population projections and other health program data. Nevertheless, we are primarily examining data sources where data are collected through different methods and determining their level of agreement.

2.7 Measuring data quality

Based on the modified routine data quality framework (see Figure 2.2 above), I will review the most common metrics used in the literature to quantify the four data quality dimensions used in this thesis: completeness and timeliness, internal consistency of reported data, external consistency, and validity.

Dimension 1: Completeness and timeliness

The data quality dimension of completeness and timeliness describes the extent to which facility data are available and current for events, situations, outcomes, or resources available. The data quality metrics for completeness, along with accuracy of facility reporting, are among the most reviewed in the literature. Completeness also has been referred to as availability.[43 90 107-111] The base calculations for completeness and timeliness metrics have been uniform in the literature: the metrics include a numerator that indicates how many units have provided data and a denominator that indicates how many units are expected to provide data. However, the application of the metric can vary: the metric can be measured for a facility or group of facilities, at one point in time or across time, for a small or large set of data elements.

Metric 1: Completeness of unit reporting

To assess completeness of unit reporting, the unit may be defined as the facility or the administrative unit (i.e., LGA or state) where reports are generated and submitted to the next level of supervision. The reports can be for any frequency (i.e., monthly, quarterly, annually). Regardless of the content of the report (even if it contains missing data), a completeness of unit reporting of 100% indicates that all the expected units have submitted a report.[75]

For my literature review, Appendix 1 lists 42 studies which included a metric for completeness of facility reporting, typically calculated as follows:

$$\text{Completeness of unit reporting (\%)} = \frac{\text{Number of unit reports submitted}}{\text{Number of unit reports expected}} * 100\%$$

Determining the numerator could be based on a physical count of paper-based facility reports as described by Gimbel et al (2011) or reviewing electronic versions of the report in information systems software such as DHIS 2 as described by Manya et al (2016).[108 112]

Metric 2: Completeness of data

The completeness of data metric reflects the extent to which select data have been reported. Ideally, completeness of data distinguishes between true zero values (the service was offered, but no one came for the service) and missing values (the service was offered and provided, but there was no value reported). When the health information system is not designed to distinguish between true zero values and missing values, the completeness of data metric could be an underestimate as facilities reporting true zero values are not counted in the numerator. A completeness of data of 100% indicates that a value was submitted for all instances where a value was expected for a specified data element.[75]

For my literature review, Appendix 1 lists 66 studies which included a metric for completeness of data, usually calculated in one of two ways:

Metric 2A: Completeness of data (%)

$$\text{Completeness of data (\%)} = \frac{\begin{array}{c}\text{Number of reports submitted}\\ \text{with a non-zero (or non-missing) value}\\ \text{for the specified data element}\end{array}}{\begin{array}{c}\text{Number of reports expected}\\ \text{to have a value for the data element}\end{array}} * 100\%$$

Metric 2B: Missing data (%)

$$\text{Missing data (\%)} = \frac{\text{Number of reports submitted with a missing value for the specified data element}}{\text{Number of reports expected to have a value for the data element}} * 100\%$$

As mentioned earlier, the application of this metric can vary. For example, Makombe et al (2008) calculated the completeness of data based on non-missing/non-zero values for six prevention of mother-to-child transmission of HIV indicators and presented findings as the number of facilities where non-missing data was present for all six indicators.[113] By contrast, Mphatswe et al (2012) also calculated completeness of data for six indicators based on non-missing/non-zero values, but presented the extent of completeness for each indicator separately.[114]

Metric 3: Timeliness of unit reporting

The timeliness of unit reporting metric is an extension of the 'completeness of unit reporting' metric and further restricts the numerator to the number of reporting units (i.e., states, LGAs, or facilities) that have submitted their data by a given deadline. Similar to completeness, a timeliness of unit reporting of 100% indicates that all the expected units have submitted a report on time.[75]

For my literature review, Appendix 1 lists 28 studies which included a metric for timeliness of unit reporting, usually as follows:

$$\text{Timeliness of unit reporting (\%)} = \frac{\text{Number of unit reports submitted on time}}{\text{Number of unit reports expected}} * 100\%$$

Given that timeliness is usually considered at the report-level, not at the indicator-level, the presentations of findings have been fairly uniform.

Dimension 2: Internal consistency of reported data

For the data quality dimension of internal consistency, metrics are assessed based on data reported to a higher level of supervision. The metrics quantify the extent to which the reported data are consistent with each other in terms of plausible values, expected trends, and level of agreement within and across data sources. Similar to completeness and timeliness, the application of each metric assessment can vary: the metric can be measured for a facility or group of facilities; at one point in time or across time; for a small or large set of data elements.

Metric 1: Outliers

The assessment of outliers measures the extent to which a reported data value within a given dataset is extreme or potentially implausible compared to the other values in the dataset. For my literature review, Appendix 1 lists 11 studies which included an assessment of outliers in one of two ways:

Metric 1A: Moderate and extreme outliers, using standard deviations from the mean

Values within a given set of data can be assessed as a moderate outlier (+/-2 standard deviations, SD) or an extreme outlier (+/-3 SD) in relation to the mean value.[75]

Outlier:

> -3 SD	-2-3 SD	<-2 SD		<+2 SD	+2-3 SD	>+3 SD
extreme outlier	moderate outlier	plausible value	mean value	plausible value	moderate outlier	extreme outlier

Nisingizwe et al (2014) and Ouedraogo et al (2019) both provide an example of evaluating routine data for moderate and extreme outliers in Rwanda at the national level and Ethiopia at the sub-national level, respectively, using standard deviations in relation to the mean value.[34 115]

Metric 1B: Outliers, using a modified z-score

Alternatively, outliers can be assessed through a modified z-score applied to the median in a set of values, where a z-score greater than 3.5 is considered an outlier. The WHO data quality review toolkit has recommended this metric for smaller samples and is preferred over the unmodified z-score, which is applied to the mean, to better tolerate extreme values.[69] The value 0.6745 in the equation below refers to the 75th quartile of a standard normal distribution.[75 116] Maïga, et al (2019) provides an example where z-scores are used to detect outliers for four data elements in sub-national units across 14 countries.[38]

$$\text{Modified z-score } (M_i) = \frac{0.6745 * [\text{value} - (\text{median of sample values})]}{[\text{median}(|\text{value}_i - (\text{median of sample values})|)]}$$

Metric 2: Consistency over time

The consistency over time metric assesses the extent to which an indicator or data element exhibits (i) similar patterns as previous seasons or (ii) resembles an expected trend (i.e., increasing, steady, or decreasing trend). The approach for assessing consistency over time are not substantively different from an assessment of health coverage over time. For example, examining trends in first antenatal care visits over a three-year period can be a health program assessment of access to care or a data quality assessment of consistency over time. The difference is not in the data used, but in the intention to assess the plausibility and consistency of the indicator from a data quality review perspective.

For my literature review, Appendix 1 lists 7 studies which assessed an indicator's consistency over time with the intention of reviewing data quality.

Metric 2A: Consistency over time, using the mean of the comparison seasons

Five studies[34 115 117-119] assessed consistency over time as recommended by the WHO data quality review toolkit: (i) comparing the value of reference season to the mean value of the previous seasons and (ii) if the expected trend is similar to previous seasons, the reference value should be within +/-33% of the mean value of the previous seasons.[75] The metric was typically calculated as:

$$\text{Consistency over time} = \frac{\text{Cumulative value of data element for reference season}}{\text{Mean value of data element for the comparison seasons}}$$

Metric 2B: Consistency over time, using a modified z-score

Using the same metric as *Metric 1B* for outliers, a modified z-score was used for Maïga et al (2019) to assess consistency over time. For this assessment, the value of the reference period was considered to have "good consistency" if its modified z-score was lower than 1 SD from the median of the previous three years.

Metric 3: Consistency between related data

The consistency between related data metric quantifies the extent to which values for two or more data elements exhibit an expected relationship. For example, we would expect the number of women who received a uterotonic during the third stage of labor in a facility to be equal to or lower than the number of facility deliveries. When the expected relationship is not observed, this may suggest challenges with data quality.[75]

For my literature review, Appendix 1 lists 15 studies which included an assessment of the consistency between related data. The base calculation is uniform across studies, using the percentage difference or the ratio between the two values as follows:

$$\text{Ratio of data values} = \frac{\text{Value of data element \#1}}{\text{Value of data element \#2}} * 100\%$$

Where the assessments may differ is in the data elements or data sources that are compared. The metric for consistency between related data examines data that are collected at the same level of the health system, compared to the accuracy of reporting metric described later in this chapter which assesses consistency of the same data between different levels of the health system. Thus, the data may compare the relationship between data within the same register, such as the relationship between the first and third doses of diphtheria-tetanus-pertussis or the first and fourth antenatal care visits, both examined by Ouedraogo et al (2019). It may compare data across registers such as the relationship between first antenatal care visits and the first dose of diphtheria-tetanus-pertussis, as described by Nisingizwe et al (2014), or the relationship between antiretroviral treatment and tuberculosis treatment for patients living with HIV and AIDS, as described by Jamieson et al (2019). When the related data elements are expected to be equal, the WHO data quality review toolkit has recommended that the calculated ratio should be 100% ±10% (i.e., 90%-110%, inclusive).[75]

Metric 4: Accuracy of facility reporting

The accuracy of facility reporting metric involves a verification exercise in which reported data are compared to a fresh re-count of the source documents. This metrics examines the ability to tally and aggregate data as expected. Along with metrics for completeness, this is the most assessed metric within the literature and often referred to as "accuracy".

For my literature review, Appendix 1 lists 90 studies which included a comparison of reported data with a re-count of the data contained in the facility's source documents. The metric was quantified in at least 3 ways:

Metric 4A: Verification factor

The verification factor, also referred to as the accuracy ratio or consistency ratio, was the most common method of assessing accuracy of facility reporting. Sixty-seven (67) studies used the verification factor calculation to compare the aggregate data reported by facilities with a re-count of the data from the facility records and registers. The verification factor has been typically calculated as follows:

$$\text{Verification factor} = \frac{\text{Value of data element reported}}{\text{Value of data element when re-counted during assessment}} * 100\%$$

Among the earliest studies for this metric come from evaluation of immunization programs, boosted by the Gavi initiative and the WHO Immunization Data Quality Audit tool.[43 95 120-122] While the WHO data quality review toolkit has recommended that the assessed data values be within 10% of each other, such that the verification factor should range from 90%-110% inclusive, earlier studies had used different acceptability criteria.[43 113 122]

Metric 4B: Concordance

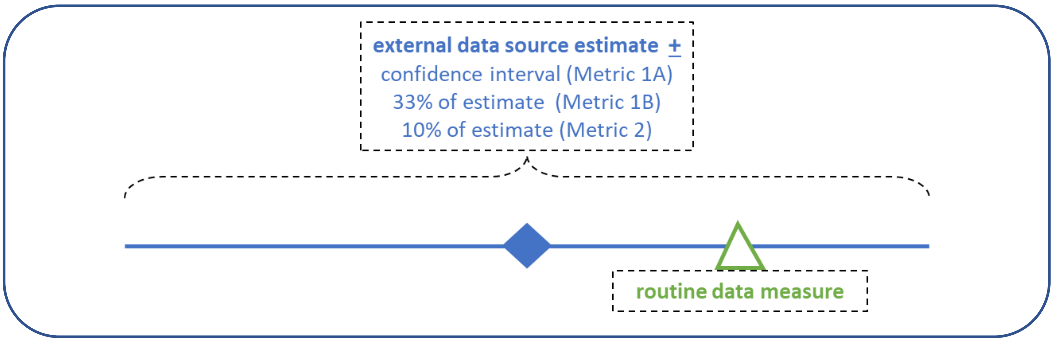
Concordance, as described by Wagenaar et al (2015) and Muthee et al (2018), has been used to assess the level of agreement between the documented and reported data as the aggregate data moves through the levels of the health system.[123 124] For example, in Wagenaar et al. (2015), a concordance score of 4/4 per facility (indicating 100% concordance) would be achieved for one indicator if the data maintained consistency across five health systems levels: paper facility register, paper facility report, paper district facility report, electronic district report, and electronic provincial report.

$$\text{Concordance} = \frac{\text{X data elements * Y reporting levels in agreement}}{\text{X data elements * Y reporting levels}} * 100\%$$

Metric 4C: Bland-Altman plots

Bland Altman analytical methods can be used to assess the agreement of two related data elements. Bland Altman plots provide a graphical presentation of the measurements with an upper and lower limit of agreement to indicate expected variation in measurement agreement. Bland Altman plots the absolute differences in the measurements (y-axis) against the mean of the two measurements (x-axis).[125 126] Hamainza et al (2014), Nicol et al (2016), and Ouedraogo et al (2019) provide examples of Bland-Altman plots to assess the agreement between re-counted and reported facility data.[115 127 128]

Dimension 3: External consistency



The data quality dimension of external consistency describes the level of agreement between routine data and an external data source for the same indicator.[75] For my literature review, Appendix 1 lists 23 studies which included a metric for external consistency. The general method for comparisons was the same, but the acceptability criteria for agreement depended on which data sources were being compared.

Metric 1: External comparison with survey results

As depicted in *Metric 1A* and *Metric 1B* in the above diagram for external consistency, when routine data are compared with external data sources such as the Demographic and Health Survey or Multiple Indicator Cluster Survey, these data are considered consistent if the routine data fall within the survey confidence intervals. The WHO data quality review toolkit further recommends that the routine data fall within +/-33% of the survey estimate if survey confidence intervals are not available.[75] For example, in Gimbel et al (2011), the authors compare facility-based data coverage for antenatal care, institutional birth, and the third dose of a diphtheria-tetanus-pertussis vaccine with estimates from the Demographic and Health Survey and Multiple Indicator Cluster Survey. The authors concluded that the routine data were acceptable for program monitoring as the routine data coverage estimates fell within the confidence intervals of the survey estimates.[108]

Metric 2: Consistency with UN population projections, consistency of denominators

To reflect the external consistency of routine data with population data from the United Nations or national statistical offices, such as Nigeria's National Bureau of Statistics, more stringent criteria can be applied to the absolute level of agreement between the data sources. WHO suggested that +/-10% be the criterion for agreement as these denominators could be used for monitoring and evaluation of health programs.[75] Two successive annual assessments in Cambodia demonstrated the consistency of the official national population projection within United National population projections, falling within the WHO-recommended agreement criteria for both years.[118 119]

Dimension 4: Validity

The data quality dimension of validity describes the extent to which a comparison data source (i.e., women's recall in a household survey or health workers' documentation in facility registers) reflects the process, event, situation, or outcome as they occurred. Assessment of this dimension requires a gold standard, such as a trained observer who witnessed the event and documented according to a comprehensive and pre-tested checklist. This is a resource-intensive exercise and is less feasible as an activity for continuous measurement and monitoring of data quality. When a gold standard is specified, the calculations have been uniform across studies and settings.[129-135] However, the data source designated as the gold standard may differ.

	Gold standard: event/behavior present	*Gold standard:* event/behavior not present
Comparison data source: Event/behavior present	True positive	False positive
Comparison data source: Event/behavior not present	False negative	True negative

Metric 1: Sensitivity

The sensitivity metric assesses the extent to which those who received a service or intervention according to the gold standard were correctly classified as having received the service or intervention in the comparison data source (i.e., women's recall in a survey or health worker documentation).[136 137]

$$\text{Sensitivity (\%)} = \frac{\text{true positive}}{\text{true positive + false negative}} * 100\%$$

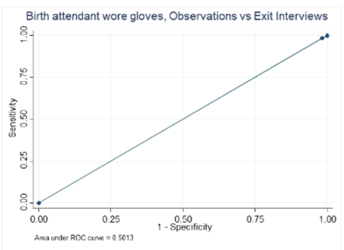
Metric 2: Specificity

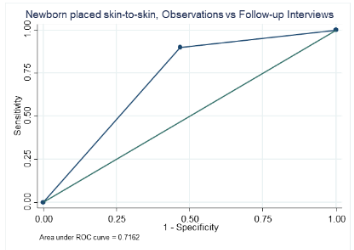
The specificity metric assesses the extent to which those who did not receive a service or intervention according to the gold standard were correctly classified as not having received the service or intervention in the comparison data source (i.e., women's recall in a survey or health worker documentation).[136 137]

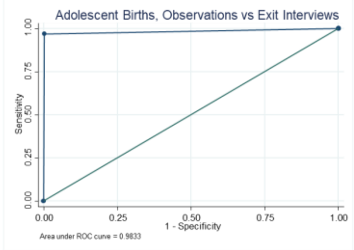
$$\text{Specificity (\%)} = \frac{\text{true negative}}{\text{true negative + false positive}} * 100\%$$

Metric 3: Area under the receiver operating characteristic curve

The area under the receiver operating characteristic curve (AUC) metric assesses the individual-level reporting validity for an indicator, such as whether a newborn was placed skin-to-skin immediately after birth. The AUC calculates the area under the curve which plots the 1-specificity against the sensitivity of a comparison data source (see below). The AUC represents the tradeoff between true positives and false positives in measuring the indicator. AUC values range from 0 to 1. An AUC of 1 indicates that the comparison data source (i.e., health worker documentation in facility registers) is a completely accurate measure of whether a service or intervention was received; an AUC of 0.5 is equivalent to a random guess.[137] An example of the AUC for values from 0.5 to 1 are as follows:







AUC = 0.5	**AUC = 0.7**	**AUC = 1.0**

Metric 4: Inflation factor

The inflation factor (IF) metric assesses the population-level validity for a given indicator. The IF is the ratio of the estimated population-based survey prevalence to the gold standard prevalence. Thus, the IF is used to determine the extent to which a survey-based prevalence would over- or under-estimate the 'true' population coverage. The IF changes as the population-based prevalence changes.[137] To determine the 'estimated population-based survey prevalence', the indicator's 'true' gold standard prevalence is applied to the indicator's calculated sensitivity (true positives fraction) and 1-specificity (false positives fraction); the formula for 'estimated population-based survey prevalence' is derived from Vecchio (1966).[136]

$$\text{Inflation factor} = \frac{\text{estimated population survey prevalence}}{\text{gold standard prevalence}} = \frac{[(\text{gold standard prevalence} * \text{sensitivity})] + [(1 - \text{gold standard prevalence})*(1 - \text{specificity})]}{\text{gold standard prevalence}}$$

2.8 Factors affecting the quality of routine data

Following the PRISM framework (see Figure 1.3, page 19), organization, behavioral, and technical factors affect the quality and use of routine data.[89] In this section, I present the factors cited in my literature review and organized them by the RHIS processes in the PRISM framework: data collection and reporting, data transmission and processing, data quality checking and feedback.

All RHIS processes (cross-cutting): A recurring theme while reviewing the literature was that the workforce itself at every level of the health system affects all RHIS processes. At the facility-level, the health workers' primary responsibility of care provision affects every RHIS process, including completeness and timeliness of data capturing and reporting.[29 120 138] At all levels, all RHIS processes are further affected by organizational factors such as staff shortage, attrition, turnover, and absenteeism, in addition to poorly defined roles and responsibilities for data-related tasks.[138-146] Finally, the attitude, level of knowledge, confidence, competence, and motivation to perform the data-related tasks affect how the RHIS processes are executed.[139 142 145-150]

Data collection and reporting: Assessments to evaluate routine data quality, including those using the PRISM framework, have noted considerably poorer data quality at the facility-level than at district-, state-, and national-levels, citing challenges in accurate data capture as well as in tallying and summarizing service data for monthly reporting.[89 151 152] Legibility and design of treatment cards and registers affect facility reporting, in addition to follow-up care. While compiling documentation for reporting, a health care worker's handwriting may be illegible on its own or exacerbated by the form's design which may not provide sufficient space or response options for the information requested.[142 153-158] In addition to suboptimal design of the tools, the tools may not be consistently available [139 142 146 148 158-160], with health care workers improvising their own tools [110 153 155 161 162]. While preparing reports, facility staff may be unclear about indicator definitions due to insufficient training or complex treatment guidelines.[141 146 147 157 158 163 164] Several studies noted the challenge of having multiple documentation sources for capturing data and multiple channels for reporting data.[74 139 156]

[158 165-168] For example, for malaria, data may be reported to at least two different information systems, surveillance information system and health management information system, and potentially a donor-mandated information system. Further, the multiple data elements for one client may be included in the outpatient register, inpatient register, and lab register. The health worker's behavioral factors may also affect data capture and reporting, such as perceiving the data collection redundant or irrelevant to their work [29 120], manipulating data due to financial incentives or fear of adverse consequences in employment when targets are not reached [76 120 121 142 149] However, at least one study noted improvements in MNH data completeness, timeliness, and accuracy with financial reimbursements to facilities offering delivery services for free.[112] Finally, lack of standard operating procedures or supplies for confidentiality and document storage may result in lost data or records.[121 147 153 169]

Data transmission and processing: Lack of resources such as regular electricity, transportation, or internet connectivity may prevent timely data transmission.[141 144 160 168 170 171] Paper-based information systems can be hampered by data collation at the facility- and district-levels and by miscalculations or data entry errors at all levels. [120 121 128 158 164] Efforts to digitize aspects of the RHIS processes, such as the use of electronic medical records or DHIS 2, have accelerated the aggregation of data at all levels and the creation of datasets to inform program monitoring and decision making. Nevertheless, data processing can be affected by suboptimal maintenance of the technology-based solutions such as the proliferation of duplicate indicators and facilities in software such as DHIS 2, which in turn affect how process and coverage indicators can be calculated without substantial additional data cleaning.[171 172]

Data quality checking, supervision, and feedback: Based on my literature review, among the most often cited factors contributing to poor data quality is the limited supervision to provide timely feedback on data collection and reporting.[27 30 36 43 74 123 128 138 139 145 158 166 167 173-175] This may be related to governance issues where there is no formal guidance on how supervision and feedback are to take place for data quality issues or poor coordination between staff across health system levels.[140 143 145 156] Further, this may be related to insufficient skills in data quality checking at different levels of the health system.[146]

Quantitative studies have also highlighted factors associated with routine data quality. Staffing availability is associated with data quality[113 123 145 171 176 177], with appointed staff for data entry and reporting[113 145 177] and training in data management associated[145 177] with favorable data quality. However, one study conducted in Malawi found a lack of association between data quality and the presence of a dedicated data clerk.[171] The receipt of supervision by a facility was also associated with higher completeness and accuracy. [113 145 177] In three studies, facility type was associated with data quality, with better quality associated with higher levels of care such as hospitals.[113 176 177] Of note, a study across 26 facilities in Sofala, Mozambique assessed factors associated with concordance for four indicators transmitted through five reporting levels. Higher concordance was associated with a higher number of facility staff employed, higher antenatal care visits, fewer inpatient beds, and lack of recent stockouts in essential commodities.[123]

2.9 Improving routine data quality

Interventions with the aim of improving data quality have been implemented which address the technical, behavioral, and organizational factors affecting the performance of the routine health information system (see PRISM framework, Figure 1.3 on page 19). This literature review highlights the range of interventions where: (i) the improvement of routine data quality was among the stated objectives and (ii) there was a quantification of at least one metric to measure any possible changes in data quality.

Data quality checks with feedback, which are cited RHIS processes within the PRISM Framework, have been the fundamental building block of the interventions from my literature review. They have been noted as a low-resource and low-cost activity for strengthening data quality, particularly when implemented as a routine activity.[29 114 123 147 178] Data quality checks with feedback have differed by frequency (i.e., intermittent versus regular reviews) and "objectivity" (i.e., assessment by an internal/supervision team versus an external team). To highlight a study where data quality checks with feedback were the main components to assess data quality changes over time, we can look to the Bosch-Capblanch et al (2009) study of 41 countries which underwent an initial data quality audit for immunization programs supported by Gavi the Vaccine Alliance. An external research team assessed the accuracy of facility reporting for a third dose of diphtheria-tetanus-pertussis vaccine using the verification factor score. Six countries which "failed" the routine data quality audit were assessed again approximately two years later. During the second audit, the verification factor for five of the countries was not seen to differ substantially from the initial assessment. It should be noted that not even this was a pure "data quality check with feedback" intervention as acceptable quality of the reported data was a condition for payment for performance.[43] Another example of a data quality check with feedback but with greater frequency and internal data quality checks is the Umar et al (2018) study which assessed accuracy of facility reporting at the ward (sub-district) level. This was deemed more of a feasibility study. While accuracy of facility reporting was the stated objective, only results for completeness and timeliness were published, both metrics noting an improvement over approximately six months. Completeness of data improved from 97.5% to 98.6% and timeliness of reporting improved by 7.2%.[179] A study, by Westercamp et al (2019), compared the results of internal data quality checks with the results of an external team's audits. The study found that the internal team's self-assessment tended to be more optimistic about the accuracy of facility reporting, with the sites' self-assessment of discrepancies between registers and reports being, on average, 2% points less than audits conducted by the external evaluation team.[180]

Most interventions also included a knowledge transfer or knowledge sharing activity. These activities differed by the level of individual attention and content expertise of the facilitator (i.e., mentoring, training/workshop, coaching, supervision) as well as setting (i.e., on-the-job versus centralized). Knowledge transfer activities, such as mentoring, training, or workshops, offered an opportunity to receive additional skills building in data quality checking or data use. [74 114 143 149 165 170 181-186] Knowledge sharing activities such as data review meetings often bring together different health system-levels or peers within a health system level.[74 114 143 164 165 187 188] The content of these data review meetings could include understanding the relative performance of teams on service coverage indicators or on dimensions of data quality. In some studies, dashboards, district league tables, and rankings were used to visualize and communicate relative performance.[187 189 190] The often-cited Mphatswe et al (2012) study highlights the use of these components: trainings by an external team; monthly data review meetings by internal supervision teams using results of data quality checks by an external team; and intermittent audits conducted by external teams. Over 26 months, there was a reported increase in completeness of information for six data elements from 26% to 64%. Overall accuracy of facility reporting for these six data elements increased from 37% to 65%.[114]

To date, it is still unclear which combination of data quality assessments and knowledge transfer/sharing mechanisms optimize the quality and use of routine data. Table 2.2 highlights the range of interventions found in my literature review to improve the quality of routine data.

Table 2.2 Range of interventions to improve the quality of routine data

“Building blocks” of intervention
• Data quality checks at baseline and endline • Feedback
+ Knowledge transfer, knowledge sharing
• Supervision/in-service training[113 165 179 182 183 187 189 191-195] • Mentoring/coaching[149 170 188 195 196] • Training/workshop[74 114 143 149 165 170 181-186] • Data review meetings/collaboratives[74 114 143 164 165 187 188] • Rankings/league tables[187 189 190] • Ongoing data quality assessments[143 164 165 179 182 186 192 197-200]
+ Technology-based solution
Hardware: • Internet connectivity, servers[184 185] • Computer, tablets, phones[127 178 184-187 194 201-205] Software: • Health information system software for aggregate data, such as DHIS 2[74 178 184 185 206-209] • Software for individual records, such as electronic medical records and registers[124 165 176 178 183 197 205 210-214] • Data visualization and report generation[74 143 188]
+ Data collection and reporting
• Reporting forms[181 215] • Registers, records[74 178 188 206 216] • Workforce adjustments, task shifting[170 181 187 217]
+ Planning, improvement
• Notification/reminder systems for data collection and reporting[184 194 218] • Developing workplans, plan-do-study-act cycles[149 165 188 195]
+ Incentives
• Payment for performance[43 184 194]

The introduction of technology, either software such as DHIS 2 or a device to enhance data collection such as a tablet, has demonstrated improvements in completeness, timeliness, and error detection. However, these technology-based initiatives often required supervision, monitoring, and feedback to ensure errors were resolved and that data entered were accurate and consistent.[176 178 185 202] Similarly, addressing the complexity of data collection and reporting forms have demonstrated increased completeness of data, but mixed results on accuracy.[74 178 188 215 216] These activities required supervision and feedback to ensure that health care workers understood how the data should be tallied and summarized for accurate reporting.

While payment for performance has not been an explicit data quality improvement activity, linking data quality to payment has been used in immunization programs such as Gavi the Vaccine Alliance.[43 122] Motivation has been explored in qualitative studies of factors affecting data quality, but there is limited knowledge on tested incentive-based interventions that promote data quality improvement.[112]

Based on this review, evidence suggests that data quality improvement interventions such as those listed in Table 2.2, can improve the completeness, timeliness, and accuracy of facility reporting across reporting levels. Nevertheless, our understanding of how these interventions affect data quality beyond this subset of metrics is limited. There appears to be an implicit assumption that improvement in completeness, timeliness, and accuracy of facility reporting metrics would likely lead to an improvement in the other data quality metrics, but this relationship is not well-established in the literature.

Chapter 3: Aim and objectives

3.1 Aim

This thesis aims to evaluate the quality of routine data documented in primary health care facilities to monitor maternal and neonatal care in Gombe State, northeastern Nigeria.

3.2 Specific objectives

Objective 1: To quantify quality metrics for completeness and timeliness, internal consistency, and external consistency of routine MNH data *reported by*[**] facilities

Study 1 in chapter 5 addresses this objective and is presented as a published manuscript, drawing mainly on facility-reported data in DHIS 2 to assess the data quality metrics from the WHO data quality toolkit for facility data.[75]

Objective 2: To validate routine data *documented by*[**] facilities for monitoring maternal and newborn care

Study 2 in chapter 6 addresses this objective and is also presented as a published manuscript, drawing mainly on direct clinical observation data collected for a sample of women who gave birth in primary care facilities. Using the clinical observation data as a gold standard, we examined the validity of facility registers and women's self-reported data at different recall periods.

Objective 3: To assess changes in the quality of routine MNH data *reported by*[**] facilities before and after a district-level data quality intervention

Study 3 in chapter 7 addresses this objective and is presented in the format submitted to the journal. The study used similar analyses to that used for Objective 1 (Study 1), this time examining the data quality dimensions before and after the IDEAS Phase 2 data quality intervention (see "IDEAS Phase 2 data quality intervention", page 27).

[**] As noted in Chapter 1 "Overview of the thesis": This thesis draws a distinction between data *documented by* facilities at the time of service delivery, which would be used to aggregate the routine data *reported by* facilities.

Chapter 4: Methodology and data sources

4.1 Overview of thesis methodology

For this thesis, evaluating the multi-dimensional nature of routine data quality included two descriptive studies, with one study devoted to completeness, timeliness, and consistency and another study devoted to validity. The third study was a before-and-after study which assessed the data quality metrics with respect to the IDEAS Phase 2 Project data quality intervention. Below, I describe the design of each study.

Study 1: assessing the quality of data reported by facilities (thesis objective 1)

As the first study of this thesis to examine the quality of data reported by facilities, I was guided by WHO data quality review toolkit and its recommended metrics.[75] By using this collection of consensus-driven metrics, the study design choice seemed straightforward: a cross-sectional descriptive study of the quality of facility-reported data for July 2016-June 2017. This study period, July 2016-June 2017, was chosen as it aligned with the two most recent rounds of data collection from the IDEAS Phase 2 Project. Importantly, these data collection rounds included data extraction from facility registers which could be analyzed for the data quality metric accuracy of facility reporting. For the remaining desk review-based metrics, I used the facility-reported data in DHIS 2, the electronic version of the paper-based monthly reports. There has been evidence to support that the transcription of the paper-based monthly reports into DHIS 2 poses relatively less data quality challenges than the tallying and summarizing from the facility documentation to the paper-based facility reports.[90 142 161 219] There also has been a precedent for using the electronic monthly reports for comparison with the facility registers.[108 114 146 162 220]

Study 2: validating routine data documented by facilities (thesis objective 2)

To validate the data documented by health workers in the facility maternity registers, I was guided by the Improving Coverage Measurement for Maternal, Newborn, and Child Health Core Group which had developed and implemented a standard approach to validating MNH coverage indicators.[137] A collection of criterion validity studies were published which aimed to validate women's responses during household surveys compared to a gold standard measure for the "objective truth" such as direct observation of clinical care.[129-133 135 137 221] Understanding health worker documentation as a form of standardized self-report for service delivery, I chose to apply this approach to health worker documentation in facility registers for comparison with the direct observation of childbirth care. As a criterion validation study for childbirth care events and outcomes, sensitivity, sensitivity, and area under the receiver operating characteristic curve were the principal metrics for assessing individual-level reporting accuracy. The inflation factor metric, which compares the estimated population-based prevalence to the gold standard prevalence, was the principal metric for assessing population-level validity. While I describe the data sources in more detail later on in this chapter, there were three data sources of interest in this study for comparing with the direct clinical observations: women's recall approximately 24 hours after childbirth; women's recall 9-22 months after childbirth; and health worker documentation of childbirth events in facility register. This study combined five rounds of data collection from the IDEAS Phase 2 Project.

Study 3: assessing changes in routine data quality before and after a district-level intervention (thesis objective 3)

The last study included in the thesis provided a comprehensive assessment of the metrics before and after a data quality intervention (Study 3, Objective 3). As described in chapter 2 (see IDEAS Phase 2 Project and data quality intervention, page 26), the Gombe State Primary Health Care Development Agency requested support for a state-wide intervention. This was a non-randomized intervention to be rolled out at once in all 11 LGAs of Gombe State. A neighboring or similar state could have been chosen as a concurrent comparison group. However, the extensive IDEAS Phase 2 population- and facility-level data collection was available for Gombe State only. No resources were available to conduct the same level of data collection in other states, which would have allowed us to measure two metrics: (i) external comparisons with survey results using the population-level data; and (ii) accuracy of facility reporting using the data from facility register data extraction. For the remaining metrics of completeness, timeliness, and internal consistency, DHIS 2 data was available for other states and their facilities. Ultimately, I decided that being able to measure the accuracy of facility reporting metric was essential given their prominence in the literature as a key data quality metric within the internal consistency dimension. Thus, a concurrent comparison group was not possible to better understand the changes in data quality.

Focusing on the Gombe State Primary Health Care Development Agency as the audience and decisionmaker to continue, change, or end the proposed intervention, I chose a before-and-after study design to assess the nine data quality metrics and communicate their results.[222] The pre-intervention period would serve as the comparison group. I also considered an interrupted time-series analysis. The intervention had a defined starting point and for seven of nine data quality metrics, the routine data were available on a monthly basis. Indeed, two data quality intervention studies, Wagenaar et al (2015) and Westercamp et al (2017) had undertaken a time-series analyses.[123 149] However, for both studies the time-series were restricted to quantifying accuracy of reporting and an additional analysis on completeness of data.

Ultimately, with the Gombe State Primary Health Care Development Agency as the primary audience, it seemed sensible to present the same type of before-and-after analyses for each of the nine data quality metrics. I describe more of the strengths and limitations of the study design in the discussion chapter (chapter 8).

Table 4.1 below shows how the data quality metrics were assessed across Studies 1-3 (chapters 5-7), along with the data sources. Data sources are described later in this chapter.

Table 4.1 Summary of data quality metrics assessed in each results paper and the data sources

Routine data quality metric	Study 1	Study 2	Study 3	Data sources
Dimension 1: Completeness and timeliness				
Completeness of facility reporting	X		X	DHIS 2
Timeliness of facility reporting	X		X	
Completeness of data	X	X	X	
Completeness of information			X	
Dimension 2: Internal consistency of reported data				
Outliers	X		X	DHIS 2
Consistency over time	X		X	
Consistency between related data	X		X	
Accuracy of facility reporting	X		X	DHIS 2, facility registers
Dimension 3: External consistency of reported data				
External comparison with survey results	X		X	DHIS 2, household surveys
Dimension 4: Validity of routine data				
Sensitivity of routine data and women's recall, compared to birth observations		X		birth observations with: (i) matched facility registers, (ii) matched exit interviews, (iii) matched household interviews
Specificity of routine data and women's recall, compared to birth observations		X		
Area under receiver operating characteristics curve (individual-level validity)		X		
Inflation factor (population-level validity)		X		

4.2 Indicator selection

For the MNH indicators used for this thesis, I referred to two global strategy documents: Ending Preventable Maternal Mortality and Every Newborn Action Plan.[1 2] These documents described priority indicators to monitor progress towards targets during the Sustainable Development Goals era. The indicators in the strategy documents included both routine and rare events. Given the focus on routine data for monitoring in the WHO data quality review toolkit, I focused on care that every woman and newborn should receive and did not emphasize rare events or outcomes such as deaths, complications, extra care for women and their newborns.[75] The MNH indicators used for this thesis are included in Tables 4.2-4.4 of the next section, "Data sources".

4.3 Data sources

This thesis draws on multiple secondary datasets to measure the broadest set of quality metrics for routine data: DHIS 2, facility surveys, household surveys, and direct clinical observations. A brief description of each data source is provided below, followed by the analytical methods applied to answer each thesis objective.

Nigeria DHIS 2 for facility monthly reports

Description: The facility monthly reports in DHIS 2 are the electronic copies of reports submitted by facilities and entered into DHIS 2 by the LGA M&E officer. This thesis took monthly MNH data from DHIS 2 for Studies 1 and 3 (chapters 5 and 7). These data are listed in Table 4.2. An abridged version of the facility monthly report, in paper form and as in DHIS 2, is in Appendix 2.

Data quality dimensions and metrics: For this thesis, the facility data from DHIS 2 were used to calculate all metrics of three data quality dimensions in Table 4.2: completeness and timeliness, internal consistency, and external consistency. Two metrics, accuracy of facility reporting and external comparison with survey results, required DHIS 2 to be compared to facility registers and household surveys, respectively.

Table 4.2 Data elements downloaded from Nigeria DHIS 2 for analysis

	Assessing facility reported data in DHIS 2 (Study 1)	Assessing data quality intervention (Study 3)
Main denominators		
Facility deliveries	X	X
Facility live births	X	X
First antenatal care visits	X	X
Contact indicators		
Four or more antenatal care visits	X	
Total antenatal care visits		X
Delivery by a skilled birth attendant	X	X
Early postpartum-postnatal care for women and newborns	X	X
Content of care indicators – antenatal care		
Anemia: blood test	X	X
Proteinuria: urine test	X	
Syphilis testing		X
Iron supplementation	X	X
Tetanus protection	X	X
Intermittent preventive treatment of malaria in pregnancy	X	X
Known HIV status or tested for HIV and received results	X	
Content of care indicators – labor and delivery, postnatal care		
Baby weighed at birth		X
BCG vaccination during postnatal period	X	X
Oral polio vaccination at birth	X	X
Exclusive breastfeeding up to 6 months	X	
Newborn outcomes		
Live birth or still birth		X
Total	15	15

IDEAS facility surveys, including data extraction from facility registers

Description: Facility-level surveys, done in July/August each year of 2016-2018, were conducted in 97 primary and 18 referral facilities across Gombe State. The surveys were done to assess the capacity to provide maternal and newborn health services. Modeled after the WHO Service Availability and Readiness Assessment, the primary and referral facilities were drawn from a state-wide random sample of all government-owned primary health facilities and a census of all 18 government-owned referral health facilities.[223]

Importantly for this thesis, the facility surveys included data extraction from two facility registers (Nigeria health management information system, version 2013): (i) the antenatal and postnatal care register and (ii) the labor and delivery register. Table 4.3 lists the relevant data extracted from the facility registers. At each survey, facility register data were extracted for the six-month period immediately before the survey. For example, the survey conducted in July 2017 extracted the facility's register data for January-June 2017. Further, data extracted was at the aggregate level. To continue our example, when the data collector was extracting data for "first antenatal care visits" in January-June 2017, one value was reported for January-June 2017 rather than six separate monthly values (i.e., one value for each month). A copy of the facility survey data extraction sheet is in Appendix 3.

Data quality dimensions and metrics: The facility register data were compared with facility DHIS 2 data to measure one key metric of the data quality dimension of internal consistency of reported data: accuracy of facility reporting.

Table 4.3 Data elements extracted from maternity facility registers to compare with DHIS 2 data

Main denominators
Facility deliveries
First antenatal care visits
Contact indicators
Total antenatal care visits
Delivery by a skilled birth attendant
Total postnatal care visits
Early postpartum-postnatal care for women and newborns
Content of care indicators – antenatal care
Syphilis testing
Content of care indicators – labor and delivery, postnatal care
Use of partograph during delivery

IDEAS household surveys

Description: Household-level surveys, also done in July/August each year of 2016-2018, were conducted in the catchment areas of the aforementioned 97 primary health facilities to assess access to and quality of maternal and newborn services.[65] These catchment areas represented 79 enumeration areas, with some facilities serving more than one enumeration area. All households in each enumeration area were surveyed (or in a segment of 75 households from the enumeration area if more than 75 households were present). The household survey contained two modules of interest: (1) a women's module asked all women aged 13-49 years and normally resident in the household about the health care available to them, their recent contact with frontline workers and their birth history in the two years preceding the survey; and (2) a mother's module asked all women who reported a birth in the last two years (identified in the women's module) a detailed set of questions about their contact with health services across the continuum of care from pregnancy to postnatal care. Table 4.4 lists the relevant coverage estimates determined from the household surveys. An abridged version of the IDEAS Phase 2 Project household survey is in Appendix 4.

Data quality dimensions and metrics: For this thesis, household survey estimates for maternity-related events and services were compared with DHIS 2 data for the same recall period. These data were used to examine one metric of the data quality dimension of external consistency: external comparison with survey results.

Table 4.4 Coverage estimates from the household surveys to compare with DHIS 2 data

Contact indicators
Four or more antenatal care visits
Delivery by a skilled birth attendant
Early postpartum-postnatal care for women and newborns
Content of care indicators – antenatal care
Anemia: blood test
Proteinuria: urine test
Syphilis testing
Tetanus protection
Intermittent preventive treatment of malaria in pregnancy
Content of care indicators – labor and delivery, postnatal care
Baby weighed at birth
Polio vaccination at birth
BCG vaccination during postnatal period

IDEAS facility births observations, matched with data sources

Overall description: Five rounds of direct childbirth observations took place approximately every six months, starting from June 2016 and ending in August 2018. Each data collection round lasted three weeks. To select the facilities for birth observations, a state-wide random sample of 107 facilities was drawn in November 2015 from the Gombe State's primary health facilities. The maternity registers were reviewed to determine the volume of births occurring in the previous six months. The 10 facilities with the highest number of births were selected for birth observations.[224]

Data quality dimensions and metrics: For this thesis, data collected from these five rounds of childbirth observations were used to examine the data quality dimension of validity. To examine the extent to which different data sources reflect childbirth events in the facility, direct childbirths observations were compared to: (i) data documented by health workers in facility registers; (ii) women's recall during facility exit interviews; and (iii) women's recall during household follow-up interviews 9-22 months after childbirth. Each of these data sources are described below.

Facility childbirth observations checklist

Description: The facility childbirth observation checklist was an extensive and structured checklist of approximately 375 items. A trained midwife-observer documented the checklist items which covered childbirth-related events and procedures from admission through the first hour after delivery. The checklist included the initial client assessment, each stage of delivery, immediate postpartum-postnatal care, and detailed items for any complications such as newborn resuscitation and postpartum hemorrhage.

Matched facility maternity register entries

Description: For each childbirth observation, regardless of newborn outcome (live birth or still birth), the midwife-observer extracted data about the observed woman from the labor and delivery register. In contrast to the IDEAS facility survey, data extraction here was at the individual-level and thus, was able to include details on each woman's background characteristics. Further, as will be noted in Study 1 (chapter 5), this data extraction was able to include data elements such as "active management of third stage of labor" and "essential newborn care", which are documented by facilities but not required to be reported by facilities in monthly reports.

Matched facility exit interviews

Description: Each observed woman leaving the facility with a live newborn was invited to participate in an exit interview. The exit interview included information recorded during the observation and harmonized with questions asked of women for childbirth-related events in the Demographic Health Survey and Multiple Indicator Cluster Survey. Women were asked about background characteristics, companionship during labor and delivery, perceptions of respectful care received, procedures and events that took place for her and her newborn such as blood pressure being taken and initiation of breastfeeding.

Matched household follow-up interviews, nine to 22 months after childbirth

Description: In March 2018, a subset of 445 women from three previous rounds of childbirth observations were followed-up in their home to validate their understanding of the childbirth-related events and procedures at a later recall period, 9-22 months after childbirth. The women were asked the same questions as in the facility exit interviews described above.

4.4 Data analysis

In this section, I provide an overview to the analyses undertaken, to complement the more detailed descriptions within each results chapter.

Objective 1: To quantify quality metrics for completeness and timeliness, internal consistency, and external consistency of routine MNH data *reported by* facilities (Study 1)

In Study 1 (chapter 5), we quantified the quality of 15 routine MNH data elements (see Table 4.2, page 67) reported by facilities in DHIS 2. Figure 4.1 provides an outline of the data quality metrics assessed, the criterion used for each metric, and the data sources and timelines compared. We assessed eight data quality metrics (see Table 4.1, page 65) across three routine data quality dimensions of completeness and timeliness; internal consistency; and external consistency. The analyses undertaken in Chapter 5 adhered to the guidance calculations provided by the WHO data quality review toolkit.[75]

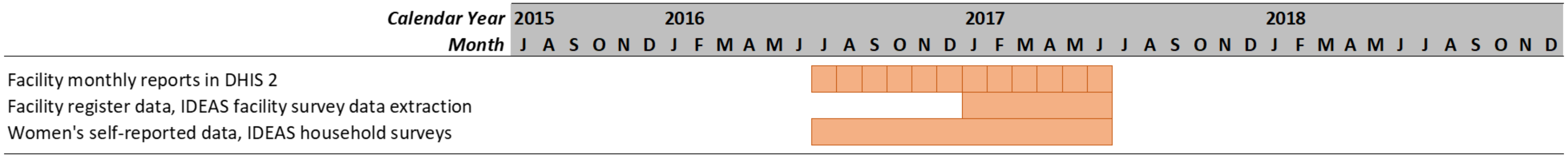
We assessed the quality of routine data reported by facility for July 2016-June 2017. Of the 615 facilities listed in DHIS 2, we assessed the routine data for 497 facilities offering antenatal-postnatal services and for 486 facilities offering labor and delivery services. We accessed three data sources for this study: (i) facility monthly reports in DHIS 2 for July 2016-June 2017; (ii) facility register data for January-June 2017; and (iii) women's self-reported data in household surveys for maternity-related events for birth occurring approximately from July 2016-June 2017.

DHIS 2 data for this study were downloaded at one time in March 2018. These included the 15 MNH data elements for the reference year, July 2016-June 2017. Data for comparison years July 2013-June 2016 were downloaded at this time for the internal consistency metric: consistency over time.

While the metric calculations followed the WHO data quality review toolkit, the presentation of the findings emphasized indicator-level achievements of data quality, with less emphasis on enumerating the facilities and districts meeting acceptability criteria for data quality.

Figure 4.1 Objective 1 (assessing the quality of routine data reported by facilities): data sources, data quality metrics, and data collection timelines

Assessing the quality of routine data *reported by* facilities (Study 1, Chapter 5)



Routine data quality metric	Data sources	Analysis/Calculation	WHO data quality review guidance[75]
Dimension 1: Completeness and timeliness			
Completeness of facility reporting	DHIS 2	Proportion of expected monthly reports submitted	*Completeness of reporting should be ≥75%*
Timeliness of facility reporting		Proportion of expected monthly reports submitted on time	*No specified guidance*
Completeness of data		Proportion of non-missing values for a given data element in expected monthly reports	*Non-missing values should be present in 90% or more monthly reports*
Dimension 2: Internal consistency of reported data			
Outliers	DHIS 2	Number of moderate outliers (±2-3SD from the mean) and extreme outliers (±3SD from the mean) of monthly values during the reference year	*Value of data element for a given month should be within ±2SD from the mean*
Consistency over time		Ratio of aggregate value of data element for reference year compared to the mean of preceding 3 years	*Ratio should be within ±33% of mean of preceding 3 years*
Consistency between related data		Ratio of values of related data elements	*Data element-pairs that should be roughly equal should be within ±10% of each other*
Accuracy of facility reporting	DHIS 2, facility registers	Ratio of data element values in original facility register count to facility monthly summary report in DHIS 2	*Facility register count and value in DHIS 2 should be within ±10% of each other*
Dimension 3: External consistency of reported data			
External comparison with survey results	DHIS 2, household surveys	Ratio of coverage estimates in household surveys for facility catchment areas to matching facilities in DHIS 2	*Coverage estimates from DHIS 2 should be within ±33% of household survey value or within confidence limits of household survey.*

Objective 2: To validate routine data *documented by* facilities for monitoring maternal and newborn care (Study 2)

In Study 2 (chapter 6), we assessed the extent to which different data sources reflected facility-based childbirth events and procedures. We accessed three data sources for validation: health worker documentation in maternity registers, women's self-report during a facility exit interview, and women's self-report during a household follow-up interview 9-22 months after childbirth.

We assessed the individual-level and population-level validity for 25 indicators, focusing on the content of childbirth care (Table 4.5): skilled birth attendance and companionship during labor and delivery; care for the woman (maternal background characteristics, provider practices and respectful care, clinical care) and care for the newborn (immediate postnatal care and newborn outcomes).

Table 4.5 Childbirth care indicators assessed for individual- and population-level validity

<table>
<tr><th colspan="2">Skilled attendance and companionship during labor and delivery</th></tr>
<tr><td colspan="2">• Main provider – doctor, nurse, or midwife
• More than one provider present at birth
• Support person present at birth</td></tr>
<tr><th>Care for the woman</th><th>Care for the newborn</th></tr>
<tr><td>Maternal background:
• Maternal age at delivery (binary: adolescent birth, yes/no)
• Prior parity (binary: priority parity, 4 or more births, yes/no)

Provider practices and respectful care:
• Woman allowed to move and change position during labor
• Woman allowed to drink liquids and eat during labor
• Women allowed to deliver in preferred position
• Woman allowed to have a support person at birth
• Birth attendant washed hands with soap before examinations
• Birth attendant wore gloves during examinations
• Partograph used to monitor labor and delivery

Clinical care:
• Blood pressure taken – initial client assessment
• Episiotomy performed
• Prophylactic uterotonic administered</td><td>Immediate postnatal care:
• Mother and newborn kept in the same room after delivery
• Essential newborn care
• Newborn immediately dried with a towel
• Newborn immediately placed skin-to-skin
• Immediate initiation of breastfeeding
• Chlorhexidine applied to newborn's cord
• Baby weighed at birth

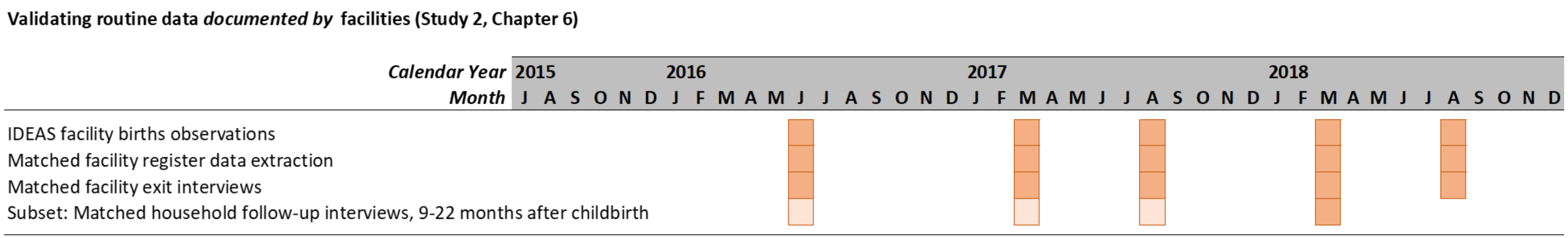
Newborn outcomes:
• Baby's birthweight (binary: low birthweight, <2500 grams)
• Pre-term birth
• Stillbirth, fresh or macerated</td></tr>
</table>

To measure individual-level reporting accuracy, we constructed two-by-two tables for each indicator which compared the birth observation to each data source. For two-by-two tables with at least five observations per cell, we calculated the sensitivity and specificity for each indicator. We quantified the area under the receiver operating characteristic curve (AUC) and estimated 95% confidence intervals. An AUC value of 0.7 or higher was chosen as the cutoff criteria for high individual-level reporting accuracy to align with guidance from the Improving Coverage Measurement for Maternal, Newborn, and Child Health Core Group.[137]

To measure the population-level validity, we calculated each indicator's inflation factor (IF), which reflects the degree to which an indicator would be over- or under-estimated in a population-based survey. An IF value between 0.75 and 1.25 was the chosen cut-off criteria for low population-level bias also to align with guidance from the Improving Coverage Measurement for Maternal, Newborn, and Child Health Core Group.[137]

Figure 4.2 provides an outline of the data quality metrics assessed, the criterion used for each metric, and the data sources and timelines compared.

Figure 4.2 Objective 2 (validating routine data documented by facilities): data sources, data quality metrics, and data collection timelines



Routine data quality metric	Data sources	Analysis/Calculation[225]
Dimension 4: Validity of documented data		
Sensitivity of routine data and women's recall, compared to birth observations	clinical observations with: (i) matched facility registers, (ii) matched exit interviews, (iii) matched household interviews	Proportion of individuals who truly received an intervention who were classified as having received the intervention
Specificity of routine data and women's recall compared to birth observations		Proportion of individuals who truly did not receive an intervention who were classified as not having received the intervention
Area under receiver operating characteristics curve (individual-level validity)		Probability that a test will correctly classify a randomly selected set of one positive observation and one negative observation
Inflation factor (population-level validity)		Ratio of the estimated population-based prevalence compared to the gold standard's prevalence

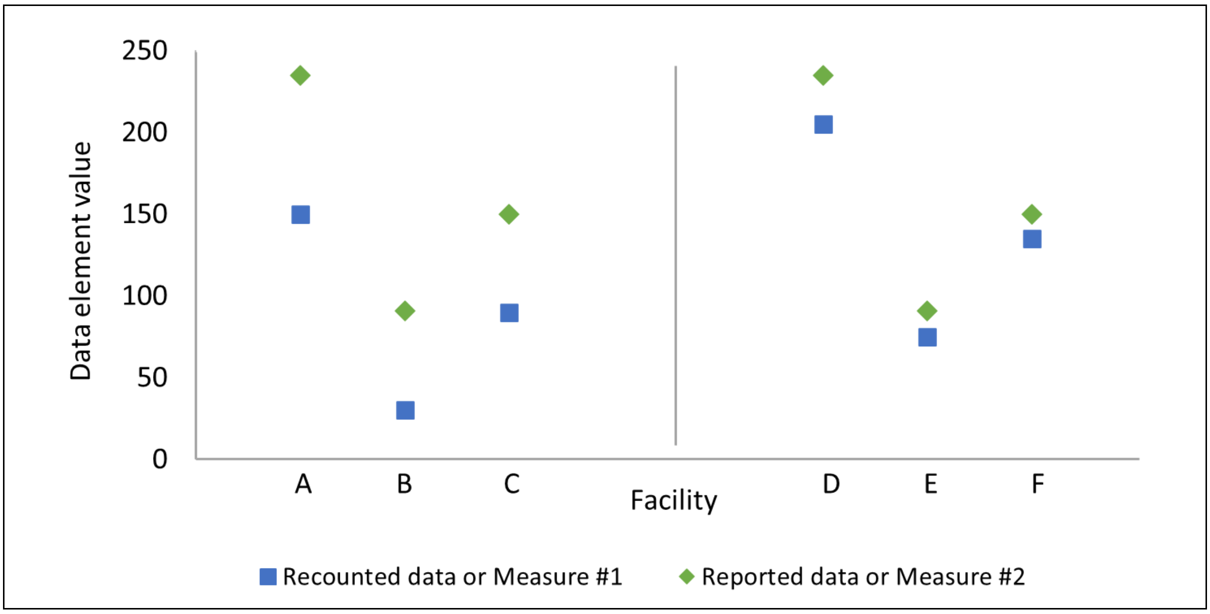
Objective 3: To assess the changes in the quality of routine MNH data *reported by* facilities before and after a district-level data quality intervention (Study 3)

In Study 3 (chapter 7), we quantified the changes in quality for routine MNH data reported by facilities in DHIS 2 before and after the IDEAS Phase 2 Project data quality intervention in Gombe State. Figure 4.3 provides an outline of the data quality metrics assessed, the criterion used for each metric, and the data sources and timelines compared. We assessed nine data quality metrics (see Table 4.1, page 65) across the three dimensions of completeness and timeliness; internal consistency; and external consistency.

The analyses undertaken in Study 3 were similar to Study 1, with two changes to the metrics. First, an additional metric was assessed under the dimension of completeness and timeliness: completeness of information (dataset). The completeness of information metric is distinct from the completeness of data metric as it assesses the extent to which a defined dataset might be available to take action for a given health program. We specified a dataset of 14 priority MNH data elements from Table 4.2 above (see page 67). 'Facility live births' is not included in this dataset as a separate data element as it is a component of the 'live births or still births' data element. We assessed the extent to which the 14 data elements were complete in each submitted report. This measure could be a binary (yes/no for all 14 data elements being present) or a continuous (proportion of 14 data elements present for a given facility). Here, we have used the metric as a continuous measure:

$$\text{Completeness of information (\%)} = \frac{\text{Number of expected data elements which contain a valid value}}{\text{Number of expected data elements}} * 100\%$$

Second, for both internal consistency metrics of (i) consistency between related data and (ii) accuracy of facility reporting, we used intraclass correlation coefficient (ICC) in place of the WHO-recommended ratio/verification factor. The ICC is based on analyses of variances and, generally, is a ratio of the variation between the individual subjects (i.e., facilities) to the total variation (i.e., facilities, data element values, residual error).[226 227] Whereas the Pearson correlation coefficient, as used in Mphatswe et al (2012), could be used to determine the relative agreement between two related data elements, the ICC could be used to capture the absolute agreement between two related data elements.[114] For example, let us consider the accuracy of facility reporting to assess the agreement between re-counted data (measure #1) and reported data (measure #2). Here, there is an expectation that the re-counted/reported data pair for a given facility would be similar to each other. Further, there is an expectation the re-counted/reported data pair within a facility would be more similar to each other than re-counted/reported data pair measures from other facilities, as can be seen in the following illustration of six facilities[227]:



In facilities A, B, and C above, there is poorer agreement between the re-counted and reported data within the same facility, compared to facilities D, E, and F where we can see greater agreement between the re-counted and reported data. As the agreement between the re-counted data (measure #1) and reported data (measure #2) increases, we expect that the intra-facility variation between measure#1 and measure #2 to decrease; the remaining observed variation would be due to between-facility variation and residual error. In this case, the ICC would approach 1.0, indicating greater agreement.

Below is the calculation of the ICC, aligned with Shrout and Fleiss (1979), where we consider a two-way analysis of variance to account for the measures of variance between-facilities and between re-counted and reported data (termed ‘between-measures’ below) within each facility:

$$\text{Intraclass correlation coefficient} = \frac{\text{between-facilities MS} - \text{residual MS}}{\text{between-facilities MS} + [(k-1)*\text{residual MS}] + [k*(\text{between-measures MS} - \text{residual MS})/n)]}$$

where MS = mean square; k = number of measures; n = number of facilities

We assessed the quality of routine data for the 21-month intervention period, April 2017-December 2018, compared to the 21-month pre-intervention period, July 2015-March 2017. We accessed three data sources for this study: (i) facility monthly reports in DHIS 2; (ii) facility register data; and (iii) women’s self-reported data in household surveys for maternity-related events.

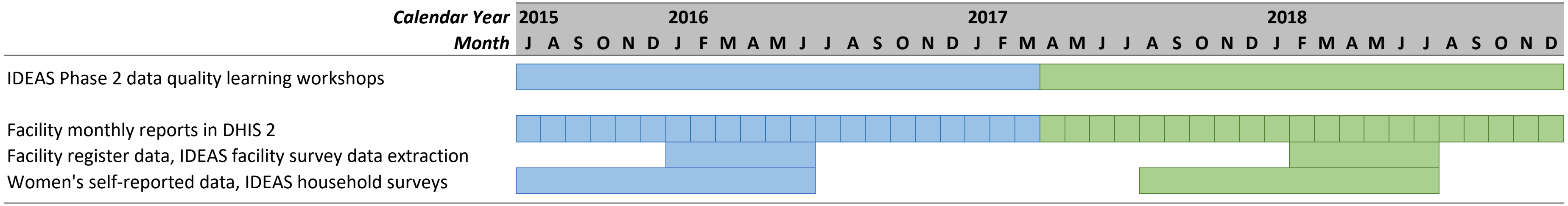
DHIS 2 data for 492 facilities providing antenatal-postnatal care and labor and delivery services were downloaded at one time in May 2019. These included the MNH data elements cited in Table 4.2 (see page 67) for July 2015-December 2018 to compare the 21-month pre-intervention period (July 2015-March 2017) to the 21-month intervention period (April 2017-December 2018).

4.5 Ethical review and approval

Ethical approval for the methods described in this thesis has been received from the London School of Hygiene & Tropical Medicine’s Research Ethics Committee (reference 14091) and the Health Research Ethics Committees for Nigeria (reference NHREC/01/01/2007) and Gombe State (reference ADM/S/658/Vol. II/66).

Figure 4.3. Objective 3 (assessing data quality changes before-and-after intervention): data sources, data quality metrics, and data collection timelines

Assessing changes in routine data quality before-and-after a district-level intervention (Study 3, Chapter 7)



Routine data quality metric	Data sources	Analysis/calculation	WHO guidance[75]
Dimension 1: Completeness and timeliness			
Completeness of facility reporting	DHIS 2	Proportion of expected monthly reports submitted	*Completeness of reporting should be ≥75%*
Timeliness of facility reporting		Proportion of expected monthly reports submitted on time	*No specified guidance*
Completeness of data		Proportion of non-missing values for a given data element in expected monthly reports	*Non-missing values should be present in 90% or more monthly reports*
Completeness of information (dataset)		Proportion of expected reports where all specified data elements contain a valid value	*No specified guidance*
Dimension 2: Internal consistency of reported data			
Outliers	DHIS 2	Number of moderate outliers (±2-3SD from the mean) and extreme outliers (±3SD from the mean) of monthly values during the reference year	*Value of data element for a given month should be within ±2SD from the mean*
Consistency over time		Ratio of aggregate value of data element for reference year compared to the mean of preceding 3 years	*Ratio should be within ±33% of mean of preceding 3 years*
Consistency between related data		Intraclass correlation coefficient	*N/A: WHO recommended calculation not used*
Accuracy of facility reporting	DHIS 2, facility registers	Intraclass correlation coefficient	*N/A: WHO recommended calculation not used*
Dimension 3: External consistency of reported data			
External comparison with survey results	DHIS 2, household surveys	Ratio of coverage estimates in household surveys for facility catchment areas to matching facilities in DHIS 2	*Coverage estimates from DHIS 2 should be within ±33% of household survey value or within confidence limits of household survey.*

Chapter 5: Assessing the quality of routine data *reported by* facilities

Objective 1:

To quantify quality metrics for completeness and timeliness, internal consistency, and external consistency of routine MNH data *reported by* facilities

5.1 Introduction

In Chapter 5, we initiated the examination of the quality of routine facility data. We examine three of the four dimensions of data quality used in this thesis: completeness and timeliness, internal consistency of reported data, and external consistency. This chapter aimed to fulfill thesis objective 1, where we assess data *reported by* facilities.

This manuscript was included in the PLOS High Quality Health Systems Collection for the Lancet Global Health Commission on High Quality Health Systems in the Sustainable Development Goals Era as a case study on the quality of routine facility data for monitoring priority maternal and newborn indicators in DHIS 2. To compose this manuscript, I conceptualized and designed the study with Tanya Marchant. I prepared the data for analyses, cleaning and merging the data in DHIS 2, IDEAS facility surveys, and IDEAS household surveys. The analyses undertaken here were faithful to the guidance and calculations prescribed by the WHO data quality review toolkit for facility data. I conducted the analyses, with advice from Joanna Schellenberg on refining indicator selection as the calculations proposed by the WHO were most appropriate for events and services all women and newborns should receive. As a result, rare outcomes and events were excluded. I wrote the first draft, with critical feedback provided by all authors. I led on all revisions suggested by co-authors and PLOS ONE peer reviewers.

This study was published under the creative commons license CC BY 4.0 on 25th January 2019.

5.2 Research paper cover sheet for Study 1

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First Name(s)	Antoinette Alas		
Surname/Family Name	Bhattacharya		
Thesis Title	Evaluating the quality of routine data in primary health facilities for monitoring maternal and newborn care in Gombe State, northeastern Nigeria		
Primary Supervisor	Dr Tanya Marchant		

If the Research Paper has previously been published please complete Section B, if not please move to Section C.

SECTION B – Paper already published

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SECTION E

Student Signature	[redacted]
Date	15 June 2020

Supervisor Signature	[redacted]
Date	15 June 2020

PLOS ONE

RESEARCH ARTICLE

Quality of routine facility data for monitoring priority maternal and newborn indicators in DHIS2: A case study from Gombe State, Nigeria

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Abstract

Introduction

Routine health information systems are critical for monitoring service delivery. District Heath Information System, version 2 (DHIS2) is an open source software platform used in more than 60 countries, on which global initiatives increasingly rely for such monitoring. We used facility-reported data in DHIS2 for Gombe State, north-eastern Nigeria, to present a case study of data quality to monitor priority maternal and neonatal health indicators.

Methods

For all health facilities in DHIS2 offering antenatal and postnatal care services (n = 497) and labor and delivery services (n = 486), we assessed the quality of data for July 2016-June 2017 according to the World Health Organization data quality review guidance. Using data from DHIS2 as well as external facility-level and population-level household surveys, we reviewed three data quality dimensions—completeness and timeliness, internal consistency, and external consistency—and considered the opportunities for improvement.

Results

Of 14 priority maternal and neonatal health indicators that could be tracked through facility-based data, 12 were included in Gombe's DHIS2. During July 2016-June 2017, facility-reported data in DHIS2 were incomplete at least 40% of the time, under-reported 10%-60% of the events documented in facility registers, and showed inconsistencies over time, between related indicators, and with an external data source. The best quality data elements were those that aligned with Gombe's health program priorities, particularly older health programs, and those that reflected contact indicators rather than indicators related to the provision of commodities or content of care.

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Competing interests: Mr Felix Habila and Mr Ahmed Audu are members of the Gombe State Primary Health Care Development Agency. This does not alter our adherence to PLOS ONE policies on sharing data and materials. The authors declare no other competing interests.

Conclusion

This case study from Gombe State, Nigeria, demonstrates the high potential for effective monitoring of maternal and neonatal health using DHIS2. However, coordinated action at multiple levels of the health system is needed to maximize reporting of existing data; rationalize data flow; routinize data quality review, feedback, and supervision; and ensure ongoing maintenance of DHIS2.

Introduction

Routine health information systems are critical for monitoring service delivery. One distinctive feature of routine health information systems is the availability of data at a frequency and level of disaggregation seldom possible through nationally representative household surveys such as the Demographic and Health Surveys and Multiple Indicator Cluster Surveys. [1–3]

Global initiatives including the Sustainable Development Goals and Countdown to 2030 emphasize the contribution of routine health information systems to monitor progress and enable course correction. [4–6] Two major maternal and newborn health initiatives, Ending Preventable Maternal Mortality and Every Newborn Action Plan, have identified strategies to achieve goals for reduced maternal and newborn mortality by 2030 to a global average of 70 per 100,000 live births and 12 per 1,000 live births, respectively. Both initiatives have identified priority indicators as signals for progress, with a vision that facility-based data should contribute to monitoring. [7, 8] The District Health Information System, version 2 (DHIS2), is a flexible open source electronic information system currently used in over 60 countries to manage and visualize routine health data, particularly facility-based data.[9] Here, we present a case study for Gombe State, north-eastern Nigeria, to examine the availability and quality of routine facility data in DHIS2 for this monitoring purpose.

A routine health information system is a sub-system of a national health information system's effort to capture, process, report, and use information to support policymaking and program implementation. [10, 11] A facility-based information system is a further sub-system that includes data captured by health facility workers during their day-to-day activities. These facility-based data include paper-based and electronic-based medical records, service delivery registers, and aggregate service delivery reports. When facility-based data are of sufficient quality, they can be used at the facility level for effective clinical management, at the district-level to understand the extent to which their facilities are functioning as intended, and at the state- and national-levels to review policies and allocation of resources. [1, 12] At all levels of the health system, good quality facility-based data can contribute to reliable estimates of service delivery coverage to understand if communities are accessing and receiving needed services, such as the proportion of facility births attended by a skilled health worker. [1, 3, 12, 13].

While facility-based information systems are often unable to maintain the good quality needed for monitoring [14, 15], DHIS2 is considered an innovation for transmitting and aggregating data faster than paper-based information systems and for improving data quality by limiting errors in how data are transmitted and aggregated from the facility to higher levels of the health system. Further, DHIS2 has the potential to promote program monitoring because its digital platform increases the accessibility of data for health managers and stakeholders at the district-, state-, and national levels. [3, 9, 16]

With Nigeria having one of the highest maternal mortality ratios and newborn mortality rates in the world (576 maternal deaths per 100,000 live births in 2015 and 37 newborn deaths per 1,000 live births in 2017), the Government has developed action plans to reduce preventable deaths for mothers and newborns and has made considerable investment in strengthening information systems, including DHIS2, to support performance management and service delivery. [17–22]

The aim of this study was to determine the quality of routine facility-based data in DHIS2 to monitor priority maternal and neonatal health indicators in Gombe State, north-eastern Nigeria. Using the World Health Organization data quality review toolkit, we focused on metrics for the data quality dimensions of completeness and timeliness, internal consistency, and external consistency. [23] For data defined as poor quality by the toolkit, we discussed opportunities for improvement.

Methods

Ethical approval

Gombe State approval for the study was obtained from Gombe State Ministry of Health. Ethical approval was obtained from the London School of Hygiene & Tropical Medicine (reference 14091).

Study setting

Gombe State has a projected population of 2.9 million (2006 census: 2.4 million) and is located within north-eastern Nigeria, where maternal and newborn mortality are estimated to be higher than the rest of the country (1,549 maternal deaths per 100,000 live births in 2015 and 35 neonatal deaths per 1,000 live births in 2017). [22, 24–26] In 2017, Gombe State had a total of 615 health facilities across 11 Local Government Areas (LGA, equivalent to a district); each LGA has 10–11 political wards (114 wards, total). As in other states in Nigeria, Gombe facility staff generally complete 13 paper-based registers to document the services they provide. Every month, a subset of data in these registers are tallied and summarized in a paper-based report and sent to the LGA (district) health office to be entered into DHIS2.

Data sources

We accessed three data sources for this study: facility-reported data in DHIS2, an external facility survey, and an external household survey as described below.

In 2017, DHIS2 contained monthly reports for 615 Gombe public and private health facilities across 11 districts: 587 primary facilities offering basic preventative and curative services and 28 referral facilities offering specialized care. Of these, 471 of the 587 primary facilities had been appointed to provide antenatal care and postnatal care services, 460 of the 587 primary facilities provided labor and delivery services, and 26 of the 28 referral facilities were equipped to provide both types of services, in addition to specialized care. Therefore, in total, 497 facilities provided antenatal and postnatal care services and 486 facilities provided labor and delivery services. For these 497 and 486 facilities, respectively, monthly aggregated DHIS2 data for the reference year July 2016-June 2017 were downloaded at one time and included 15 maternal and newborn health-related data elements. Additionally, we downloaded data for July 2013-June 2016 as comparison years for assessing the consistency of data over time.

In July 2017, a facility-level survey was conducted in 97 primary and 18 referral facilities across Gombe to assess their readiness to provide maternal and newborn health services. Detailed methods are reported elsewhere.[27] Briefly, these primary and referral facilities were a state-wide random sample drawn from all government-owned primary health facilities and a census of all 18 government-owned referral health facilities. The facility survey protocol was similar to a Service Availability and Readiness Assessment, which included an inventory of equipment and supplies that were available and functioning on the day of survey; an inventory of staff employed at the facility, their cadre, training and whether they were present on the day of survey; and an interview with the in-charge of the facility about the services available at that facility and about recent supervision visits they had received. Additionally, this survey included data extraction from the facility's paper-based antenatal and postnatal care register and the labor and delivery register (Nigeria health management information system, version 2013). [28] A trained third party data collection team tallied and recorded the register data for each month of the six-month period immediately prior to the survey: January-June 2017. We compared the facilities' paper-based register data with the facilities' data downloaded from DHIS2. These extracted data are shown in Table 1.

Table 1. Priority maternal and newborn health data in Gombe State's facility registers and reports in DHIS2.

Priority maternal and newborn health data element:	Gombe's routine health information system	
	Facility registers	DHIS2
Main denominators		
Facility deliveries	x	x
Facility live births	x	x
First antenatal care visits	x	x
Coverage indicators: care for all women and newborns		
Four or more antenatal care visits	x	x
Skilled attendant at birth	x	x
Institutional delivery		
Oxytocin immediately after birth for prevention of postpartum hemorrhage	x	
Early postpartum-postnatal care for woman and newborn*	x	x
Met need for family planning		
Essential newborn care	x	
Content of antenatal care		
Hypertension: blood pressure taken		
Anemia: blood test	x	x
Proteinuria: urine test	x	x
Iron supplementation	x	x
Tetanus protection	x	x
Intermittent preventive treatment of malaria in pregnancy	x	x
Known HIV status or tested for HIV and received results	x	x
Counseling on pregnancy complications		
Content of postnatal care		
No pre-lacteal feeds during first three days of life		
BCG vaccination during postnatal period	x	x
Polio vaccination at birth	x	x
Respectful maternity care		
Exclusive breastfeeding up to 6 months	x	x

Notes:

Indicators in *italic* type cannot be calculated only from routine facility data.

*Gombe facility registers and DHIS2 track early postpartum-postnatal care within 1 and 3 days of birth. To ensure exclusion of care provided to mothers and newborns during labor and delivery, we used early postpartum-postnatal care within 3 days of birth.

https://doi.org/10.1371/journal.pone.0211265.t001

Also in July 2017, a household-level survey was conducted in catchment areas of the 97 primary facilities from the July 2017 facility survey to assess access to and quality of maternal and newborn services. [27] These catchment areas represented 79 enumeration areas: some facilities serving more than one enumeration area. All households in each enumeration area were surveyed (or in a segment of between 75 households from the enumeration area if more than 75 households were present). The household survey comprised of three modules. (1) A household module asked all household heads about characteristics of the household, ownership of commodities and registered all normally resident people in the household. (2) A women's module asked all women aged 13–49 years and normally resident in the household about the health care available to them, their recent contact with frontline workers and their birth history in the two years preceding the survey. (3) A mother's module asked all women who reported a birth in the last two years (identified in the women's module) a detailed set of questions about their contact with health services across the continuum of care from pregnancy to postnatal care. Informed consent was obtained at the community leadership-level and at the individual-level for each respondent; all invited participants agreed be interviewed. Among 965 surveyed women who reported a live birth in the 12 months prior to the survey, 588 women had visited the facility at least once during their pregnancy and 377 women gave birth at a facility. For DHIS2 reported indicators that were also estimated in the household survey, we compared estimates from this household survey to those from the 79 matching facilities in DHIS2. Calculations of point estimates and their 95% confidence intervals were done using the svyset Stata command (StataCorp, College Station, USA) to adjust for clustering at the enumeration area-level.

Selection of priority maternal and newborn health indicators to assess in Gombe's DHIS2

To determine globally-defined priority maternal and newborn health data in DHIS2, we referred to the Ending Preventable Maternal Mortality and Every Newborn Action Plan strategy documents which described priority indicators to monitor progress towards targets during the Sustainable Development Goals era. [7, 8] For content of care indicators that were referenced by these strategy documents, but not yet fully defined, we referred to indicators defined in Carvajal-Aguirre et al. [29]

We focused our data quality review on health services that should be received by all pregnant women and newborns accessing either primary or referral health facilities. Therefore, rare events and outcomes such as deaths, adolescent births, pre-term births, deliveries by caesarean section, and kangaroo mother care were excluded from our analyses.

For Gombe State, we identified 14 priority maternal and newborn health indicators that were captured at the facility-level by health care workers. (Table 1) These 14 indicators are made up of 17 distinct data elements contained within the paper-based facility registers, including three denominators to determine how many women and newborns have accessed these facilities for services: women who visited the facility at least once during their pregnancy; women who gave birth in a facility; and live births among the facility births.

For Gombe State, 15 of these 17 distinct data elements were reported in DHIS2; the data for women receiving oxytocin for the prevention of postpartum hemorrhage and newborns receiving essential care were captured in facility registers, but not reported in DHIS2. Therefore, the final set of data assessed included 15 data elements used to calculate 12 priority indicators.

Data quality assessment

We reviewed the quality of the DHIS2 data according to metrics of three routine data quality dimensions outlined by the World Health Organization data quality review toolkit:

Table 2. Data quality metrics and data sources reviewed.

Data quality metric	Analysis/calculation, *WHO guidance for quality**	Source(s)	Facilities
***Data quality dimension 1*: Completeness and timeliness of data**			
Completeness of facility reporting in DHIS2: Extent to which each facility submitted a monthly summary report	Number and % of facility's expected monthly reports actually submitted. *Completeness of facility reporting should be 75% or higher**	DHIS2	497 ANC-PNC facilities (471 primary, 26 referral facilities) 486 labor and delivery facilities (460 primary, 26 referral facilities)
Timeliness of facility reporting in DHIS2: Extent to which each facility submitted a monthly summary report on or before specified timeline	Number and % of facility's expected monthly reports actually submitted on time. *No specified guidance on timeliness of facility reporting*	DHIS2	497 ANC-PNC facilities 486 labor and delivery facilities
Completeness of indicator data in DHIS2: Extent to which select indicator data within submitted reports contained a non-missing (or non-zero) value	Number and % non-missing values for a given indicator in expected monthly reports. *Non-missing values for a given indicator should be present in 90% or more monthly reports**	DHIS2**	497 ANC-PNC facilities 486 labor and delivery facilities
***Data quality dimension 2*: Internal consistency of data**			
Consistency over time: Extent to which indicator data exhibit similar patterns as in previous seasons	Ratio of value of indicator for reference year to the mean of preceding 3 years *Ratio of value of indicator for reference year should be within ±33% of mean of preceding 3 years**	DHIS2	497 ANC-PNC facilities 486 labor and delivery facilities
Outliers in reference year: Extent to which the values reported for a given indicator are extreme and potentially implausible	Number of moderate outliers (±2-3SD from the mean) and extreme outliers (±3SD from the mean) of monthly values during the reference year *Value of indicator should be within ±2SD from the mean*	DHIS2	497 ANC-PNC facilities 486 labor and delivery facilities
Consistency between related data: Extent to which the values for two or more indicators exhibit the predicted relationship	Ratio for values of indicator-pairs that have a predictable relationship *Indicator-pairs that should be roughly equal should be within ±10% of each other*	DHIS2	497 ANC-PNC facilities 486 labor and delivery facilities
Consistency between original facility registers and reported data in DHIS2: Extent to which values for given indicators agree between two internal data sources	Ratio of indicator values in original facility register count to facility monthly summary report in DHIS2 *Indicator values in original facility register count and facility monthly report in DHIS2 should be within ±10% of each other.*	Facility registers; DHIS2	110 ANC-PNC facilities (92 primary, 18 referral) 108 labor and delivery facilities (90 primary, 18 referral)
Data quality dimension 3*: *External consistency of data			
Consistency between household surveys and reported data in DHIS2: Extent to which values for given indicators agree with an external data source	Ratio of indicator values in household surveys for facility catchment areas to matching facilities in DHIS2 *Indicator values from facility reports in DHIS2 should be within ±33% of household survey value or within confidence limits of household survey.*	Household surveys; DHIS2	79 ANC-PNC facilities (primary facilities) 79 labor and delivery facilities (primary facilities, same facilities as ANC-PNC facilities)

Notes:

ANC = antenatal care, PNC = postnatal care, SD = standard deviation.

* WHO threshold for good data quality should be adapted for each health program and/or country.

**For the period under review, downloaded data from Gombe State's DHIS2 did not distinguish between missing values and true zero values; both are presented as missing values.

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completeness and timeliness; internal consistency; and external consistency. [23] Table 2 outlines the data quality metrics assessed, the criterion for each metric, and the data sources used. A stratified analysis was performed by facility type for primary and referral facilities.

Results

We present the quality of 15 data elements which represented 12 priority maternal and neonatal health indicators included in DHIS2 for Gombe State.

Completeness and timeliness of facility reporting

For settings such as Gombe, the World Health Organization guidance defined 75% to represent satisfactory completeness of facility reporting, that is each facility annually submitted at least nine of the 12 expected reports. [23] In Gombe State, facilities providing antenatal and postnatal care services (n = 497 facilities) and labor and delivery services (n = 486 facilities) submitted, on average, 75% of the expected reports during July 2016-June 2017 (nine of 12 expected reports submitted per year, standard deviation: 2.9 reports). Of these, 84% of reports were submitted on-time, although referral facilities were less likely than primary facilities to submit their reports on time (p<0.01 for both antenatal and postnatal care facilities and labor and delivery facilities). Figs 1 and 2 present the completeness of facility reporting, alongside completeness of indicator data described below.

Completeness of priority maternal and newborn data in DHIS2

To assess the completeness of indicator data (the extent to which health facilities reported for specific indicators), we observed that Gombe's DHIS2 data did not distinguish between missing values and true zero values. For example, a remote facility may have been equipped to provide antenatal care services but had no clients for antenatal care during a review month (true zero value); in contrast, a facility may have provided antenatal care services to clients but did not include this in their monthly report (missing value). In Gombe's DHIS2, both situations are presented as missing data.

The World Health Organization defined completeness of indicator data to be satisfactory when less than 10% of the expected data were missing values. In Figs 1 and 2, the priority data elements in DHIS2 with the least missing values were for the number of times pregnant women visited a facility for antenatal care (first antenatal care visits, four or more antenatal care visits), deliveries taking place in a facility (facility deliveries), the provision of tetanus

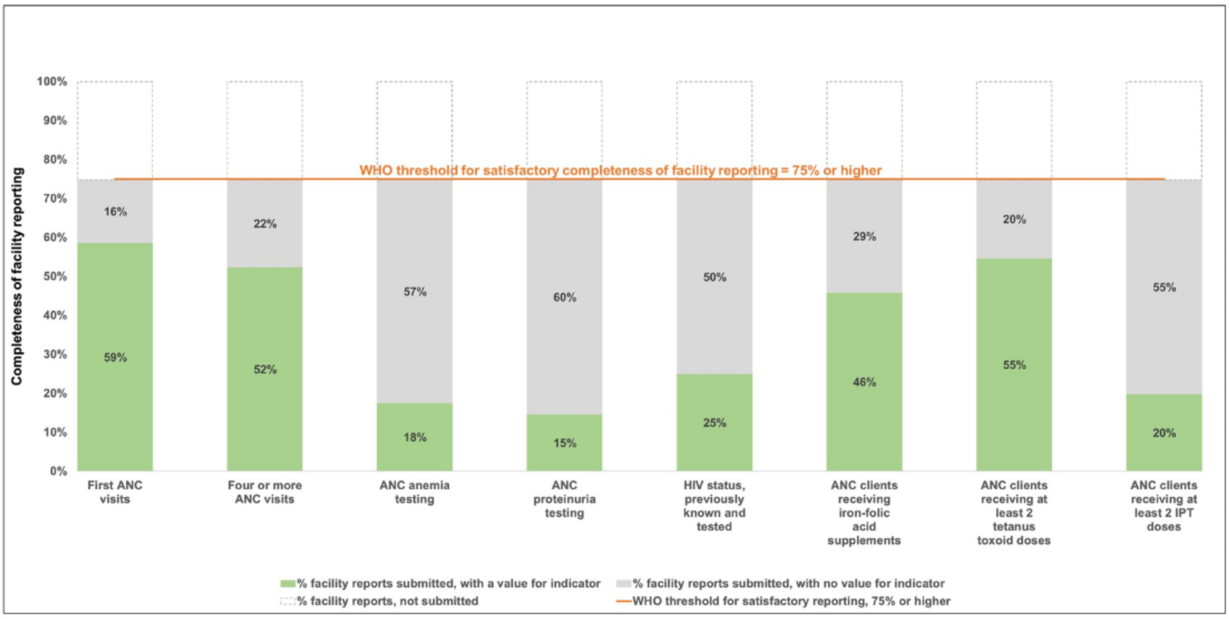

Fig 1. Antenatal care: Completeness of facility reporting and indicator data in Gombe State, Nigeria, July 2016-June 2017. Notes: ANC = antenatal care; HIV = human immunodeficiency virus; IPT = intermittent preventive treatment of malaria in pregnancy.

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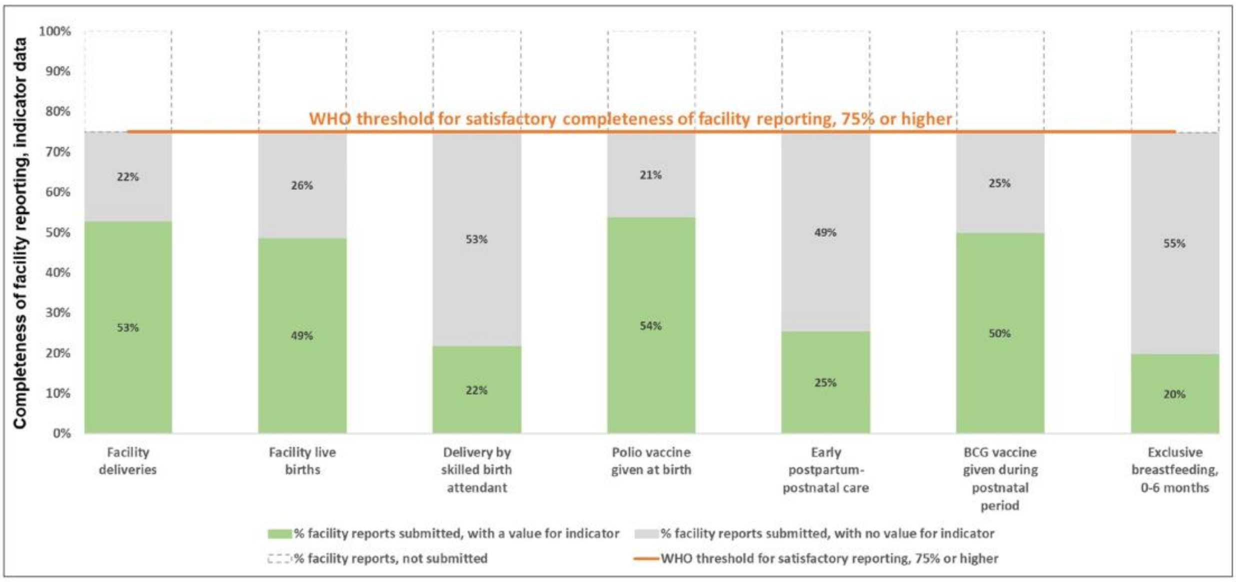

Fig 2. Labor, delivery and postnatal care: Completeness of facility reporting and indicator data in Gombe State, Nigeria, July 2016-June 2017.

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toxoid vaccinations to pregnant women, and the provision of Bacillus Calmette-Guérin (BCG) vaccinations to newborns. Facilities reported a value for these data in at least 52% of the expected monthly reports and 65% of submitted reports. By contrast, the priority data elements with the most missing values were for the provision of screening tests for anemia and proteinuria as well as malaria intermittent preventive treatment. Facilities reported a value for these data in less than 25% of expected monthly reports and less than 33% of submitted monthly reports.

Differences in the completeness of indicator data were noted by facility type. Primary facilities were more likely than referral facilities to report that any woman and her newborn received early postpartum-postnatal care (early postpartum-postnatal care) ($p<0.01$), any newborn was given a polio vaccine at birth ($p<0.01$), and any mother reported exclusively breastfeeding her infant up to six months of age ($p = 0.01$). Referral facilities were more likely to report any pregnant women received a screening test for anemia ($p = 0.03$) and for proteinuria ($p = 0.02$).

Consistency over time

When assessing the extent to which a data element's reported value was consistent over time, the World Health Organization guidance recommended that the reported value for the reference year be within ±33% of the mean value for the preceding three years, taking into consideration any expected changes in the patterns of service delivery. For Gombe State, facilities were more likely to report consistently, compared to the preceding three years, for 7 of 15 data elements (Table 3): first antenatal care visits; four or more antenatal care visits; women receiving at least two doses of malaria intermittent preventive treatment during pregnancy; facility deliveries; deliveries by a skilled birth attendant; newborns receiving BCG vaccinations; and mothers reporting exclusive breastfeeding through six months of age. Facilities did not report consistently, compared to the preceding three years, for women having a live birth in a facility (live births); early postpartum-postnatal care; antenatal care commodities and services

Table 3. Consistency over time for priority maternal and neonatal health indicators in DHIS2: Gombe State, Nigeria, July 2013-June 2017.

	DHIS2 count for priority maternal and newborn health indicators					
	Year 1, July 2013-June 2014	Year 2, July 2014-June 2015	Year 3, July 2015-June 2016	Year 4, July 2016-June 2017	Mean of Year 1-Year 3	Ratio of Year 4 to Mean of Year 1-Year 3
Main denominators						
Facility deliveries	52,055	53,330	83,785	65,312	63,057	1.04
Facility live births	31,214	25,089	50,049	51,001	35,451	***1.44***
First antenatal care visits	110,534	79,848	152,992	143,786	114,458	1.26
Coverage: care for all women and newborns						
Four or more antenatal care visits	63,642	53,026	104,344	96,185	73,671	1.31
Deliveries by a skilled birth attendant	11,059	22,573	17,404	20,205	17,012	1.19
Early postpartum-postnatal care for woman and newborn	2,738	2,906	6,675	7,067	4,106	***1.72***
Content of antenatal care:						
Anemia testing	36,269	35,216	63,076	65,737	44,854	***1.47***
Proteinuria testing	41,340	34,193	64,536	76,559	46,690	***1.64***
Known HIV status, previously known or tested	45,528	63,973	102,591	138,894	70,697	***1.96***
Iron-folic acid supplementation	106,955	123,200	209,338	347,828	146,498	***2.37***
At least 2 doses of TT	43,542	46,357	93,202	90,046	61,034	***1.48***
At least 2 doses of IPT	32,995	21,743	27,802	21,579	27,513	0.78
Content of postnatal care:						
BCG vaccine given during postnatal period	66,279	63,153	115,012	99,142	81,481	1.22
Polio vaccine given at birth	42,431	46,667	84,040	78,396	57,713	***1.36***
Exclusive breastfeeding up to 6 months of age	18,724	12,364	26,843	23,798	19,310	1.23

Notes:TT = tetanus toxoid; IPT = intermittent preventive treatment in pregnancy for malaria; BCG = Bacillus Calmette-Guérin. Values in ***italic and bold*** indicate data that were considered inconsistent over time. According to WHO guidance, ratios <0.67 or >1.33 indicate reported data in DHIS2 for reference year was inconsistent with the mean of the preceding 3 years.

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provided, except for the provision of malaria intermittent preventive therapy; and newborns receiving the polio vaccine at birth.

We observed differences in consistency over time by facility type, with referral facilities more likely to report an inconsistent and higher number of events for July 2016-June 2017 compared to the mean of the previous three years for six data elements (for each data element: $p<0.05$): four or more antenatal care visits; facility deliveries; live births; deliveries by a skilled birth attendant; newborns receiving a polio vaccination; and newborns receiving a BCG vaccination.

Outliers in the reference year

When assessing indicator data for unlikely or extreme values (outliers) in the reference year, the World Health Organization guidance defined an individual monthly value of a given data element to be a moderate outlier if it was between two and three standard deviations from the mean value and an extreme outlier if it was more than three standard deviations from the mean value for the year.

For Gombe State, outliers were present during the reference year for nine of the 15 data elements (Table 4). Primary facilities were responsible for reporting all outliers, with the monthly outlier values being higher than the reported mean number of events for the year. Primary

Table 4. Outliers for priority maternal and neonatal health indicators in DHIS2: Gombe State, Nigeria, July 2016-June 2017.

	Jul 2016	Aug 2016	Sep 2016	Oct 2016	Nov 2016	Dec 2016	Jan 2017	Feb 2017	Mar 2017	Apr 2017	May 2017	Jun 2017	Jul 2016-Jun 2017
Main denominators													
Facility deliveries	4,662	4,197	3,881	4,418	4,926	5,537	5,700	5,574	5,704	6,284	6,124	**8,305**	65,312
Facility live births	3,918	3,632	3,201	3,494	3,974	4,130	4,467	5,031	5,009	4,094	5,027	5,024	51,001
First antenatal care visits	10,815	12,053	10,148	12,646	13,863	12,197	**15,382**	11,365	12,282	10,358	12,895	9,782	143,786
Coverage: care for all women and newborns													
Four or more antenatal care visits	5,846	8,397	6,367	8,349	9,856	8,028	10,009	8,276	8,174	7,405	8,009	7,469	96,185
Deliveries by skilled birth attendant	1,122	868	758	1,439	1,434	1,603	1,780	1,538	2,287	1,650	1,380	**4,346**	20,205
Early postpartum-postnatal care	423	523	449	523	616	560	783	563	666	567	698	696	7,067
Content of antenatal care:													
Anemia testing	4,286	5,656	5,897	4,770	5,798	6,293	6,386	5,269	6,338	4,792	5,511	4,741	65,737
Proteinuria testing	4,353	4,379	5,858	4,684	5,341	6,361	7,189	5,447	***13,457***	6,262	7,409	5,819	76,559
Known HIV status, previously known or tested	7,301	7,476	7,744	***55,355***	8,087	7,429	8,146	7,103	8,477	7,550	7,833	6,393	138,894
Iron-folic acid supplementation	14,316	14,533	13,905	***148,304***	17,954	15,628	23,231	18,108	28,338	16,963	19,327	17,221	347,828
At least 2 doses of TT	6,079	6,895	5,830	8,666	8,510	7,312	8,591	6,936	7,233	7,214	8,799	7,981	90,046
At least 2 doses of IPT	1,749	1,610	1,435	***3,896***	2,001	1,480	1,799	1,407	1,472	1,417	1,635	1,678	21,579
Content of postnatal care:													
BCG vaccine given during postnatal period	7,767	8,576	7,706	9,972	9,594	8,989	11,058	8,966	8,710	6,941	**4,441**	6,422	99,142
Polio vaccine given at birth	5,256	6,571	5,589	5,916	7,151	6,803	7,506	6,483	6,588	6,093	7,143	7,297	78,396
Exclusive breastfeeding, 0–6 months	1,724	2,107	1,789	1,653	1,453	1,624	**3,103**	1,864	1,710	1,911	2,729	2,131	23,798

Notes:

TT = tetanus toxoid; IPT = intermittent preventive treatment in pregnancy for malaria; BCG = Bacillus Calmette-Guérin. Monthly values in **bold** indicate a moderate outlier between 2 and 3 standard deviations from the mean. Monthly values in ***italic and bold*** indicate an extreme outlier more than 3 standard deviations from the mean.

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facilities reported moderate monthly outlier values for: first antenatal care visits; facility deliveries; deliveries by a skilled birth attendant; newborns receiving a BCG vaccination; and mothers reporting exclusively breastfeeding their infant up to six months of age. Primary facilities reported extreme monthly outlier values for pregnant women receiving a screening test for proteinuria; women whose HIV status was known or tested for; pregnant women given iron-folic acid supplementation; and pregnant women receiving at least two doses for malaria intermittent preventive therapy. Three extreme outliers were reported in October 2016, mostly due to one primary health facility's reported values contributing 60% towards Gombe State's aggregate value for women receiving at least two doses of IPT, 87% towards the aggregate value for women who were tested for HIV or with previously known HIV status, and 90% the aggregate value for women who received iron-folic acid supplementation.

Consistency between related data reported in DHIS2

When reviewing the extent to which data make sense with respect to each other (internal consistency between related indicators), the World Health Organization guidance recommended that pairs of data elements that we expect to be equal in value fall within ±10% of each other.

For example, for Gombe State, it was expected that the number of facility births would equal the sum of live births and still births. Internal consistency between related data can also be examined by comparing the number of unique women who have accessed the facility for services (e.g., first antenatal care visits or facility deliveries) to the number of women who have received an individual service. If we find that not every woman has received the expected service, this could represent low service uptake or under-reporting. For example, the number of women tested for anemia could be compared to the number of first antenatal care visits; the use of partograph during delivery could be compared to the number of facility deliveries.

For Gombe State, related indicators that should have equal values did not meet the World Health Organization guidance: (i) the total number of deliveries (n = 65,312) did not equal the sum of live births and still births (n = 52,943) and (ii) the total reported number of women and newborns receiving early postpartum-postnatal care (n = 51,382) did not equal the sum of the visit categories (n = 34,686). (Fig 3 for antenatal and postnatal services, Fig 4 for labor and delivery services) Also in Figs 3 and 4, across all facilities, none of the priority data elements compared demonstrated the expected numerical relationship. For example, of the 143,786 first antenatal care visits, expected services provided during this first visit for anemia testing and proteinuria testing were reported for 65,732 women and 76,555 women, respectively. Primary facilities reported lower than expected numbers for 10 of the priority data elements which could be due to either low service uptake or under-reporting.

Consistency between original facility registers and reported data in DHIS2

When assessing the extent to which data match across sources (consistency of original facility registers and reported data in DHIS2), the World Health Organization guidance defined the

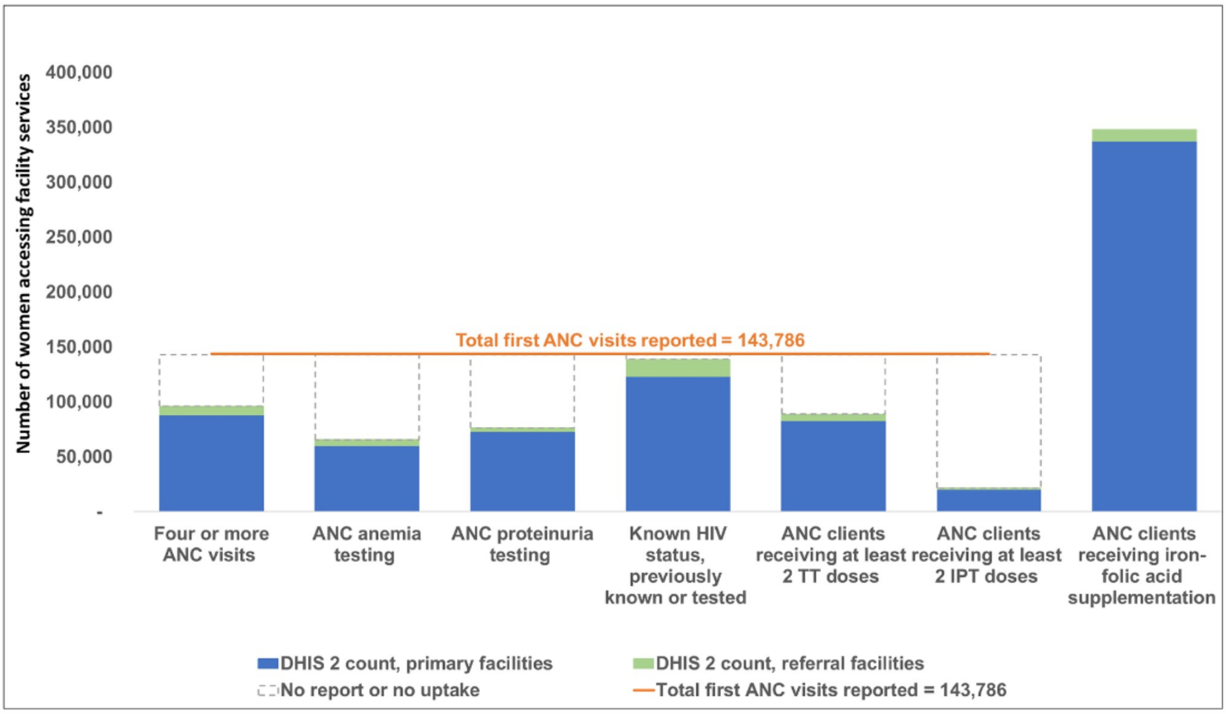

Fig 3. Consistency between related indicators: Facility-reported indicators for antenatal care in Gombe State, Nigeria, July 2016-June 2017, for 471 primary facilities and 26 referral facilities.

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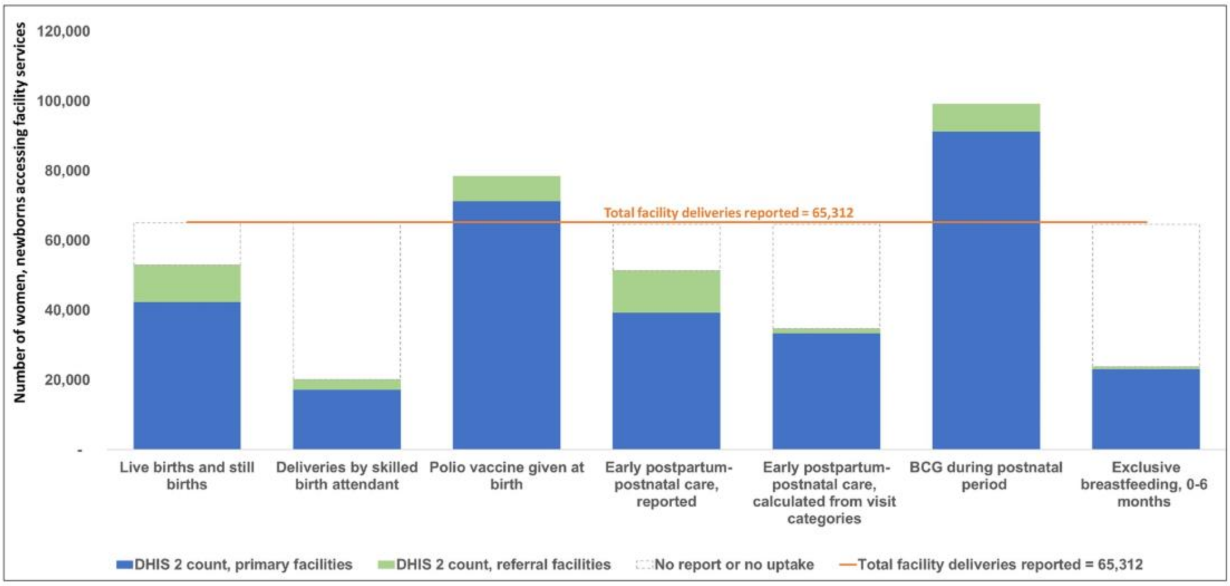

Fig 4. Consistency between related indicators: Facility-reported indicators for labor and delivery services in Gombe State, Nigeria, July 2016-June 2017, for 460 primary facilities and 26 referral facilities.

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data to be consistent when the reported value (e.g., in DHIS2) was within ±10% of the facility register's value. This review of consistency, in part, reflected the capacity to tally and report service statistics as intended.

For the five data elements compared (Fig 5), reported data in DHIS2 consistently agreed with the original facility registers for the priority indicators' three main denominators: first antenatal care visits, facility deliveries, and live births. In general, facilities submitted higher numbers to DHIS2 (over-reported) compared to their original facility registers by 50%-60% for deliveries by skilled birth attendants and early postpartum-postnatal care.

By facility type, the frequency and magnitude of under-reporting was greater for referral facilities. While referral facilities' data in DHIS2 consistently agreed with original facility records for early postpartum-postnatal care, referral facilities under-reported by more than 10% for the main denominators first antenatal care visits, facility deliveries, and live births and under-reported by more than 50% for deliveries by a skilled birth attendant. For primary facilities, data in DHIS2 consistently agreed with original facility registers for the abovementioned main denominators, but over-reported by more than 50% for deliveries by a skilled birth attendant and for early postpartum-postnatal care.

External consistency between household surveys and reported data in DHIS2

When assessing the extent to which the data in DHIS2 are consistent with estimates from external data sources (external consistency), such as household surveys, the World Health Organization guidance recommended that the value of the routine data lie within the confidence limits or be within ±33% of the survey result. [23]

Fig 6 presents a comparison of the data reported in DHIS2 to the estimates from household surveys for four data elements. Comparing women who had visited a facility at least once during their pregnancy in 79 matching facilities and catchment areas, the routine data in DHIS2 did not fall within the confidence limits nor within ±33% of the survey results for the three

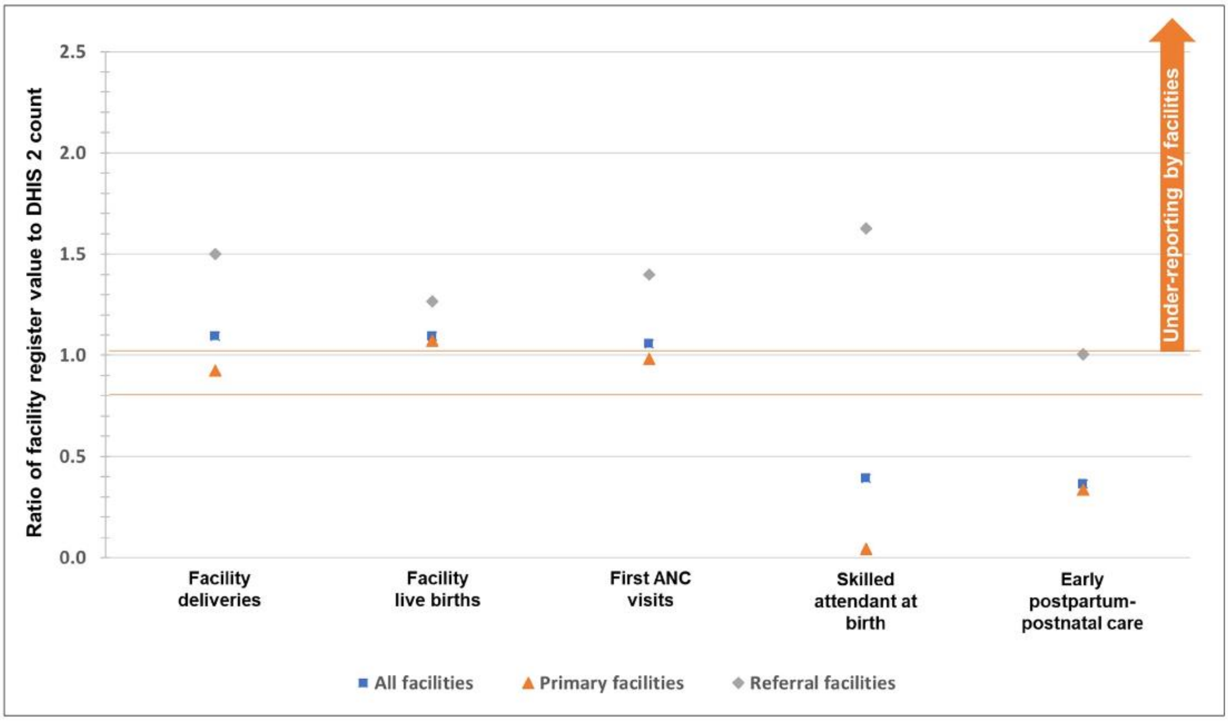

Fig 5. Consistency of data between original facility registers and reported data in DHIS2, January-June 2017. Notes: According to WHO guidance, ratios <0.9 or >1.1 indicate that reported data in DHIS2 were inconsistent with data extracted from the original facility register. For the 97 primary facilities where facility surveys and data extraction took place, five facilities offering antenatal and postnatal care services and seven facilities offering labor and delivery services were excluded as the facility registers were unavailable at the time of the survey.

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antenatal care services reviewed: four or more antenatal care visits, women receiving a screening test for anemia, and women receiving a screening test for proteinuria. Comparing women who had delivered in a facility, the routine data in DHIS2 did not fall within the confidence limits nor within ±33% of the survey results for deliveries by a skilled birth attendant. Further, no pattern emerged in which the routine data in DHIS2 consistently overestimated or underestimated the results from the household survey.

Discussion

We assessed the quality of routine data in DHIS2 to monitor priority maternal and newborn health indicators in Gombe State, north-eastern Nigeria. Of 14 facility-based indicators reflecting services that every woman and her newborn should receive, data elements to estimate 12 priority indicators were included in Gombe State's DHIS2. However, similar to other studies assessing routine data, the routine maternal and newborn health data in DHIS2 for Gombe State did not meet all defined criteria for sufficient quality. [30–48]

During the reference year July 2016-June 2017, the data in DHIS2 did not regularly reflect what was in the facilities' service registers, were incomplete, and exhibited inconsistencies over time, between related indicators, and with an external data source. Nevertheless, the data quality metrics assessed were not equally poor across all priority indicators. This variability suggests high quality routine data is achievable.[49] Data were of better quality when aligned with Gombe's health program priorities, particularly for older health programs; there were also differences in data quality by indicator type.

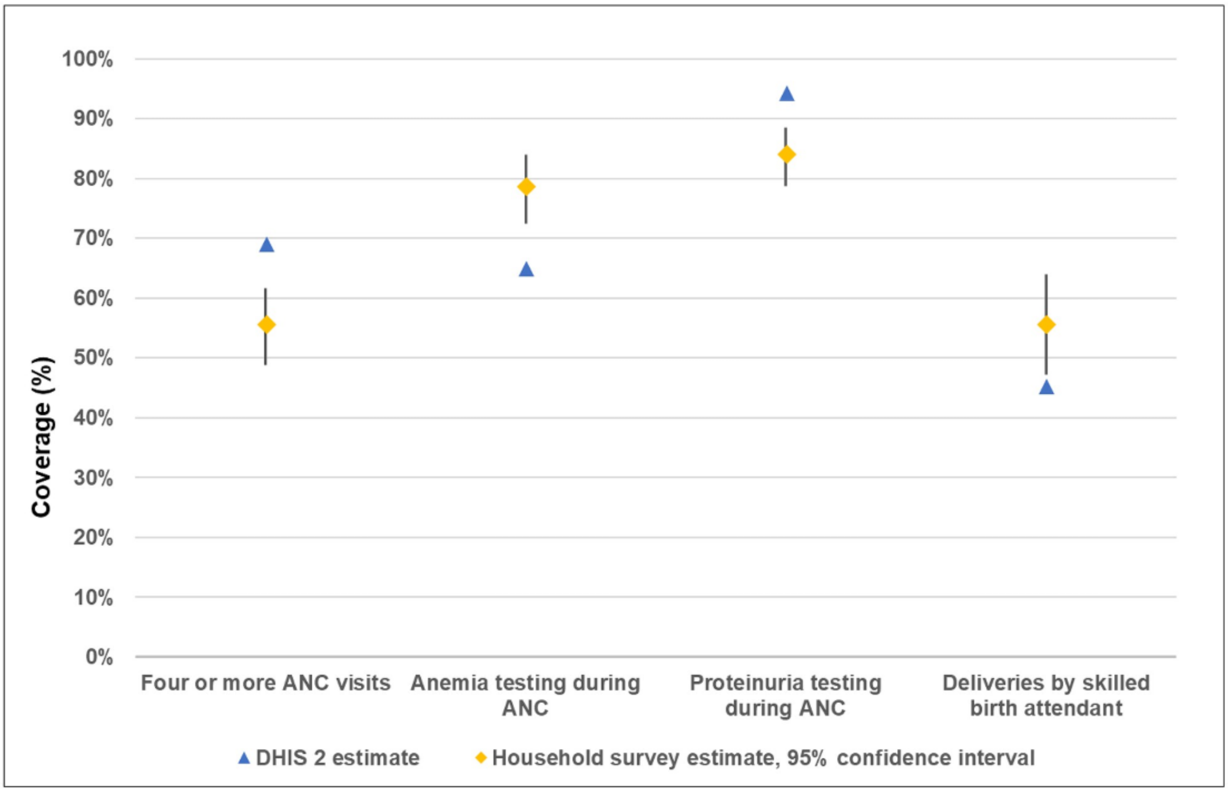

Fig 6. External consistency of priority MNH indicators, comparing DHIS2 data for July 2016-June 2017 with matched facility-clusters of a household survey in Gombe State, Nigeria (n = 79 facilities). Notes: ANC = antenatal care. Household survey denominator for (i) four or more ANC visits, (ii) anemia testing during ANC, and (iii) proteinuria testing during ANC: number of women who had received at least one ANC visit while pregnant during the one year prior to the survey (n = 377 women). Household survey denominator for deliveries by skilled birth attendant: number of women who had given birth in a facility during the one year prior to the survey (n = 588 women).

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Contact indicators, which reflect attendance at a facility, had the highest overall data quality among the priority indicators: first antenatal care visits, four or more antenatal care visits, facility deliveries, live births, deliveries by a skilled birth attendant, and early postpartum-postnatal care. [29, 50] These are well-defined events to document, which may ease the tallying and reporting of these data. In particular, the main denominators—first antenatal care visits, facility births, and live births—had the highest completeness of indicator data rates in our study, were more consistent over time, lacked extreme outliers, and demonstrated the greatest level of agreement between facility registers and DHIS2 data. Further, these have been key denominators for local program planning because they track the number of women accessing antenatal or postnatal care and labor and delivery services at health facilities. These data have been prioritized for monitoring progress in previous global initiatives including the Millennium Development Goals and Countdown to 2015. [51, 52] Four or more antenatal care visits and deliveries by a skilled birth attendant are also long-standing priority indicators for these initiatives and had the same data quality characteristics as the three denominators above. However, the lower overall data quality for deliveries by a skilled birth attendant may in part be reflective of the Gombe context where the majority of facility deliveries in primary facilities are managed by community health extension workers, rather than more highly trained nurses or doctors, following the recent political instability there.[53] Finally, early postpartum-postnatal care, an acknowledged "neglected period for the provision of quality care" had the lowest data quality metrics within this type of indicator. [54]

Indicators related to the provision of a commodity or vaccination that every woman or newborn should have received had the next highest level of overall data quality. While these indicators' overall data quality was not as consistent as the contact indicators, they had relatively high completeness, relatively low inconsistencies over time and between related indicators. While reporting for these indicators may reflect the ease of accounting for a dispensed commodity, most commodities tracked by these indicators have been a part of Nigeria's routine immunization program where completeness of indicator data and agreement across data sources have been emphasized.[55]

The last type of indicator reviewed is related to screening or testing pregnant women for anemia, proteinuria, or HIV. These had much lower completeness of indicator data rates, lower consistency between related indicators, and more outliers. These indicators reflect a more complex encounter between the client and health care provider and have been gaining attention as the maternal and neonatal health program priorities expand to include the content of care. [56, 57] They also tended to exhibit less consistency over time, possibly reflecting the increased attention. [58]

The configuration and use of DHIS2 in Gombe State underscores government commitment to using data to improve service delivery and health outcomes. As this study was reviewed from a program monitoring lens, we did not examine all facility-level characteristics and factors associated with data quality, but outline below actions at multiple levels that could improve data quality.

Maximize the use of existing data

Data for two priority indicators of life-saving care are already captured at facility level, but are not included in monthly monitoring reports: women receiving oxytocin to prevent post-partum hemorrhage and newborns receiving essential newborn care. Monitoring these two indicators would align with recent efforts to focus on the content of care received at critical timepoints during labor and delivery. [59, 60]

Rationalize data flow

Comparing facility registers to data entered in DHIS2, referred elsewhere as "accuracy", highlighted differences by facility type. Both primary and referral facilities were affected by challenges in data flow. At the primary level, client antenatal "treatment" cards were often kept at the facility, and data were later transferred to a register, which was the primary data source for reporting. If the data from treatment cards had not been transferred to the register when the monthly report was prepared, data was taken directly from the cards into the monthly report, resulting in apparent over-reporting. At referral facilities, the physical task of gathering data from "treatment" cards and facility registers dispersed across the hospital grounds was a challenge. The person filling in the summary form was relatively far from services provided and relied on possibly incomplete or unavailable registers, resulting in under-reporting.

Our study suggested that facility staff could strengthen accuracy and completeness of documentation by ensuring that the most complete data source, whether it is the client's antenatal treatment card or the service register, be the primary source for tallying and summarizing the services provided in the facility's monthly report. At the state and national-levels, another action could be to review the role that the client cards play in the data flow, given that they remain in the facility as a medical record; a simple job aid could be developed to help tally across the treatment cards, rather than intensive data transcription to service registers that may no longer be fit for purpose. A cohort register, based on month of first antenatal visit date, could be developed to combine the longitudinal information needs of a treatment card with the tallying and summarization needs of the register; however, this type of tool development may not be realistic in the near-term.

Routinize data quality reviews and feedback at all levels of the health system

Data quality review, feedback, and supervision are essential to optimize routine data for monitoring. [33, 35, 41, 43, 44, 46, 61–69] Studies specifically considering technology-based innovations, including DHIS2, noted that while innovations can make reviews of completeness and internal consistency more efficient, feedback and supervision remain essential to achieving and maintaining improvements in data quality. [33, 49, 66, 70] At the facility level, staff responsible for reporting should review the monthly reports for completeness and internal consistency, ensuring that related data elements have the expected numerical relationships, before submitting the report to the district level. This provides an important opportunity to review relationships between the number of clients and the services/commodities received to understand gaps in service uptake or gaps in data quality related to data capture or reporting; feedback can be provided to staff and supervised to address any gaps identified. At the district level, health management teams could take on these same practices and additionally structure their review and feedback to regularly allow for facilities to confront their own data and for comparison with neighboring or similar facilities in the context of where data quality metrics for completeness, timeliness, and internal consistency could be improved. [41, 43, 46, 62–64, 66, 67, 69, 71–73]

Optimize and maintain DHIS2

Many global initiatives are looking to the DHIS2 platform to promote better quality data and improve access for monitoring at all health management levels. DHIS2's platform allows Governments to develop a responsive information system. [33, 74] Based on our study, it is difficult to determine to what extent those features have been used to control data quality. For example, at the time of this review, DHIS2 for Gombe contained inactive facilities and administrative units, duplicate entries for active facilities and data elements, and did not distinguish between missing data and true zero values. [75, 76] These required additional preparation for our analyses, suggesting that comprehensive data quality reviews could not take place in DHIS2 in its current form. An investment in DHIS2 should include ongoing reviews of its content to promote data quality and fitness for purpose.[11, 33, 35, 70, 74]

There were limitations to this study. Similar to other assessments, we did not validate the data through direct clinical observations [41, 43–45, 49, 64, 77] nor did we compare the paper-based monthly summary reports to their electronic versions in DHIS2. [32, 34, 41, 44, 61, 78] For the assessment of consistency, the facility-level and household-level surveys used in this study could not be considered a gold standard, but we did consider them to be relevant references for reviewing the consistency of routine facility-based data in DHIS2. Understanding consistency between multiple data sources is a perennial problem for health managers who frequently have to make sense of different estimates. The surveys were conducted similarly to the Demographic and Health Surveys and Multiple Indicator Cluster Surveys at the household-level, and the Service and Readiness Assessment at the facility-level, where estimates of priority maternal and newborn coverage and service delivery indicators have been obtained.[28, 79, 80] Despite close attention to quality control, these surveys might still be susceptible to errors in data recording, including incorrectly tallying the number of events in the original facility registers for comparison with data in DHIS2. Further, for some maternal and newborn health events, household survey measures may not provide a valid representation of care provided in health facilities.[81] Acknowledging these short-comings highlights the importance of working to improve the utility of routine data sources. We did not review rare events or outcomes such as deaths or complications and extra care for women and their newborns, as our primary interest was in the contribution of DHIS2 data to routine program monitoring. Lastly, this study reviewed the quality of routine data for maternal and neonatal health and may not be representative of indicators for the planning and service provision for other health programs.

Our study adds new evidence showing the potential of data in DHIS2 for local, real-time monitoring of maternal and newborn health services. While the quality of data in DHIS2 could be strengthened, the data quality metrics for priority indicators were not universally nor equally poor. Coordinated action at multiple levels of the health system is needed to maximize reporting of existing data; rationalize data flow; routinize data quality review, feedback and supervision; and ensure the ongoing maintenance of DHIS2.

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Author Contributions

Conceptualization: Antoinette Alas Bhattacharya, Tanya Marchant.

Formal analysis: Antoinette Alas Bhattacharya.

Methodology: Antoinette Alas Bhattacharya, Tanya Marchant.

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Writing – original draft: Antoinette Alas Bhattacharya.

Writing – review & editing: Nasir Umar, Ahmed Audu, Habila Felix, Elizabeth Allen, Joanna R. M. Schellenberg, Tanya Marchant.

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Chapter 6: Validating routine data *documented by* facilities

Objective 2:
To validate routine data *documented by* facilities for monitoring maternal and newborn care

6.1 Introduction

In Chapter 6, we examined the fourth dimension of routine data quality: validity of routine data documented within facilities. To situate this examination of monitoring data for maternal and newborn care, we examined the validity of routine facility data alongside other MNH data sources such as women's recall during facility-level exit interviews and household-level follow-up interviews. This manuscript sought to fulfill thesis objective 2.

To compose this manuscript, Tanya Marchant and Elizabeth Allen initially conceptualized a study to validate women's recall at different interval periods (facility-level exit and household follow-up interviews), using direct clinical observations of childbirth as a gold standard. I joined this effort, conceptualizing the validity of routine data, i.e., the documentation of health workers in facility maternity registers. The validity of routine facility data, particularly for maternal and newborn care in rural primary health facilities, was a unique contribution to the literature for data sources monitoring MNH. From that point, I conducted all analyses for five rounds of data collection. I wrote the first draft, with critical feedback from all co-authors. I led on all revisions suggested by co-authors and the Journal of Global Health peer reviewers.

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6.2 Research paper cover sheet for Study 2

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SECTION A – Student Details

Student ID Number	1602264	**Title**	
First Name(s)	Antoinette Alas		
Surname/Family Name	Bhattacharya		
Thesis Title	Evaluating the quality of routine data in primary health facilities for monitoring maternal and newborn care in Gombe State, northeastern Nigeria		
Primary Supervisor	Dr Tanya Marchant		

If the Research Paper has previously been published please complete Section B, if not please move to Section C.

SECTION B – Paper already published

Where was the work published?	Journal of Global Health		
When was the work published?	25 July 2019		
If the work was published prior to registration for your research degree, give a brief rationale for its inclusion			
Have you retained the copyright for the work?*	**Yes**	Was the work subject to academic peer review?	**Yes**

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SECTION C – Prepared for publication, but not yet published

Where is the work intended to be published?	
Please list the paper's authors in the intended authorship order:	

Stage of publication	Choose an item.

SECTION D – Multi-authored work

For multi-authored work, give full details of your role in the research included in the paper and in the preparation of the paper. (Attach a further sheet if necessary)	I conceived and designed the study with Tanya Marchant and Elizabeth Allen. I designed the analysis with Tanya Marchant and Elizabeth Allen. I carried out all analyses presented in the paper. I wrote the first draft. I led on all revisions and incorporated feedback from co-authors and reviewers.

SECTION E

Student Signature	[redacted]
Date	15 June 2020

Supervisor Signature	[redacted]
Date	15 June 2020

Electronic supplementary material:
The online version of this article contains supplementary material.

journal of global health

PAPERS

Monitoring childbirth care in primary health facilities: a validity study in Gombe State, northeastern Nigeria

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Background Improving the quality of facility-based births is a critical strategy for reducing the high burden of maternal and neonatal mortality and morbidity across all settings. Accurate data on childbirth care is essential for monitoring progress. In northeastern Nigeria, we assessed the validity of childbirth care indicators in a rural primary health care context, as documented by health workers and reported by women at different recall periods.

Methods We compared birth observations (gold standard) to: (i) facility exit interviews with observed women; (ii) household follow-up interviews 9-22 months after childbirth; and (iii) health worker documentation in the maternity register. We calculated sensitivity, specificity, and area under the receiver operating curve (AUC) to determine individual-level reporting accuracy. We calculated the inflation factor (IF) to determine population-level validity.

Results Twenty-five childbirth care indicators were assessed to validate health worker documentation and women's self-reports. During exit interviews, women's recall had high validity (AUC≥0.70 and 0.75<IF<1.25) for 9 of 20 indicators assessed; six additional indicators met either AUC or IF criteria for validity. During follow-up interviews, women's recall had high validity for one of 15 indicators assessed, placing the newborn skin-to-skin; two additional indicators met IF criteria only. Health worker documentation had high validity for four of 10 indicators assessed; three additional indicators met AUC or IF criteria.

Conclusions In addition to standard household surveys, monitoring of facility-based childbirth care should consider drawing from and linking multiple data sources, including routine health facility data and exit interviews with recently delivered women.

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The childbirth process presents a time of great risk of death for women and their newborns [1,2]. Of the estimated 303 000 maternal deaths and 2.5 million neonatal deaths that occurred in 2015, 113 000 maternal deaths and over 1 million neonatal deaths were attributed to complications from childbirth and the immediate postpartum period [3,4]. The distribution of this risk of death is uneven. While 36% of the world's population lives in sub-Saharan Africa and Southern Asia, these regions account for 86% of maternal deaths and at least 78% of the newborn deaths [1-5]. For facility-based births, improving the quality of care for women and newborns especially during the intrapartum period is considered one of the most effective strategies for reducing maternal and neonatal mortality and morbidity across all settings [1,6-10].

Global and national monitoring of facility-based care often includes self-reported retrospective data collected in household surveys such as the Demographic and Health Survey (DHS) and Multiple Indicator Cluster Survey (MICS) [11-13]. For population-based coverage estimates of childbirth care, these periodic and nationally representative surveys collect a limited set of data which include maternal background characteristics and birth history, delivery by a skilled birth attendant, and newborn care practices [14,15]. A small number of criterion validity studies of childbirth care which measured the extent to which the women's self-reported data at different recall periods align with a gold standard, have demonstrated mixed results on the accuracy of data in household surveys [16-22]. Understanding how best to accurately monitor childbirth care is an emerging research priority and evidence from different contexts is required [23,24].

Routine data can be used to monitor the content of facility-based care, but concerns about completeness, consistency, and accuracy have hampered their use [13]. Most studies on the accuracy of routine data have focused on verifying the aggregate data reported by facilities to higher management levels and comparing these to data documented by health workers [25-30]. However, similar to the population-based surveys, the extent to which the data documented by health workers reflect the "truth" of care is also not well-established [31].

In the high mortality setting of northeastern Nigeria, we assessed the extent to which different data recording methods could contribute to the global- and national-level monitoring of maternal and newborn health. Using direct birth observations as a gold standard, we compared these observations to: (i) facility exit interviews with women after childbirth; (ii) household follow-up interviews with women nine to 22 months after childbirth; and (iii) health worker documentation of childbirth events in the facility maternity register.

METHODS

Ethical review

Study approvals were obtained from the London School of Hygiene & Tropical Medicine (reference 14091) and the Health Research Ethics Committees for Nigeria (reference NHREC/01/01/2007) and Gombe State (reference ADM/S/658/Vol. II/66).

Study setting

Gombe State, northeastern Nigeria, has high maternal and newborn mortality at 814 per 100 000 live births and 35 per 1000 live births, respectively; nationally, maternal mortality estimates are also 814 per 100 000 live births and neonatal mortality estimates are 39 per 1000 live births [3,4,14,15]. Gombe is predominantly rural and 44% of the population have some primary school education. Most women access maternity care through public facilities. Seventy-two percent of women reported at least one antenatal care visit during their last pregnancy and 29% gave birth in a health facility [15]. In 2018, over 70% of facility deliveries took place in rural primary health facilities [32].

Indicator selection

Twenty-five indicators were selected, focusing on the content of childbirth care (**Table 1**): skilled birth attendance and companionship during labor and delivery; care for the woman (maternal background characteristics, provider practices and respectful care, clinical care); and care for the newborn (immediate postnatal care and newborn outcomes). To select these indicators, we referred to the Ending Preventable Maternal Mortality and Every Newborn Action Plan strategy documents for priority indicators to monitor progress towards Sustainable Development Goals targets [33,34]. We also sought to complement indicators collected in the Nigeria Demographic and Health Survey as well as earlier studies validating childbirth care indicators [14,16-20].

In Gombe, maternity registers defined essential newborn care as the immediate initiation of breastfeeding and the baby being kept warm within 30 minutes of birth [35]. To determine if the maternity register provided a sufficient approximation to globally-defined indicators, we compared the maternity register's essential newborn care data to being kept warm and the initiation of breastfeeding within the first hour

Table 1. Childbirth care indicators and data recording methods compared with birth observations (gold standard) for validation analyses

		Comparison data recording method*		
Indicator	Births observation	Facility exit interview	Household follow-up interview	Facility maternity register
Skilled birth attendance and companionship during labor and delivery:				
Main provider – doctor, nurse, or midwife	X	X	X	X
More than one provider present at birth	X	X	X	
Support person present at birth	X	X	X	
Care for the woman:				
Maternal background†:				
Age at delivery (adolescent births)	X			X
Prior parity (prior parity, 4 or more births)	X			X
Provider practices and respectful care:				
Woman allowed to move and change position during labor	X	X		
Woman allowed to drink liquids and eat during labor	X	X		
Woman allowed to deliver in preferred position	X	X		
Woman allowed to have a support person at birth	X	X	X	
Birth attendant washed hands with soap before examinations	X	X	X	
Birth attendant wore gloves during examinations	X	X	X	
Partograph used to monitor labor and delivery	X			X
Clinical care:				
Blood pressure taken – initial client assessment	X	X	X	
Episiotomy performed	X	X	X	
Prophylactic uterotonic administered during third stage of labor to prevent postpartum hemorrhage	X	X	X	X
Care for the newborn:				
Immediate postnatal care:				
Mother and newborn kept in same room after delivery	X	X	X	
Newborn immediately dried with a towel	X	X	X	
Newborn immediately placed skin-to-skin	X	X	X	
Immediate initiation of breastfeeding	X	X	X	
Essential newborn care‡	X	X	X	X
Chlorhexidine applied to newborn's cord to prevent infection	X	X		
Baby weighed at birth	X	X	X	X
Newborn outcomes:				
Low birthweight, <2500 g†	X	X		X
Pre-term birth	X			X
Stillbirth, fresh or macerated	X			X
Total indicators	25	20	15	10

*Observed women were interviewed before discharge from the facility (exit interview) and at home nine to 22 mo after childbirth (follow-up interview). Health workers documented childbirth events in facility maternity registers.
†For validation analyses, the following indicators were converted into binary variables: age at delivery (adolescent births); prior parity (prior parity, four or more births); and baby's birthweight (low birthweight, <2500 g).
‡In the facility maternity register, essential newborn care is a composite indicator for (i) immediate initiation of breastfeeding and (ii) baby kept warm.

of birth [34]. For validation analyses, the following indicators were converted into binary variables: maternal age at delivery (adolescent births); prior parity (prior parity, four or more births); and baby's birthweight (low birthweight, <2500 g).

Study sites and data sources

As part of an initiative to improve care in Gombe State, data were collected between 2016-2018, including facility-based birth observations [36]. A summary of each data recording method is provided in Figure 1; detailed descriptions follow.

Birth observations

Starting in June 2016, five rounds of birth observations took place in 10 primary health facilities. Each round took place roughly every six months and lasted three weeks. To select the facilities for birth observations, a state-wide random sample of 107 facilities was drawn in November 2015 from approximate-

	June 2016	March 2017	August 2017	March 2018	August 2018	Total
Birth observations (gold standard)	373	385	361	416	354	1889
Exit interview after observed childbirth*	340	360	344	394	336	1774
Follow-up interview 9-22 months after observed childbirth†	←--------	--------	--------	445		445
Facility maternity register		365	358	403	347	1474

Figure 1. Data recording methods, data collection rounds, and the number of women observed and interviewed. *Of the 1889 women observed, 115 (6%) did not participate in an exit interview: 11 (0.5%) were discharged with their newborn and refused to be interviewed; 104 (5.5%) women were not interviewed (21 were referred to another facility; 61 still births with 1 maternal death; 22 newborn deaths). †A total of 445 women were followed up at home in March 2018, 9-22 months after their observed childbirth: 147 women from deliveries in June 2016; 146 women from deliveries in March 2017; 152 women from deliveries in August 2017.

ly 500 government-owned primary health facilities. The maternity registers were reviewed to determine the volume of births occurring in the previous six months. The 10 facilities with the highest number of births were selected for birth observations [37]. An average of 15.7 births (standard deviation SD = 12.0) occurred per month in the 10 primary health facilities, compared to the state-level average of 4.3 births (SD = 6.3) per month in primary health facilities [38].

All women attending the facility for delivery were invited to participate, excluding women admitted for monitoring before the onset of labor. Women were given a description of the study and the procedures, including the right to withdraw participation at any time. A trained observer (local midwives, not employees of the assigned facility) stayed in the same room to continuously document labor and delivery processes through the first hour after birth, using a structured checklist. Labor and delivery took place in the same room. The mother and newborn were usually kept together until discharged from the facility.

Two observers and one clinical supervisor were assigned per facility to work in shifts and cover all deliveries. Although observers were trained midwives, they had no legal right to intervene in clinical care during the observation period because they were not employed in the same facilities where they were doing the observations. At all times during the observation, the observer prioritized safety of the mother and newborn over data collection; protocols were established on how to seek help in the event of any life-threatening event. Priorities for the supervisor were (i) to ensure that consenting procedures were carried out; (ii) to observe data collection and carry out interrater reliability checks; (iii) to assist in the case of a query from facility employees or from clients and families; (iv) to collect and check digital data at the end of each day.

Before each round, observers underwent four days of practical training to conduct unobtrusive observations, train on safety and confidentiality protocols, and ensure consistency of rating between observers. Observations were recorded onto a Lenovo A3300 tablet using CSPro version 7.0 (United States Census Bureau and ICF Macro, Suitland, MD, USA). Each observed woman was assigned a unique observation number to facilitate linking information to other data sets.

Facility maternity registers

Following the birth observation, regardless of newborn outcome, the observer extracted data about the woman from the maternity register. Data extraction took place on the same day as the observed birth after the first hour of birth. Data were directly entered into the tablet.

Facility exit interviews

Women were usually discharged within 24 hours of delivery. Each observed woman leaving the facility with a live newborn was invited to participate in an exit interview. The exit interview covered information recorded during the observation and harmonized with questions asked in the DHS and MICS. Each interview was conducted in Hausa by a member of the observation team assigned to the facility. Interview questions are available in Table S1 in **Online Supplementary Document.**

Household follow-up interviews, nine to 22 months after childbirth

In addition to recall during exit interviews, it was of interest to understand the validity of women's recall in the context of household surveys, such as DHS and MICS. For this purpose, we conducted household-level follow-up interviews with a subset of the observed women to recall childbirth events. To represent a range of recall periods that may be encountered during a household survey, in March 2018 we selected approximately 150 women from each of the first three rounds of birth observations which occurred in June 2016 (22 months recall), March 2017 (15 months recall), and August 2017 (9 months recall); this selection was done by a simple random sample of a de-identified list of women observed per round. Each interview was conducted in Hausa and the women were asked the same questions as in the exit interview.

Sample size

To estimate the sample size, 50% prevalence from clinical observations (gold standard) was set for all indicators as we expected variability in the frequency of indicators. Sensitivity was set at 60% ± 7% precision and specificity at 70% ± 7% precision. Type 1 error was set at 0.05, assuming a normal approximation to a binomial distribution. Thus, a minimum sample size of 400 was required for observed women at exit interviews, at follow-up interviews, and in the maternity register.

Analysis

To combine the data from five rounds of data collection, we tested for marginal homogeneity using Yang's chi-square test for clustered binary matched pair data using the clust.bin.pair package in R [39,40]. Of the 45 matched pairs analyzed (see **Table 1**), one indicator showed evidence of clustering across time when comparing birth observations and women's self-reports at exit and follow-up interviews: birth attendant washed hands with soap before examinations. Given the number of matched pairs analyzed, we considered there to be sufficient evidence that the data collection rounds could be combined.

Validation analyses were performed using Stata 14.2 (Stata Corp, College Station, TX, USA) [41]. Using birth observations as the gold standard, we assessed each indicator's validity at the individual- and population-level.

To measure individual-level reporting accuracy, we constructed three two-by-two tables for each indicator which compared the birth observation to each data recording method [16,18-20,23]. Missing and "don't know" responses were excluded from the two-by-two tables. We calculated percent agreement between the birth observation and each data recording method.

For two-by-two tables with at least five observations per cell, we calculated the sensitivity (true positive rate) and specificity (true negative rate) for each indicator. We quantified the area under the receiver operating characteristic curve (AUC) and estimated 95% confidence intervals (CI) assuming a binomial distribution. AUC values range from 0 to 1, with 0.5 representing a random guess and 1 representing complete accuracy. An AUC value of 0.7 or higher was chosen as the cutoff criteria for high individual-level reporting accuracy [23].

To measure the population-level validity, we calculated each indicator's inflation factor (IF), which is the ratio of the estimated population-based survey prevalence to the gold standard's prevalence. The IF reflects the degree to which an indicator would be over- or under-estimated in a population-based survey. To estimate the population-based survey prevalence, we used the following equation [42]: estimated population survey prevalence = (gold standard prevalence × sensitivity) + [(1 − gold standard prevalence) × (1 − specificity)]. An IF value between 0.75 and 1.25 was the chosen cut-off criteria for low population-level bias [23].

RESULTS

Sample description

Characteristics of the women observed during childbirth are presented in **Table 2**. Women's age ranged from 15 to 47 years, with a median age of 24 years (interquartile range (IQR) = 20-28). Forty-four percent of women had at least 4 prior deliveries, 47% of women had no formal education, and 99% were married.

For each indicator and data recording method: indicator prevalence, "don't know" responses, percent agreement with gold standard, sensitivity, specificity, AUC, and IF values are summarized in **Table 3**.

Table 2. Characteristics of women observed during childbirth

	Number of women, N(%), N = 1774*
Data collection round:	
June 2016	340 (19)
March 2017	360 (20)
August 2017	344 (19)
March 2018	394 (22)
August 2018	336 (19)
Age of client at delivery:†	
15-19	351 (20)
20-24	600 (34)
25-29	402 (23)
30-34	243 (14)
35-39	126 (7)
40+	47 (3)
Prior parity:‡	
0	41 (2)
1	355 (20)
2	339 (19)
3	255 (14)
4 or more	779 (44)
Educational attainment:	
None	827 (47)
Primary	412 (23)
Secondary	490 (28)
Higher	45 (3)
Marital status:	
Single, never married	12 (1)
Married	1759 (99)
Widowed	3 (0)
Time of delivery:§	
Day, 8:00am-6:59pm	1038 (59)
Night, 7:00pm-7:59am	715 (40)
Day of delivery:‖	
Weekday	1194 (67)
Weekend	567 (32)
Main provider during labor and delivery:¶	
Doctor, nurse, or midwife	184 (10)
Community health extension worker, junior CHEW	690 (39)
Hospital assistant	387 (22)
Other facility staff	461 (26)
Other non-staff, including traditional birth attendant	51 (3)

CHEW – community health extension worker
*Distribution of characteristics based on the 1774 respondents during exit interviews. Percentages do not always add up to 100% due to rounding, missing responses (up to 1.1%), and "don't know" responses (0.2%).
†"Age of client at delivery" had 1 (0.1%) missing response and 4 (0.2%) "don't know" responses.
‡"Prior parity" had 6 (0.3%) missing responses.
§"Time of delivery" had 19 (1.1%) missing responses.
‖"Day of delivery" had 13 (0.7%) missing responses.
¶"Main provider during labor and delivery" had 1 (0.1%) missing response.

Figure 2 presents a summary of the validity criteria met across data recording methods.

"Don't know" responses, which indicate the extent to which recall may or may not be possible, were greater than 5% for: birth attendant washed hands with soap before examinations (exit and follow-up); baby weighed at birth (exit and follow-up); and low birthweight (exit only). Health workers documented in maternity registers most frequently for: baby weighed at birth (99% completeness), maternal age at delivery (97%), and prior parity (97%). Documentation was least frequent for the composite indicator essential newborn care (82% completeness) and pre-term birth (77%).

Skilled birth attendance and companionship during labor and delivery

Health worker documentation of the main provider's cadre had high overall validity, meaning AUC≥0.70 for high individual-level accuracy and 0.75<IF<1.25 for low population-level bias. During exit interviews, women's recall had high overall validity for the presence of more than one provider at birth and high individual-level accuracy for the main provider's cadre and the presence of a support person during labor and delivery. During follow-up, women's recall for these three indicators met neither validity criteria.

Care for the woman

Health worker documentation in maternity registers had high overall validity for maternal age at delivery and prior parity and high individual-level accuracy for reporting the use of a partograph. While there was insufficient variation in responses for validation analysis, health worker documentation had near complete agreement with the gold standard for the administration of a prophylactic uterotonic.

During exit interviews, women's recall on four provider respectful care indicators met at least one validity criteria, with high overall validity for two indicators: allowed to move and change positions during labor and allowed to have a support person during labor and delivery. During follow-up, women's recall of being allowed to have a support person maintained low population-level bias only.

During exit interviews, women's report of clinical care received had high overall validity for having her blood pressure taken before delivery and low population-level bias only for the administration of prophylactic uterotonic. During follow-up, only administration of a prophylactic uterotonic was able to maintain the low population-level bias.

Care for the newborn

For two indicators requiring the mother's involvement, immediate initiation of breastfeeding and placing the newborn skin-to-skin, women's recall during exit interviews had high overall validity. During follow-up, women's recall of her baby being placed skin-to-skin maintained high overall validity, whereas recall of immediate breastfeeding met neither validity criteria. Health worker documentation of these practices as a composite indicator of essential newborn care met neither validity criteria; health workers documented a 95% prevalence for being kept warm and initiation of breastfeeding within 30 minutes of birth whereas birth observations documented 39% prevalence for these practices within one hour of birth.

Birth attendance and companionship during labor and delivery	Exit interviews	Follow-up interviews	Maternity register
Main provider - doctor, nurse, or midwife	AUC	no criteria met	AUC IF
More than one provider present at birth	AUC IF	no criteria met	
Support person present at birth	AUC	no criteria met	

	Care for the woman	Exit interviews	Follow-up interviews	Maternity register
Maternal background	Maternal age at delivery (adolescent births)			AUC IF
	Prior parity (prior parity, 4 or more births)			AUC IF
Provider practices and respectful care	Woman allowed to move and change position during labor	AUC IF		
	Woman allowed to drink liquids and eat during labor	IF		
	Woman allowed to deliver in preferred position	AUC		
	Woman allowed to have a support person at birth	AUC IF	IF	
	Birth attendant washed hands with soap before examinations	>5% dk	>5% dk	
	Birth attendant wore gloves during examinations	no criteria met	<5 / cell	
	Partograph used to monitor labor and delivery			AUC
Clinical care	Blood pressure taken – initial client assessment	AUC IF	no criteria met	
	Episiotomy performed	<5 / cell	<5 / cell	
	Prophylactic uterotonic administered	IF	IF	<5 / cell

	Care for the newborn	Exit interviews	Follow-up interviews	Maternity register
Immediate postnatal care	Mother and newborn kept in the same room after delivery	IF	<5 / cell	
	Essential newborn care*	AUC IF	no criteria met	no criteria met
	Newborn immediately dried with a towel	AUC IF	<5 / cell	
	Newborn immediately placed skin-to-skin	AUC IF	AUC IF	
	Immediate initiation of breastfeeding	AUC IF	no criteria met	
	Chlorhexidine applied to newborn's cord	AUC IF		
	Baby weighed at birth	>5% dk	>5% dk	IF
Newborn outcomes	Baby's birthweight (low birthweight, <2500 grams)	>5% dk		AUC
	Pre-term birth			<5 / cell
	Stillbirth, fresh or macerated			AUC IF

Figure 2. Summary of childbirth care indicator validity criteria across data recording methods. Observed women were interviewed before discharge from the facility (exit interview) and at home nine to 22 months after childbirth (follow-up interview). Health workers documented childbirth events in facility maternity registers. AUC = area under the receiver operating characteristic curve; IF = inflation factor; >5%dk = >5% "don't know" responses; <5/cell = less than 5 observations per cell in two-by-two table validating data recording method against gold standard; AUC criteria for high individual-level reporting accuracy: AUC≥0.7; IF criteria for low population-level bias: 0.75<IF<1.25. *In the facility maternity register, essential newborn care is a composite indicator for (i) immediate initiation of breastfeeding and (ii) baby kept warm.

Table 3. Validation analyses: comparing birth observations with women's self-reports at facility exit interviews, women's self-reports at household follow-up interviews nine to 22 months after childbirth, and health worker documentation in maternity registers

Birth observations (gold standard)		Comparison data recording method*,†				Matched pairs							
N	Prevalence (95% CI)		N	Don't know (%)	Prevalence (95% CI)	Matched pairs, N	Agreement (%)	5 counts per cell?	Sensitivity (95% CI)	Specificity (95% CI)	AUC‡ (95% CI)	IF‡	Criteria met‡
Skilled birth attendance and companionship during labor and delivery:													
Main provider – doctor, nurse, or midwife:													
1889	10 (4-24)	Exit interview, women's self-report	1775	0	32 (24-41)	1775	72	Yes	67 (60-74)	72 (70-75)	0.70 (0.66-0.73)	3.04	AUC
445	13 (5-27)	Follow-up interview, women's self-report	426	0	48 (37-60)	426	55	Yes	62 (48-75)	54 (49-59)	0.58 (0.51-0.65)	3.76	none
1516	12 (4-31)	Maternity register, health worker documentation	1327	0	12 (4-29)	1327	97	Yes	92 (87-96)	98 (97-99)	0.95 (0.93-0.97)	1.05	AUC, IF
More than one provider present at birth:													
1869	57 (45-68)	Exit interview, women's self-report	1774	0	58 (48-66)	1755	93	Yes	95 (93-96)	90 (88-92)	0.93 (0.91-0.94)	1.02	AUC, IF
444	55 (43-67)	Follow-up interview, women's self-report	426	0	80 (67-89)	418	60	Yes	86 (80-90)	26 (20-33)	0.56 (0.52-0.60)	1.45	none
Support person present at birth:													
1127	35 (22-49)	Exit interview, women's self-report	1075	0	57 (41-72)	1067	75	Yes	97 (94-98)	64 (60-67)	0.80 (0.78-0.82)	1.65	AUC
443	31 (17-50)	Follow-up interview, women's self-report	426	0	82 (74-88)	419	41	Yes	88 (81-93)	21 (16-26)	0.54 (0.51-0.58)	2.64	none
Care for the woman:													
Maternal age at delivery (adolescent births):§													
1516	20 (17-24)	Maternity register, Health worker documentation	1472	0	20 (17-23)	1463	98	Yes	95 (92-97)	99 (98-100)	0.97 (0.96-0.98)	0.98	AUC, IF
Prior parity (prior parity, 4 or more births):§													
1515	47 (42-52)	Maternity register, health worker documentation	1474	0	49 (43-56)	1471	93	Yes	95 (94-97)	91 (88-93)	0.93 (0.92-0.94)	1.06	AUC, IF
Woman allowed to move and change position during labor:													
712	78 (66-87)	Exit interview, women's self-report	1075	1	71 (58-81)	674	84	Yes	92 (89-94)	57 (49-66)	0.75 (0.70-0.79)	1.04	AUC, IF
Woman allowed to drink liquids and eat during labor:													
712	91 (88-93)	Exit interview, women's self-report	1075	1	92 (88-94)	674	91	Yes	98 (96-99)	25 (14-37)	0.61 (0.56-0.67)	1.05	IF
Woman allowed to deliver in preferred position:													
773	52 (43-61)	Exit interview, women's self-report	1075	1	75 (66-83)	691	81	Yes	95 (92-97)	63 (58-69)	0.79 (0.76-0.82)	1.29	AUC
Woman allowed to have support person at birth:													
1885	63 (43-80)	Exit interview, women's self-report	1773	1	59 (41-75)	1757	85	Yes	85 (83-87)	85 (82-88)	0.85 (0.83-0.87)	0.94	AUC, IF
443	60 (36-80)	Follow-up interview, women's self-report	426	1	67 (56-77)	422	57	Yes	71 (65-76)	36 (29-44)	0.53 (0.49-0.58)	1.14	IF
Birth attendant washed hands with soap before examinations:													
1872	30 (21-41)	Exit interview, women's self-report	1775	16	40 (31-49)	1492	81	Yes¶	–	–	–	–	–
444	19 (13-26)	Follow-up interview, women's self-report	426	16	77 (65-85)	359	26	No	–	–	–	–	–
Birth attendant wore gloves during examinations:													
1872	75 (66-83)	Exit interview, women's self-report	1775	0	98 (98-99)	1769	75	Yes	98 (98-99)	2 (1-3)	0.50 (0.49-0.51)	1.30	none
444	90 (73-97)	Follow-up interview, women's self-report	426	1	98 (94-99)	419	90	No	–	–	–	–	–
Partograph used to monitor labor and delivery:													
1516	21 (14-29)	Maternity register, health worker documentation	1308	0	39 (29-50)	1306	79	Yes	95 (91-97)	75 (72-77)	0.84 (0.83-0.87)	1.92	AUC
Blood pressure taken – initial client assessment:													
1515	31 (21-44)	Exit interview, women's self-report	1435	0	34 (23-47)	1429	92	Yes	91 (88-94)	92 (90-93)	0.91 (0.90-0.93)	1.10	AUC, IF
444	22 (10-43)	Follow-up interview, women's self-report	426	2	58 (48-67)	417	56	Yes	82 (73-89)	48 (43-54)	0.65 (0.60-0.70)	2.62	none
Episiotomy performed:													
1504	1 (1-2)	Exit interview, women's self-report	1435	0	2 (1-3)	1429	98	No	–	–	–	–	–
444	1 (0-4)	Follow-up interview, women's self-report	426	2	9 (1-17)	424	91	No	–	–	–	–	–
Prophylactic uterotonic administered during third stage of labor to prevent postpartum haemorrhage:													
1867	96 (93-98)	Exit interview, women's self-report	1775	0	94 (92-95)	1763	93	Yes	95 (94-96)	33 (22-45)	0.64 (0.58-0.70)	0.98	IF
442	96 (93-97)	Follow-up interview, women's self-report	426	1	83 (78-87)	420	82	Yes	84 (80-88)	26 (9-51)	0.55 (0.45-0.66)	0.88	IF

Table 3. Continued

Birth observations (gold standard)		Comparison data recording method*,†				Matched pairs							
N	Prevalence (95% CI)		N	Don't know (%)	Prevalence (95% CI)	Matched pairs, N	Agreement (%)	5 counts per cell?	Sensitivity (95% CI)	Specificity (95% CI)	AUC‡ (95% CI)	IF‡	Criteria met‡
1501	96 (92-98)	Maternity register, health worker documentation	1338	0	93 (90-95)	1332	90	No	–	–	–	–	–
Care for the newborn:													
Mother and newborn kept in the same room after delivery:													
1755	97 (96-98)	Exit interview, women's self-report	1775	1	96 (94-97)	1704	97	Yes	98 (97-99)	40 (24-58)	0.69 (0.61-0.77)	1.00	IF
427	95 (90-98)	Follow-up interview, women's self-report	426	0	88 (81-93)	406	85	No	–	–	–	–	–
Essential newborn care:‖													
1889	42 (29-56)	Exit interview, women's self-report	1774	0	51 (36-65)	1774	87	Yes	92 (90-94)	83 (81-85)	0.88 (0.86-0.89)	1.15	AUC, IF
445	36 (19-57)	Follow-up interview, women's self-report	445	0	64 (44-80)	445	60	Yes	83 (76-89)	47 (41-53)	0.65 (0.61-0.69)	1.77	none
1516	39 (26-53)	Maternity register, health worker documentation	1297	0	95 (90-97)	1297	44	Yes	97 (95-98)	6 (5-8)	0.52 (0.51-0.53)	2.46	none
Newborn immediately dried with a towel:													
1472	95 (89-98)	Exit interview, women's self-report	1435	2	94 (89-97)	1393	98	Yes	99 (98-99)	68 (53-81)	0.83 (0.77-0.90)	1.00	AUC, IF
430	91 (81-96)	Follow-up interview, women's self-report	426	3	91 (78-97)	397	86	No	–	–	–	–	–
Newborn immediately placed skin-to-skin:													
1759	77 (57-89)	Exit interview, women's self-report	1775	3	72 (53-85)	1681	94	Yes	94 (92-95)	93 (90-95)	0.93 (0.92-0.95)	0.96	AUC, IF
427	67 (38-87)	Follow-up interview, women's self-report	426	1	75 (50-90)	402	78	Yes	90 (86-94)	52 (43-61)	0.71 (0.66-0.76)	1.15	AUC, IF
Immediate initiation of breastfeeding:													
1744	49 (34-63)	Exit interview, women's self-report	1775	2	51 (37-65)	1686	90	Yes	94 (92-95)	87 (84-89)	0.90 (0.89-0.92)	1.08	AUC, IF
424	42 (23-63)	Follow-up interview, women's self-report	426	0	67 (46-83)	404	62	Yes	87 (81-92)	44 (38-50)	0.66 (0.62-0.70)	1.66	none
Chlorhexidine administered to newborn's cord to prevent infection:													
1425	85 (74-92)	Exit interview, women's self-report	1435	5	80 (68-89)	1323	95	Yes	96 (95-97)	84 (77-89)	0.90 (0.87-0.93)	0.99	AUC, IF
Baby weighed at birth:													
1785	84 (76-90)	Exit interview, women's self-report	1774	9	80 (64-90)	1603	86	Yes¶	–	–	–	–	–
439	78 (71-84)	Follow-up interview, women's self-report	426	11	62 (40-80)	377	66	Yes¶	–	–	–	–	–
1439	90 (76-96)	Maternity register, health worker documentation	1421	0	94 (84-98)	1403	87	Yes	95 (93-96)	16 (10-23)	0.55 (0.52-0.58)	1.04	IF
Newborn outcome: low birth weight§:													
1604	5 (3-8)	Exit interview, women's self-report	1424	57	3 (1-5)	606	98	Yes¶	–	–	–	–	–
1432	6 (3-10)	Maternity register, health worker documentation	1338	0	17 (9-32)	1180	83	Yes	62 (50-73)	85 (83-87)	0.73 (0.68-0.79)	3.22	AUC
Newborn outcome: pre-term birth:													
1515	2 (1-7)	Maternity register, health worker documentation	1169	0	2 (1-7)	1167	99	No	–	–	–	–	–
Newborn outcome: stillbirth:													
1516	3 (1-6)	Maternity register, health worker documentation	1375	0	3 (1-5)	1365	99	Yes	82 (66-92)	100 (99-100)	0.91 (0.84-0.97)	0.97	AUC, IF

CI – confidence interval, IF – inflation factor, AUC - area under the receiver operating curve

*Observed women were interviewed before discharge from the facility (exit interview) and at home nine to 22 mo after childbirth (follow-up interview). Health workers documented childbirth events in facility maternity registers.

†For health worker documentation in facility maternity registers, data were available for 4 of 5 data collection rounds (N = 1516 observations): March 2017, August 2017, March 2018, and August 2018. For exit interviews, data from June 2016 data collection (round 1) were not available for: (i) blood pressure taken – initial client assessment; (ii) episiotomy performed; (iii) newborn immediately dried with a towel; and (iv) chlorhexidine applied to newborn's cord to prevent infection. For exit interviews, data from June 2016 and March 2017 data collection (rounds 1 and 2) were not available for: (i) woman allowed to move and change positions during labor; (ii) woman allowed to drink and eat during labor; and (iii) woman allowed to deliver in preferred position.

‡AUC = area under the receiver operating characteristic curve; IF = inflation factor. AUC criteria for high reporting accuracy: AUC≥0.7; IF criteria for low population bias: 0.75<IF<1.25.

§For validation analyses, the following indicators were converted into binary variables: age at delivery (adolescent births); prior parity (prior parity, four or more births); and baby's birthweight (low birthweight, <2500 g).

‖In the facility maternity register, essential newborn care is a composite indicator for (i) immediate initiation of breastfeeding and (ii) baby kept warm.

¶For these indicators with >5 observations per cell, validation analyses were not conducted due to >5% "don't know" responses.

For additional immediate newborn care indicators assessed, women's recall during exit interviews had high overall validity for immediate drying of the newborn and the application of chlorhexidine on the newborn's cord. Women's recall of whether she and her newborn were kept in the same room after delivery nearly met the criteria for high overall validity, AUC = 0.69 (95% confidence interval (CI) = 0.61-0.77) and IF = 1.00. For whether the baby was weighed at birth, health worker documentation met criteria for low population-level bias.

For indicators related to low prevalence newborn outcomes, health worker documentation met high overall validity for whether a baby was stillborn and high individual-level accuracy for whether a newborn had low birthweight.

DISCUSSION

Providing high quality facility-based childbirth care with a skilled provider is essential for improving the health and survival of women and newborns. Accurate information on the care received is essential to monitoring progress. In Gombe state, where women predominantly seek childbirth care in rural primary health facilities, our study suggests that health worker documentation in facility registers, facility-level exit interviews, and household-level follow-up interviews can all contribute to accurate monitoring, but no individual method provided a broad understanding of the provision and experience of childbirth care.

Our validation of health worker documentation against a gold standard of birth observations differed from other accuracy studies of facility-based data. To date, studies assessed the extent to which data sources agreed when aggregated, reflecting the critical capacity to tally and report consistently between levels of the health system. Focusing on individual-level validity, health worker documentation had high validity ($AUC \geq 0.70$ and/or $0.75 < IF < 1.25$) for select indicators about the main provider, maternal background characteristics, and newborn outcomes. Unsurprisingly, health workers were well-positioned to determine the provider's cadre and newborn outcomes such as stillbirths. Maternal background characteristics were also relatively stable data which could be verified during the antenatal period.

However, health worker documentation did not meet any validity criteria for essential newborn care, a composite indicator of immediate breastfeeding and keeping the baby warm. As noted earlier, the prevalence for essential newborn care within 30 minutes of birth documented by the health worker was 95% (95% CI = 90%-97%), whereas the observed prevalence for immediate breastfeeding and placing the newborn skin-to-skin within one hour of birth was only 39% (95% CI = 26%-53%); health workers markedly overestimated the prevalence. Given the complexity of the essential newborn care definition, this may reflect the format of the documentation source which did not distinguish between care elements, as well as potential differences in interpretation between the observer and the health worker.

Our study adds new evidence to the validity of women's self-reports at different recall periods and focused on women who delivered in rural primary health facilities. We found that exit interviews had high validity for four immediate newborn care practices: drying the newborn with a towel; placing the newborn skin-to-skin; immediate breastfeeding; and applying chlorhexidine to a newborn's cord. In contrast to our study, two validation studies using hospital exit interviews in Mexico and Kenya did not report high validity for immediate drying of the newborn, placing the newborn skin-to-skin, and immediate breastfeeding [18,19]. Facility environment may explain part of the differences observed, which may in turn influence the frequency of "don't know" responses or the low specificity from a positive facility reporting bias [18,19]. For example, in our study, the practice of placing the newborn with the mother immediately after birth was 97%, compared to 10% in Mexico and 58% in Kenya.

Similar to other validation studies, we found that women's self-reports during follow-up nine to 22 months after childbirth had low validity across indicators assessed. Placing a newborn skin-to-skin immediately after birth was the one exception, consistent with a follow-up study in Mozambique which included a nation-wide sample of rural and urban health facilities, but inconsistent with the Kenyan study [16,20]. One possible explanation for this being a memorable event for northeastern Nigerian women may be that the practice of immediate skin-to-skin contrasts with longstanding cultural beliefs on early bathing of newborns and the negative perceptions of vernix [43,44].

Indicators that met criteria for low population-level bias only, such as the administration of prophylactic uterotonic (exit, follow-up), permission to drink and eat during labor (exit), and baby weighed at birth (maternity register) had high prevalence, which masked a high false positive rate among the small number of clients that did not receive the service. Thus, we recommend caution when interpreting these indicators and triangulation with other data sources.

Our findings highlight the importance of expanding the sources of data for monitoring the content of childbirth care. In addition to standard household surveys, monitoring of facility-based childbirth care should consider drawing from and linking multiple data sources including routine health facility data and exit interviews with recently delivered women. Facility-based routine data, such as registers, and exit interviews are useful sources for determining an accurate numerator when monitoring facility-based care; linkages to population-level data are still critical to determine the denominators for population in need and underserved subgroups [13]. At a global level, as greater emphasis is placed on respectful maternity care and the clients' experience of care, exit interviews are being included in the monitoring frameworks for assessing the quality of facility-based care [45]. Further, recent calls for greater investment in routine health information systems, if successful, would allow for monitoring beyond the global- and national-levels, as routine data are available at a greater level of disaggregation and frequency [13,46,47].

The limitations of exit interviews and routine data still need careful consideration, however. Facility registers capture limited information about service delivery and, hence, provide a narrower but more frequent picture of quality of care. Health worker documentation and exit interviews are susceptible to reporting biases, whereby health workers record information only for the services they provide and women report receiving an intervention because of social desirability bias or a higher quality of care that might be assumed with a facility delivery [17,18].

Among the strengths of this study was the use of birth observations as the gold standard which was compared to facility exit interviews, household follow-up interviews, and health worker documentation in maternity registers. The longitudinal study design allowed us to assess the validity of women's self-reports for different recall periods: before discharge from a facility and at nine to 22 months after childbirth, which more closely reflects the recall period and interviewing conditions of household surveys. Further, this study was novel as this setting was predominantly rural, based in the primary health care context, and included validation of health worker documentation in maternity registers. Among the limitations of the study, our findings primarily reflect the reporting accuracy of women who seek facility-based care. Further, women participating in household surveys are not usually interviewed twice; however, individual-level reporting accuracy decreased in our study which is different from what we would expect for repeated measurements. The gold standard could be susceptible to error from incorrect observer interpretation, errors in data recording, or changing behaviour because of the Hawthorne effect, even in the presence of quality control mechanisms [48]. Even with pre-testing, the questions in the exit and follow-up interviews may not have been interpreted as intended. Further, some observed indicators had such high or low coverage and were unsuitable for validation analyses. Finally, while not strictly a limitation, relatively stringent cut-off criteria were chosen for AUC and IF to align with other studies [23].

CONCLUSION

The childbirth process presents a time of great risk of death for women and newborns. Health worker documentation, facility-level exit interviews, and household-level follow-up interviews with women after childbirth each have a role to play in the accurate monitoring of facility-based childbirth care to improve the health and survival of women and their newborns.

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Authorship contributions: AAB, TM, EA conceived, designed, and carried out the analyses. AAB and TM composed the initial draft. EA, JRM, NU, AU, HF, AA reviewed the early drafts. All authors approved the final draft.

Competing interests: Mr Felix Habila and Mr Ahmed Audu are members of the Gombe State Primary Health Care Development Agency. All authors have completed the Unified Competing Interest form at www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author), and declare no further conflicts of interest.

Additional material

Online Supplementary Document

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6.4 Supplementary material for Study 2

Supplementary Table S1. Childbirth care indicators assessed across data recording methods

Data recording method	Childbirth care indicator item/question
Birth attendance and companionship during labor and delivery	
Main provider – doctor, nurse, or midwife	
Facility exit interview, Household follow-up interview	Thinking about the main person helping you during birth, what was the cadre of that person?
Maternity register	Who took delivery of the child?
More than one provider present at birth	
Facility exit interview, Household follow-up interview	Did more than one health worker assist with the birth?
Support person present at birth	
Facility exit interview, Household follow-up interview	Did you have a support person present during labor and childbirth?
Care for the woman	
Maternal age at delivery (adolescent births)	
Maternity register	Age
Prior parity (prior parity, four or more births)	
Maternity register	Parity
Woman allowed to move and change position during labor	
Facility exit interview, Household follow-up interview	Were you encouraged to move and change position during labor?
Woman allowed to drink liquids and eat during labor	
Facility exit interview, Household follow-up interview	Were you encouraged to have some light food during labor and delivery?
Woman allowed to deliver in preferred position	
Facility exit interview, Household follow-up interview	Were you allowed to deliver in the position you wanted to deliver?
Woman allowed to have a support person at birth	
Facility exit interview, Household follow-up interview	Were you encouraged to have a support person present during labor and childbirth?
Birth attendant washes hands with soap before examinations	
Facility exit interview, Household follow-up interview	Did the birth attendant wash his/her hands with soap and water or use antiseptic before examining you?
Birth attendant wears gloves during examinations	
Facility exit interview, Household follow-up interview	Did the birth attendant wear gloves when examining you?

Partograph used to monitor labor and delivery	
Maternity register	Partograph used to monitor labor and delivery? [yes/no]
Blood pressure taken – initial client assessment	
Facility exit interview, Household follow-up interview	When you were there did anyone check your blood pressure (put a strap around your upper arm and take a measurement)?
Episiotomy performed	
Facility exit interview, Household follow-up interview	When you gave birth, did the attendant need to cut your privates to get the baby out (also called an episiotomy)?
Prophylactic uterotonic administered during third stage of labor to prevent postpartum hemorrhage	
Facility exit interview, Household follow-up interview	Immediately after the birth, were you given an injection or drugs to help stop the bleeding? (also called a uterotonic)?
Maternity register	Active management of third stage of labor? [yes/no]
Care for the newborn	
Mother and baby kept in the same room after delivery	
Facility exit interview, Household follow-up interview	Were you and the baby kept in the same room after delivery?
Essential newborn care	
Facility exit interview, Household follow-up interview	Immediately after the birth, did you put the baby to your breast to help start breastfeeding, with or without the help of the health worker? AND Immediately after the birth, was the baby placed on your body "skin to skin"?
Maternity register	Essential newborn care: immediate initiation of breastfeeding, baby kept warm
Newborn immediately dried with a towel	
Facility exit interview, Household follow-up interview	Immediately after the birth, was the baby dried with a towel or cloth?
Newborn immediately placed skin-to-skin	
Facility exit interview, Household follow-up interview	Immediately after the birth, was the baby placed on your body "skin to skin"?
Immediate initiation of breastfeeding	
Facility exit interview, Household follow-up interview	Immediately after the birth, did you put baby to your breast to help start breastfeeding, with or without the help of the health worker?
Chlorhexidine applied to newborn's cord to prevent infection	
Facility exit interview, Household follow-up interview	Did the health worker put chlorhexidine on the baby's cord to prevent infection?
Baby weighed at birth	

Facility exit interview, Household follow-up interview	Was your baby weighed at birth?
Maternity register	<2500 grams or ≥2500 grams
Baby's birthweight (Low birthweight, <2500 grams)	
Facility exit interview, Household follow-up interview	If the baby was weighed, can you tell me the birthweight (kg)?
Maternity register	<2500 grams or ≥2500 grams
Pre-term birth	
Maternity register	Pre-term birth? [yes/no]
Stillbirth, fresh or macerated	
Maternity register	Stillbirth, fresh or macerated

Chapter 7: Assessing changes in routine data quality before-and-after a district-level intervention

Objective 3:

To assess changes in the quality of routine MNH data *reported by* facilities before and after a district-level data quality intervention

7.1 Introduction

In Chapter 7, we examined the quality of routine data before and after an LGA-level data quality intervention in Gombe State. Similar to Study 1 (chapter 5), we examined three data quality dimensions: completeness and timeliness, internal consistency of reported data, and external consistency. This chapter sought to fulfill thesis objective 3.

To compose this manuscript, I conceptualized and designed this study with Tanya Marchant. I prepared the data for analyses, cleaning and merging the data in DHIS 2, IDEAS facility surveys, and IDEAS household surveys. The analyses undertaken here built on the calculations prescribed by the WHO data quality review toolkit for facility data. As described in chapter 4, we calculated an additional metric for completeness: completeness of information (dataset). We also updated the methods for assessing consistency between related data and accuracy of facility reporting. For these internal consistency metrics, we used intraclass correlation coefficient as a reliability index to capture agreement and correlation. Elizabeth Allen provided critical feedback on the analytical approach, particularly the relevance of using intraclass correlation coefficients. Finally, a secondary objective of this study was to consider the usefulness of assessing all proposed WHO metrics, what the additional metrics offer in understanding data quality beyond the often-studied metrics of completeness and accuracy of facility reporting.

For Study 3, I conducted all of the analyses presented in the paper. I wrote the first draft, with feedback provided by all authors. I led on all revisions suggested by co-authors. The manuscript has been submitted to BMJ Open and is awaiting an editorial decision (June 15, 2020).

7.2 Research paper cover sheet for Study 3

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RESEARCH PAPER COVER SHEET

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SECTION A – Student Details

Student ID Number	1602264	**Title**	
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Thesis Title	Evaluating the quality of routine data in primary health facilities for monitoring maternal and newborn care in Gombe State, northeastern Nigeria		
Primary Supervisor	Dr Tanya Marchant		

If the Research Paper has previously been published please complete Section B, if not please move to Section C.

SECTION B – Paper already published

Where was the work published?			
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SECTION C – Prepared for publication, but not yet published

Where is the work intended to be published?	BMJ Open
Please list the paper's authors in the intended authorship order:	Antoinette Alas Bhattacharya, Elizabeth Allen, Nasir Umar, Ahmed Audu, Habila Felix, Joanna RM Schellenberg, and Tanya Marchant

Stage of publication	**Submitted**

SECTION D – Multi-authored work

For multi-authored work, give full details of your role in the research included in the paper and in the preparation of the paper. (Attach a further sheet if necessary)	I conceived and designed the study with Tanya Marchant. I designed the analysis with Elizabeth Allen. I carried out all analyses presented in the paper. I wrote the first draft. I led on all revisions and incorporated feedback from co-authors.

SECTION E

Student Signature	[redacted]
Date	15 June 2020

Supervisor Signature	[redacted]
Date	15 June 2020

7.3 Submitted manuscript (Study 3)

Improving the quality of routine data captured in primary health facilities through an integrated district-focused intervention in northeastern Nigeria

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ABSTRACT

Introduction

Improving the quality of routine facility data is essential for local and national evidence-based monitoring of universal health coverage. We developed an integrated district-focused data quality intervention in a high mortality setting in northeastern Nigeria, and quantified change in the data quality metrics before and after the intervention.

Methods

Between April 2017-December 2018, we implemented an integrated data quality intervention in 11 local government areas (district-equivalent) overseeing 492 primary health facilities providing maternal and newborn care. We assessed 9 metrics across the data quality dimensions of completeness and timeliness, internal consistency, and external consistency. Data from facility registers, District Health Information Software version 2, and household surveys were used to assess these metrics for 14 maternal and newborn health data elements, comparing the 21-month period before the intervention (July 2015-March 2017) to the 21-month intervention period. We also considered whether assessing the data quality metrics beyond completeness and accuracy of facility reporting offered new insight into reviewing routine data quality.

Results

The data quality intervention was associated with improvements in 7 of 9 data quality metrics assessed including availability and timeliness of reporting, completeness of data elements, accuracy of facility reporting, consistency between related data elements, and frequency of outliers reported. Improvement differed by data element type, with content of care and commodity-related data improving more than contact-related data. Increases in the consistency between related data elements demonstrated improved internal consistency within and across facility documentation.

Conclusion

An integrated district-focused data quality intervention – including regular self-assessment of data quality, peer review and feedback, learning workshops, workplanning for improvement, and ongoing support through social media – can increase the completeness, accuracy, and internal consistency of facility-based routine data.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- We extended the evidence on integrating data quality interventions within existing systems to improve the quality of facility-based data for monitoring and planning.
- We demonstrate the value of an integrated district-focused data quality intervention to include regular self-assessments of data quality, peer review and feedback, workplanning for improvement, and ongoing support through social media.
- We assessed the usefulness of the World Health Organization's catalogue of data quality metrics to measure and monitor the quality of routine facility data, as data quality studies primarily review completeness and accuracy of facility reporting.

1. Without a concurrent comparison group, our before-and-after analyses cannot eliminate the effects of concurrent events and activities on data quality metrics.

INTRODUCTION

Routine health information systems provide essential data for governments and stakeholders to make decisions for managing performance and optimizing service delivery.[27 30 34] Routine health information systems, which include facility-based data, have the potential to provide disaggregated statistics important for understanding disparities and inequities in the provision of quality services and related health outcomes.[123 139]

Effective use of routine health data is dependent, in part, on the quality of data.[30 38 74 114 123 178] Studies assessing the quality of routine health data have shown persistent challenges in incomplete and untimely reporting, incomplete indicator-level data, inaccurate facility reporting, and imprecise target population estimates for coverage.[37 43 122 166] Further, studies have noted considerably poorer data quality at the facility-level than at district-, state-, and national-levels, citing challenges in accurately capturing data as well as in tallying and summarizing service data for monthly reporting.[89 151 152]

Efforts to improve the quality of routine data have included trainings, workshops and review meetings, data verification surveys, strengthening feedback mechanisms, district- and case-based electronic information systems, and the provision of supplies and equipment such as facility registers and computers.[43 108 114 123 124 165] Activities which aligned with user priorities and were integrated within existing government systems were perceived to be advantageous as well as more likely to be adopted and adapted.[165]

Within the context of routine health information systems, the World Health Organization (WHO) has characterized routine data quality into four broad dimensions: completeness and timeliness; internal consistency; external consistency; and external comparisons.[33] While the abovementioned data quality interventions have demonstrated increases in completeness and accuracy of facility reporting[74 114 123 124 228], there are few peer-reviewed studies that quantitatively assessed changes in data quality metrics beyond this.[34 38 108]

In this study, our primary objective was to measure the changes in data quality metrics before and after the introduction of an integrated district-focused intervention in northeastern Nigeria for routine facility data captured in primary health facilities. A secondary objective was to determine the extent to which expanding data quality metrics beyond completeness and accuracy of facility reporting offered new insight into reviewing data quality.

METHODS

Study design

This was a before-and-after study design for a data quality intervention in all 11 local government areas (LGA, district-equivalent) of Gombe State, northeastern Nigeria. We present results for the state (n=492 facilities), comparing the 21-month period before the intervention, July 2015-March 2017, with the 21-month period after introducing the intervention, April 2017-December 2018.

Study approvals

Study approvals were obtained from the London School of Hygiene & Tropical Medicine (reference 14091) and the Health Research Ethics Committees for Nigeria (reference NHREC/01/01/2007) and Gombe State (reference ADM/S/658/Vol. II/66).

Patient and public involvement

Patients or the public were not involved in the design, conduct, reporting, or dissemination of the research described here.

Study setting

Gombe State is located in northeastern Nigeria, a region with high maternal and newborn mortality at 1,549 per 100 000 live births and 35 per 1,000 live births, respectively.[66 67] With an estimated population of 2.9 million, Gombe is predominantly rural and 35%% of the women have some primary school education.[50 68] Most women access maternity care through public facilities. Seventy-two percent of women reported at least one antenatal care visit during their last pregnancy and 28% gave birth in a health facility.[50 67] In 2018, over 70% of facility deliveries took place in rural primary health facilities.[69]

Under Nigeria's national policy of *Primary Health Care Under One Roof*, the Gombe State Primary Health Care Development Agency oversees the administration and service delivery for primary health facilities across 11 local government areas (LGA); each LGA has 10-11 political wards (114 wards, total).[53,54] LGA monitoring and evaluation officers are responsible for community- and facility-level data collection, validation, and reporting to the state office. LGA maternal, neonatal, and child health (MNCH) coordinators support the supervision and implementation of services for women and children.

During the intervention period, Gombe State had 492 primary health facilities providing antenatal and childbirth services. As in other states in Nigeria, Gombe facility staff generally completed 13 paper-based registers to document the services they provide (Nigeria Health Management Information Systems, version 2013). Every month, a subset of data in these registers were tallied and summarized in a paper-based report and sent to the LGA health office to be entered into District Health Information Software, version 2 (DHIS 2).

Data quality intervention

The routine data quality intervention period spanned 21 months, from April 2017 through December 2018. The intervention emphasized the partnership between the LGA monitoring and evaluation officer and the LGA maternal, newborn, and child health program coordinator to underscore the link between the quality and use of routine data.[74] It was designed as a facilitative layer to existing LGA-level supervision responsibilities, leveraging scheduling of ongoing activities to minimize cost, adding job aids and defining performance standards to provide structure to data quality checking duties and to target feedback to facilities.

The intervention included the following activities: (i) data quality learning workshops to present data quality self-assessment findings and develop workplans for improvement; (ii) defining data quality performance standards and milestones for completeness, timeliness, and consistency; (iii) introduction of job aids to self-assess data quality according to the WHO data quality metrics; (iv) monthly state- and LGA-level data quality summary reports; (v) intentional practice on providing constructive feedback to peers and low-performing facilities to promote a positive culture of data use; and (vi) ongoing engagement on data quality issues through government-approved communication channels, including the social media application WhatsApp.

Twenty-six main attendees participated in the workshops and ongoing communication in-between workshops. This included two participants from each of the 11 LGAs, a monitoring and evaluation officer and the maternal, newborn, and child health program coordinator. At the state-level, four officials participated: the director of the state planning, research, and statistics department, the state monitoring and evaluation officer, the state health management information systems officer, and the state maternal, newborn, and child health coordinator.

Four data quality learning workshops took place every six to nine months. The two-day workshops included the introduction of job aids and practical sessions to strengthen data quality checking skills, the presentation of the state's and each LGA's self-assessment of data quality, and the development of six-month workplans to improve the quality of facility-based routine data. Using materials designed for post-graduate learning and teaching, there was intentional practice on how to provide constructive feedback to peers and facilities to promote a positive culture of information use.[76]

At each workshop, a major theme emerged during the workplanning sessions (Figure 1). For example, at the first workshop, participants were concerned with inconsistencies observed between the paper-based facility registers and the facility's monthly summary reports. Activities enacted from the workplanning session were to revitalize dormant groups previously set up to address program monitoring and evaluation activities: (i) LGA data validation committee meetings, where facilities bring their registers for verification against their submitted monthly facility report. and (ii) a social media WhatsApp group of LGA actors and facilities. The LGA teams posted pictures and comments on these facility interactions on the WhatsApp group for encouragement and accountability.

After the first workshop, the Gombe State monitoring and evaluation officer disseminated monthly state- and LGA-level data quality summary reports. LGAs were assessed according to the WHO data

Figure 1. Data quality learning workshops in Gombe State, April 2017-December 2018

Workshop 1

Learning and practice:
- Data quality dimensions, metrics
- Job aids for self-assessment
- Workplanning for improvement

Participant presentation:
Present findings for select data quality metrics (completeness of reporting and agreement between facility register data and reports)

Main outputs from workplanning:
- Finalize standards and milestones for data quality reporting by LGAs
- Revitalize monthly LGA validation committee
- Revitalize WhatsApp group for ongoing communication

Workshop 2

Learning and practice:
- Quarterly self-assessment practice with job aids
- Interpreting and visualizing self-assessment findings

Participant presentation:
Present quarterly self-assessment findings for peer review and feedback

Main outputs from workplanning:
- Adjust data quality metric calculations to exclude inactive facilities and indicators in DHIS2
- Improve completeness of data elements
- Identify facilities with low data quality metrics and call/visit them to problem solve

Workshop 3

Preparation before workshop:
- Quarterly data quality self-assessment, January-March 2018
- Investigate reasons for facilities' higher/lower data quality metrics

Learning and Practice:
- Interpreting and visualizing self-assessment findings
- Comparing LGA-level findings with performance of Gombe State and with neighboring LGA
- Providing positive and constructive feedback

Participant presentation:
Joint presentation (with neighboring LGA) of quarterly review findings

Main outputs from workplanning:
- Clean up inactive facilities and indicators in DHIS2
- Identify facilities with low data quality metrics and call/visit them to problem solve
- Practice positive feedback

Workshop 4

Preparation before workshop:
- Bi-annual data quality self-assessment, May-October 2018
- Investigate reasons for facilities' higher/lower data quality metrics

Learning and Practice:
- Elements of an effective presentation and feedback

Participant presentation:
- Bi-annual data quality findings and priorities for next 6 months
- Demonstrating positive feedback to presenters

Main outputs from workplanning:
- Improve consistency between related data elements, focus feedback on facilities with higher inconsistency between ANC1 and related services
- Provide faster, real-time feedback to facilities

quality metrics and recommendations for improvement were offered. Initially, this activity was designed for the external workshop facilitators to compose and disseminate, while building the capacity of the state officer to take on this task over time.

Outcomes

Using the WHO data quality review toolkit for routine facility data, we assessed 9 metrics across the three data quality dimensions of completeness and timeliness; internal consistency; and external consistency.[75] The data sources and analyses for each data quality metric are described in the following section. Supplementary table S1 provides additional information on each data quality metric assessed and the data sources reviewed.

Data analysis and data sources

Three data sources were used to assess the routine data quality metrics, described below: facility-reported data in DHIS 2; external facility surveys; and external household surveys.

DHIS 2 contained monthly reports for the 492 primary facilities providing antenatal care, childbirth, and postnatal care services. Monthly aggregated DHIS 2 data for July 2015-December 2018 were downloaded at one time and included 14 maternal and newborn health-related data elements. These data were used to assess availability of facility reporting; timeliness of facility reporting; completeness of all 14 priority maternal and newborn health data elements, per monthly facility report; completeness of data element; presence of moderate and extreme outliers; consistency of indicator values over time; and consistency between related data elements. We calculated the intraclass correlation coefficient (ICC) as a measure of reliability for the consistency between related data elements. ICC values range between 0 and 1, where values approaching 1 represented greater reliability.

In 2016 and 2018, facility-level surveys were conducted in 97 primary facilities across Gombe to assess their readiness to provide maternal and newborn health services. The two surveys represented the approximate midpoints of the pre-intervention and intervention period. The selected facilities were a state-wide random sample drawn from all primary health facilities. Detailed methods are reported elsewhere.[65] The facility survey protocol was similar to a Service Availability and Readiness Assessment and also included data extraction from the facility's paper-based antenatal and postnatal care register and the labor and delivery register (Nigeria health management information system, version 2013).[223] A trained third party data collection team tallied and recorded the register data for each month of the six-month periods immediately prior to the survey: January-June 2016 and February-July 2018.

The facility-level survey data were used to assess the accuracy of facility reporting (also referred to as data accuracy, data verification, or concordance in peer-reviewed literature). We compared the facilities' paper-based registers data with the facilities' monthly reported data in DHIS 2. As with the consistency between related data elements, we calculated the ICC as a measure of reliability for the facility's reporting of the indicator in DHIS 2. ICC values approaching 1 represented greater reliability.

In 2016 and 2018, household-level surveys were conducted in the catchment areas of the abovementioned 97 primary facilities to assess access to and quality of maternal and newborn services.[65] These catchment areas represented 79 enumeration areas since some enumeration areas were served by more than one facility. All households in each enumeration area were surveyed. The household surveys included a mother's module which asked all women who reported a birth in the last year a detailed set of questions about their contact with health services across the continuum of care from pregnancy to postnatal care. Informed consent was obtained at the community leadership-level and at the individual-level for each respondent. All invited participants agreed be interviewed.

The household-level survey data were used for external consistency during the pre-intervention and intervention periods. We compared coverage estimates from household surveys to those from the 97 matching facilities in DHIS 2. We compared the same recall period for the surveys and the DHIS 2. The DHIS 2 data are considered consistent if they fall within the confidence intervals of the external household survey estimates.

Calculations of point estimates and their 95% confidence intervals were done using the svyset Stata command (StataCorp, College Station, USA) to adjust for clustering. We chose the highest-order clustering level to provide the most conservative confidence interval estimates.[229]

RESULTS

An integrated district-focused data quality intervention was implemented across 11 LGAs overseeing 492 primary health facilities providing maternal and newborn care services. Below, we present the results for 9 data quality metrics.

Completeness and timeliness

Table 1 summarizes the completeness and timeliness of reporting at the facility- and indicator-levels.

At the facility-level, the availability of monthly facility reports improved from 72% to 82% (p<0.001) and timeliness of submitting the reports increased from 60% to 72% (p<0.001). The proportion facility-months where all 14 priority maternal and newborn health data elements contained a value within the monthly report increased from 62% to 68% (p<0.001).

At the indicator-level, seven of 14 data elements assessed improved in completeness compared to the pre-intervention period. Indicator-level completeness did not change for contact indicators such as first antenatal care visits, total antenatal care visits, and facility deliveries.

Table 1. Facility- and indicator-level completeness and timeliness, Gombe State (n=492 facilities)

	Pre-intervention Jul '15-Mar '17 % (95% CI)	Intervention Apr '17- Dec '18 % (95% CI)
Facility-level		
Availability of monthly facility reports	72 (69-74)	82 (80-84)
Timeliness of monthly facility reports	60 (57-62)	72 (70-74)
Completeness of all 14 priority maternal and newborn health data elements, per monthly facility report	62 (60-63)	68 (66-70)
Indicator-level		
For every 100 facilities that submitted a monthly facility report, the percentage of facilities reporting a value for the following services:		
First antenatal care visits	76 (67-85)	77 (70-84)
Total antenatal care visits	100 (99-100)	100 (100-100)
Facility deliveries	68 (59-77)	67 (60-74)
For every 100 facilities that reported a value for first ANC visit, the percentage of facilities reporting a value for the following services:		
Antenatal care anemia testing	28 (16-39)	36 (24-49)
Antenatal care syphilis testing	42 (23-61)	29 (23-35)*
Iron-folic acid supplementation	80 (75-84)	89 (85-92)
At least one dose administered of intermittent preventive treatment of malaria	45 (34-56)	56 (49-62)
At least one dose administered of tetanus toxoid vaccine	90 (86-93)	89 (86-91)
For every 100 facilities that reported a value for a facility delivery, the percentage of facilities reporting a value for the following services:		
Delivery by skilled birth attendant	43 (25-61)	86 (81-91)
Live birth or still birth	90 (86-95)	96 (94-97)
Baby weighed at birth	89 (83-95)	95 (94-97)
Oral polio vaccine given at birth	79 (70-87)	86 (82-90)
Early postpartum-postnatal care within 3 days of birth	45 (38-53)	55 (46-64)
Bacillus Calmette-Guérin vaccine given during postnatal care period	79 (71-88)	81 (77-86)

Notes:
* During the intervention period, commodities for antenatal care syphilis testing were redistributed and restricted to 57 facilities. For these 57 facilities, completeness of data for antenatal care syphilis testing increased from 48% (95% CI: 28-68) to 77% (95% CI: 69-86).

Internal consistency: consistency between related data elements

To assess the consistency between related data elements with a predictable relationship, two types of relationships were reviewed (Figure 2). The first type of relationship assessed concurrent tallying across different data elements within and across facility registers. For example, (1) normal deliveries + caesarean deliveries + assisted deliveries = live births + still births; and (2) total postpartum visits reported = sum of the postnatal visit categories reported. For Gombe State, the ICC of delivery types (normal, caesarean, assisted) to birth types (live births, still births) improved from 0.78 (95%CI: 0.67-0.85) to 0.95 (0.91-0.97). Similar patterns of improvement were noted for postnatal visit tallying from an ICC of 0.54 (0.38-0.65) to 0.87 (0.74-0.93).

The second type of relationship assessed was a service provision compared to a contact indicator (e.g., the number of antenatal care syphilis testing done compared to antenatal care first visits, the number of babies weighed at birth compared to the number of facility deliveries). During the pre-intervention period, one of the 10 relationships reflected high consistency: iron-folic acid supplementation. During the implementation period, five of the 10 relationships reflected improved consistency.

Internal consistency: accuracy of facility reporting

Comparing the facilities' registers with their submitted monthly reports, accuracy of facility reporting (data accuracy) had improved for 6 of 7 indicators, reflecting greater agreement during the intervention period (Figure 3). For total postnatal care visits, considerable variation between facilities can be seen with an ICC of 0.59 (95% CI: 0.44-0.71) during the intervention period.

Figure 2. Internal consistency: consistency between data elements with a predictable relationship (n=492 facilities)
Notes: ICC values range from 0 to 1, with values approaching 1 representing greater reliability.

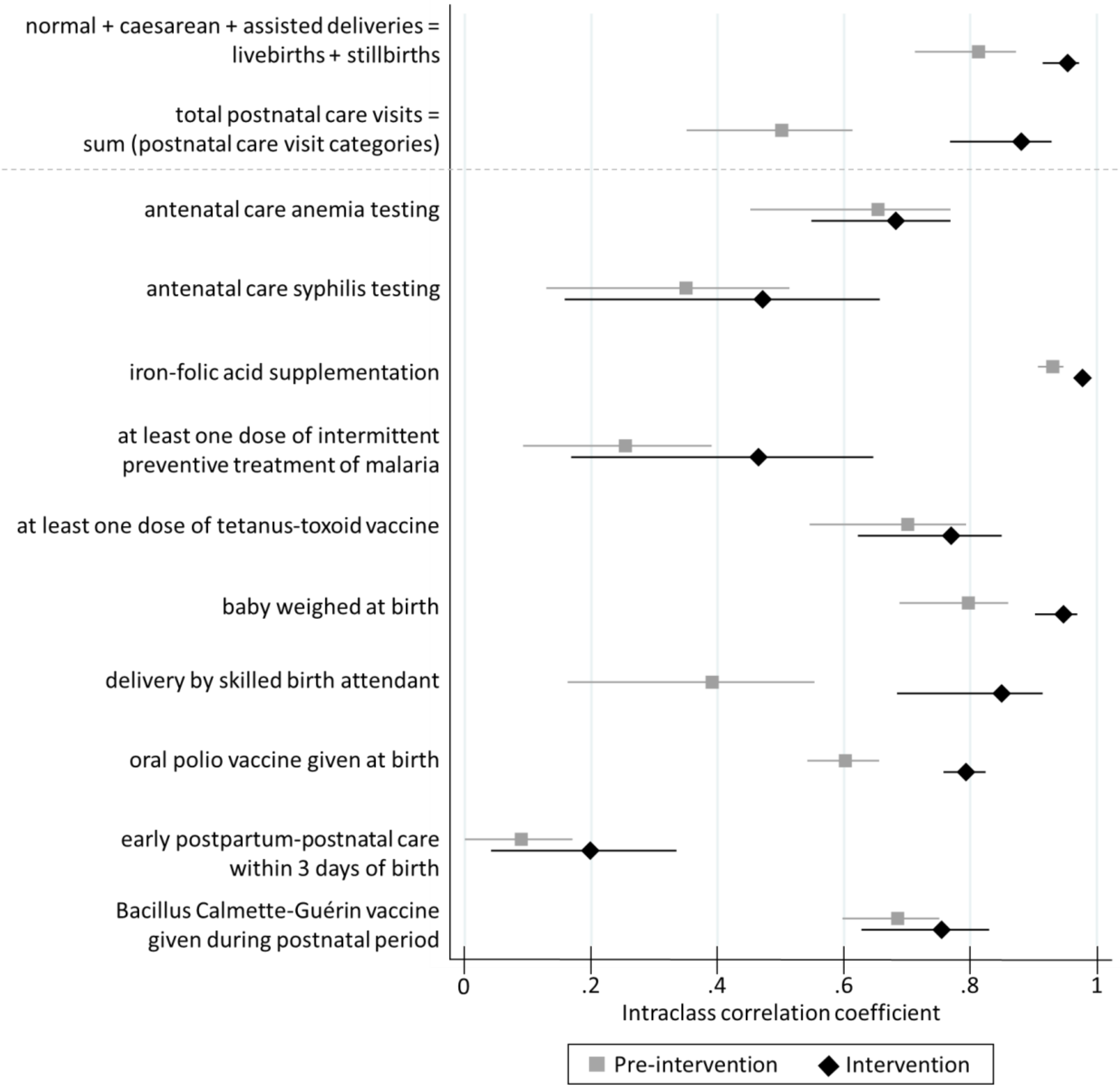
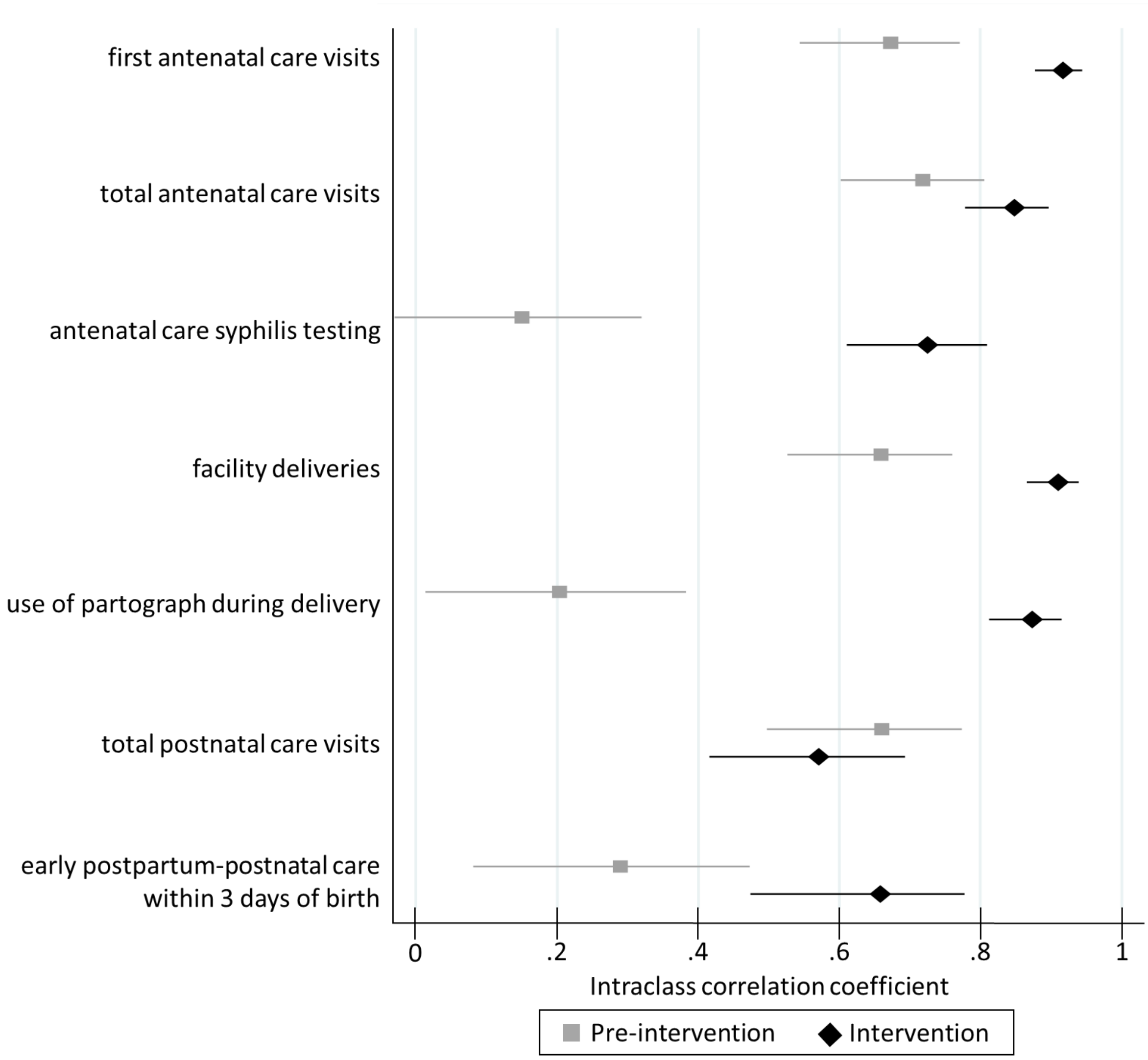


Figure 3. Accuracy of facility reporting: comparison of paper-based facility records and facility monthly reports in DHIS 2 (n=97 facilities)
Notes: ICC values range from 0 to 1, with values approaching 1 representing greater reliability.



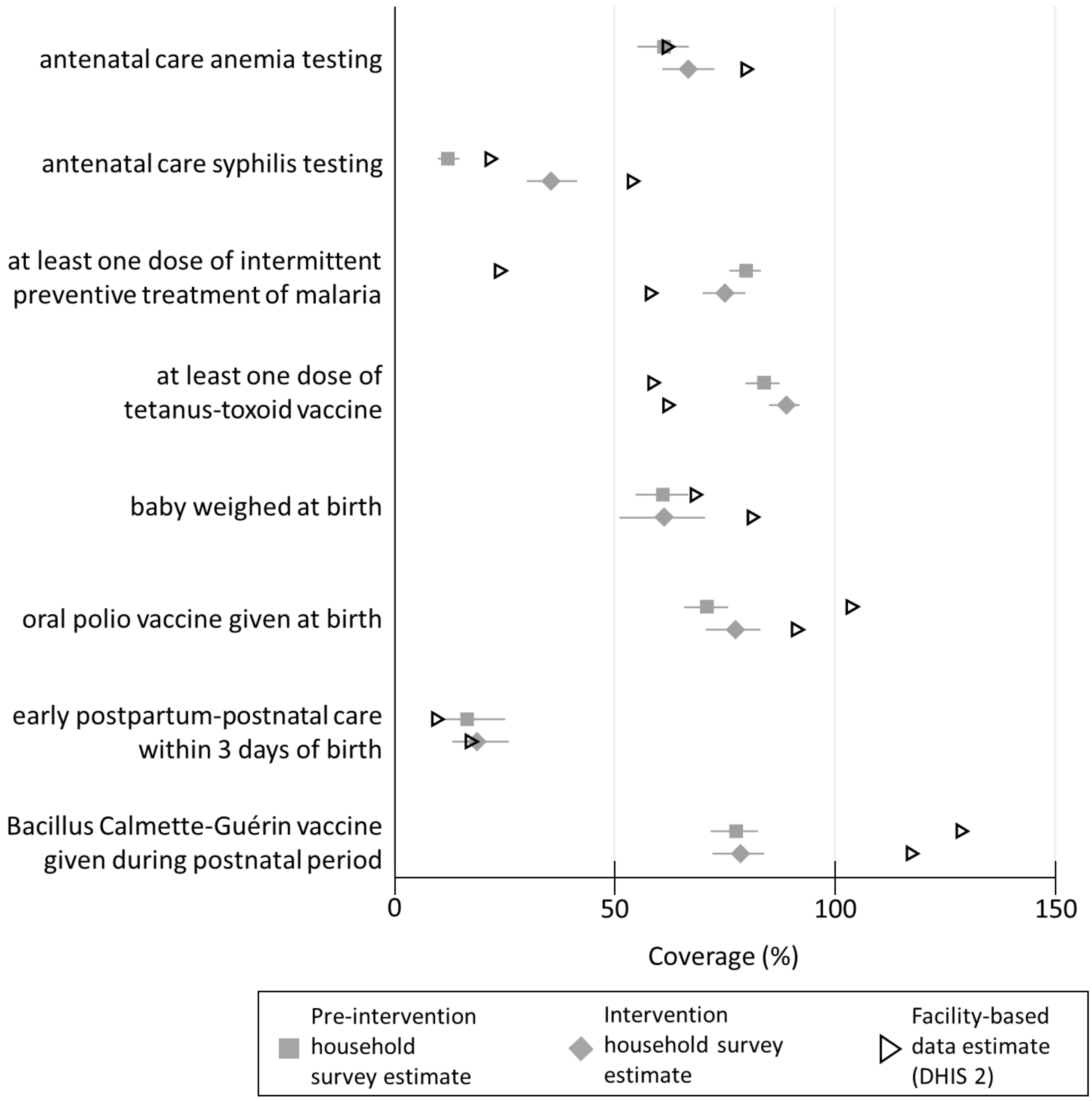
Internal consistency: outliers and consistency over time

Supplementary tables S2 and S3 summarize the presence of outliers and the consistency over time for the 14 maternal and newborn data elements. The frequency of months when outliers were reported decreased during the intervention period. However, 11 moderate outliers were reported during the intervention period compared to eight moderate outliers and two extreme outliers reported during the pre-intervention period. All 11 outliers reported during the intervention period occurred in May 2018 during a health worker strike. Of the 14 data elements assessed, six data elements were inconsistent over time due to reported increases in services when comparing the final year of the intervention 2018 to the mean value of the last 3 years and when comparing the pre-intervention and intervention periods.

External consistency: agreement between facility summary reports in DHIS 2 and household surveys

Figure 4 summarizes external consistency, which is the agreement between facility-based routine data in DHIS 2 compared to household-level surveys in the catchment areas of these facilities. Other than the indicator for early postpartum-postnatal care, there was no agreement nor any consistent pattern of agreement between facility-based routine data and the household surveys. DHIS 2 underestimated compared to the household survey for at least one dose of intermittent preventative therapy for malaria in pregnancy and at least one dose of tetanus toxoid. DHIS 2 overestimated compared to the household survey for baby weighed at birth, oral polio vaccine given at birth, and Bacillus Calmette-Guérin given during postnatal period. For antenatal care anemia testing, facility-based estimates were within the household survey estimate confidence interval but overestimated compared to the household survey during the intervention period.

Figure 4. External consistency: comparison of household-level survey and facility summary reports in DHIS 2 (n=97 facilities)



DISCUSSION

Facility-based routine data are an important source for monitoring, performance management, and planning.[38] Our study found that an integrated district-focused data quality intervention – which included regular self-assessment of data quality, peer review and feedback, learning workshops, workplanning for improvement, monthly data quality reports, and ongoing support through social media – was associated with improvements across most WHO data quality metrics. There were differences in data quality improvement by data element type.[230] Data related to content of care or the provision of commodities, such as syphilis testing and intermittent preventative therapy for malaria, improved more across data quality metrics compared to contact indicators which had relatively higher data quality metrics before the intervention, such as first antenatal care visits and facility deliveries.

This was an integrated data quality intervention designed to facilitate existing state- and district-level data quality checking responsibilities and emphasize the partnership between the monitoring and evaluation officers and the maternal, newborn and child health program coordinators to expand local access to the DHIS 2 data, use the data, and problem solve.[38] The evolution of the intervention through the workplanning sessions prompted local solutions defined by the participants as feasible and within their resources to implement. In particular, the participants' decision to revitalize the data validation committees during the first workshop engaged the facilities early on to ensure the facility's register counts matched the facility's monthly report aggregate value. This early engagement with facilities could have contributed to the increased ICCs for accuracy of facility reporting observed during the intervention period (as shown in Figure 3). A formative phase of the intervention might have captured activities such as the data validation committee as a pre-defined intervention activity. Including a formative phase should be a consideration for future implementation.

Our findings aligned with previous studies reporting improvements in completeness, timeliness, and accuracy of facility reporting after intervention. However, this study's relative gains may reflect the scale of working through 11 districts with 492 primary health facilities.[74 114 123 124 228] A data quality intervention in KwaZulu-Natal province, South Africa, which included trainings, monthly data meetings, and external data quality audits across 78 facilities improved completeness of six data elements from 26% to 64% and the agreement between facility records and reports (data accuracy) from 37% to 65%.[114] A province-wide data quality intervention in Sofala, Mozambique, for 26 facilities included regular district-level review meetings for health workers and managers, data dashboards for tracking trends and rankings, human resource optimization models, and equipment purchase and maintenance. The summary measure used to evaluate data quality improvement, concordance, improved from 56% to 88% during the intervention period.[123] The introduction of an electronic medical record to support data quality improvement in 27 facilities across Kenya recorded a decline in missing data from 31% to 13% for 24 data elements, with a mean concordance score increasing across facilities by 1.79 (95% CI:0.25-3.33).[124]

While our findings align with previous studies for increased completeness, timeliness, and accuracy, our study reviewed additional WHO metrics to give a more comprehensive picture of the dimensions of data quality. This study also provided an opportunity to reflect on the relative usefulness of assessing all WHO data quality metrics to understand the quality of routine data in a given context. Sharp increases in service uptake due to health campaigns or targeted health projects make the assessment of moderate outliers and consistency over time less insightful about data quality, especially in the context of urgent efforts towards achieving universal health coverage. Our study found that, other than early postpartum-postnatal care within three days of birth, there were no instances of agreement between the facility-based routine data and external household surveys. However, an emerging body of criterion validity studies have demonstrated mixed results in the ability of women to recall facility-based pregnancy- and childbirth-related events in household surveys.[130-132 134 231] More research is needed on how to reconcile health facility and household survey data, while also reconsidering the emphasis on the household surveys as the reference standard.

In addition to the completeness and accuracy regularly reported in the literature, the data quality metrics to assess the completeness of information and the consistency between related data elements provided useful insights. Distinct from completeness of data which is an indicator-level metric, completeness of information is a facility-level metric which defines a dataset necessary to monitor and take action to improve service delivery. Assessing the data relationship for a service provision compared to a contact indicator (e.g., ANC anemia testing compared to ANC first visits) allows for discussion on whether observed discrepancies are due to low service uptake or poor reporting, an important consideration given the emphasis on improving quality of care and understanding effective coverage.[232] Further, assessing data relationships that require concurrent tallying of services/information across data sources (e.g. facility attendance = inpatient + outpatient; normal delivery + caesarean delivery + assisted delivery = live births + still births), provides useful insight about whether a facility is paying attention to the internal consistency of their data within and across facility documentation. Focus on accuracy of facility reporting, a more common metric assessed in the peer-reviewed literature (referred to as data accuracy or concordance), is an important data quality metric as subnational-, national-, and global-level monitoring cannot take place effectively without the confidence that the facilities have summarized and tallied the data as intended. However, this focus on the accuracy of facility reporting up through the different levels of the health system do not require that these data be internally consistent with other data.

Our study had limitations. Without a concurrent comparison group, our before-and-after analyses cannot eliminate the effects of concurrent events and activities on data quality metrics. It is possible that other activities contributed to the observed data quality improvements. Given the high burden of maternal and neonatal mortality, the Gombe State Primary Health Care Development Agency spearheaded an initiative to improve maternal and neonatal services with the aim of having one fully functional primary health facility in each of its 114 wards. During the intervention period, 57 facilities (12% of the 492 maternity facilities) received support including facility-level quality improvement support as well as community-based outreach and education to increase uptake of services. Facility-level activities included support on data quality to monitor trends in services provided and the provision of computers and facility registers. Additionally, similar to other data quality assessments, we did not validate the data through direct clinical observations[43 113 114 123 166 176 233] nor did we compare the paper-based monthly summary reports to their electronic versions in DHIS 2[108 114 128 138 166 234]. Despite close attention to quality control, the facility- and household-level surveys might still be susceptible to errors in data recording, including incorrectly tallying the number of events in the original facility registers for comparison with data in DHIS 2.

Improving the quality of routine facility data is essential for local and national evidence-based monitoring of universal health coverage. We found that an integrated district-focused data quality intervention was associated with increases across most WHO data quality metrics for routine facility-based data. Future initiatives should aim to incorporate national- and higher subnational-levels of the health system to determine scalability and sustainability of integrated data quality interventions in the long-term.

References

References cited in this submitted manuscript are located in the overall ‘References’ section of the thesis, starting on page 175.

Acknowledgements

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Contributors

AAB and TM conceived and designed the study. AAB and EA designed the analyses. AAB carried out the analyses and composed the initial draft. JS, TM, EA, NU, AA, HF reviewed the early drafts. All authors approved the final draft.

Data sharing statement

Data for this study are available from the London School of Hygiene & Tropical Medicine public repository: http://datacompass.lshtm.ac.uk/229/.

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Competing interests

Mr Felix Habila and Mr Ahmed Audu are members of the Gombe State Primary Health Care Development Agency. The authors declare no other competing interests.

7.4 Supplementary material for Study 3

Supplementary Table S1. Data quality metrics and data sources reviewed

Data quality metric	Analysis/calculation	Source(s)
Data quality dimension 1: Completeness and timeliness		
Facility-level metrics		
Availability of monthly facility reports	Proportion of facility's expected monthly reports actually submitted	facility monthly reports (DHIS 2)
Timeliness of monthly facility reports	Proportion of facility's expected monthly reports actually submitted on time	facility monthly reports (DHIS 2)
Completeness of all 14 priority maternal and newborn health data elements, per monthly facility report	Proportion of facility's submitted reports that have a value reported for all 14 priority maternal and newborn health data elements	facility monthly reports (DHIS 2)
Indicator-level metrics		
Completeness of data element	Proportion of non-missing values for a given data element in expected monthly reports	facility monthly reports (DHIS 2)
Data quality dimension 2: Internal consistency		
Outliers	Number and frequency of moderate outliers (±2-3SD from the mean) and extreme outliers (±3SD from the mean) of monthly values	facility monthly reports (DHIS 2)
Consistency over time	Ratio of value of indicator for the intervention period to the mean of preceding 3 years	facility monthly reports (DHIS 2)
Consistency between related data elements	Reliability index (intraclass correlation coefficient, ICC) comparing two sets of related data elements	facility monthly reports (DHIS 2)
Accuracy of facility reporting (data accuracy, concordance)	Reliability index (intraclass correlation coefficient, ICC) comparing original facility register count to monthly facility report in DHIS 2	facility registers; facility monthly reports (DHIS 2)
Data quality dimension 3: External consistency		
Consistency between household surveys and monthly facility reports	Ratio of indicator values in household surveys for facility catchment areas to matching facilities in DHIS 2	household surveys; facility monthly reports (DHIS 2)

Notes:
DHIS 2=District Health Information Software version 2, SD=standard deviation, ICC=intraclass correlation coefficient.

Supplementary Table S2. Consistency over time, 2015-2018 (Gombe State, n=492 facilities)

Indicator, data element		2015	2016	2017	2018	Mean (2015-2017)	Ratio of 2018 to Mean (2015-2017)	Mean (2015-2016)	Ratio of Mean (2017-2018) to Mean (2015-2016)
Main denominators									
First antenatal care visits		108,136	131,263	132,715	128,924	124,038	1.04	119,700	1.09
Total antenatal care visits		194,141	365,251	351,596	300,404	303,663	0.99	279,696	1.17
Facility deliveries		59,731	48,335	65,211	52,122	57,759	0.90	54,033	1.09
Data elements									
Antenatal care anemia testing	Number	47,809	58,514	68,189	97,128	58,171	**1.67**	53,162	**1.55**
	Coverage	44%	45%	51%	75%	47%	**1.61**	44%	**1.43**
Antenatal care syphilis testing	Number	26,231	24,569	34,461	47,393	28,420	**1.67**	25,400	**1.61**
	Coverage	24%	19%	26%	37%	23%	**1.60**	21%	**1.46**
	Number	172,447	317,420	248,404	282,221	246,090	1.15	244,934	1.08
Iron-folic acid supplementation	Coverage	89%	87%	71%	94%	82%	1.14	88%	0.94
At least one dose of intermittent preventive treatment of malaria	Number	32,960	27,209	30,292	76,482	30,154	**2.54**	30,085	**1.77**
	Coverage	30%	21%	23%	59%	25%	**2.40**	26%	**1.60**
At least one dose of tetanus toxoid vaccine	Number	69,374	76,754	83,058	85,293	76,395	1.12	73,064	1.15
	Coverage	64%	58%	63%	66%	62%	1.07	61%	1.05
	Number	18,912	10,240	32,725	47,042	20,626	**2.28**	14,576	**2.74**
Delivery by skilled birth attendant	Coverage	32%	21%	50%	90%	34%	**2.63**	26%	**2.66**
Live births and still births	Number	33,492	39,892	47,715	49,053	40,366	1.22	36,692	1.32
	Coverage	56%	83%	73%	94%	70%	1.35	69%	1.21
Baby weighed at birth	Number	32,719	39,145	46,850	48,162	39,571	1.22	35,932	1.32
	Coverage	55%	81%	72%	92%	69%	**1.34**	68%	**1.21**
Oral polio vaccine at birth	Number	50,587	60,636	66,895	64,457	59,373	1.09	55,612	1.18
	Coverage	85%	125%	103%	124%	104%	1.19	105%	1.08
Early postpartum-postnatal care within 3 days of birth	Number	3,930	6,265	8,575	12,868	6,257	**2.06**	5,098	**2.10**
	Coverage	7%	13%	13%	25%	11%	**2.27**	10%	**1.94**
Bacillus Calmette-Guérin vaccine given during postnatal period	Number	75,491	84,670	87,525	81,362	82,562	0.99	80,081	1.05
	Coverage	126%	175%	134%	156%	145%	1.07	151%	0.96

Supplementary Table S3. Presence of outliers in facility summary reports in DHIS 2 in Gombe State, July 2015-December 2018 (n=492 facilities)

	July 2015-March 2017		April 2017-Dec 2018	
Indicator, data element	**Moderate Outliers**	**Extreme Outliers**	**Moderate Outliers**	**Extreme Outliers**
First antenatal visits	1 (Jan 2017)	0	1 (May 2018)	0
Total antenatal visits	1 (Oct 2016)	0	1 (May 2018)	0
Facility deliveries	0	0	1 (May 2018)	0
Antenatal care anemia testing	0	0	1 (May 2018)	0
Antenatal care syphilis testing	0	0	0	0
Iron-folic acid supplementation	0	1 (Oct 2016)	1 (May 2018)	0
At least one dose of intermittent preventive treatment of malaria	0	1 (Oct 2016)	0	0
At least one dose of tetanus toxoid vaccine	1 (Oct 2016)	0	1 (May 2018)	0
Delivery by skilled birth attendant	1 (Mar 2017)	0	1 (May 2018)	0
Live births and still births	1 (Mar 2017)	0	1 (May 2018)	0
Baby weighed at birth	1 (Mar 2017)	0	1 (May 2018)	0
Oral polio vaccine at birth	0	0	1 (May 2018)	0
Early postpartum-postnatal care within 3 days of birth	1 (Jan 2017)	0	0	0
Bacillus Calmette-Guérin vaccine given during postnatal period	1 (Jan 2017)	0	1 (May 2018)	0
TOTAL OUTLIERS	**8**	**2**	**11**	**0**
	2 (Oct 2016), 3 (Jan 2017), 3 (Mar 2017)	2 (Oct 2016)	11 (May 2018)	0

Chapter 8: Discussion

8.1 Introduction

This thesis aimed to evaluate the quality of routine data documented in primary health facilities for monitoring maternal and newborn care in Gombe State, northeastern Nigeria. Using facility-level and population-level data sets, the thesis included three studies which examined quantitative metrics for the multi-dimensional quality of facility data.

The discussion chapter starts with a summary of the findings, followed by a review of the main strengths and limitations of the thesis approach. This chapter concludes with implications for policy, practice, and research.

8.2 Summary of findings

Objective 1: To quantify quality metrics for completeness and timeliness, internal consistency, and external consistency of routine MNH data *reported by* facilities

In Study 1 (chapter 5), we quantified eight quality metrics of routine MNH data reported by facilities in DHIS 2 for the following data quality dimensions: completeness and timeliness, internal consistency, and external consistency. We identified priority MNH indicators for monitoring by referring to the strategy documents for Ending Preventable Maternal Mortality and Every Newborn Action Plan. We then mapped these indicators to the available data in Gombe's facility registers and monthly reports. For Gombe state, 12 of 14 facility-based priority indicators were available to monitor services that every woman and her newborn should receive. However, during the study review period July 2016-June 2017, data reported by facilities in DHIS 2 were incomplete, did not regularly reflect the content of facility service registers, and showed inconsistencies over time, between related indicators, and with an external data source such as population-level household surveys.

While the quality of data in DHIS 2 could be strengthened, the data quality metrics for priority indicators were not universally nor equally poor. Contact indicators, such as first antenatal care visits and facility deliveries, had higher overall data quality than indicators related to the provision of commodities or content of care. Our study added new evidence demonstrating the potential of data in DHIS 2 for regular monitoring of MNH services. We concluded that coordinated action at multiple levels of the health system was needed to maximize reporting of existing data; rationalize data flow; routinize data quality review, feedback and supervision; and ensure the ongoing maintenance of technology solutions, such as DHIS 2.

Objective 2: To validate routine data *documented by* facilities for monitoring maternal and newborn care

In Study 2 (chapter 6), we assessed the extent to which different data sources reflected childbirth care in primary health facilities. Using birth observations as a gold standard, we compared the observations to health worker documentation in facility registers; women's recall during facility exit interviews after childbirth; and women's recall during household interviews nine to 22 months after childbirth. We found that health workers documented accurately in maternity registers for select indicators: the main birth attendant; maternal background characteristics such as age at delivery and parity; and newborn outcomes such as low birthweight and still births. Women's recall of childbirth events was more valid during exit interviews compared to the household follow-up interviews for the same questions. During exit interviews after childbirth, women reported accurately for select indicators about clinical care, provider respectful care, and immediate newborn care. However, during follow-up household interviews nine to 22 months after childbirth, women continued to report accurately for only one indicator from the exit interviews: placing the newborn skin-to-skin. Our findings highlight that routine facility data, exit interviews, and household surveys each provide valid data on some aspect of the provision and experience of maternal and newborn care. A substantial part of the measurement agenda remains in determining the most valid set of indicators for each data collection method. For indicators where routine data can be considered valid, this would allow for continuous monitoring even at subnational levels, as routine data are available at a greater degree of disaggregation and frequency.

Objective 3: To assess changes in the quality of routine MNH data reported by facilities before and after a district-level data quality intervention

In Study 3 (chapter 7), we quantified any changes in the quality of routine data before-and-after an intervention implemented in Gombe State's 11 LGAs which oversaw 492 primary health facilities providing maternal and newborn care. We developed and implemented this district-level intervention for 21 months (April 2017-December 2018). Similar to the analyses presented for Study 1 (chapter 5), we assessed nine metrics across the data quality dimensions of completeness and timeliness, internal consistency, and external consistency. As studies assessing data quality interventions typically quantified changes in completeness and accuracy of facility reporting, our study also considered whether examining the broad set of data quality metrics offered additional insight.

Using a before-and-after study design, we compared the 21-month pre-intervention period (July 2015-March 2017) to the 21-month intervention period to examine any changes in data quality. We found that the data quality intervention was associated with improvements in 7 of 9 data quality metrics assessed including availability and timeliness of reporting, completeness of data elements, completeness of information, accuracy of facility reporting, consistency between related data elements, and frequency of outliers reported. However, the routine data did not display external consistency with population-based household surveys. Content of care and commodity-related data improved more than contact-related data, which already had a higher baseline data quality. Further, facilities demonstrated increased completeness of information for MNH data and consistency between data within and across facility records.

We concluded that an integrated district-focused data quality intervention in northeast Nigeria – including regular self-assessment of data quality, peer review and feedback, learning workshops, planning for improvement, and ongoing support through social media – was associated with increased completeness, accuracy, and internal consistency of facility-based routine data. Further, quantitative assessments of routine data quality metrics should expand beyond completeness and accuracy of facility reporting and include measurements of internal consistency between related data.

8.3 Strengths and limitations

The specific strengths and limitations of each study are discussed within the relevant chapters. In this section, I discuss some of the over-arching strengths and limitations of the thesis approach.

Study design

For the assessments of data quality reported by facilities (Study 1, chapter 5) and documented by facilities (Study 2, chapter 6), the observational cross-sectional study design suited the objectives of quantifying the degree to which the chosen metrics fulfilled each data quality dimension.

As discussed in the methodology chapter (chapter 4), there were a few considerations when designing the evaluation of the data quality intervention. In brief, extensive multi-year IDEAS Phase 2 Project population- and facility-level data collection was available for Gombe State only. No additional resources were available to do the same in a similar or neighboring state to serve as a concurrent comparison group. Further, to provide the Gombe State Primary Health Care Development Agency with information they could use in deciding to continue, change, or end the proposed intervention, I chose a before-and-after study design to assess the nine data quality metrics and communicate their results.

Before-and-after analyses provide a level of confidence that the intervention has at least partly led to the intended outcomes. Further, before-and-after studies can provide good evidence for an intervention if the effects observed are large. However, this study design is prone to confounding, which is where factors other than the intervention might fully or partially explain the outcomes observed.[222 235] Observed changes in data quality could be due to concurrent events or other factors that might change over time such as a health worker strike (which occurred in May 2018 in Gombe State) or other project initiatives. Analyses are restricted to only those potential confounding factors that have been measured. Other factors, which have not been measured, could have affected the outcomes observed and resulted in residual confounding. While it is difficult to say in which direction the bias would be by not including the unmeasured factors, it is possible that the contributions of the measured factors might be overestimated.

Extensive assessment of metrics for routine data quality dimensions

This thesis provided an extensive examination of routine data quality metrics across multiple dimensions. While it has been long acknowledged that data quality is a multi-dimensional concept, based on the literature review presented in Chapter 2, studies that aimed to assess data quality primarily quantified metrics of completeness and accuracy of facility reporting. This approach was different in comprehensively assessing data quality dimensions, not just as descriptive studies, but also in evaluating an intervention aimed at strengthening routine data quality. By undertaking a more extensive assessment of data quality, we could systematically examine if the predominant focus on completeness and accuracy of facility reporting provided sufficient insight into routine data quality.

While this comprehensive assessment of routine data quality was a strength and added new evidence, the limitation of this approach was the ability to communicate these multiple metrics simply and clearly. As a researcher looking to communicate findings to state- and district-level audiences, it would have been preferable to have a summary measure. Currently, there are no tested recommendations, even within the WHO data quality review toolkit, on how to bring together the multi-dimensionality of data quality for routine data.

Validity study of routine facility data and women's recall of maternal and newborn care

In exploring a broader set of quality metrics, a strength of this thesis was including a study to validate the routine facility data, an often-cited limitation of routine data quality studies.[43 113 114 123 166 176 233] This study may complement an upcoming larger validation study, EN-BIRTH, comparing clinical observations with routine data for over 20,000 births in five hospitals in Tanzania, Bangladesh, and Nepal.[236] Further, we also validated women's self-report of maternal and newborn care at different recall periods. We were able to review the relative contributions towards valid MNH data that each type of data source might provide. We found women's recall in household-level surveys provided some valid and some invalid data on MNH, highlighting potential challenges in using women's recall as a gold standard for assessing the external consistency of routine data.

While the inclusion of this study was a strength, challenges remained for this and similar studies as there are no definitive criteria for considering data valid. We used stringent criteria, aligned with international monitoring group recommendations[137] and other studies[130-135], but the criteria could still be construed as arbitrary.

Learning from this study, future opportunities could include assessing more indicators that overlapped across the three data sources. I might have asked for clinical observers to take note on when the health workers documented in the facility records in relation to services provided, to quantify timeliness of documentation. Taking advantage of existing datasets limited us from proactively including more indicators to compare across data sources. However, we were able to have at least one indicator from different aspects of service delivery to compare across sources.

Working within existing structures to strengthen and evaluate routine data quality

This thesis leveraged existing resources to advance the understanding of routine data quality to monitor maternal and newborn care. It also leveraged existing conceptual frameworks such as the PRISM framework for optimal RHIS performance and the WHO data quality review toolkit for assessing facility data quality within RHIS.[75 99] Given that I was involved in both the delivery of the intervention and in its assessment (see chapter 1, IDEAS Phase 2 Project, page 26), it was important to use an existing external framework and the metrics for assessing data quality to ensure I could approach the evaluation as objectively as possible. It was also helpful to use the data from DHIS 2 and the IDEAS Phase 2 Project to quantify the metrics, as these were secondary datasets where I did not play any role in the data collection.

The data quality intervention focused on strengthening the data quality checking skills of the existing M&E officers and MNCH coordinators, where there was an expectation that they provide feedback to facilities as part of their supervision responsibilities. The intervention introduced job aids and obtained consensus on data quality standards to help the LGA staff structure to their data quality checking duties and to target feedback to facilities based on performance. The intervention aimed to optimize sustainability of the intervention activities by working within existing supervision structures and leveraging scheduling for ongoing activities to minimize cost. Even workplans developed as outputs during the data quality learning workshops leveraged existing resources, such as a dormant WhatsApp group, to promote information-sharing on data quality-related activities.

Using existing resources was also a limitation. As noted above in the validity study, while substantial datasets already existed, we could not proactively select the indicators and ensure their representation in each dataset. The cost to supplement the existing datasets with additional data collection to ensure comparability across every indicator of interest did not outweigh the benefit and potential lessons that could be taken from working within the existing health program setting. Nevertheless, while it might not have affected the key messages of this thesis, having pre-defined datasets was a limitation and one that I would reconsider if given the opportunity to create a comprehensive data quality assessment with fresh resources. With respect to the intervention, working within existing systems meant that moving forward with decisions which required formal approval by state- or national-level officials took time. For example, while the data quality intervention participants noted the value in granting MNCH coordinators direct user access to DHIS 2, this was not achieved during the intervention period due to the multi-step justification and approval process necessary to create the individual user accounts.

8.4 Implications

Positively, Gombe's RHIS, which mirrors Nigeria's RHIS, has the potential to generate quality data for continuous monitoring of maternal and newborn care services. Facility tools capture 14 facility-based priority MNH indicators; M&E officers and MNCH coordinators are in place for data quality checking activities, supervision, and feedback; and there are defined schedules and data flow processes for collection, transmission, and processing.[237]

Even with structures in place to generate priority MNH data, there are opportunities to boost the completeness, consistency, and measurement of the routine data. When compared with 23 low- and middle-income countries, Nigeria's RHIS was aligned with the majority of countries in its design to track MNH data and were similar to all 23 countries in its challenges in ensuring the data had the specificity needed for effective monitoring.[44] Thus, the implications of this thesis for Gombe may be relevant in similar settings.

Implications for policy and practice

Maximizing the reporting and specificity of documented data. It is important to maximize the reporting of data already being documented, but not reported for supervision and monitoring. As noted in Study 1, data for essential newborn care and the administration of uterotonics during the third stage of labor were documented in facility registers but not reported in their monthly report form. This could have been due to priority setting, where MNH indicators later deemed a priority were given less emphasis when the data collection or reporting tools were designed. While the recommended action is straightforward, it has implications for revising reporting forms and the costs associated with production and distribution. These changes, while affecting both paper-based and electronic-based (or mixed) information systems, can pose more of a challenge for paper-based systems.

Relatedly, it is also important to improve the specificity of documented data. As above, these have the same implications regarding costs associated with redesign, production, and distribution. For example, Gombe State collects key contact, content, and outcome data for maternal and newborn care, but the degree of specificity could be improved for effective monitoring. Gestational age has been documented in facility registers as a binary value indicating before 37 weeks (indicating a pre-term birth, yes/no) and birth weight has been captured as <2500 grams or $\geq$2500 grams (indicating low or normal birthweight). These types of data elements provide blunt measures for monitoring content of care and assessing consistency between related data, for example, reconciling data on birthweight and data on caring for small and sick newborns (typically <2000 grams). In the next section, Implications for research, I discuss more about the opportunities to understand further how health workers engage with facility documentation during service delivery.

Ensuring high-quality implementation of electronic information systems such as DHIS 2. The use of information systems, such as DHIS 2, have accelerated the accessibility of health facility data for monitoring and performance management. However, as noted in Study 1, ensuring quality digitization of facility data requires ongoing attention and investment. Satisfactory digitization would include the ability to distinguish (i) active/inactive facilities; (ii) facilities according to the services they are designated to provide; (iii) active/inactive indicators; and (iv) zero and missing values to highlight facilities which offer a service and reported zero clients versus facilities with poor reporting practices. Thus, each active facility would have a unique record within the information system and would ensure that the most appropriate denominator is used for coverage estimates and for measuring completeness of reporting and completeness of data/information. Without ongoing maintenance, the in-application tabulations and visualization of systems such as DHIS 2 would retain the data flaws from poor digitization of facility data. Further, the adjustments to correct for poor digitization might be restricted to those with advanced skills to conduct these analyses outside of the information system software.

Building a culture of information use includes addressing the organizational, technical, and behavioral aspects of data quality checking. Reflecting on Study 3, the data quality intervention combined activities that addressed the organizational, technical, and behavioral aspects of data quality checking. With regard to organizational factors, we emphasized the partnership and joint responsibility for self-assessment of the data quality coming from the facilities in their LGA. We devoted time and space to self-assessment and peer review of findings. With regard to technical factors, we introduced data quality checking job aids which promoted a granular knowledge of metrics, enhanced their vocabulary to discuss aspects of data quality with facilities, provided templates on how to identify and communicate with lower performing facilities. With regard to behavioral factors, the intervention included skills sessions on providing feedback. The M&E officers and MNCH coordinators were expected to deliberately practice constructive feedback throughout the workshops and during the WhatsApp interactions. There was an underlying assumption that if the findings of data quality checking were available, the M&E officers and MNCH coordinators would know how to provide feedback in a way to boost the performance of the individuals they were supervising. At first, the MNCH coordinators and M&E officers found their feedback difficult to frame constructively and to include positive areas of performance; with practice, they were able to highlight progress as well as the areas that could be improved.

The intervention focused on MNH data, but a next step could be to apply this model with a wider health programming lens and/or apply this model across more health system levels. Another extension for this work could be to assess the degree to which continued self-assessment of data quality by district- and state-level teams are substantively different from the findings of an external data quality audit and if the differences would affect the interpretation and the actions that could be taken to further improve the quality of data.

Adjusting the metrics emphasized for data quality assessments. By reviewing the multiple metrics and dimensions of routine data quality, we were able to consider whether a focus on completeness and accuracy of facility reporting provided sufficient insight into routine data quality, given that these metrics have been a predominant focus in peer-reviewed literature.

Through this thesis, there is evidence to suggest that the emphasis on completeness and accuracy of facility reporting provides a narrow, management-driven assessment of data quality. The focus on completeness and accuracy of facility reporting emphasizes reporting compliance, an important output to ensure that the data used at higher levels reflect the primary data sources. However, high completeness of reporting, completeness of data, and accuracy of facility reporting do not necessarily mean that the routine data contain plausible values and demonstrate the expected relationships between data.

Governments, institutions, and global health initiatives could gain more insight about the routine data by including the metrics for completeness of information (dataset) and consistency between related data. Both metrics can be calculated from the same data source used to calculate completeness of reporting or completeness of data. Additional data collection should not be necessary.

In Study 3, we assessed completeness of information for 14 MNH data elements. By assessing the completeness of information (dataset), perhaps in place of assessing the completeness of data, priority is given to the set of data elements necessary to understand and take action on service delivery or coverage for a given health program (e.g., immunization), life cycle (e.g., pregnancy and childbirth), or other general health focus (e.g., primary care). This is separate from completeness of data which may focus on individual data elements or tracer data elements.

Also in Study 3, we assessed the consistency between related data for 12 data relationships. First, reviewing the data relationship for a service provision compared to a contact indicator (e.g., ANC anemia testing compared to ANC first visits) allowed for discussion on whether observed discrepancies are due to low service uptake or poor reporting, an important consideration given the emphasis on improving quality of care and understanding effective coverage.[232] Further, assessing data relationships that require concurrent tallying of services/information (e.g. normal delivery + caesarean delivery + assisted delivery = live births + still births), provided insight about whether a facility has put in more conscientious effort to ensure internal consistency of their data within and across facility documentation.

Implications for research

Further examination of surveys as the gold standard for external consistency. Women's recall in surveys, such as Demographic and Health Survey and Multiple Indicator Cluster Survey, are often considered the gold standard for MNH coverage estimates due to the survey's rigorous design, data collection methods, and standardization.[75 107] Coverage estimates from routine data, when compared to survey results to assess external consistency metrics, also have held the survey results as the gold standard.[38 108 115 117-119 238]

In Study 2, our validity research added to the growing evidence that women's recall in surveys also present challenges providing valid MNH coverage estimates.[129-132 134 135 221] Both routine facility data and women's recall at different interval periods provided some valid and some invalid data on different aspects of maternal and newborn care. An implication of this research might be to reconsider the extent to which RHIS external consistency metrics should hold survey data as the gold standard for MNH estimates. Rather, we should further explore the role of external consistency in assessing the quality of routine data and alternative methods for reconciling MNH data coming from facility-based and population-based sources.

The ambitious global MNH measurement agenda to improve monitoring for maternal and newborn care may provide insight on how to address the external consistency of routine data.[1,2] It will be especially useful to understand where exit interviews and routine data can provide valid and complementary data to valid household survey data. Facility data, at its best, provides a limited but continuous picture on MNH service uptake and content of care. Health worker documentation may provide more valid data on clinical outcomes, maternal background characteristics, and clinical aspects of immediate postnatal care; these would not include the women who never or infrequently use facility services. Further, routine data may not be able to supplant women's recall for respectful care and some aspects of quality of care. In determining the most valid data source for each MNH indicator, the gold standard for assessing the external consistency of routine facility data may be dependent on the indicator or type of indicator.

Exploring other data quality dimensions or metrics necessary as electronic-based information systems scale-up. As electronic-based information systems scale-up, either exclusively or mixed with a paper-based system, the routine data quality framework may need to consider new metrics within internal consistency or new data quality dimensions to reflect this context. As noted earlier, the ongoing maintenance of DHIS 2 should be emphasized, at the very least to ensure that the master facility list and data elements are not redundant and can be distinguished as active or inactive. Two possible data quality dimensions or metrics to consider, or re-introduce, for fully or mixed electronic-based RHIS are uniqueness and relevance. Uniqueness could reflect the non-redundancy of the aspects of a database, such as ensuring one record per facility or one variable for reporting a data element. Relevance could reflect the extent to which the data being collected or present in the database remains relevant for the context as priorities change over time. Both uniqueness and relevance are features applicable to both paper-based and electronic-based systems. However, challenges with uniqueness and relevance are amplified in electronic-based systems where records can proliferate due to poor digitization of reported data.

Applying human-centered design for improvements in the quality of routine data. Human-centered design approaches in global health are grounded in the users' perspectives, needs, and experiences to guide processes and innovations which improve health and health care delivery.[239] Iteration and the continuous refinement of these processes and innovations are a key feature of human-centered design; design, implementation, and evidence generation are not seen as distinct, linear phases. Human-centered approaches can be applied towards a near- or medium-term project or with a view towards longer-term and sustained improvements.[239 240] Below, I offer three suggestions for human-centered design: the first suggestion on improving the process of capturing data in health facilities, the second suggestion on improving the capacity to examine data quality, and the third suggestion on establishing learning health systems for continuous improvement.

While this thesis did not set out to examine data flow and facility documentation design, the quality of routine data is affected by how health care workers capture service delivery data and the design of the facility records and registers. A potential area for research is to gain a deeper understanding of how health care workers directly engage with facility documentation to take action in providing quality care: how data are documented in tandem with the provider-client encounter and how the documentation design facilitates the provider-client interaction and decision making. Further, there is value in understanding how the timeliness of documentation is affected by the documentation design and, relatedly, how timeliness of documentation affects the validity of data.

As noted in the discussion section of Study 1, rationalizing data flow could include reconsidering the fitness for purpose of the facility register in documenting and enhancing the quality of care provided. Implementation research is underway by the Swiss Tropical & Public Health Institute in Nigeria, Cote d'Ivoire, and Mozambique to test new facility documentation for immunization and child health which were developed with a human-centered design approach. One objective of the study is to understand the extent to which newly designed paper-based records could be used for clinical decision making.[241] This approach could be extended to MNH and primary health care, designing and comparing paper-based and electronic-based records with the purpose of understanding its relationship to improving the provision of care as well as the validity, completeness, and timeliness of documentation.

A second human-centered design approach could also be used to adapt technology for asynchronous or synchronous capacity building. For example, an interactive application could simulate or gamify the strengthening of skills necessary to improve the quality of routine data. Real data could be extracted from a database, such as DHIS 2, and be used to practice data quality assessments, working within multi-disciplinary teams, identifying poor performing facilities or health programs, and providing feedback and improving supervision. The skills building application could focus only on data quality or be combined with improving data use skills. Developing this kind of training tool would draw on the strengths and lessons learned from platforms which have used mobile technology to train health care workers, such as the Life-saving Instruction for Emergencies project, led by the University of Oxford, where a smartphone-based simulation training platform uses a virtual hospital environment to simulate emergencies for training health care workers.[242]

Finally, establishing learning health systems would apply a human-centered design approach to improving the quality of routine data and overall RHIS performance. A first step is to establish collaborations among health system actors who have different responsibilities but a shared interest in generating and using local data to drive improvement in health and health service delivery.[42] As the infrastructure necessary for the broad use of electronic health records expands, optimal learning health systems could be established whereby electronic health records are a key data source for continuous quality improvement, research, measurement, and performance management.

Developing and applying a summary measure for routine data quality. WHO and partners have long discussed the multi-dimensionality of data quality.[95 98 101] As demonstrated in this thesis, careful assessment of data quality metrics across multiple dimensions has been both a strength and a limitation. While WHO has provided detailed guidance on how to assess the multiple dimensions of routine data quality, there is little formal guidance on how to synthesize the findings of the distinct metrics. Within DHIS 2, a WHO data quality module, which is in an early phase of deployment in at least six countries, offers an automated way to review the individual metrics.[38] This looks promising as an in-depth data quality assessment tool, though its effective use is hampered by the same challenges of poor digitization of facility data and it currently does not include a measurement or visualization to aid interpretation across the data quality metrics.

A natural extension of this thesis is to develop and test a means of summarizing the data quality dimensions into a composite score from a health programming perspective. Two types of scores could be developed, which include and do not include data verification (accuracy of facility reporting), a metric which could require more resources and limit ongoing monitoring. Another concrete research contribution could be the application of the scores for continuous quality monitoring methods such as statistical process control or for evaluating data quality intervention outcomes using interrupted time-series.

The levels of the health system that would benefit from a composite data quality score should be considered. At the national-, state-, and possibly district-levels, the composite score could be calculated by data analysts to facilitate supervision and feedback, whereby the composite score eases the ongoing monitoring and the individual metrics suggest the specific areas for improvement. This composite score may be less useful at the service delivery and district-levels during self-assessment of data quality, unless it is accompanied by an informative visualization of how each metric contributes to the overall score to aid the interpretation of what actions to take.

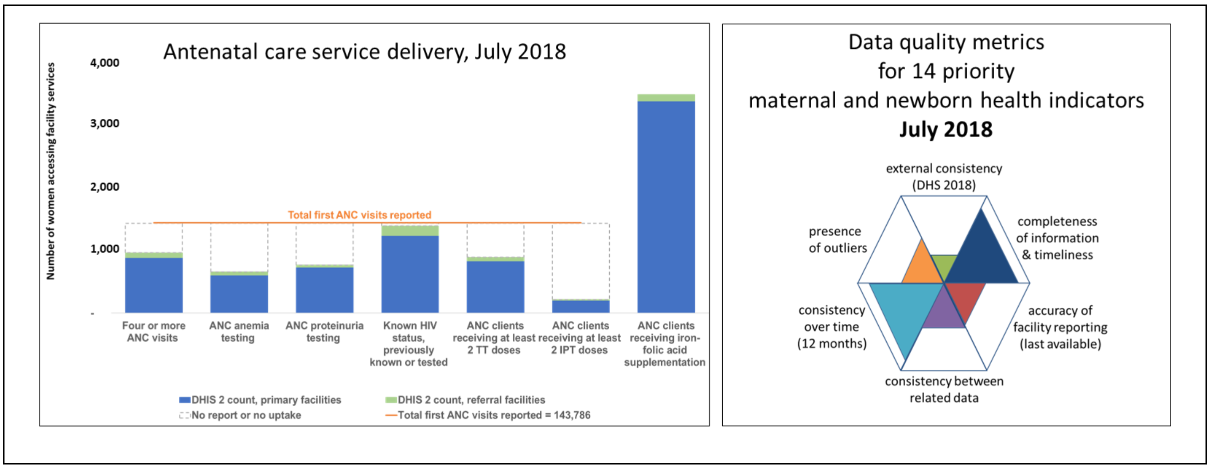
Further reflections on the WHO routine data quality assessment methods

Expanding the focus and value of data quality reviews. As noted in the literature review (see chapter 2, sections 2.5 and 2.7), the tools developed and the majority of articles published to assess routine data quality prioritized the metrics for completeness of reporting, completeness of data, and accuracy of facility reporting. Unintentionally, the emphases on these reporting compliance metrics may have contributed to a suboptimal culture of information in which data were valued primarily for their use at higher levels of the health system.

Data quality could improve for monitoring at all levels of the health system if data are considered useful at the level they are captured. With increasing focus on universal health coverage and the local use of evidence to improve health and health care, there is an opportunity through the WHO data quality review toolkit to advocate for expanding assessments beyond completeness and accuracy of facility reporting to include more metrics of consistency to ensure that the data are logical and free of errors for meaningful analyses.

Study 3 suggested the usefulness of metrics such as completeness of information (dataset) and consistency between related data to indicate whether facility staff were paying attention to their data within and across documentation. Whereas completeness of reporting and accuracy of facility reporting are helpful to understand effective data transmission across health system levels, completeness of information (i.e., is the complete dataset necessary to make decision and take action available?) and consistency between related data (i.e., are the data exhibiting the expected logical relationships?) are corollary metrics to suggest suitability of data for processing and use within the health system level.

Underscoring the link between data quality and data use. Analysis and interpretation of health data cannot take place meaningfully without understanding its data quality limitations. As data quality and data use are interrelated (increased data use improves data quality, improved data quality increases data use)[74], health data such as maternal and newborn outcomes and coverage estimates should be presented, and preferably visualized, alongside data quality metrics. Understanding whether a low health coverage estimate is an indication of poor service uptake or poor reporting begins with the same data calculations: health coverage estimates are also measurements for the consistency between related data metric; and trends for health coverage estimates over time are also measurements for the consistency over time metric. An illustrative example of this visualization is below for seven antenatal care indicators and its consistency with first antenatal care visits:



While the above example illustrates the antenatal care service delivery as a snapshot in time, it is also feasible to visualize these data as part of a continuous monitoring activity using a data quality composite score, as described in the previous 'Implications for research' section (see page 168).

As noted in the description of Study 3, one of the intervention components was a fostering the partnership between each district's monitoring and evaluation officer and the program coordinator to underscore the link between quality and use of maternal and newborn data. Because the program coordinators were less familiar with the terminology and tools for reviewing routine data quality, data visualizations such as the example above have been useful to facilitate understanding of how investment in data quality checking activities could affect their understanding of health statistics and their trust in using routine data for decision making and monitoring.

Understanding and addressing data quality by type of indicator. All studies in this thesis found that data quality differed by type of indicator, which reflected the range of observations, events, resources, and interventions that may affect ease of documentation. Our studies identified three types of indicators; future studies may identify new indicator types or further disaggregate those already identified. Contact indicators, which reflected attendance at a facility for a given service, had the highest data quality metrics. Other observable, concrete events such as the provision of commodities had relatively high data quality as well. However, content of care indicators, including patient-provider interactions which require multiple steps for successful completion, had the poorest data quality. Systems-wide or integrated health services data quality reviews usually aim to include a small number of tracer indicators from each the relevant health programs. However, tracer indicators tend to overrepresent contact indicators; results from these data quality reviews may overestimate the quality of the routine data and may mask the extent of data quality challenges present. Rather than striving to include select indicators to represent each program, it may be more helpful to include data elements from each type of indicator to adequately review the quality of the RHIS data.

Reflecting on the data quality metrics and their thresholds. The quantitative thresholds of the data quality metrics recommended by WHO for demonstrating acceptable data quality were not directly challenged in this thesis. (See Figure 4.1 on page 73 for data quality metric thresholds). Rather, the studies in this thesis were among the first to comprehensively evaluate the metrics before and after an intervention using the proposed WHO data quality framework for facility data.

Reflecting on the data quality analyses undertaken in Studies 1 and 3 as well as the implementation of the data quality intervention, the proposed threshold values are a reasonable starting point for consideration. The WHO guidance has noted that these thresholds can be modified based on context, though reminders of the threshold flexibility are not consistency visible in their guidance documents. While the proposed threshold values for data quality metrics might be considered arbitrary, these threshold values have endured through the multiple expert-level adaptations and applications of the tools for vertical health programs and country contexts.

Perhaps more useful than recommending threshold values, WHO tools could provide guiding questions to support the selection of data quality metric thresholds relevant for the country or setting. For example, one component of the IDEAS project data quality intervention in Study 3 was to support the selection of data quality metric thresholds values for acceptable performance, using the WHO data quality review toolkit thresholds as a starting point. For completeness, the WHO guidance suggested that a completeness of reporting rate of greater than 75% could be considered acceptable performance. Examples of the questions we asked the district teams: What has been the completeness of reporting rate for the last 6-12 months? Should the completeness of reporting thresholds be different for referral and primary facilities? Should thresholds take into consideration the population covered by each facility’s catchment area? (i.e., would 90% completeness of reporting be acceptable if the remaining 10% of unreported data mainly came from high-volume facilities?) The district teams came to a consensus that the completeness of reporting rate should be higher for Gombe state: 90%. While completeness of reporting for Gombe state did not reach the desired 90%, the ongoing monitoring of this metric during the intervention period resulted in the teams’ increased capacity to confidently identify and communicate with the facilities that were not reporting regularly and devise a plan for collecting data from these hard-to-reach areas.

8.5 Conclusion

Accurate routine data are essential for monitoring and improving the quality of care for women and their newborns. This thesis aimed to evaluate the quality of routine data documented in primary health care facilities for monitoring maternal and newborn care. The findings of this thesis advanced the understanding of which routine data can provide valid information on maternal and newborn care and demonstrated the potential to improve data quality with extensive assessments to appreciate and appraise its multi-dimensional nature.

Further opportunities to improve data quality rely on strengthening existing systems and re-adjusting the emphases of existing efforts, including: maximizing the reporting and specificity of existing data; expanding assessments beyond completeness and accuracy of facility reporting; refining supervision to facilitate constructive feedback on the metrics of data quality; and ensuring effective digitization of facility data in information systems such as DHIS 2. Further research opportunities include: deepening our understanding of how health workers directly engage with the facility documentation to facilitate their provision of care; and developing and applying a composite score to summarize the multi-dimensionality of routine data as a measure for continuous data quality monitoring and as an outcome for data quality interventions.

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Below are the references cited for the narrative sections of this thesis and the submitted manuscript in Chapter 7 (Study 3). References cited in the published manuscripts are located within the respective chapters, starting on page 100 for Study 1 and on page 119 for Study 2.

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Appendix 1: Literature search results: studies assessing data quality metrics

This appendix lists the 155 studies from my literature review search that assessed at least one data quality metric. The table lists the studies in chronological order. Following the table, the full citation of each study is included for reference, as not all of them are individually cited in the thesis.

#	Authors	Year	Completeness of facility reporting	Completeness of data	Timeliness of facility reporting	Outliers	Consistency over time	Consistency between related data	Accuracy of facility reporting	External consistency	Validity
1	Onta, et al.	1998							■		
2	Murray, et al.	2003								■	
3	Chilundo, et al.	2004		■	■			■	■		
4	Mavimbe, et al.	2005							■		
5	Ronveaux, et al.	2005							■		
6	Ayoub, et al.	2007		■					■		
7	Erhart, et al.	2007								■	
8	Otwombe, et al.	2007		■					■		
9	Makombe, et al.	2008		■					■		
10	Bosch-Capblanch, et al.	2009							■		
11	Fajardo, et al.	2009							■		
12	Huaman, et al.	2009			■				■		
13	Mate, et al.	2009		■					■		
14	Aqil, et al.	2010		■	■				■		
15	Barrington, et al.	2010	■	■					■		
16	Butts, et al.	2010		■				■	■		
17	Porapakkham, et al.	2010									■
18	Young, et al.	2010		■					■		
19	Gimbel, et al.	2011	■						■	■	
20	Maokola, et al.	2011		■				■			
21	WHO, et al.	2011	■	■		■	■	■	■	■	
22	Chiba, et al.	2012		■					■		
23	Ferguson, et al.	2012							■		
24	Lambdin, et al.	2012		■					■		
25	Makinde, et al.	2012a	■								
26	Makinde, et al.	2012b	■								
27	Makinde, et al.	2012c	■								
28	Makinde, et al.	2012d	■								
29	Makinde, et al.	2012e	■								
30	Mphatswe, et al.	2012		■					■		

#	Authors	Year	Completeness of facility reporting	Completeness of data	Timeliness of facility reporting	Outliers	Consistency over time	Consistency between related data	Accuracy of facility reporting	External consistency	Validity
31	Ngana, et al.	2012			■				■		
32	Tuncalp, et al.	2012									■
33	WHO, et al.	2012	■	■		■	■	■	■	■	
34	Admon , et al.	2013							■		
35	Broughton, et al.	2013									■
36	Ferede, et al.	2013							■		
37	Hahn, et al.	2013		■					■		
38	Liu, et al.	2013									■
39	Stanton, et al.	2013									■
40	WHO, et al.	2013	■	■		■	■	■	■	■	
41	Alyko, et al.	2014						■			
42	Githinji, et al.	2014							■		
43	Hamainza, et al.	2014	■						■		
44	Kayode, et al.	2014							■		
45	Kiberu, et al.	2014	■	■	■						
46	Mlambo, et al.	2014		■					■		
47	Neupane, et al.	2014							■		
48	Nisingizwe, et al.	2014	■	■		■	■	■	■		
49	Noureldin, et al.	2014		■					■		
50	Sychareun, et al.	2014						■	■		
51	Wilms, et al.	2014		■					■		
52	Bernson, et al.	2015				■					
53	Bi, et al.	2015							■		
54	Getachew, et al.	2015	■	■	■				■		
55	Glèlè Ahanhanzo, et al.	2015	■						■		
56	Kaposhi, et al.	2015							■		
57	McCaw-Binns, et al.	2015								■	
58	Mitsunaga, et al.	2015							■		
59	Mpimbaza, et al.	2015								■	
60	Ndizeye, et al.	2015	■	■	■				■		
61	Rutagwera, et al.	2015			■						
62	Soto, et al.	2015		■							
63	Steinhardt, et al.	2015								■	
64	Tshikamba, et al.	2015	■		■				■		
65	Wagenaar, et al.	2015							■		
66	Balisanga, et al.	2016		■		■			■	■	
67	Blanc, et al.	2016a									■
68	Blanc, et al.	2016b									■
69	Guilavogui, et al.	2016		■							
70	Hu, et al.	2016							■		

#	Authors	Year	Completeness of facility reporting	Completeness of data	Timeliness of facility reporting	Outliers	Consistency over time	Consistency between related data	Accuracy of facility reporting	External consistency	Validity
71	Hussain, et al.	2016	■		■						
72	Joos, et al.	2016		■							
73	Kabakama, et al.	2016		■	■				■		
74	Kariuki, et al.	2016		■	■				■		
75	Makinde, et al.	2016		■							
76	Manya, et al.	2016	■		■				■		
77	McCarthy, et al.	2016									■
78	N'Gbichi, et al.	2016	■								
79	Nicol, et al.	2016		■					■		
80	Ohiri, et al.	2016	■	■					■		
81	Puttkammer, et al.	2016		■	■			■	■		
82	Tuti, et al.	2016	■								
83	Westercamp, et al.	2016		■					■		
84	Yourkavitch, et al.	2016	■						■		
85	Yugi, et al.	2016			■						
86	Ahsan, et al.	2017								■	
87	Candrinho, et al.	2017	■		■						
88	Cherifatou, et al.	2017	■		■				■		
89	Fan-Osuala, et al.	2017		■							
90	Githinji, et al.	2017	■	■							
91	Karemere, et al.	2017		■	■						
92	Kheleroa, et al.	2017	■	■							
93	Maina, et al.	2017	■								
94	Medhanyie, et al.	2017		■		■			■		
95	Mutsigiri-Murewanhema, et al.	2017		■	■						
96	O'Hagan, et al.	2017	■	■					■		
97	Omoleke, et al.	2017							■		
98	Porter, et al.	2017	■	■					■		
99	Regeru, et al.	2017							■		
100	Scott, et al.	2017							■		
101	Van, et al.	2017		■							
102	Ward, et al.	2017	■		■				■		
103	Westercamp, et al.	2017		■					■		
104	Abiy, et al.	2018		■							
105	Bassett, et al.	2018		■							
106	Carter, et al.	2018									■
107	Chang, et al.	2018									■
108	Hong, et al.	2018	■								
109	Lucero, et al.	2018							■		
110	McCarthy, et al.	2018									■

#	Authors	Year	Completeness of facility reporting	Completeness of data	Timeliness of facility reporting	Outliers	Consistency over time	Consistency between related data	Accuracy of facility reporting	External consistency	Validity
111	Miyoshi, et al.	2018								■	
112	Mremi, et al.	2018		■		■			■		
113	Munos, et al.	2018									■
114	Muthee, et al.	2018		■					■		
115	Nuri, et al.	2018		■					■	■	
116	Nyangara, et al.	2018		■					■		
117	Porter, et al.	2018						■			
118	Sun, et al.	2018	■	■						■	■
119	Tiye, et al.	2018	■	■	■				■		
120	Ugwa, et al.	2018		■							
121	Umar, et al.	2018	■	■	■						
122	Wanzira, et al.	2018		■							
123	Zulu, et al.	2018								■	
124	Afulani , et al.	2019									■
125	Battle, et al.	2019								■	
126	Belizaire, et al.	2019	■	■	■				■		
127	Bhattacharya, et al.	2019a									■
128	Bhattacharya, et al.	2019b	■	■	■	■	■	■	■	■	
129	Burnett, et al.	2019		■	■				■		
130	Abiy, et al.	2019							■	■	
131	Chukwu, et al.	2019a							■		
132	Chukwu, et al.	2019b		■							
133	Davlantes, et al.	2019								■	
134	Day, et al.	2019									■
135	Endriyas, et al.	2019							■		
136	Euvrard, et al.	2019								■	
137	Gleason, et al.	2019	■		■				■		
138	Jamieson, et al.	2019		■				■	■		
139	Karami, et al.	2019		■					■		
140	Khanji, et al.	2019								■	
141	Kwak, et al.	2019							■		■
142	Maïga, et al.	2019	■			■	■	■		■	
143	Marongwe, et al.	2019							■		
144	Michel, et al.	2019							■		
145	Nagbe, et al.	2019							■		
146	Ouedraogo, et al.	2019	■	■	■	■	■	■	■	■	
147	Rajaobary, et al.	2019	■	■					■		
148	Saturno-Hernandez, et al.	2019		■							
149	Seifi, et al.	2019							■		
150	Tembei, et al.	2019		■							

#	Authors	Year	Completeness of facility reporting	Completeness of data	Timeliness of facility reporting	Outliers	Consistency over time	Consistency between related data	Accuracy of facility reporting	External consistency	Validity
151	Tlale, et al.	2019									
152	Westercamp, et al.	2019									
153	Ye, et al.	2019									
154	Colborn, et al.	2020									
155	Moomba, et al.	2020									

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Appendix 2: Monthly facility reports, Nigeria HMIS version 2013

In this appendix, I have listed the contents from the facility monthly reports relevant for the thesis.

The content list is from the 2013 version of the Nigeria Health Management Information System Monthly Summary Form for Health Facilities. The 2013 version was used by the health facilities during the thesis study period. The full facility monthly report contains 233 lines of health information. The numbers on the left-hand side of the document correspond to the serial number on the full report.

Identification
Health Facility
Political Ward
LGA
State
Facility code
Month
Year
Public or Private

Health Facility Attendance
1 Facility Attendance
Male: 0 -28 days, 29days-11months, 12-59 months,5-9 years, 10-19yrs, 20 years+
Female: 0 -28 days, 29days-11months, 12-59 months,5-9 years, 10-19yrs, 20 years+
Total: 0 -28 days, 29days-11months, 12-59 months,5-9 years, 10-19yrs, 20 years+
2 OPD Attendance

Maternal Health (Ante & Postnatal Care)
3 Antenatal attendance - total
4 Antenatal first visit before 20 weeks
5 Antenatal first visit 20 weeks or later
6 Antenatal first visit – total
7 Pregnant women that attended antenatal clinic for 4th visit during the month
8 ANC syphilis test done
9 ANC syphilis test positive
10 ANC syphilis case treated
11 Pregnant women who received malaria IPT1
12 Pregnant women who received malaria IPT2
13 Pregnant women who received LLIN
14 Pregnant women who received Haematinics' (IFAs - Iron and Folic Acid supplements)
15 Postnatal attendance – total
16 Postnatal clinic visits within 1 day of delivery
17 Postnatal clinic visits within 3 days of delivery
18 Postnatal clinic visits =7 days of delivery

Maternal Health (Labour and Delivery)

19 Deliveries - total
20 Deliveries - SVD (Spontaneous Vaginal Delivery)
21 Deliveries - assisted
22 Deliveries - caesarean section
23 Deliveries - complications
24 Deliveries - preterm
25 Deliveries by HIV positive women
26 Live birth by HIV positive women
27 Deliveries amongst HIV positive women - Booked
28 Deliveries amongst HIV positive women - Unbooked
29 Deliveries monitored using a partograph
30 Deliveries taken by a skilled birth attendant

Tetanus Toxoid (Women of child bearing age)

31 TT1: Pregnant, Non Pregnant
32 TT2: Pregnant, Non Pregnant
33 TT3: Pregnant, Non Pregnant
34 TT4: Pregnant, Non Pregnant
35 TT5: Pregnant, Non Pregnant

Pregnancy Outcome - Live Births

36 Live Births
Male: <2.5kg, ≥2.5kg
Female: <2.5kg, ≥2.5kg
Total: <2.5kg, ≥2.5kg

Pregnancy Outcome - Still Births

37 Still births
38 Fresh still births (FSB)
39 Abortions (Induced)
40 Abortions (Total)

Pregnancy Outcome - Complications

41 Birth asphyxia: Male, Female, Total
42 Neonatal sepsis: Male, Female, Total
43 Neonatal tetanus: Male, Female, Total
44 Neonatal jaundice: Male, Female, Total
45 Low birth weight babies placed in KMC: Male, Female, Total
46 Newborns with low birth weight discharged after KMC: Male, Female, Total

Immunization

47 OPV 0 birth: <1 year (fixed, outreach), >1 year (fixed, outreach)
49 BCG: <1 year (fixed, outreach), >1 year (fixed, outreach)
50 OPV 1: <1 year (fixed, outreach), >1 year (fixed, outreach)

Nutrition

71 Children 0-6 months reporting being exclusively breast fed: Male, Female, Total

Laboratory

118 ANC anaemia test done
119 ANC anaemia test positive
120 ANC proteinuria test done
121 ANC proteinuria test positive

PMTCT - Mother

162 ANC women with previously known HIV status (At ANC)
163 Pregnant women who received HIV counseling, testing and received results at ANC
164 Pregnant women who received HIV counseling, testing and received results at L&D
165 Women who received HIV counseling, testing and received results at PNC

Malaria in Pregnancy

195 Pregnant women with clinically diagnosed Malaria
196 Pregnant women with confirmed Malaria

Appendix 3: IDEAS Phase 2 facility register data extraction sheet

This appendix is an unabridged copy of the data collection sheet used by the IDEAS Phase 2 Project to extract data from the antenatal-postnatal attendance register and the labor and delivery register.

The data collection sheet below was used to extract data for January-July 2016. The content and format were identical for subsequent bi-annual data collection rounds in 2017 and 2018.

IDEAS Phase 2: Data extraction sheet from facility registers

Cluster number/Facility number |__||__||__||__|

Date of survey |__||__|/|__||__|/2016 **Name of LGA|_____________________________|**

Name of ward |__________________________| **Name of facility ____________________________|**

Cluster number/Facility number |__||__||__||__| **Name of interviewer ___________________|**

Daily antenatal clinic and postnatal attendance register

Num	*Question*		*Response*
1	**Interviewer:** Is a daily antenatal clinic and postnatal attendance register available today? *(1)yes (2)no*		|__|
2	**Interviewer:** Please describe the register. Is it a standard register allocated by the State?	___________________ ___________________ ___________________	
3a-f	**Interviewer:** We want to record information for the last 6 months (1st January 2016-31st July 2016). Which months are available from the registers you have access to today? *Tick the months you have been able to extract records from*	Jan |__| Feb |__| Mar |__| Apr |__| May |__| Jun |__|	

Count and enter the data as carefully as possible. If data is not available for any question, enter 9999

Num	*Question*	*Response*
4	First time ANC visits *(count the number)*	|__|__|__|__|
	Of the first time ANC visitors: what number are recorded as:	
5	Syphilis testing and treatment: not done	|__|__|__|__|
6	Syphilis testing and treatment: positive	|__|__|__|__|
7	Syphilis testing and treatment: negative	|__|__|__|__|
8	Syphilis testing and treatment: treated	|__|__|__|__|
9	Total return ANC visits *(count the number)*	|__|__|__|__|
	Of the total return ANC visitors: what number are recorded as:	
10	Syphilis testing and treatment: not done	|__|__|__|__|
11	Syphilis testing and treatment: positive	|__|__|__|__|

12	Syphilis testing and treatment: negative	|__|__|__|__|
13	Syphilis testing and treatment: treated	|__|__|__|__|
	Total number of PNC visits *(count the number at each of the following)*	|__|__|__|__|
14	Number at 1 day	|__|__|__|__|
15	Number at 3 days	|__|__|__|__|
16	Number at 7 days and after	|__|__|__|__|
	Neonatal complications *(count number for each of the following)*	
17	Neonatal sepsis	|__|__|__|__|
18	Neonatal tetanus	|__|__|__|__|
19	Neonatal jaundice	|__|__|__|__|
	KMC *(count number of ticks for each of the following)*	
20	A	|__|__|__|__|
21	DS	|__|__|__|__|

Daily labour and delivery register

Num	*Question*		*Response*
22	**Interviewer:** Is a daily labour and delivery register available today? *(1)yes (2)no*		|__|
23	**Interviewer:** Please describe the register. Is it a standard register allocated by the State?	____________________ ____________________ ____________________	
24 a-f	**Interviewer:** We want to record information for the last 6 months (1st January 2016-31st July 2016). Which months are available from the registers you have access to today? *Tick the months you have been able to extract records from*	Jan |__| Feb |__| Mar |__| Apr |__| May |__| Jun |__|	

Count and enter the data as carefully as possible. If data is not available for any question enter 9999

Num	*Question*	*Response*
25	Women listed on the register *(count the total number)*	|__|__|__|__|
	From this total number, how many:	
26	Had mode of delivery: SVD	|__|__|__|__|
27	Had mode of delivery: CS	|__|__|__|__|
28	Had mode of delivery: AD	|__|__|__|__|
29	Had a partograph used (Y entered)	|__|__|__|__|
30	Had Active Management of Third Stage of Labour (Y entered)	|__|__|__|__|
	How many had the following Material Complications in the register:	
31	APH	|__|__|__|__|
32	PPH	|__|__|__|__|
33	RPC	|__|__|__|__|
34	PL	|__|__|__|__|
35	ET	|__|__|__|__|

36	RU	|__|__|__|__|
37	Sep	|__|__|__|__|
38	OL	|__|__|__|__|
	About mothers: How many were listed as follows in the register?	
39	Admitted	|__|__|__|__|
40	Discharged	|__|__|__|__|
41	Referred	|__|__|__|__|
42	Dead	|__|__|__|__|
43	If Dead, was MDR conducted?	|__|__|__|__|
	About the newborns: How many were listed as follows in the register?	
44	Abortion (Induced)	|__|__|__|__|
45	Abortion (spontaneous)	|__|__|__|__|
46	Pre-term	|__|__|__|__|
47	Birth asphyxia	|__|__|__|__|
48	Birth weight <2.5kg	|__|__|__|__|
49	Birth weight >2.5kg	|__|__|__|__|
50	Still birth: FSB/Fresh	|__|__|__|__|
51	Stillbirth: MSB/Macerated	|__|__|__|__|
52	Dead	|__|__|__|__|
	Who took delivery of the child *(count the number for each cadre type)*	
53	Doctor, midwife, nurse	|__|__|__|__|
54	Other CHEW etc	|__|__|__|__|
55	How many newborns had immediate newborn care (put to breast within 30 minutes of life and given thermal care) *Count the number ticked*	|__|__|__|__|

Appendix 4: IDEAS Phase 2 household survey

This appendix is an abridged copy of the household survey used by the IDEAS Phase 2 Project. It contains the survey questions relevant for the external consistency data quality dimension analyses for Studies 1 and 3. Exit interview and household survey questions used for the validation study (Study 2) can be found in the “Supplementary material for Study 2” section, starting on page 121.

The household survey below was used to extract data for July/August 2016. The content and format were identical for subsequent yearly data collection rounds in 2017 and 2018. The household survey questions were pre-tested and conducted in Hausa but presented here in English.

IDEAS Phase 2 HOUSEHOLD SURVEY
Gombe State, Nigeria, 2016

MODULE 2: WOMENS MODULE: Health

All resident women aged 13-49 years

W5	***Interviewer***: Have you read her the consent form? *(1) yes (2) no*	|__|
W6	***Interviewer***: Does the woman agree? *(1) yes (2) no* **IF NO, END INTERVIEW HERE.**	|__|

Now I would like to ask you some questions about any pregnancies that you have had.

W94a	Just to ask you again, have you ever been pregnant even if that pregnancy did not lead to a live birth? *(1) yes* (**Continue)** *(2) no* **(End of interview)**	|__|
W95	What was the date of your last live birth since 2014? (Enter date dd/mm/yyyy; don’t know date enter 99 for dd, probe for month and year; ask for a birth certificate to verify date if one is available)	|__|
W96	Was it a single or multiple birth? (1) single (2) twins (3) three or more babies	|__|

W100	I just want to check, have you had any other live births after the one you just told me about? **(If the answer here is yes, go back and check the responses from W94 onwards again)**	|__|

MODULE 2 continued for women with a recent live birth
Women aged 13-49 who had a live birth since 2014

Now I want to talk to you about the last birth you had that ended in [DATE], with the birth of [NAME]

M3	When pregnant with [NAME], did you receive any care during pregnancy? **Probe: care at the health facility, or visits at home from a community health volunteer/worker** *(1)Yes (2)No* ***(SKIP TO M14d)***	|__|
M4	During that pregnancy, did you receive pregnancy care from a health facility *(1)yes (2)no* **(go to M9)**	|__|
For women who received pregnancy care at a health facility:		
M5	How many times did you attend the health facility for pregnancy (antenatal) care that pregnancy? *Enter the number of times*	|__|

	When you were pregnant that time, did you have the following at any time? *(enter yes or no;* **verify with health card if available)**	*(1)yes* *(2)no*
M16	Did you give a urine sample for a test (1)yes (2)no	|__|
M24	Did you give blood for any test? (1)yes (2)no	|__|
M26	Did you receive a test result for syphilis? (1)yes (2)no	|__|
M36a	Were you tested for anaemia? (1) yes (2) no (3) don't know	|__|

M40	Were you given an injection in the arm to prevent the baby from getting tetanus, that is, convulsions after birth? *1)yes (2) no (3)don't know* **IF NO SKIP TO M43**	|__|
M41	**If yes:** How many times did you get a tetanus injection? *(write number of times)* ***IF 2 or more times SKIP TO M45***	|__|
M42	**If less than 2 times:** At any time before this pregnancy did you receive any tetanus injections? (*1)yes (2) no* ***- SKIP TO M45***	|__|
M43	**IF M40 WAS NO or M42 was yes** Before this pregnancy, how many times did you receive a tetanus injection? (*write number of times; i**f zero skip to M45)***	|__|
M44	**If M43 was >0:** How many years ago did you receive the last tetanus injection before this pregnancy? *Write number of years ago*	|__|

M83	Now about your delivery: Who assisted with the delivery? **Probe for most senior person present** *(1)Doctor (2)Nurse/Midwife (3)CHEW/CHO (4) FOMWAN (5)Traditional birth attendant (6) Relative/friend (7)No-one* ***(go to M85)*** *(8) Other (specify)*	|__|
M83a	Was anyone else present? *(1)yes (2)no* **– go to M83c**	|__|
M83b	Who else was present at the delivery? *(1)Doctor (2)Nurse/Midwife (3)CHEW/CHO (4) FOMWAN (5)Traditional birth attendant (6) Relative/friend (7)No-one* ***(go to M85)*** *(8) Other (specify)*	|__|
M85	Where did you give birth? (1)home –skip to M88a(2)primary health facility (3) hospital(secondary level care)(4)other (specify)	|__|

Now I have some questions about what happened to [NAME] at the birth and immediately after.

M112	Was [NAME] weighed at birth? *(1)yes (2)no* **– SKIP TO M114**	|__|

Now about care after the birth:		
M139	In the month after [NAME] was born, how many times did a health care provider check on his/her health? *Write number of times*	|__|
M140	How long after delivery did the first check take place? *(Record number of days;***if same day as delivery enter 0***)*	|__|

M154	Have you ever taken [NAME] for a vaccination? **PROBE – HEALTH FACILITY OR VACCINATION DAY** *(1)yes (2)no* **– GO TO M174**	|__|
Has [NAME] received the following vaccinations?		
M156	BCG	|__|
M157	**If yes**: *record date given, or 01/01/2099 if date not available*	|_||_|/|_||_|/|_||_|/|_||_|
M158	Polio 0 (Polio given at birth and given in the mouth (oral))	|__|
M159	**If yes:** *record date given, or 01/01/2099 if date not available*	|_||_|/|_||_|/|_||_|/|_||_|
M160	Polio 1	|__|
M161	**If yes**: *record date given, or 01/01/2099 if date not available*	|_||_|/|_||_|/|_||_|/|_||_|
M162	Polio 2	|__|
M163	**If yes**: *record date given, or 01/01/209 if date not available*	|_||_|/|_||_|/|_||_|/|_||_|