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IMPACT OF NON-HEALTH SECTOR DETERMINANTS ON CHILD HEALTH AND THE ROLE OF THE SUSTAINABLE DEVELOPMENT GOALS

MODELS, PRACTICES AND PERCEPTIONS IN CAMBODIA AND GLOBALLY

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Cover illustration: Child in the center of the SDGs, Jerker Lokra.

Impact of Non-health Sector Determinants on Child Health and the Role of the Sustainable Development Goals - Models, Practices and Perceptions in Cambodia and Globally

Thesis for Doctoral Degree (Ph.D.)

By

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The world cannot be understood without numbers.
But the world cannot be understood with numbers alone.
– Hans Rosling

Popular science summary of the thesis

Significant strides have been made in improving child health in Cambodia and globally in recent decades, and in 2015, all countries adopted the Sustainable Development Goals (SDGs) as a comprehensive framework for sustainable development. However, despite this progress, there remains a lack of understanding regarding the influence of non-health sector determinants on child health, how multisectoral collaborations for child health work, and the determinants of child mortality and infectious diseases.

This thesis aims to address these gaps by examining the relationship between child health and the SDGs in Cambodia and across low- and middle-income countries (LMICs). Through a combination of qualitative and quantitative methods, this thesis seeks to shed light on the underlying factors shaping child health outcomes.

The findings reveal that except for SDG 15 (Life on land), the interactions between child health and the SDGs in Cambodia are perceived to be synergistic, with SDG 16 (Peace, justice, and strong institutions) having the most potential to contribute to improvements in child health. However, challenges persist in translating multisectoral collaboration theories into practice, highlighting the need for more grounded implementation strategies. Analysis of data from the most recent Demographic Health Survey (DHS) in Cambodia unveils several key determinants of under-five mortality and child morbidity from infectious diseases. Maternal and household factors such as contraceptive use of the mother, available water source in the household, and wealth play important roles in determining child health outcomes. Similarly, established child, maternal and household characteristics were found to still be key determinants for under-five mortality and infectious disease morbidity in LMICs across the globe.

Overall, this thesis underscores the importance of taking advantage of the synergies between the SDGs while managing trade-offs to improve child health outcomes in Cambodia and globally. Despite the aspirational perspective promoted by the adoption of the SDGs, fundamental child, maternal, and household characteristics continue to influence vulnerabilities and determine child health outcomes. By prioritizing the most vulnerable children and adopting a holistic approach to child health interventions, meaningful steps can be taken towards achieving equitable and sustainable improvements for children in Cambodia and globally.

Abstract

Background: Child health has improved significantly over the last decades in Cambodia and globally. With the global adoption of the Sustainable Development Goals (SDGs) in 2015, a broad set of interlinked global goals to promote sustainable development was introduced. However, a systematic assessment of how the SDGs influence child health, the role of multisectoral collaboration and the determinants of child mortality and morbidity from infectious diseases are not well understood in Cambodia or globally.

Aims: The overall aim of the thesis was to explore the non-health determinants of child health in Cambodia and provide an updated investigation of the determinants of child mortality as well as morbidity from infectious diseases in Cambodia and in low- and middle-income countries (LMICs).

There were four specific aims:

Study I. To investigate the interactions between child health and the SDGs in Cambodia.

Study II: To understand how stakeholders perceive the SDGs, child health in the era of the SDGs and multisectoral collaborations for child health in Cambodia.

Study III: To explore factors that are associated with under-five mortality and child morbidity from infectious diseases in Cambodia.

Study IV: To investigate determinants of under-five mortality and morbidity from infectious diseases in LMICs in the SDG era.

Material and Methods

SDG Synergies approach (Study I): Based on the semi-qualitative SDG Synergies approach, an interdisciplinary Cambodian stakeholder group evaluated 272 interactions between 16 Cambodian SDGs and child health. From this, a cross-impact matrix was derived, and network analysis was applied to determine the first- and second-order effects of the interactions, with a focus on child health.

Qualitative investigation (Study II): Through purposive sampling, semi-structured interviews were conducted with 29 key child health stakeholders from a range of government and non-governmental organizations in Cambodia. Guided by the research aim through framework analysis, themes, subthemes, and categories were derived.

Combining Demographic Health Survey data with traditional and machine learning methods in Cambodia (Study III) and globally (Study IV): Using the most recent Demographic Health Survey (DHS) in 2021-2022, we applied a multivariable logistic regression model and a conditional random forest to explore possible determinants of under-five mortality and morbidity in Cambodia from infectious diseases. Based on DHS from 44 LMICs that had available data after 2015, we used a survey-weighted multivariable logistic regression model and a

conditional random forest to explore individual, maternal and household determinants of under-five mortality and under-five child morbidity from infectious diseases.

Results: Except for SDG 15 (Life on land) the interactions are perceived to be synergistic between child health and the SDGs, and progress on Cambodian SDG 16 (Peace, justice and strong institutions) could have the largest potential to contribute to the achievement of the Cambodian SDGs (**Study I**). We found that the adoption of the SDGs led to increased possibility for action and higher ambitions for child health in Cambodia. There is a discrepancy between the desired step-by-step theory of conducting multisectoral collaboration and the real-world complexities (**Study II**). Maternal determinants such as contraceptive use was associated with under-five mortality, while household determinants in the form of geographical region, water source, and wealth quintile were associated with infectious disease in Cambodia (**Study III**). Expanding the analysis to LMICs globally after 2015, we found child-specific (sex, twin and birth order) and more general socioeconomic determinants of the mother and household (for example the education level of the mother and household access to electricity) to be associated with under-five mortality and infectious diseases (**Study IV**).

Conclusions: To improve child health in Cambodia there is a need to capitalize on the synergies between the SDGs while carefully handling potential trade-offs. The adoption of the SDGs promoted an aspirational perspective on child health allowing for multisectoral collaborations to be effective if implemented in a grounded context. Nevertheless, fundamental child, maternal and household characteristics still determine vulnerabilities of children in Cambodia and globally. A focus on the most vulnerable children and a holistic approach to designing interventions should be considered to accelerate improvements in child health in Cambodia and globally.

List of scientific papers

I. **A stakeholder group assessment of interactions between child health and the Sustainable Development Goals in Cambodia**
Daniel Helldén, Thy Chea, Serey Sok, Linn Järnberg, Helena Nordenstedt, Göran Tomson, Måns Nilsson, Tobias Alfvén
Nature Communications Medicine 2022 Jun 16;2:68

II. **Sustainable development goals and multisectoral collaborations for child health in Cambodia: a qualitative interview study with key child health stakeholders**
Daniel Helldén, Serey Sok, Thy Chea, Helena Nordenstedt, Shyama Kuruvilla, Helle Mölsted Alvesson, Tobias Alfvén
BMJ Open 2023 Nov 21;13(11):e073853

III. **Exploring the determinants of under-five mortality and morbidity from infectious diseases in Cambodia – a traditional and machine learning approach**
Daniel Helldén, Serey Sok, Alma Nordenstam, Nicola Orsini, Helena Nordenstedt, Tobias Alfvén
Submitted

IV. **Determinants of under-five mortality and morbidity from infectious disease in low- and middle-income countries**
Daniel Helldén*, Alma Nordenstam*, Serey Sok, Nicola Orsini, Helena Nordenstedt, Tobias Alfvén
* Equal contribution
Manuscript

Scientific papers not included in the thesis

I. **Situating Health Within the 2030 Agenda—A Practical Application of the Sustainable Development Goals Synergies Approach**
Daniel Helldén, Nina Weitz, Måns Nilsson, Tobias Alfvén
Public Health Reviews 2022 Apr 7;43;1604350

II. **Interactions between Health and the Sustainable Development Goals: The Case of the Democratic Republic of Congo**
Landry Egbende, Daniel Helldén, Branly Mbunga, Mattias Schedwin, Benito Kazenza, Nina Viberg, Rhoda Wanyenze, Mapatano Mala Ali, Tobias Alfvén
Sustainability 2023 Jan 9;15(2);1259

III. **Finding Linkages between the Sustainable Development Goals in Uganda, a Key to attain health and Well-being for All.**
Irene Wanyana, Daniel Helldén, Rawlance Ndejjo, Marat Murzabekov, Tobias Alfvén, Rhoda K. Wanyenze, Nina Viberg
Submitted

IV. **Linkages between the Sustainable Development Goals and health in Somalia**
Rage Adem* Hassan W. Nor*, Mohamed M. Fuje, Abdinor H. Mohamed, Tobias Alfvén, Rhoda K. Wanyenze, Ahmed Y. Guled, Mohamed M. Biday, Nina Viberg[&], Daniel Helldén[&]
* and [&] equal contribution
BMC Public Health 2024 Mar 27;24(1):904

V. **Climate change adaptation across the life-course - from pregnancy to adolescence – it's time to advance the field of climate change and child health.**
Daniel Helldén, Rawlance Ndejjo, Amanda Sturm, Ida Persson, Rhoda Wanyenze, Kristie L. Ebi, Maria Nilsson, Tobias Alfvén
Environmental Research: Health 2023 1(2);3001

VI. **Climate change and child health: a scoping review and an expanded conceptual framework**
Daniel Helldén, Camilla Andersson, Maria Nilsson, Kristie L. Ebi, Peter Friberg, Tobias Alfvén
Lancet Planetary Health 2021 Mar 5(1);e164-e174

Contents

List of abbreviations

CI	Confidence Interval
DHS	Demographic Health Survey
CDHS	Cambodian Demographic Health Survey
CSDGs	Cambodian Sustainable Development Goals
DALYs	Disability Adjusted Life Years
ERW	Explosive Remnants of War
GBD	Global Burden of Disease
LMICs	Low- and Middle-Income Countries
MDG	Millennium Development Goals
MICS	Multiple Indicator Cluster Surveys
SDGs	Sustainable Development Goals
UN	United Nations
UNICEF	United Nations Children´s Fund
WHO	World Health Organization

1 Literature review

1.1 A snapshot of global child health

Child health can be defined as a state of physical, mental, intellectual, social and emotional well-being and not merely the absence of disease or infirmity of people aged under 18 years in line with the United Nations (UN) Convention on the Rights of the Child[1] and the constitution of the World Health Organization (WHO).[2] Traditionally, the focus of child health has been to reduce child mortality, particularly for children under five years of age. The number of children dying before their fifth birthday has more than halved, from approximately 12.6 million in 1990 to 4.9 million in 2022, while the number of neonatal deaths has fallen from 5.2 million to 2.3 million during the same period.[3] The slower pace of reduction in neonatal mortality is likely due to a combination of a lack of attention, investments and the more complex underlying causes of neonatal death.[4,5] Despite the advancements made there exist significant disparities in child mortality between and within countries.[6] The causes of death are still predominantly related to communicable diseases for under-five children, while it is a more diverse picture when it comes to older children and adolescents (**Figure 1**).[7]

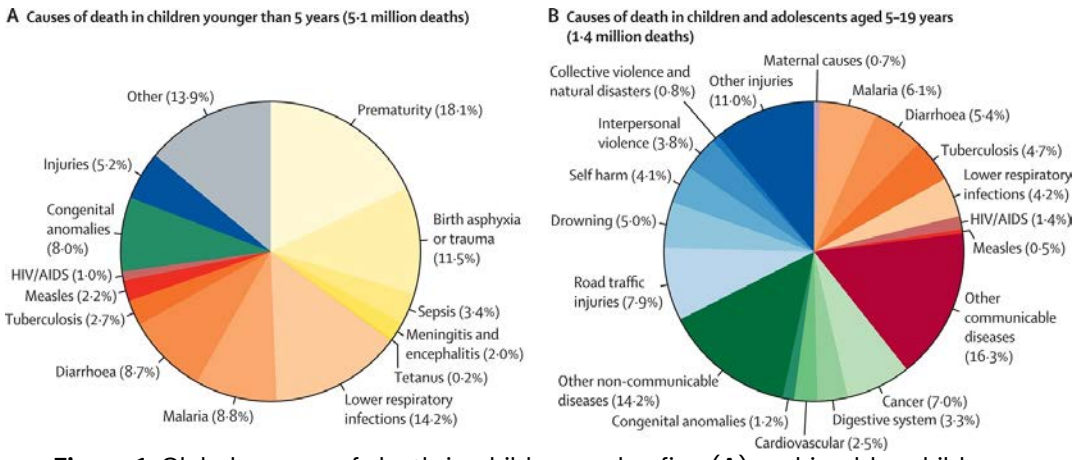


Figure 1. Global causes of death in children under-five (**A**) and in older children and adolescents (**B**) in 2021. From Villavicencio et al.[7] Reproduced with permission from the journal.

Following the classical framework of determinants for child survival by Mosley and Chen[8] and the more established social determinants of health approach championed by Marmot[9] various efforts have been made to try and decipher the most important factors contributing to the reduction of under-five mortality in low- and middle- income countries (LMICs). The most prominent has been the success factor studies initiative[10] led by the Partnership for Maternal, Newborn & Child Health at WHO, which aimed to investigate the determinants of under-five mortality among LMICs using quantitative and qualitative research methods.

Kuruvilla et al.[10,11] showed that improvements in health sector determinants of child health (for instance access to healthcare, immunization rates and number of skilled birth attendants) contributed to around half of the reduction of child deaths between 1990 and 2010. They conclude that improvements in non-health sector determinants (for example education level, access to clean water, higher income and good governance) could be attributed to the remaining 50% of the reduction. Building on this work, Cohen et al.[12] used multivariable regression analysis on data from LMICs between 1980-2010 to estimate that approximately 44-66% of the reduction in under-five mortality could be attributed to improvements in non-health sector child health determinants.

Global child morbidity has received less attention than child mortality, which might be due to the more complex causes and differences in morbidity burden across the developmental stages and adolescence.[13] The overall global child morbidity burden has decreased between 1990 and 2017, however not at the same pace as mortality rates.[14] In 2016, the leading causes of years lost to disability among young children were congenital anomalies, malnutrition and diarrheal diseases while older children and adolescents suffered mainly from anemia due to iron deficiency, asthma and psychiatric disorders with considerable differences between geographic regions.[15] The survival, health and well-being of children are essential to end extreme poverty and promote the development of societies.[16] Simultaneously, social, economic, political, environmental, and cultural determinants have central impacts on child mortality and morbidity.[9] Hence, developments and improvements outside the health sector are set to promote child health while specific child health interventions are essential to broader development.[17,18] Recognizing the unfinished progress in child mortality and morbidity, the global community adopted the global strategy for women´s, children´s and adolescents´ health in 2015 which calls on policy makers, researchers, and practitioners to work toward a world where all children and adolescents not only survive but thrive.[16]

1.2 Global child health and the SDGs

With the Millennium Development Goals (MDGs) ending in 2015, the UN General Assembly agreed on the Sustainable Development Goals (SDGs) as a framework for sustainable development: the 2030 Agenda.[19] There are 17 SDGs, 169 targets and 231 unique indicators aligned across three dimensions of sustainable development: environment, economic and social. SDG target 3.2 is concerned with child mortality; "*By 2030, end preventable deaths of newborns and children under five years of age, with all countries aiming to reduce neonatal mortality to at least as low as 12 per 1,000 live births and under-five mortality to at least as low as 25 per 1,000 live births*".[20] Most middle- and high-income countries have already or are on track to achieve this target by 2030. However, 65 countries, mostly found in Sub-Saharan Africa and Asia will likely not achieve the reductions necessary to meet the target by 2030.[21] Several other targets are related to child health in some

way, with United Nations Children´s Fund (UNICEF) identifying at least 35 indicators in the SDG monitoring framework pertaining to children. They primarily concern SDG 1 (No poverty), SDG 2 (Zero hunger), SDG 3 (Good health and well-being), SDG 4 (Quality education), SDG 5 (Gender equality), SDG 6 (Clean water and sanitation) and SDG 16 (Peace, justice and strong institutions). There is a lack of data for tracking these indicators, and in general many LMICs will need to accelerate the work towards achieving the other child health related targets as well.[22]

The SDGs and their targets are directly and indirectly connected. Although these interactions are made explicit in the preamble of the 2030 Agenda, this recognition is not reflected in the formulation of the SDG targets and indicators.[23] This lack of clarity has led researchers to develop different approaches to analyze these interactions, from more quantitative modeling methods[24,25] to document reviews.[26,27] As a response to this challenge, researchers at Stockholm Environment Institute developed the SDG Synergies approach which utilizes the knowledge of a stakeholder group to assess the interactions between SDG goals or targets, explicitly incorporating the context-specificity of the interactions.[28,29] Form the assessment, a score on a scale from -3 to +3 is made usually through a consensus approach, and the scores of the interactions are the basis of more advanced analysis of interactions through network analysis. In this way, both the individual scoring and the "ripple" they make through the network can be calculated and illustrated.[28,30,31] A simplified SDG Synergies approach was used by Blomstedt et al.[32] when they assessed interactions between child health and 34 targets among the non-health SDGs based on literature and expert consultation. Their generic analysis suggested that progress on SDGs 1 (No poverty), 2 (Zero hunger), 4 (Quality education), 5 (Gender equality), 8 (Decent work and economic growth), 11 (Sustainable cities and communities) and 17 (Peace, justice and strong institutions) have potentially synergetic interactions with child health and showed promise of how the SDG Synergies approach could be of use to untangle the interactions between child health and the SDGs. Yet, a generic approach to describing interactions will not generate scientific evidence that policy makers can make use of, since the strength, position and nature of the interactions are highly context specific.[32–34]

Capturing the complexity of child health in the 21st century, the SDGs frames the most pressing issues for child health while the global community has increasingly acknowledged that the development and improvements in child health has been at the expense of the environment and the health of future generations of children.[35] The effects of the COVID-19 pandemic on child health mortality and morbidity have yet to be fully captured, they have undoubtably hampered efforts to accelerate the work towards realizing the child related SDG targets.[36] Indeed, there is an urgent need to revitalize focus on the health and well-being of children and adolescents if continued progress is to be made.[37] Placing children at the center of the SDGs (**Figure 2**) will be paramount if significant achievements are to be made until 2030.[18]

Figure 2. Child in the center of the SDGs. From Alfvén et al.[18] Reproduced with permission from the journal.

1.3 Data on global child health and machine learning

1.3.1 Sources for data on child mortality and morbidity

There are several data sources that contain information on various aspects of child health. Country or sub-country census or health administrative data have been the cornerstone of information on child health, mainly in upper-middle-income and high-income countries. However, given resource constraints LMICs have traditionally not had the capacity to provide child health data through a census or health administrative approach.[38]

Perhaps the most important sources of data on child health and different determinants in low-income countries are the Demographic Health Surveys (DHS) and Multiple Indicator Cluster Surveys (MICS). DHS was initiated in 1980s by the US Agency for International Development and aims to conduct a nationally representative household survey to capture key elements of maternal and child health indicators. The DHS consists of standardized questionnaires that have changed over the decades, but together with the nationally representative nature of the survey, they allow for concrete estimation of key indicators on a country level, how they change over time, and compare across countries.[39] Trying to work in tandem, UNICEF developed MICS in the 1990s to conduct a similar nationally representative household survey for countries that did not engage with the DHS. The questionnaires used have gone through several iterations but are similar to DHS standardized to allow for comparison over time and across countries.[40]

Altogether, more than 400 DHS and 350 MICS have been conducted in more than 110 countries since their inception. Despite this extraordinary achievement, there are very few data points on indicators beyond child mortality in low-income countries before the 2000s, and there remains a large data gap regarding causes of death and morbidity over time, particularly in fragile settings where primary data collection can be difficult.[41]

With the aim of providing a best estimate of child mortality in locations where data was not available and providing a fuller understanding of not only mortality but also morbidity from different diseases and disorders, the Global Burden of Disease (GBD) began in 1991. Over time, GBD has evolved significantly and currently provides country and, in some cases, sub-country estimates of 371 diseases, disorders, and injuries from 1990-2021 divided into different age brackets.[42] Over the last decade, when the estimations have been updated regularly, it has become one of the premier sources of data on child health, and there has been a tendency to see the estimations as a true reflection of the actual burden of disease. Although relying on country-specific surveys and other sources of data, the estimates in GBD are the result of complex ensemble temporospatial modeling analyses that are not straightforward to understand or replicate and do not necessarily reflect the true burden of disease or realities in the country.[43]

1.3.2 Machine learning and global child health

Researchers have used traditional statistical methods such as standard linear or logistic regression or a mix thereof as the primary tool for examining the determinants of child mortality and morbidity, as exemplified by Shyama et al.[10,11] and Cohen et al.[12] mentioned above. These approaches might be limited when the data being analyzed does not follow assumptions of normality and has a high degree of correlation between explanatory variables and random noise.[44] Despite the potential of alternative methods to increase the accuracy of predictions and give new insights, machine learning approaches have rarely been applied in LMICs[45,46] and within child health generally only in clinical settings.[47]

Machine learning is commonly defined as the use of algorithms to identify patterns in a dataset and focuses on patterns of variables, the accuracy of prediction, and the relative importance of variables making a certain prediction.[48] A detailed description of various machine learning algorithms and their possible uses are beyond this literature review, however in general a machine learning approach consists of three steps.[49] First, the algorithm is applied to a subset of the data where it "learns" or optimizes its parameters to accurately predict a selected outcome variable. Second, the algorithm tries to predict the outcome variable, and the results are compared with the actual outcome values. Third, the most important variables for the algorithm (when it accurately predicts the outcome value) can be estimated in various ways depending on the algorithm. An overarching challenge with machine learning is that there is often a balance between the accuracy and interpretability of the algorithm.[50]

This trade-off is often not made explicit and for many algorithms not fully understood. A machine learning algorithm (such as a random forest) might have the potential to showcase how it came to a certain conclusion or result through some form of variable importance measure. However more complex algorithms (such as neural networks) might provide more accurate results, but the inherent complexity of the algorithm makes it almost impossible to understand how it came to that specific conclusion.

A few studies have used machine learning approaches to explore the predictors or determinants of child mortality in LMICs. Bizzago et al.[51] applied a random forest algorithm on data from MICS from 27 countries to derive the most important variables for predicting under-five deaths. They found that the age of women, the wealth index score of the household, and the types of fuel used for cooking were the three most important variables in the dataset. Similarly, Adegbosin et al.[52] used DHS data from LMICs and applied a random forest algorithm to examine the most important variables and investigated the predictive accuracy of deep-learning machine algorithms (deep neural network, convolutional neural network and hybrid deep neural networks) with standard logistic regression. They found that the random forest algorithm identified duration of breastfeeding, household wealth index, postnatal care and maternal education to be the variables influencing the risk of under-five death the most. Further, the deep-learning machine algorithms were superior in predicting under-five deaths compared with standard logistic regression. Focusing on data from a DHS in Ethiopia, Bitew et al.[53] compared three machine learning algorithms (random forest, logistic regression and K-nearest neighbor) with standard logistic regression, concluding that the random forest algorithm could most accurately predict under-five deaths and that household size, time to source of water and number of births in the proceeding five years seemed to be important variables for the prediction. Exploring important determinants of child morbidity in Bangladesh, Methun et al.[54] applied a logistic classifier machine learning algorithm on data from the 2019 MICS in the country, showcasing that younger children and those born to younger mothers had a higher risk of morbidity from infectious diseases.

In summary, a robust machine learning approach holds promise to provide new insights and complementary perspectives on the health and non-health related determinants of child mortality and morbidity, an opportunity not yet investigated in Cambodia or on a broader set of determinants in LMICs in the SDG era.

1.4 Sustainable Development and Cambodia

1.4.1 A brief history of Cambodia

From the end of the 8th century until around the 15th century the Khmer empire was a regional powerhouse of technology, culture and trade. By the mid 18th century the French intervened in South-east Asia, negotiating a treaty with the Cambodian king that placed the country under French control. Managing to gain its independence in 1953, it became unwillingly entangled in the Indo-American war of the 60s and 70s. Following the destabilization from US, North, and South Vietnamese actions on Cambodia territory, an insurgency first supported by the North Vietnamese and later China started to gain power – the Khmer Rouge.[55] The communist nationalist movement ousted the regime after the US had left in 1975 and remained in control until a Vietnamese invasion drove them from Phnom Penh in 1979. The aim of the regime was to reorient the country into an agricultural communist society, with all industrial modes of production being abandoned and people being forced from cities to work and live in the countryside. During the regime, almost 25% of the population starved to death or were murdered, and the societal institutions that had been developed were destroyed.[56] After the Khmer Rouge reign ended, Cambodia remained in a state of fragility and violence until an UN-backed peace deal in 1991 finally ended most hostilities.[55]

The first official democratic elections took place in 1993, with the subsequent approval of a constitution that proclaimed Cambodia to be a multiparty liberal democracy as a constitutional monarchy. The leader of the Cambodian People´s Party Hun San became prime minister. Initially sharing some of his political power with Norodom Ranariddh of the Front Uni National pour un Cambodge Indépendant, Neutre, Pacifique, et Coopératif, Hun San orchestrated an elaborate coup in 1997 to regain control of the administration. Since then, the Cambodian People´s Party has solidified its hold on the governmental institutions in Cambodia.[56]

The governance structure of the country has traditionally included a hierarchical structure with the country being divided into provinces, districts, communes and villages.[57] In recent years, the government has leaned towards a decentralized governance structure, with local districts and communes receiving increased funding and decision-making power.[58] Collaboration beyond the government occurs on the national or at the lower administrative levels with the government often taking the convening and agenda-setting initiative.[59,60] The Ministry of Health and its National Maternal and Child Health Center oversee healthcare services across Cambodia. The Ministry of Health often engages in committees or technical groups with other relevant ministries and collaborates with international and local non-governmental organizations. Lower government levels, provincial health departments and operational health districts lead the implementation of national strategies and technical guidelines together with national and local non-governmental organizations in a more spontaneous manner.

From 1993 and onwards the country has made significant reforms in virtually all sectors, mainly focusing on the economy. Trade restrictions were lifted, allowing for private companies to produce and export openly with other countries, and Cambodia joined the Association of Southeast Asian Nations Free Trade Area in 1999 and the World Trade Organization in 2003. The country successfully increased foreign direct investments from multinational firms and countries for productivity development predominantly within the labor-intensive garment industry. State control over the economy was initially minimized, and the private sector became increasingly important.[61] The economy has sustained an expressive average growth rate of 8% between 1998 and 2018, making it one of the fastest-growing economies in the world and leading to lower-middle-income status and aiming for upper-middle-income status by 2030.[62]

With the rapid economic growth, poverty fell sharply in Cambodia. According to official estimates, the poverty rate in 2014 was 14% compared to 48% in 2007. About 90% of the population under the national poverty line live in rural areas and around 4.5 million people remain near-poor, vulnerable to falling back into poverty when exposed to economic and other external shocks. While Cambodia achieved the MDG of halving poverty in 2009, the vast majority of families who escaped poverty did so by a small margin.[63] Unfortunately, there is no quality data before the year 2000 and many data gaps exist for indicators of sustainable development. An overview of indicators reflecting the SDGs is provided in **Table 1,** and all available historic data from the SDG Indicator database[64] as well as the most recent data provided by the government line ministries has been compiled in a database (see publicly available file at https://ki.se/en/gph/research-projects). As seen in **Table 1**, the economic development and improvements in other sustainable development areas such as education or water and sanitation are not mirrored in the SDGs representing the environment (SDG 13, 14 and 15) or quality institutions (SDG 16) which shows a troubling trend.

Table 1. Overview of key Sustainable Development Goal indicators

SDG	Indicator description	2000	2005	2010	2015	2020	Source
1	Proportion of population living below the national poverty line (%)	50 (2003)	45 (2006)	22	14 (2014)		SDG Indicator database
2	Prevalence of undernourishment (%)	24 (2001)	17	13	8.9	4.6	SDG Indicator database
3 – Child health	Under-five mortality rate, by sex (deaths per 1,000 live births)	106	65	44	32	26	SDG Indicator database
	Proportion of children under-five years moderately or severely stunted (%)	49	43	40	32 (2014)	23.8	SDG Indicator database
	Proportion of children under five years moderately or severely wasted (%)	17	8.5	11	9.7 (2014)	9.6 (2021)	SDG Indicator database
4	Completion rate at primary level (%)	34	59	71	70	79	SDG Indicator database
	Completion rate at secondary level (%)	17	27	37	40	46	SDG Indicator database
5	Proportion of seats held by women in legislation institutions (%)	8.2	9.8	21	20	20	SDG Indicator database
6	Proportion of population using safely managed drinking water services (%)	17	19	22	25	28	SDG Indicator database
	Proportion of population with basic handwashing facilities on premises (%)			63	67	79	SDG Indicator database
7	Proportion of population with access to electricity (%)	17	21	31	63	86	SDG Indicator database
8	GDP per capita (current US$)	301	474	785	1162	1578	World Bank

9	Proportion of population covered by at least a 3G mobile network (%)			43 (2009)	70	92	SDG Indicator database
10	Gini index disposable income (0-100)	37	37	36		55 (2019)	Standardized World Income Inequality Database
11	Proportion of urban population living in slums (%)		79		45 (2014)	40	SDG Indicator database
12	Domestic material consumption per capita (tonnes)	3.3	3.8	8.6	6.1	8.4 (2017)	SDG Indicator database
13	Domestic fossil fuel consumption per capita (kg)			4	8	14	SDG Indicator database
14	Sustainable fisheries as a proportion of GDP (%)			1.1 (2011)	0.8	0.6 (2017)	SDG Indicator database
15	Forest area as a proportion of total land area (%)	61		60	50	46	SDG Indicator database
16	Voice and Accountability (-2.5 weak to 2.5 strong)	-0.8	-1.0	-0.9	-1.1	-1.4	The Worldwide Governance Indicators

1.4.2 Child health in Cambodia

Cambodia achieved MDG 4 by reducing the under-five mortality rate by two-thirds from 1990 to 2015.[65] The trends of child mortality in Cambodia are presented in **Figure 3**, while **Figure 4** presents development and child health related policies and their relation to economic growth and the decline in under-five mortality. A range of studies have indicated the importance of multisectoral collaborations and various cross-sectoral policies to lower poverty and improve maternal and child health over the last two decades.[66–68] The improvement in child mortality has continued beyond 2015, with the under-five mortality rate estimated to be 24 per 1000 live births in 2022. The pattern of child mortality mirrors the global phenomenon of neonatal deaths accounting for a higher proportion of the number of deaths when the overall under-five mortality rate declines.[3] Disparities exist between geographical regions and income groups with under-five mortality rates being higher in rural and north-eastern geographical areas and among lower income groups.[69]

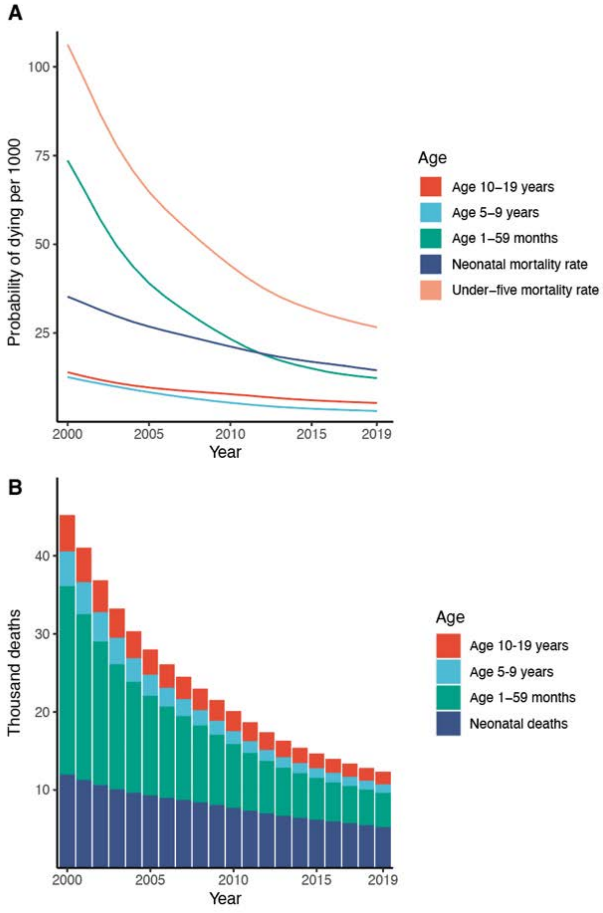


Figure 3. Child mortality trends over time in Cambodia. (**A)** Probability of dying per 1000 individuals at the start of the age. (**B)** Number of deaths per age group. Data from United Nations Inter-agency Group for Child Mortality Estimation.[70]

A few studies have tried to examine the determinants of child mortality in Cambodia. Ly et al.[71] examined the determinants of child mortality in Cambodia from the DHS conducted in 2010 and 2014 by use of parametric Weibull hazard regression models. They found that longer birth interval, maternal antenatal care visit at last birth and full vaccination of the child were associated with a reduced risk of under-five death. However, older maternal age and higher maternal educational attainment were associated with an increased risk of under-five death. Acknowledging the difficulties of applying a longitudinal panel risk analysis to a cross-sectional retrospectively conducted survey and the possibility that the parametric assumptions of a Weibull hazard regression might not hold,

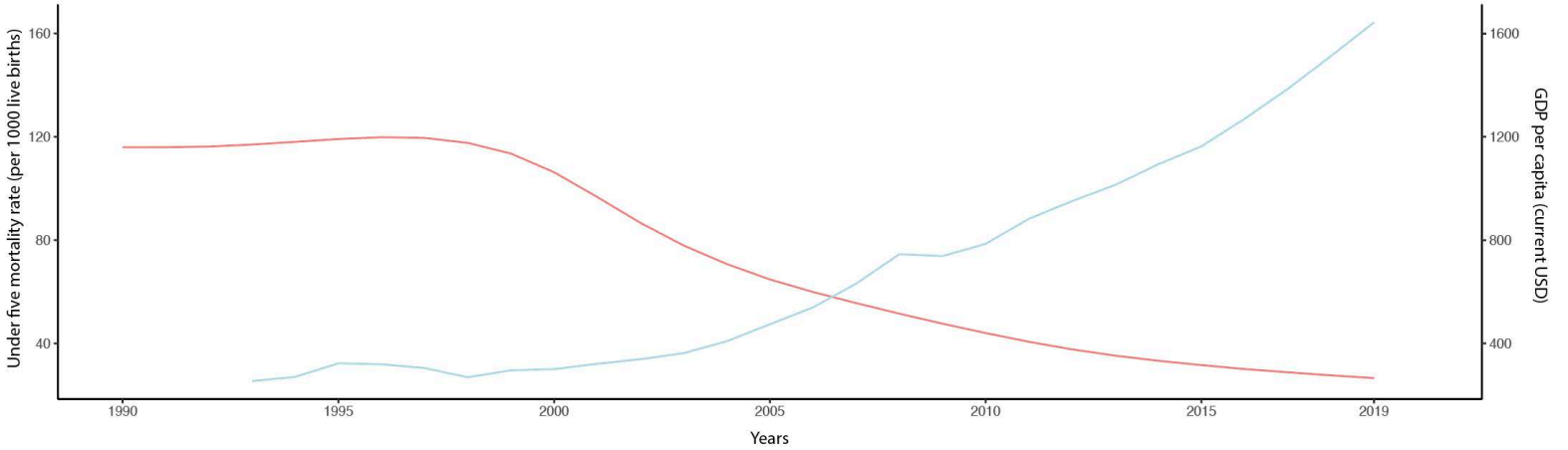
maternal education level has been shown to lead to a decreased risk of under-five death in other settings. Unfortunately the authors do not analyze this relationship further. Similarly, Um and Heng[72] used the 2014 DHS to examine the determinants of under-five deaths using multivariable logistic regression, showing that older age of the mother, lower birth weight of the child as well as rural residence of the household were associated with a higher risk of under-five death while children with mothers reporting contraceptive use had a lower risk of under-five death. Focusing on neonatal death, Hong et al.[73] utilized the same DHS datasets to highlight that neonatal mortality in Cambodia follows geographical and wealth disparities that reflect a lack of socioeconomic development critical for improving neonatal mortality.

As for child morbidity, neonatal disorders and infectious diseases continue to cause the most disability adjusted life years (DALYs) for children under five. For children aged 5-14 years the causes of morbidity are more varied but are primarily caused by non-communicable diseases and injuries.[74] The mortality rate among under-five children from lower respiratory infections has declined by more than 80% since 1990, mainly due to increased vaccination coverage, lower household air pollution and better nutritional status of children.[75] However, lower respiratory infections are still the leading infectious cause of death and DALYs with diarrhea as the second.[74] The determinants of lower respiratory infections in children in Cambodia have not been studied. A study by Vong et al.[76] using the DHS from 2014 concluded that lack of water and sanitation facilities and maternal unemployment were associated with an increased risk of diarrhea while older maternal age was associated with a decreased risk of diarrhea. Malnutrition as a multisectoral issue and cause of significant child mortality and morbidity is widely recognized.[69,77,78] Combining non-economic deprivations and data on stunting in Cambodia, Karpati et al.[79] showed how not being deprived of nutritional, water and sanitation together with health status has the largest protective influence against stunting. Moreover, there are several dimensions of poverty that are still prevalent (such as lack of quality housing and education), with nearly 50% of children experiencing three or more of such deprivations in 2018.[80]

The focus on multisectoral collaboration and cross-sectoral policies between the traditional health sector and other relevant sectors such as education and water and sanitation have been a hallmark of the success in reducing child mortality in Cambodia.[66,67] However, how stakeholders view multisectoral collaborations for child health in Cambodia has not been studied and it is evident that much remains to be done. The 2030 Agenda and the adoption of the SDGs into the localized Cambodian SDGs (CSDGs) offer an opportunity to rejuvenate the focus on a multisectoral approach to child mortality and morbidity and its vital determinants of health in Cambodia.

Figure 4. Overview of health policies, economic development and child health in Cambodia 1990-2019

1993 - Set of constitution 1994 – National Program to Rehabilitate and Develop Cambodia 1996-2000 – Socioeconomic Development Plan I 1999 – ASEAN Free Trade	2001 – Land policy 2001 – 2005 Socio-Economic Development Plan II 2002 – National Poverty Reduction Strategy 2003 – 2015 Cambodia Millennium Development Goals 2004 – Cambodia part of World Trade Organization 2005 – 2010 Small/Medium Enterprises Development Policy 2006 – 2010 National Strategic Development Plan 2009-2015 The National Nutrition Strategy	2011 – 2015 UN Development Assistance Framework 2015 – Cambodia reached middle-income status 2015 – 2025 Industrial Development Plan 2016 – 2030 Cambodian Sustainable Development Goals 2018 – 2027 National multisectoral action plan for the prevention and control of noncommunicable diseases 2019 – 2023 National Strategic Development Plan 2021 – 2030 Health Strategic Plan (HSP4)



1990 – Immunization policies enacted 1996 -Vitamin A linked with routine immunization 1996 - Health Coverage Plan developed 1996 – Health Workforce Development Plan first developed 1997 – National policy on ARI/CDD and Cholera control 1997 – National malaria and dengue control programmes 1998 – Integrated Management of Childhood Illnesses (IMCI) in health centers HSP4)	2002 – First national policy on child feeding 2003-2007 – Cambodia Nutrition Investment Plan 2003-2008 – Health Strategic Plan 2004 – Child survival benchmark review and high-level consultation 2005 - Sub-decree on marketing of products for infant & young child feeding 2006-2015 Child survival strategy 2008-2015 Health Strategic Plan (HSP1)	2008-2012 Strategic framework for food security and nutrition 2008-2015 Health Strategic Plan (HSP2) 2009-2015 The national nutrition strategy 2016-2020 Health Strategic Plan (HSP3) 2021 – 2030 Health Strategic Plan (HSP4

2 Research aims

The overall aim of the thesis was to explore the non-health determinants of child health in Cambodia and provide an updated investigation of the determinants of child mortality as well as morbidity from infectious diseases in Cambodia and in LMICs. There were four specific aims:

1) To investigate the interactions between child health and the SDGs in Cambodia (**Study I**).
2) To understand how stakeholders perceive the SDGs, child health in the era of the SDGs and multisectoral collaborations for child health in Cambodia (**Study II**).
3) To explore factors that are associated with under-five mortality and child morbidity from infectious diseases in Cambodia (**Study III**).
4) To investigate determinants of under-five mortality and morbidity from infectious diseases in LMICs in the SDG era (**Study IV**).

3 Materials and methods

This thesis includes a range of material and methods to answer the research questions, outlined below.

3.1 SDG Synergies approach applied to child health and Cambodia

The semi-quantitative SDG Synergies approach,[28] was used to try to understand the linkages between the SDGs and child health in Cambodia. We have provided a step-by-step guide on how the SDG Synergies approach can be used to situate health within the SDGs.[81] In short, the approach consists of three steps; 1) identification of the goals or targets to include in the analysis; 2) assessing the linkages between the selected goals, usually by a multistakeholder group using a 7-point scoring scale and; 3) using the score to visualize the scores and compute first and second order interactions. In **Study I**, we apply the SDG Synergies approach to the context of Cambodia and focus on child health in relation to the SDGs.

3.1.1 Identification of goals

Through matching SDG priorities with national developmental goals, ministry consultations and investigations into possible data sources, the Royal Government of Cambodia has put forward the CSDGs as 18 nationalized goals and a localized set of 88 targets from the 2030 Agenda. On a goal level, the CSDGs include one additional goal (number 18) to end the negative impact of Mine/Explosive remnants of war (ERW) and promote victim assistance (**Table 2**). The targets for each goal are fewer than the SDGs but designed to obtain data indicators to measure the progress towards the targets.[68] Guided by CSDGs,[68] the analysis done by Blomstedt et al[32] and the relevant SDG targets identified by UNICEF[22] as well as in-depth discussions within the research team and with local partners to ensure relevance to the Cambodian context, it was considered most adequate to include all CSDGs at a goal level with the exception of CSDG 17 (Partnerships for the goals) since the goal was deemed too broad for meaningful assessment. It was further decided to limit CSDG 3 (Good health and well-being) to only representing child health, which we defined as a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity among human beings below 18 years. The selection led to a total of 17 goals, translating into 272 unique pairwise interactions.

Table 2. List of included Cambodia Sustainable Development Goals and their definitions.

CSDG Goal	Definition
1	End poverty in all its forms everywhere
2	End hunger, achieve food security and improved nutrition and promote sustainable agriculture.
3	Child health In line with the WHO definition of health and the United Nations Convention on the Rights of the Child, child health is defined as a *state of complete physical, mental and social well-being and not merely the absence of disease or infirmity among human beings below 18 years*.
4	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.
5	Achieve gender equality and empower all women and girls.
6	Ensure availability and sustainable management of water and sanitation for all.
7	Ensure access to affordable, reliable, sustainable and modern energy for all.
8	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.
9	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.
10	Reduce inequality within and among countries.
11	Make cities and human settlements inclusive, safe, resilient and sustainable.
12	Ensure sustainable consumption and production patterns.
13	Take urgent action to combat climate change and its impacts
14	Conserve and sustainably use the oceans, seas and marine resources for sustainable development.
15	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.
16	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels.
18	End the negative impact of Mine/Explosive remnants of war (ERW) and promote victim assistance.

3.1.2 Assessing the interactions between the goals

Over a 2-day workshop on the 24-25th of August in 2020, 29 participants representing a range of governmental and non-governmental stakeholders assessed the interactions between the selected goals, taking advantage of the breadth of country expertise. The participants were purposively selected based on predefined criteria of having either expertise in child health in Cambodia or being from a non-health sector (for example water and sanitation, agriculture, infrastructure, etc.) reflecting the social, economic, political, environmental, and cultural determinants of health and working in a capacity that includes multisectoral collaboration in the country. Based on the SDG Synergies approach, groups of 5-6 people discussed direct interactions between pairs of goals by answering a guiding question: "In the Cambodia context, if progress is made on Goal X, how does this influence progress on Goal Y?". The group arrived at a score according to the Weimer-Jehle seven-point scale,[82] which ranges from strongly restricting (-3) to strongly promoting (+3). The participants also recorded a 1-2 sentence motivation for the score. The exercise was held in Khmer, official published Khmer CSDG descriptions of goals and targets were used, and all documents were translated and back-translated for validity. As a basis for scoring, the participants used their expertise, working knowledge, and a fact sheet for each goal with descriptions of the associated targets and key statistics derived from the 2019 Cambodia Sustainable Development Report.[83] It was emphasized that the participants should think about child health from a broad perspective, in line with the definition in **Table 2**, and not only on child mortality. After the first scoring of interactions, the groups double-checked their own scoring and verified a set of interactions originally scored by another group. All identified discrepancies and differences were discussed in a plenary session, where final scores were arrived at in consensus.

3.1.3 Cross-impact matrix and network analysis

All scores were directly entered into a tailor-made digital software[84] developed by the Stockholm Environment Institute, which also includes the statistical analysis features outlined below. From the final scoring of all interactions, a cross-impact matrix was developed, which served to illustrate the results and was the basis for applying network analysis. While the data presented in the cross-impact matrix provides information on the frequency of different types of interactions and how different goals influence the overall agenda, network analysis methods can be used to assert more systemic properties of the interactions. By using network analysis, where a goal is considered a node (*N*) and the interaction is considered a link (*L*) and the subsequent network can be described as *G = (N, L)*, the network can be visualized, clusters of more related goals highlighted, and the impact of certain goals and/or interactions more clearly assessed.[85] Moving beyond the direct interactions that are evident from the cross-impact matrix, analysis of the second-order interactions shows the net influence of a certain goal on the network as a whole as well as on other individual goals.

3.2 A qualitative approach to understanding perceptions on child health, SDGs and multisectoral collaborations

3.2.1 Study design, participant identification and recruitment

Guided by the consolidated criteria for reporting qualitative research recommendations[86] and the concept of information power[87] we utilized semi-structured interviews to investigate how Cambodian stakeholders perceive the SDGs, the concept of child health in the era of the SDGs and multisectoral collaborations for child health in Cambodia. Key child health stakeholders with country specific knowledge, as well as non-health sector stakeholders on a national level in Cambodia, were identified for participation by the research team. Participants were purposively selected based on predefined criteria of having expertise in child health or being from a non-health sector (for example, water and sanitation, agriculture, infrastructure, etc.) but with implementation knowledge of how child health interacts with other sectors in Cambodia. Efforts were made to recruit participants from many different sectors, including having participants from inside and outside of government. Further, the recruitment of participants was aimed to be balanced in terms of sex and seniority. The expected total number of participants was 30, balancing the need for reaching satisfactory information power[87] and feasibility.

3.2.2 Data collection

A total of 29 participants were interviewed between April-June 2020. Information was given verbally to all participants on the purpose of the study, what their involvement in the study would be, the risks and benefits of taking part in the study, and that they had the right to decline participation or withdraw from the study at any time for any reason. Participants were asked to sign an informed consent form, written in Khmer before the interview started. The interviews were held in Khmer, audio recorded and transcribed verbatim into English. The interviews took place in Phnom Penh city vicinity, at the participant´s place of employment or in another convenient but private location for the participant. An interview guide was developed based on established multisectoral frameworks; the SDG Synergies framework,[34] Health in all policies approach[88] and multisectoral collaborative model presented by Kuruvilla et al.[89] The interview started with general background information on the participant, including the work experience in different sectors as represented by the CSDGs and moved on to the perception of the SDGs, child health and multisectoral collaboration and then focused on multisectoral collaboration for child health within the Cambodia context (identification of problem, design, implementation, and monitoring of the collaboration as well as relationships and capacity building activities). All types of collaborations between at least two or more sectors that had the explicit goal in some way to improve child health were considered during the interview. Two pilot interviews were held where after the interview guide was slightly adjusted for clarity.

3.2.3 Data analysis

The transcripts were initially analyzed by framework method analysis.[90] The transcripts were read in full and then coded through identification of meaning units, combining these into sub-categories and then grouped into overarching categories and lastly themes following the standard methodology. The themes, categories and sub-categories were inductively developed without prior anticipation[91] and continuously developed during the review of the transcripts. As such, the concepts of child health, SDGs and multisectoral collaboration emerged inductively. The coding was cross-checked and the analysis was continuously discussed within the team to improve trustworthiness and validity.[87]

3.3 Exploring factors associated with under-five mortality and morbidity from infectious diseases in Cambodia and in low- and middle-income countries

3.3.1 Demographic Health Surveys as data sources

For **Study III** the most recent Cambodian DHS (CDHS) conducted in 2021-2022 was used as the data source. The multi-stage stratifying sampling technique and specifics of the structured questionnaire are presented extensively elsewhere, however the sampling unit was households.[92]

For **Study IV**, all LMICs with publicly available standard DHS data were considered. To ensure relevance to the SDG era, only the latest survey conducted in which its data collection had to be started during 2015 or later was included. This led to 44 country-unique DHS included from Afghanistan, Albania, Angola, Armenia, Bangladesh, Benin, Burkina Faso, Burundi, Cambodia, Cameroon, Colombia, Cote d´Ivoire, Ethiopia, Gabon, Gambia, Guinea, Haiti, India, Indonesia, Jordan, Kenya, Liberia, Madagascar, Malawi, Maldives, Mali, Mauritania, Myanmar, Nepal, Nigeria, Pakistan, Papa New Guinea, Philippines, Rwanda, Senegal, Sierra Leone, South Africa, Tajikistan, Tanzania, Timor-Leste, Turkey, Uganda, Zambia and Zimbabwe. The datasets were combined through de-normalization of the survey household weight to one complete dataset that included all country data.

3.3.2 Outcomes

The outcomes considered were the same for **Study III** and **Study IV**. The primary outcome was defined as a child dying before their fifth birthday in the last five years preceding the study. The secondary outcome was a child below the age of five having fever, acute lower respiratory disease, or diarrhea any time during the last two weeks preceding the survey.

3.3.3 Possible explanatory variables

Possible variables that could be associated with the outcomes for **Study III** were identified through established frameworks for understanding determinants of child mortality and morbidity,[8] previous studies in Cambodia[71–73] and CDHS data information.[92]

Of the identified variables, those with less than 30% missing data were used to analyze the primary and secondary outcomes further. This led our models to include the following variables: twin, birth order of child, previous birth interval of mother, mother age at birth, contraceptive use of mother, mothers' highest educational level, the number of births in the last five years of the mother, drinking water source, sanitation facility, cooking fuel, electricity, household wealth quintile, household type, geographical region, and health insurance.

When it came to **Study IV**, the possible explanatory variables were identified from established frameworks for understanding determinants of child mortality and morbidity,[8,93] previous studies[94–98] and DHS data information.[99] Of the identified variables, those with less than 30% missing data were used in the model. This led our models to include the following variables: twin, birth order of child, previous birth interval of mother, mother age at birth, contraceptive use of mother, mothers' highest educational level, the number of births in the last five years of the mother, drinking water source, sanitation facility, cooking fuel, electricity, household wealth quintile, household type, place of delivery of child and assisting person during the delivery. Lastly, children with missing data for any of the variables included in the models for **Study III** and Study **IV** were excluded.

3.3.4 Statistical approach: complementing standard statistics with a machine learning algorithm

A similar analytical approach was applied for **Study III** and **Study IV**. First, a descriptive analysis of the complete dataset of children is presented with weighted counts % (n/N), compared by sex through Wilcoxon rank-sum test for complex survey data.[100] Then a survey-weighted multivariable generalized linear model with a binomial link was used to conduct statistical inference on the primary and secondary outcome probability with robust standard errors at the household level. In this way, the complex survey design, including survey weights, cluster and strata of the DHS were accounted for in the model. Adjusted odds ratios and 95% confidence intervals (CI) for the variables included in the model were estimated. Large sample two-sided Wald-type statistical tests for the hypothesis that the odds ratios for each predictor were equal to one (no association) were conducted with a type I error fixed at 5%.

A classification random forest machine learning algorithm was applied to identify additional predictors and to complement the statistical inference provided by the multivariable logistic regression. In brief, a random forest is a supervised ensemble learning algorithm combining individual decision trees into a random forest.[101] From the original sample, several bootstrap samples are drawn, and an unpruned classification tree is fit for each bootstrap sample. The variable selection for each split in the classification tree is conducted only from a small random subset of predictor variables. In the traditional application of random forest, the split is decided based on the Gini split criterion however, this can lead to decision trees preferring variables with more categories.[102,103]

Given that we have variables with few and many categories, we use a split based on conditional inference framework provided by Hothorn et al.[104] and built upon by Strobl et al.[105] that provides unbiased classification decision trees. From the complete forest, the status of the response variable is predicted as an average or majority vote of the predictions of all trees. As such, the algorithm adjusts for the instability of the individual decision trees. In our study, we are not interested in constructing a prediction model, but rather in understanding which of the included variables in the model is most important. Interpreting variable importance from machine learning algorithms can be tricky however, for most datasets and aims, permutation importance provides a robust assessment of variable importance.[106] In short, by randomly permuting the predictor variable X_j, its original association with the response Y is broken. When the permuted variable X_j and the remaining unpermuted predictor variables used to indicate the response, the prediction accuracy (i.e., the number of observations classified correctly) decreases substantially, if the original variable X_j was associated with the response. Thus, a reasonable measure for variable importance is the difference in prediction accuracy before and after permuting X_j. One important advantage of permutation variable importance is that the measure both covers the non-linear impact of each variable on the prediction accuracy as well as the non-linear multivariable interaction with other predictor variables. In our analysis, the conditional random forest was implemented with default settings and link each observation with the household weight to account for the complex survey design. To assess variable importance, conditional permutation importance was averaged over ten permutations with the threshold level set at a p-value of <0,05. For details on the statistical properties of conditional decision trees, random forests based on such trees, and permutation importance, we refer the reader to Debeer and Strobl.[107]

3.4 Ethical considerations

Study I and **Study II**: The studies received ethical approval from the National Ethics Committee for Health Research in Cambodia (NECHR-023) and was exempt from ethical review from the Swedish Ethical Review Authority (Dnr 2022-00424-01). Written informed consent was obtained from all participants before inclusion in the studies.

Study III and **Study IV**: The surveys used in these studies have gained ethical approval from ethical institutional review board in each country, including the National Ethics Committee for Health Research in Cambodia for CDHS. Informed consent was obtained from all participants and the survey followed rigorous standardized procedures to safeguard the anonymity and personal integrity of the participants.

4 Results

4.1 Investigating the interactions between child health and the SDGs in Cambodia

A total of 272 interactions were scored, and there were a high number of perceived positive interactions (n=212, 78%) versus negative (n=12, 4%) and a significant number were deemed not to have any direct positive or negative influence (n=48, 18%) (See **Figure 5**). From the direct interactions, CSDG 16 (Peace, justice, and strong institutions) had the leading row sum and thus the largest positive influence on the network as a whole, while CSDG 11 (Sustainable cities and communities) and CSDG 6 (Clean water and sanitation) had the second largest row sum. CSDG 1 (no poverty) had the least positive influence on the other goals, with negative interactions on CSDG 11 (Sustainable cities and communities), 12 (Responsible consumption and production), 14 (Life below water) and 15 (Life on land). On the other hand, CSDG 1 (No poverty) together with CSDG 8 (Decent work and economic growth) and CSDG 3 (Child health) were deemed to be promoted the most by progress on other goals. CSDG 15 (Life on land) was promoted the least by progress on other CSDGs as expressed by the column sum.

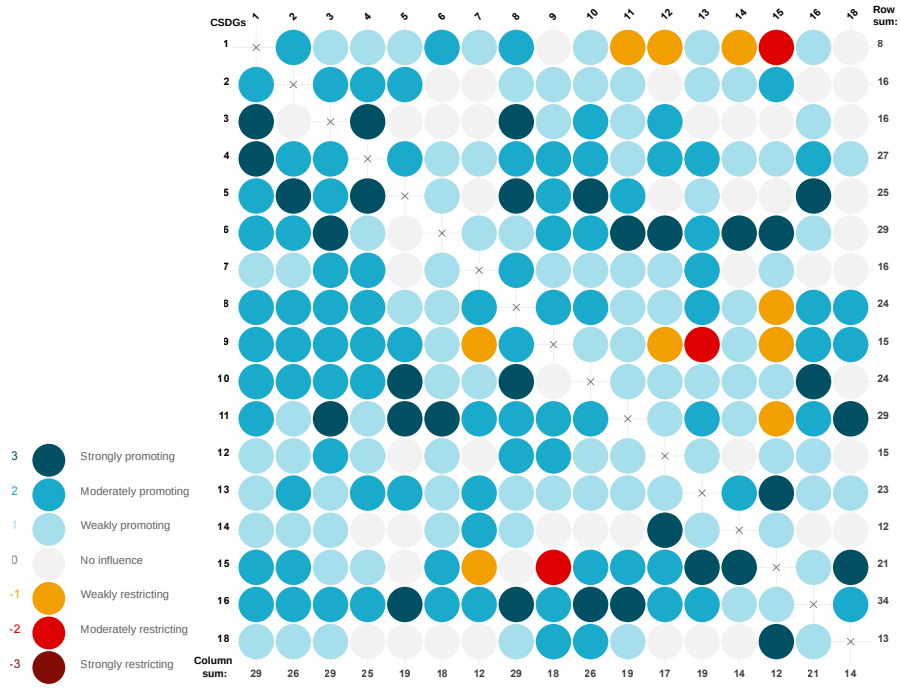


Figure 5. Cross-impact matrix of the 17 Cambodian Sustainable Development Goals. Color according to scale. The row sum implies the goal's net influence on the network, and the column sum shows how much the goal is influenced by all other goals in the network. Goals were defined in **Table 2**.

When including second-order interactions, the goals' relative rank changes slightly as illustrated in **Table 3**. CSDG 16 (Peace, justice and strong institutions) is shown to have a large net influence on the network. Notably, CSDG 6 (Clean water and sanitation) moves from 2nd to 4th rank, CSDG 5 (Gender equality) moves from 5th to 3rd and CSDG 7 (Affordable and clean energy) from 12th to 10th when considering the second-order interactions. However, the absolute net influence is quite equal, and many of the bottom ranked CSDGs do not change rank.

Table 3. The rank of goals influencing the network based on first and second-order interactions.

First-order interactions			Second-order interactions		
Rank	**Goal**	**Net influence**	**Rank**	**Goal**	**Net influence**
1	16	34	**1**	16	729
2	6	29	**2**	11	615
3	11	29	**3**	5	588
4	4	27	**4**	6	581
5	5	25	**5**	4	555
6	8	24	**6**	10	552
7	10	24	**7**	8	497
8	13	23	**8**	13	485
9	15	21	**9**	15	438
10	2	16	**10**	7	353
11	3	16	**11**	3	349
12	7	16	**12**	2	337
13	9	15	**13**	9	337
14	12	15	**14**	12	336
15	18	13	**15**	18	281
16	14	12	**16**	14	226

4.1.1 Child health within the network

Focusing on child health and the CSDGs, making progress on child health in Cambodia was found to promote progress on a number of CSDGs directly; 1 (No poverty), 4 (Quality education), 8 (Decent work and economic growth), 10 (Reduced inequalities), 12 (Responsible consumption and production), CSDG 9 (Industry, innovation and infrastructure), 11 (Sustainable cities and communities) and 16 (Peace, justice and strong institutions) (**Figure 6a**). Interestingly, a number of CSDGs were perceived not to be directly impacted by progress on child health in Cambodia; CSDG 2 (Zero hunger), 5 (Gender equality), 6 (Clean water and sanitation), 7 (Affordable and clean energy), 13 (Climate change), 14 (Life below water), 15 (Life on land) and 18 (Mine/ERW free). At the same time, we found that all other CSDGs were perceived to positively influence child health, with progress on CSDG 6 (Clean water and sanitation) and CSDG 11 (Sustainable cities and communities) being thought of as strongly promoting (**Figure 6b**).

Taking into consideration the sum of the second-order interactions **(Figure 6c** and **6d)**, all CSDGs have a net positive influence with CSDG 16 (Peace, justice and strong institutions) having the largest net positive influence. Moreover, there seems to be a positive reinforcing feedback loop where improving child health can lead to advancing child health through positive interactions with other CSDGs. A notable exception of the general positive tendency among the net influence is CSDG 15 (Life on land), which, through second-order interactions, seems to be negatively impacted by progress on child health in Cambodia.

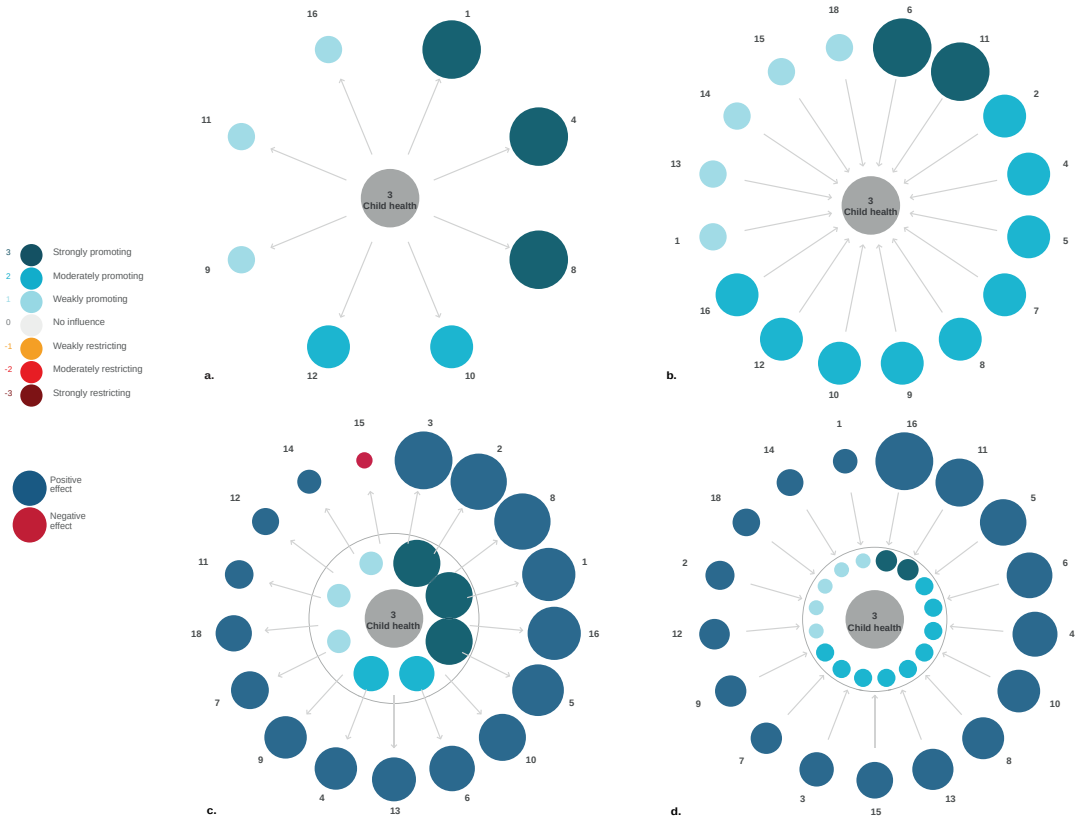


Figure 6. The Cambodia Sustainable Development Goals from the perspective of child health. a and b: Figure 3a illustrates the first-order influence of child health on the CSDGs, and Figure 3b vice versa. c and d: Figure 3c illustrate the second-order influence of child health on the CSDGs and Figure 3d vice versa. Color according to scale. Goals were defined in **Table 2.**

4.2 Perceptions and understandings of SDGs, child health and multisectoral collaboration for child health in Cambodia

A total of 29 stakeholders were interviewed (see **Supplementary Material Table S1** for participant characteristics) and a myriad of perspectives emerged. Two overarching themes were derived from these: how the SDGs and an expanded view on child health enabled change and the gap between theory and real-world complexities of conducting multisectoral collaborations for child health (**Table 4**).

Table 4. Main themes, sub-themes and categories.

Themes	SDGs and an expanded view on child health enable change		Gap between theory and real-world complexities		
Sub-themes	Possibility for action due to SDGs	Higher ambitions for child health, a multisectoral area at heart	Planned linear process of collaboration	Real-world complexities shaping the collaboration	Critically assessing collaboration
Categories	SDGs provide a common vision and guide Government commitment to and leadership of SDGs Discrepancy between ambition and actual work	Definition of child health Child health linkages across sectors Aspects of the health system and actors unique to children Special considerations for children	Identifying and framing problem Actors and topics Planning Coordination Implementation Monitoring and evaluation Dissemination	Funding Relationships Enabling environment Capacity building	Success factors Obstacles

4.2.1 SDGs, child health and uniqueness of children

The participants detailed how the SDGs worked as an overarching vision for sustainable development in the country and that the SDGs represented an extension of the MDGs with several more layers of complexity but also more relevance to each country, including Cambodia. In general, participants thought that the SDGs promoted health as a multisectoral issue and that the government had made a substantial commitment to the SDGs. However, a number of participants also expressed concerns regarding whether the commitment and objectives set also had sustainable funding and other resources necessary to succeed.

"That's the difference in perspectives between policymakers and implementers. The implementers in the ministry will complain about having lots of challenges and risks which could lead to a lower result. So, the plan to achieve many things by 2030 has already been written down. However, the implementation need budget and solutions to the challenge." - Nr 21, non-governmental organization

Throughout the interviews, participants discussed the unique vulnerabilities of children and a range of connections between non-health sectors and child health, such as education, nutrition, the environment, and social services. Many made the case that child health is indivisible from its determinants and that all actors in a society have a responsibility to improve child health.

"Like I mentioned, child health consists of physical, mental and social health. So, we need all relevant institutions to improve physical, mental and social health. We can't miss anyone to work on it." - Nr 5, governmental organization

4.2.2 Multisectoral collaboration – theoretical visions versus actual practice

The discussions around multisectoral collaborations for child health were particularly detailed and rich. Through the analysis, it became clear that participants had usually envisioned a linearly designed project process, which never came into existence. Instead, the collaboration developed and was shaped by relationships, power dynamics, and obstacles such as funding.

Both top-down and bottom-up approaches to identifying a child health problem that could be solved through a multisectoral collaboration were described, while substantial effort was commonly made to provide a detailed problem statement in a collective effort. The stakeholders involved shaped how the collaboration formed, with the government being seen as self-evident leaders while non-governmental organizations more often collaborated through a flatter network approach. It could be a complicated process to formalize partners in the collaboration, with often strong territory feelings, boundaries of mandate and skeptical views of non-governmental organizations by government representatives and vice versa.

"I am not blaming the government institutions, but there are some institutions which have too clear boundaries on their responsibilities and work. This leads to failure in our work. " – Nr 29, international organization.

A planning process was often included before the activities began, while some form of coordination mechanism (such as focal points at each stakeholder or joint committees) was put in place. Leadership and the capacity of the organization leading the collaboration were seen as essential for successfully implementing the activities. The formal and informal power held by various organizations were perceived to be the main determinant of leadership and coordination control, with power imbalances being evident in the prioritization of activities.

"For example, they (government servants) may plan 20 activities, but receive inadequate budget. So, they prioritize the activities to be done. According to my observation, district level is the same. They engage politics into their work. They like infrastructure development more than social development because it is eye-catching and visible." – Nr 9, governmental organization.

The interviewees distinguished between the national level and the sub-national administrative level and outlined how the actual activities were carried out by collaborators or extensions of their respective organizations at the local level. This repeatedly led collaborations to have different views of their priorities and responsibilities at the national versus the sub-national levels. Detailed monitoring and evaluation were seen as favorable, with quantitative statistics being preferred; however, how the success or failure of different activities should be attributed to the different stakeholders was often unclear.

"National level only work on policy. So, implementation goes to community level. I think that we should focus on provincial and communal level first to let them implement the work. We should also try to integrate the coordination with national level too by using forum to meet and discuss on the challenge." - Nr 28, international organization.

Overall, the collaboration encountered aspects that shaped the functioning of the collaboration in different ways. The first and most frequently cited was funding, seen as essential for the success of the activities and the main source of power in the collaboration. Further, person to person relationships between stakeholders could facilitate or impede the collaboration between government and non-governmental organizations. An enabling policy environment with the embracement of the SDGs was seen as favorable for the instigation of collaborations, and many participants thought that government ministries actively promoted a multisectoral approach to child health.

"More importantly, we need the money to be available at sub-national level. The partners are all institutions. If the government can't manage to work on everything, we can ask civil society to help working on that. Nowadays, we are skeptical with NGOs. But, we also have example of government providing budget for NGOs to work." Nr 4, governmental organization.

"The main thing is whether or not they have the commitment to work together. When commitment on that occur, the work can be done easily because visions created in country and global level has already been created." – Nr 17, non-governmental organization.

4.3 Factors associated with under-five mortality and child morbidity from infectious diseases in Cambodia

The CDHS included 8153 children under five years, and over the five years before the end of the survey, the neonatal mortality rate was 8.40 (95% CI 5.81-10.9) per 1000 live births, infant mortality rate 12.7 (95% CI 9.51-15.8) and under-five mortality rate 19.3 (95% CI 12.3-25.3). In total, 114 (1,4%) of children died before their fifth birthday, with the majority of deaths (N=66, 58%) occurring during the neonatal period. Sometime during the two weeks preceding the survey, 1321 (17%) of children had the secondary outcome of fever, acute lower respiratory disease, or diarrhea. An overview of the characteristics of the children included is provided in **Table 5.** There were no major differences between male and female children, apart from a higher proportion of male children being stunted versus female (11% versus 8.4%).

Table 5. Characteristics of the study population by sex.

Characteristic	Missing	Overall N = 8019	Male N = 4083	Female N = 3936	p-value
Child/Mother					
Twin* (Yes/No)	0%	1.1% (92 / 8019)	1.1% (44 / 4083)	1.2% (48 / 3936)	0.7
Birth order*	0%				0.8
- First		35% (2834 / 8019)	36% (1460 / 4083)	35% (1374 / 3936)	
- Second		35% (2813 / 8019)	35% (1413 / 4083)	36% (1401 / 3936)	
- Third		19% (1493 / 8019)	19% (772 / 4083)	18% (721 / 3936)	
- Fourth and later		11% (878 / 8019)	11% (438 / 4083)	11% (440 / 3936)	
Previous birth interval*	0.2%				0.8
- First born		35% (2834 / 8005)	36% (1460 / 4079)	35% (1374 / 3926)	
- <2 years		7.0% (559 / 8005)	6.8% (278 / 4079)	7.2% (281 / 3926)	
- 2 years		10% (835 / 8005)	10% (413 / 4079)	11% (422 / 3926)	
- 3 years		10% (802 / 8005)	9.8% (399 / 4079)	10% (403 / 3926)	
- >3 years		37% (2975 / 8005)	37% (1529 / 4079)	37% (1446 / 3926)	
Birth weight under 2500g (Yes/No)	41%	6.3% (300 / 4771)	5.8% (141 / 2440)	6.8% (159 / 2331)	0.3
Stunted weight for height (Yes/No)	54%	9.9% (363 / 3665)	11% (211 / 1861)	8.4% (152 / 1804)	0.025
Mother's age at birth*	0%				0.6
- < 20 years		8.8% (706 / 8019)	8.9% (364 / 4083)	8.7% (342 / 3936)	
- 20-34 years		77% (6144 / 8019)	77% (3144 / 4083)	76% (3000 / 3936)	
- 35-49 years		15% (1169 / 8019)	14% (575 / 4083)	15% (595 / 3936)	
Mother highest educational level*	0%				0.7
- No education		11% (884 / 8019)	12% (471 / 4083)	10% (413 / 3936)	
- Primary		41% (3294 / 8019)	41% (1667 / 4083)	41% (1627 / 3936)	
- Secondary		41% (3258 / 8019)	40% (1644 / 4083)	41% (1614 / 3936)	
- Higher		7.3% (583 / 8019)	7.4% (301 / 4083)	7.2% (282 / 3936)	
Contraceptive use* (Yes/No)	0%	64% (5124 / 8019)	62% (2545 / 4083)	66% (2579 / 3936)	0.020
Wanted pregnancy of child	39%				0.5

- Yes		81% (3977 / 4908)	81% (2030 / 2506)	81% (1947 / 2402)	
- Later		7.9% (387 / 4908)	8.4% (211 / 2506)	7.4% (177 / 2402)	
- No		11% (544 / 4908)	11% (265 / 2506)	12% (278 / 2402)	
Births in last five years*	0%				0.5
- One		72% (5756 / 8019)	72% (2932 / 4083)	72% (2824 / 3936)	
- Two or more		28% (2264 / 8019)	28% (1151 / 4083)	28% (1107 / 3936)	
Household					
Water source*	0%				0.9
- Unimproved		9.4% (756 / 8019)	9.4% (384 / 4083)	9.5% (373 / 3936)	
- Improved		91% (7263 / 8019)	91% (3699 / 4083)	91% (3564 / 3936)	
Sanitation facility*	0%				0.2
- Unimproved		11% (910 / 8019)	12% (482 / 4083)	11% (428 / 3936)	
- Improved		89% (7110 / 8019)	88% (3601 / 4083)	89% (3508 / 3936)	
Cooking fuel*	1%				0.5
- Electricity/gas		52% (4167 / 7963)	52% (2102 / 4056)	53% (2065 / 3908)	
- Kerosine/Coal/Wood or similar		48% (3796 / 7963)	48% (1953 / 4056)	47% (1843 / 3908)	
Electricity* (Yes/No)	0%	91% (7324 / 8019)	91% (3717 / 4083)	92% (3607 / 3936)	0.4
Household wealth quintile*	0%				0.5
- Poorest		22% (1732 / 8019)	23% (919 / 4083)	21% (814 / 3936)	
- Poorer		19% (1489 / 8019)	18% (742 / 4083)	19% (747 / 3936)	
- Middle		19% (1488 / 8019)	18% (740 / 4083)	19% (747 / 3936)	
- Richer		21% (1717 / 8019)	21% (873 / 4083)	21% (844 / 3936)	
- Richest		20% (1593 / 8019)	20% (808 / 4083)	20% (784 / 3936)	
Household type*	0%				0.5
- Urban		39% (3150 / 8019)	40% (1622 / 4083)	39% (1528 / 3936)	
- Rural		61% (4869 / 8019)	60% (2461 / 4083)	61% (2408 / 3936)	
Geographical region*	0%				0.2
- Phnom Penh		15% (1172 / 8019)	15% (594 / 4083)	15% (577 / 3936)	
- Plain		33% (2666 / 8019)	33% (1338 / 4083)	34% (1328 / 3936)	
- Great lake		30% (2422 / 8019)	30% (1227 / 4083)	30% (1195 / 3936)	
- Coastal		6.0% (479 / 8019)	6.7% (274 / 4083)	5.2% (205 / 3936)	
- Mountain/Plateau		16% (1280 / 8019)	16% (649 / 4083)	16% (631 / 3936)	
Health service					
Health insurance* (Yes/No)	0%	25% (1969 / 8019)	25% (1031 / 4083)	24% (939 / 3936)	0.2
Antenatal visits	42%				0.6
- 0		1.3% (58 / 4631)	1.4% (34 / 2366)	1.1% (24 / 2265)	
- 1-4		25% (1142 / 4631)	25% (583 / 2366)	25% (559 / 2265)	
- 5+		74% (3432 / 4631)	74% (1750 / 2366)	74% (1682 / 2265)	
Place of delivery	39%				0.6
- Facility with cesarian section possibility		38% (1842 / 4908)	38% (959 / 2506)	37% (884 / 2402)	
- Facility		61% (2973 / 4908)	60% (1501 / 2506)	61% (1472 / 2402)	
- Home		1.9% (92 / 4908)	1.8% (46 / 2506)	1.9% (47 / 2402)	
Assisting person during delivery	39%				0.3
- Health professional		99% (4846 / 4908)	99% (2471 / 2506)	99% (2375 / 2402)	
- Non-health profession		1.3% (62 / 4908)	1.4% (35 / 2506)	1.1% (27 / 2402)	

Any postnatal visit (Yes/No)	42%	38% (1774 / 4621)	37% (874 / 2360)	40% (900 / 2261)	0.12
DTP full vaccination (Yes/No)	40%	75% (3608 / 4814)	74% (1805 / 2448)	76% (1802 / 2366)	0.088
Polio full vaccination (Yes/No)	40%	77% (3725 / 4832)	76% (1865 / 2460)	78% (1860 / 2373)	0.081

Footnotes: All variables are weighted according to household survey weight, while taking into consideration the sampling cluster and strata. * These variables had data from all under-five children and below 30% missing data and were included in the multivariable model. Region Phnom Penh is the capital city; the Plain region consists of Kampong Cham, Kandal, Prey Veng, Svay Rieng, and Takeo; Great lake region includes Banteay Meanchey, Battambang, Kampong Chhnang, Kampong Thom, Pursat, and Siemreap; Coastal region has Kampot, Kep, Koh Kong, Preah Sihanouk; and Mountain/Plateau region consists of Kampong Speu, Kratie, Preah Vihear, Ratanak Kiri, Mondul Kiri, Stung Treng, Oddar Meanchey, and Pailin. Improved water sources include direct water, piped wells, and covered dug wells. Improved sanitation facilities include toilet or latrine connected with sewage or septic tanks.

For the outcome of under-five mortality, the logistic regression (**Figure 7**) indicates that being born fourth or later led to significantly increased odds of mortality (3.25 [95% CI 1.09-9.66]). A similar tendency was noted for being born third, a twin, living in a rural household and in a geographical region outside of Phnom Penh. On the other hand, if the mother used some form of contraception, there was significantly lower odds of mortality (0.51 [95% CI 0.32-0.80]). Although not statistically significant, being born a female and having a mother with any type of education also indicated lower odds of mortality. The permuted variable importance of the random forest (**Figure 8**) shows contraceptive use to be of the highest importance to the model, followed by birth order, previous birth interval, household wealth quintile, highest educational level of the mother, sex of the child, births in the last five years, geographical region, mother´s age at birth and type of cooking fuel while the remainder was deemed not important for the model.

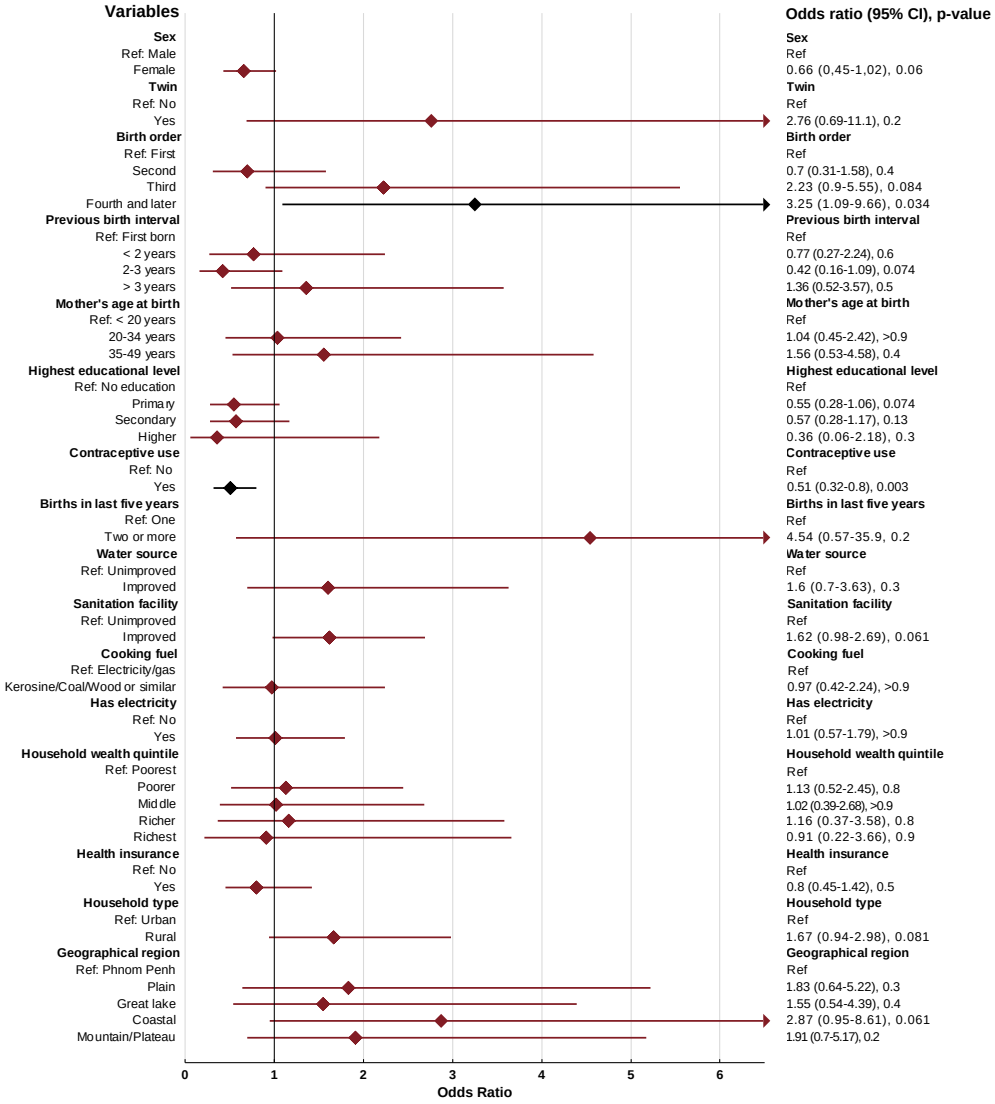


Figure 7. Multivariable logistic regression for the primary outcome of under-five mortality.

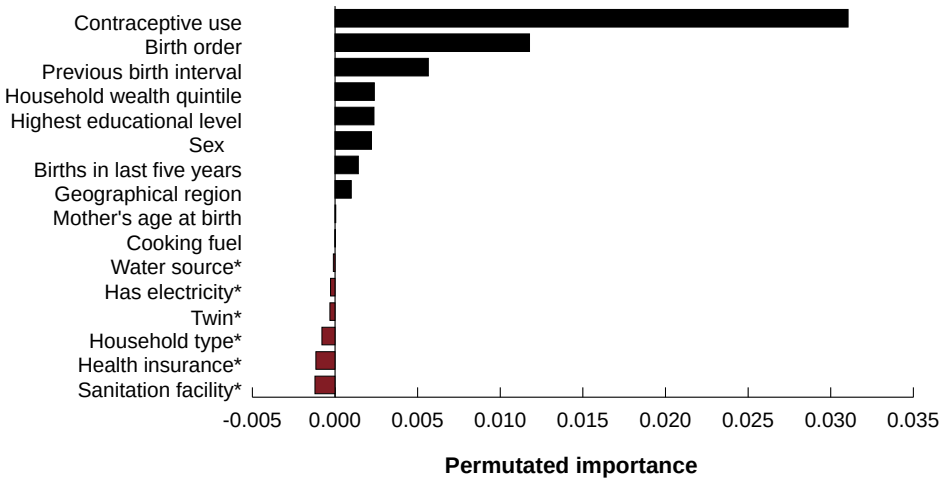


Figure 8. Permutation importance for variables in model for the primary outcome of under-five mortality in Cambodia, ranked from most important to unimportant. *A value below zero indicates that the variable is not important for the model.

When it comes to the outcome of infectious disease, the multivariable logistic regression results (**Figure 9**) indicate that there might be a significantly reduced in odds for children living in households with improved water source (0.69 [95% CI 0.52-0.91]), being in the middle (0.57 [95% CI 0.38-0.87]), richer (0.59 [95% CI 0.37-0.94]) or richest (0.42 [95% CI 0.20-0.89]) wealth quintiles. None of the child-specific variables had a statistically significant association with the infectious disease outcome. There were significantly increased odds if the child lived in the Coastal (2.30 [95% CI 1.05-5.01]) or Great Lake (2.77 [95% CI 1.27-6.03]) geographical regions. For the random forest (**Figure 10**), the most important variables were deemed to be household wealth quintile, water source, geographical region and highest educational level of the mother with the remaining being important for the model except for the number of births in the last five years, if the child was a twin or not and the mother's age at birth.

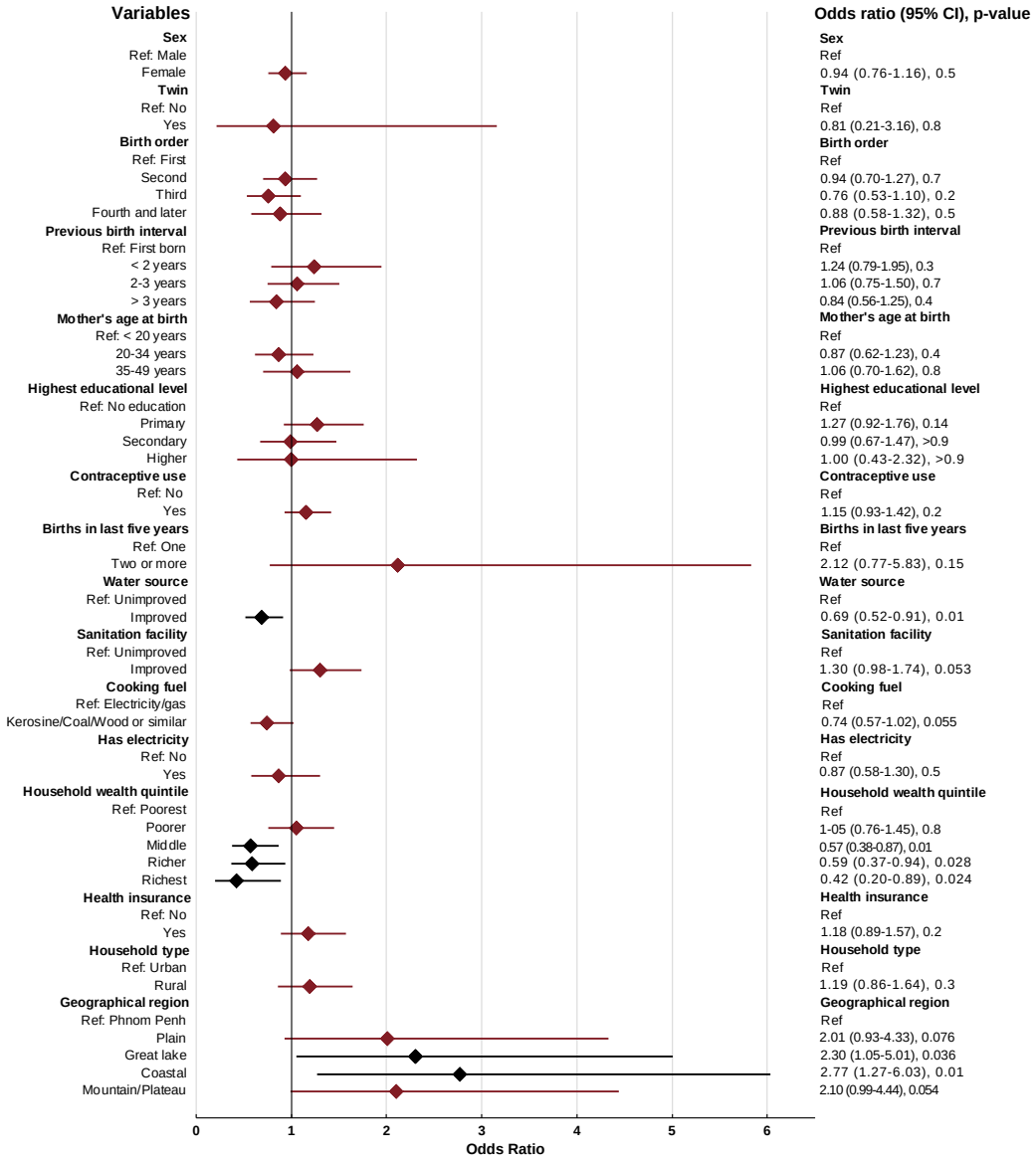


Figure 9. Multivariable logistic regression for the outcome of fever, acute lower respiratory disease or diarrhea any time in the two weeks preceding the survey.

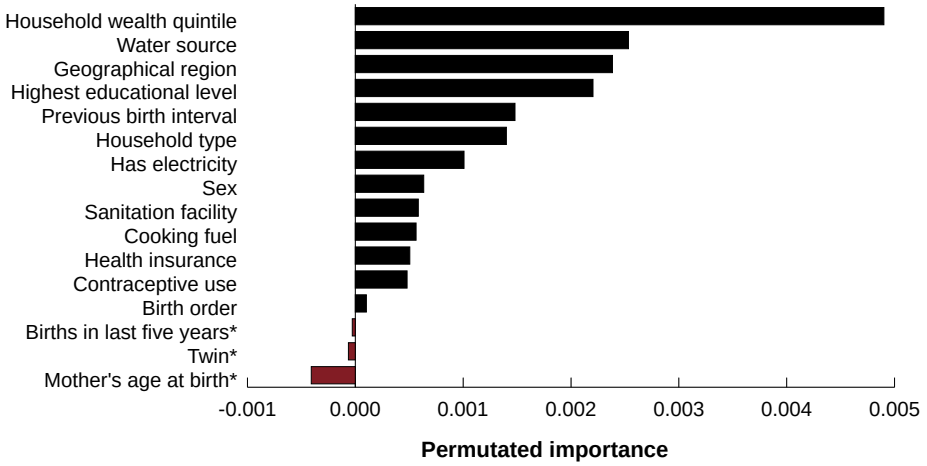


Figure 10. Permutation importance for variables in model for the outcome of fever, acute lower respiratory disease or diarrhea any time in the two weeks preceding the survey, ranked from most important to unimportant. *A value below zero indicates that the variable is not important for the model

4.4 Determinants of under-five mortality and morbidity from infectious diseases in low-and middle-income countries

In total, 681 714 children under five years were included in the complete dataset (**Table 6**), of which 31 092 (4.6%) died before their fifth birthday. Of the total 681 714 children, 17 194 (2.5%) were twins, and 107 585 (16%) of whose mothers had a previous birth interval of <2 years, 61 716 (14%) of children had low birth weight and 52 158 (13%) were stunted. Most mothers of the children had a primary or secondary education and lived in rural households with improved water sources, sanitation facilities, and electricity. Almost all mothers of the children had at least one antenatal visit, while 486 328 (75%) of the children were delivered at a facility, most often (75%) with a health professional assisting. Little less than half (41%) had any postnatal visit, and 66% had full diphtheria, pertussis, and tetanus vaccination.

Table 6. Descriptive overview of study individuals based on demographic health surveys in 44 low- and middle-income countries.

Characteristic	Missing	Overall N= 681 714	Male N=349 830	Female N=331 884	p-value
Child/Mother					
Twin* (Yes/No)	<1%	2.5% (17 194 / 681 597)	2.5% (8 650 / 349 781)	2.6% (8 544 / 331 816)	0.007
Birth order*	<1%				<0.001
- First		29% (200 510 / 681 714)	30% (103 471 / 349 830)	29% (97 039 / 331 884)	
- Second		25% (173 469 / 681 714)	25% (89 127 / 349 830)	25% (84 342 / 331 884)	
- Third		16% (111 000 / 681 714)	16% (57 452 / 349 830)	16% (53 548 / 331 884)	
- Fourth and later		29% (196 735 / 681 714)	29% (99 780 / 349 830)	29% (96 955 / 331 884)	
Birth interval*	<1%				<0.001
- First born		29% (200 510 / 679 806)	30% (103 471 / 348 927)	29% (97 039 / 330 879)	
- <2 years		16% (107 585 / 679 806)	16% (55 598 / 348 927)	16% (51 987 / 330 879)	
- 2 years		21% (145 290 / 679 806)	21% (74 295 / 348 927)	21% (70 995 / 330 879)	
- 3 years		13% (89 656 / 679 806)	13% (45 705 / 348 927)	13% (43 951 / 330 879)	
- >3 years		20% (136 765 / 679 806)	20% (69 858 / 348 927)	20% (66 907 / 330 879)	
Birth weight under 2500g (Yes/No)	35%	14% (61 716 / 441 799)	13% (29 348 / 227 797)	15% (32 368 / 214 002)	<0.001
Stunted weight for height (Yes/No)	40%	13% (52 158 / 412 263)	13% (28 261 / 210 629)	12% (23 897 / 201 634)	<0.001
Mother's age at birth*	<1%				<0.001
- < 20 years		14% (92 387 / 681 714)	14% (47 348 / 349 830)	14% (45 039 / 331 884)	
- 20-34 years		75% (514 481 / 681 714)	76% (264 730 / 349 830)	75% (249 751 / 331 884)	
- 35-49 years		11% (74 846 / 681 714)	11% (37 752 / 349 830)	11% (37 094 / 331 884)	
Mother highest educational level*	<1%				<0.001
- No education		30% (207 608 / 681 712)	30% (106 122 / 349 829)	31% (101 486 / 331 883)	
- Primary		23% (159 501 / 681 712)	23% (81 233 / 349 829)	24% (78 268 / 331 883)	
- Secondary		36% (248 817 / 681 712)	37% (128 241 / 349 829)	36% (120 576 / 331 883)	
- Higher		9.7% (65 786 / 681 712)	9.8% (34 233 / 349 829)	9.5% (31 553 / 331 883)	
Contraceptive use* (Yes/No)	<1%	44% (301 621 / 681 714)	45% (159 096 / 349 830)	43% (142 525 / 331 884)	<0.001
Births in last five years	41%				<0.001
- One		84% (336 460 / 400 468)	85% (175 998 / 207 574)	83% (160 462 / 192 894)	
- Two or more		16% (64 008 / 400 468)	15% (31 576 / 207 574)	17% (32 432 / 192 894)	
Household					
Water source*	3%				0.002
- Unimproved		19% (123 044 / 658 223)	19% (62 636 / 337 745)	19% (60 408 / 320 478)	
- Improved		81% (535 179 / 658 223)	81% (275 109 / 337 745)	81% (260 070 / 320 478)	

Sanitation facility*	1%				0.2
- Unimproved		37% (249 069 / 672 551)	37% (127 546 / 345 161)	37% (121 523 / 327 390)	
- Improved		63% (423 482 / 672 551)	63% (217 615 / 345 161)	63% (205 867 / 327 390)	
Cooking fuel*	4%				0.001
- Electricity/gas		70% (458 075 / 656 962)	70% (234 391 / 337 030)	70% (223 684 / 319 932)	
- Kerosine/Coal/Wood or similar		30% (198 887 / 656 962)	30% (102 639 / 337 030)	30% (96 248 / 319 932)	
Electricity* (Yes/No)	2%	66% (437 703 / 665 459)	66% (225 862 / 341 544)	65% (211 841 / 323 915)	<0.001
Household wealth quintile*	<1%				0.041
- Poorest		26% (179 478 / 681 714)	26% (91 697 / 349 830)	26% (87 781 / 331 884)	
- Poorer		22% (153 265 / 681 714)	22% (78 612 / 349 830)	22% (74 653 / 331 884)	
- Middle		20% (134 754 / 681 714)	20% (69 236 / 349 830)	20% (65 518 / 331 884)	
- Richer		17% (118 143 / 681 714)	17% (60 603 / 349 830)	17% (57 540 / 331 884)	
- Richest		14% (96 074 / 681 714)	14% (49 682 / 349 830)	14% (46 392 / 331 884)	
Household type*	<1%				0.8
- Urban		30% (202 817 / 681 714)	30% (104 018 / 349 830)	30% (98 799 / 331 884)	
- Rural		70% (478 897 / 681 714)	70% (245 812 / 349 830)	70% (233 085 / 331 884)	
Health service					
Antenatal visits	30%				0.14
- 0		9.5% (45 661 / 478 337)	9.5% (23 608 / 249 239)	9.6% (22 053 / 229 098)	
- 1-4		47% (224 482 / 478 337)	47% (117 189 / 249 239)	47% (107 293 / 229 098)	
- 5+		44% (208 194 / 478 337)	44% (108 442 / 249 239)	44% (99 752 / 229 098)	
Place of delivery*	5%				<0.001
- Facility		75% (486 328 / 645 148)	76% (251 154 / 331 122)	75% (235 174 / 314 026)	
- Home		25% (158 820 / 645 148)	24% (79 968 / 331 122)	25% (78 852 / 314 026)	
Assisting person during delivery*	6%				<0.001
- Health professional		75% (480 737 / 643 149)	75% (248 085 / 330 185)	74% (232 652 / 312 964)	
- Non-health profession		25% (162 412 / 643 149)	25% (82 100 / 330 185)	26% (80 312 / 312 964)	
Any postnatal visit (Yes/No)	30%	41% (195 914 / 475 652)	41% (102 738 / 247 857)	41% (93 176 / 227 795)	<0.001
DTP full vaccination (Yes/No)	42%	66% (258 925 / 392 075)	66% (132 808 / 200 608)	66% (126 117 / 191 467)	0.022
Polio full vaccination (Yes/No)	42%	62% (246 522 / 395 109)	63% (126 511 / 202 198)	62% (120 011 / 192 911)	0.020

Footnotes: All variables are weighted according to household survey weight, while taking into consideration the sampling cluster and strata. * These variables had data from all under-five children and below 30% missing data and were included in the multivariable model. Improved water sources include direct water, piped wells, and covered dug wells. Improved sanitation facilities include toilet or latrine connected with sewage or septic tanks. DTP = diphtheria, pertussis and tetanus.

A number of determinants were deemed significantly associated with the primary outcome of under-five mortality (**Table 7**). Specifically, female sex (0.83 [95% CI 0.79-0.88]), second (0.73 [95% CI 0.67-0.79]) or third (0.73 [95% CI 0.67-0.80]) and fourth and later (0.83 [95% CI 0.76-0.91]) birth order, mothers age 20-34 years (0.79 [95% CI 0.74-0.85]), primary (0.91 [95% CI 0.85-0.96]) or secondary (0.80 [95% CI 0.75-0.85]) or higher (0.61 [95% CI 0.53-0.70]) education level, contraceptive use (0.50 [95% CI 0.47-0.53]), using electricity/gas as cooking fuel (0.74 [95% CI 0.67-0.80]), access to electricity in household (0.94 [95% CI 0.88-0.99]), being in the richest household wealth quintile (0.80 [95% CI 0.72-0.90]), and the child being delivered at facility (0.85 [95% CI 0.77-0.93]) were associated with lower odds. Contrastingly, being a twin (6.06 [95% CI 5.49-6.68]), having a birth interval <2 years (3.04 [95% CI 2.82-3.28]) or 2 years (1.63 [95% CI 1.51-1.75]) were associated with higher odds.

Table 7. Estimated odds ratios and 95% confidence intervals for predictors of under-five mortality (337 878 children) and infectious diseases (290 789 children) using a survey-weighted multivariable logistic regression based on demographic health surveys in 44 low- and middle-income countries.

Variable	Under-five mortality		Infectious disease (acute respiratory infection, diarrhea or fever)	
	Odds Ratio (95% Confidence Interval)	p-value	Odds Ratio (95% Confidence Interval)	p-value
Sex				
- Ref: Male				
- Female	0.83 (0.79-0.88)	<0.001	0.94 (0.91-0.96)	<0.001
Twin				
- Ref: No				
- Yes	6.06 (5.49-6.68)	<0.001	0.95 (0.85-1.07)	0.4
Birth order				
- Ref: First				
- Second	0.73 (0.67-0.79)	<0.001	0.85 (0.82-0.89)	<0.001
- Third	0.73 (0.67-0.80)	<0.001	0.99 (0.94-1.04)	0.6
- Fourth and later	0.83 (0.76-0.91)	<0.001	1.10 (1.04-1.15)	<0.001
Birth interval				
- Ref: First born				
- <2 years	3.04 (2.82-3.28)	<0.001	0.83 (0.79-0.87)	<0.001
- 2-3 years	1.63 (1.51-1.75)	<0.001	0.77 (0.74-0.81)	<0.001
- >3 years	1.00 (0.91-1.08)	>0.9	0.94 (0.90-0.99)	0.018
Mother's age at birth				
- Ref: Mother's age at birth < 20				

- Mother's age at birth 20-34	0.79 (0.74-0.85)	<0.001	0.85 (0.81-0.88)	<0.001
- Mother's age at birth 35-49	0.91-1.10	>0.9	0.72 (0.68-0.77)	<0.001
Highest educational level				
- Ref: No education				
- Primary	0.91 (0.85-0.96)	0.002	1.04 (1.00-1.08)	0.045
- Secondary	0.80 (0.75-0.85)	<0.001	0.85 (0.82-0.89)	<0.001
- Higher	0.61 (0.53-0.70)	<0.001	0.58 (0.54-0.62)	<0.001
Contraceptive use				
- Ref: No				
- Yes	0.50 (0.47-0.53)	<0.001	1.01 (0.98-1.04)	0.5
Water source				
- Ref: Unimproved				
- Improved	1.04 (0.98-1.10	0.2	1.03 (0.98-1.07)	0.2
Sanitation facility				
- Ref: Unimproved				
- Improved	1.00 (0.94-1.06)	>0.9	0.89 (0.86-0.93)	<0.001
Cooking fuel				
- Ref: Kerosine/Coal/Wood or similar				
- Electricity/gas	0.74 (0.67-0.80)	<0.001	0.80 (0.76-0.83)	<0.001
Has electricity				
- Ref: No				
- Yes	0.94 (0.88-0.99)	0.038	0.74 (0.71-0.77)	<0.001
Household wealth quintile				
- Ref: Poorest				
- Poorer	1.03 (0.96-1.10)	0.4	0.99 (0.94-1.04)	0.7
- Middle	0.96 (0.89-1.03)	0.2	0.99 (0.93-1.06)	0.8
- Richer	0.99 (0.90-1.08)	0.8	1.05 (0.99-1.14)	0.1
- Richest	0.80 (0.72-0.90)	<0.001	1.06 (1.98-1.15)	0.2
Household type				
- Ref: Urban				
- Rural	0.99 (0.92-1.07)	0.8	1.04 (1.01-1.09)	<0.001
Place of delivery				
- Ref: Home				
- Facility	0.85 (0.77-0.93)	<0.001	0.98 (0.95-1.08)	0.55

Assisting person during delivery				
- Ref: Health professional				
- Non-health professional	1.03 (0.94-1.13)	0.5	1.18 (1.12-1.24)	<0.001

Footnotes: The under-five mortality model included 357 934 children with complete data out of which 15 031 (4.2%) had the primary outcome of death. The infectious disease model included 307 582 children with complete data, out of which 55 618 (18%) had the secondary outcome of infectious disease.

For the conditional random forest (**Figure 11**), contraceptive use, birth interval and twin had the highest permutated importance measure, while birth order, assisting person during delivery, cooking fuel, household wealth quintile, mother´s age at birth, place of birth, presence of electricity, water source and highest educational level of the mother were to a lesser degree also deemed important for under-five mortality. The type of sanitation facility in the household, rural or urban household, and the sex of the child were deemed to be unimportant variables.

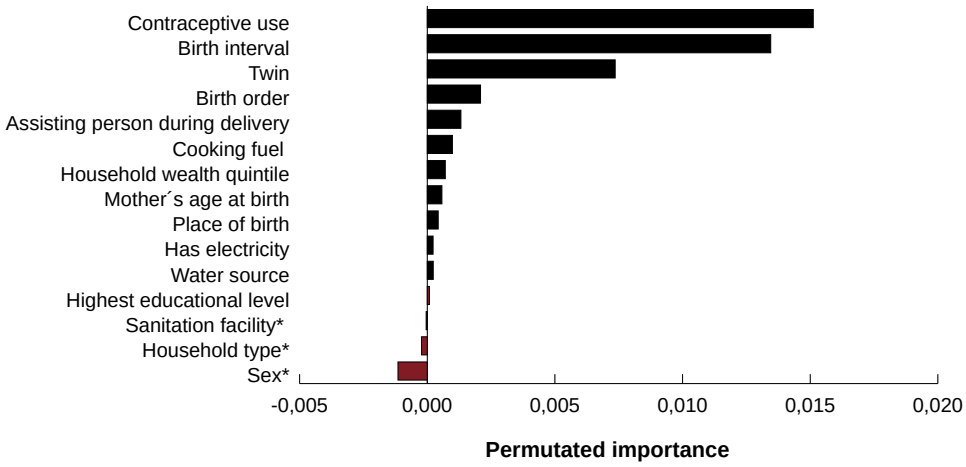


Figure 11. Permutation importance for variables in model for the primary outcome of under-five mortality among 357 934 children in low- and middle-income countries, ranked from most important to unimportant. *A value below zero indicates that the variable is not important for the model.

When it comes to the secondary outcome of infectious diseases (**Table 7**), female sex (0.94 [95% CI 0.91-0.96]), second birth order (0.85 [95% CI 0.82-0.89]), birth interval <2 years (0.83 [95% CI 0.79-0.87]) or 2-3 years (0.77 [95% CI 0.74-0.81]) or >3 years (0.94 [95% CI 0.90-0.99], mothers age 20-34 (0.85 [95% CI 0.81-0.88]) or 35-49 years (0.72 [95% CI 0.68-0.77]), secondary (0.85 [95% CI 0.82-0.89]) or higher (0.58 [95% CI 0.54-0.62]) educational level of the mother, improved sanitation facility (0.89 [95% CI 0.86-0.93]), using electricity/gas as cooking fuel (0.80 [95% CI 0.76-0.83]) and having access to electricity (0.74 [95% CI 0.71-0.77]) in household were associated with lower odds. On the other hand, birth order fourth and later (1.10 [95% CI 1.04-1.15]), primary education of mother (1.04 [95% CI 1.00-1.08]), rural household (1.04 [95% CI 1.01-1.09]) and being assisted by non-health professional during delivery (1.18 [95% CI 1.12-1.24]) were associated with higher odds.

Similarly, for the conditional random forest electricity and type of cooking fuel in the household had the highest permutated importance measures for the outcome of infectious diseases (**Figure 12**), while the highest educational level of the mother, birth order of the child, sanitation facility of household, birth interval, contraceptive use, if the child was a twin or not, mother´s age and assisting person during delivery as well as the place of birth were also considered important. If the household were rural or urban, the type of water source, wealth quintile, and sex of the child were not deemed to be important by the conditional random forest.

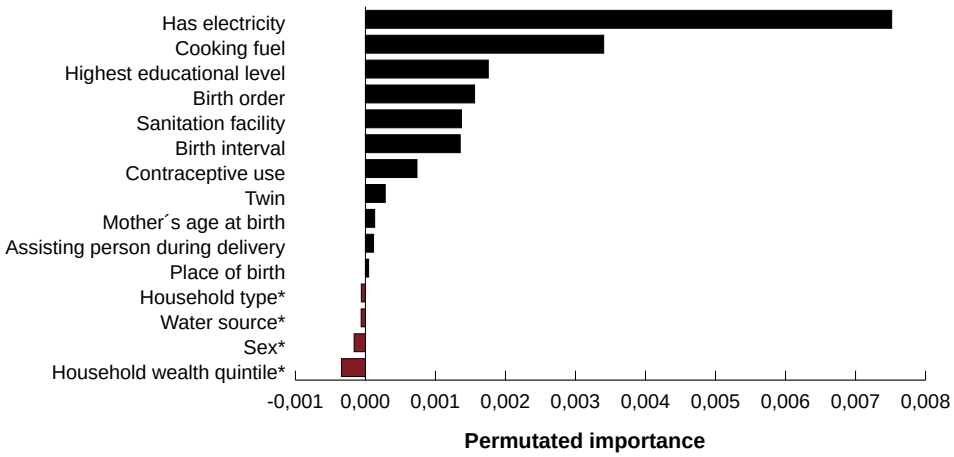


Figure 12. Permutation importance for variables in model for the secondary outcome of fever, acute lower respiratory disease or diarrhea any time in the two weeks preceding the survey among 307 582 children in low- and middle-income countries, ranked from most important to unimportant. *A value below zero indicates that the variable is not important for the model.

5 Discussion

In this thesis there are four major findings: **1**) The interactions between child health and the SDGs in Cambodia are mostly synergetic with the exception of SDG 15 (Life on land), **2**) Adoption of the SDGs led to an increased sense of ambition and possibility for multisectoral collaboration while there was a discrepancy between the envisioned best way of conducting such collaborations with how they actually were conducted, **3**) Maternal and household characteristics such as mothers use of contraceptives, improved household water source and household wealth quintile were important determinants of under-five mortality and morbidity from infectious disease in Cambodia, and **4**) Fundamental child, maternal and household characteristics are still key determinants for under-five mortality and infectious disease morbidity in LMICs in the SDG era.

5.1 Child health and the SDGs in Cambodia

5.1.1 Adoption of the SDGs in Cambodia – a success story for child health?

With a strong track record of achieving the MDGs, the Royal Government of Cambodia was relatively fast in contextualizing the broad 2030 Agenda into a country-specific framework in the form of the CSDGs in 2019. The CSDGs are fully incorporated into the national development plans and two voluntary reports have been published, all emphasizing a multisectoral approach to sustainable development.[108–110] We found an overwhelming majority of promoting interactions between the CSDGs in **Study I**, indicating the reinforcing nature of various goals toward sustainable development in Cambodia. In **Study II**, we established that the adoption of the CSDGs led to a larger focus on broader determinants of child health and promoted multisectoral collaboration. Beyond being a set of goals and targets, the SDGs and the 2030 Agenda promote norms around universality, higher ambitions for sustainable development and interconnectedness between different sectors.[111,112] Hence, the adoption of the CSDGs might assist in aligning country stakeholder norms around the higher ambition for child health and the interlinked nature of the determinants of child health and sustainable development in general. While the CSDGs are in line with the global strategy for children not only to survive but to thrive, the focus on children is not as prominent as during the MDG era, and there is a risk that child health inequalities are exacerbated if no special consideration is taken for vulnerable children living in rural low-income settings or in marginalized communities in Cambodia.

5.1.2 Focusing on synergies and handling trade-offs: child health and SDG 16 and SDG 15

Improved child health seemed to promote progress for all CSDGs except for CSDG 15 (Life on land) when considering the second-order interactions, while all CSDGs positively promoted child health (**Study I**). The close relationships between various determinants and child health, as represented by the CSDGs, have been emphasized before. However, we build on this and importantly illustrate a positive feedback-loop whereby making progress on child health leads to progress on other CSDGs that in turn promotes child health. This reinforcing relationship is essential to accelerate positive developments in child health, and it further emphasizes how improvements in child health are dependent on the state of other sectors or determinants.

When deciphering the interactions between the CSDGs and child health, it became clear that CSDG 16 (Peace, justice and strong institutions) has the most promoting potential, both when it comes to first and second-order interactions (**Study I**). The impacts of a well-functioning legislative and governance structure on child health are known as it is foundational for making progress on other CSDGs that also positively impact child health in Cambodia. Perhaps the most illustrative example of how targeted institutional programs can influence child health is the poverty identification system ID-Poor, which is a community-based program that identifies vulnerable households and provides social and health services.[66] The prominence of the participants in **Study I** and **Study II** to focus on CSDG 16 (Peace, justice and strong institutions) and government ministries' institutional power highlights interesting parallel storylines in the narrative around sustainable development in Cambodia. The positive improvements in many different sectors during political stability since the 2000s, including drastically lowering the poverty rate and having reduced under-five mortality substantially over a relatively short, is undeniably an impressive achievement. Yet, there are growing concerns regarding the increasing centralization of government power, limited freedom of speech and transparency under the banner of stability and development, which have important implications for healthcare services and other determinants of child health.[59,60,113] Over the last years there has been a shrinking space for civil society and as seen in **Study II** there are often conflicting views between civil society and government ministries on a range of issues.[114] The importance of CSDG 16 (Peace, justice and strong institutions) for child health in Cambodia could perhaps both be seen as a testament to the necessity of institutional stability for improving child health and an opportunity lost if not fully achieved as envisioned in the SDGs.

When taking into account the second-order interactions, CSDG 15 (Life on land) seemed to be negatively influenced by improvements in child health (**Study I**). Although the negative influence appears to be minor, the finding put the spotlight on trade-offs that are not evident if one would only consider the first-order interactions.

Examining the interactions leading to this negative influence, it becomes clear that child health was perceived to promote progress on CSDG 1 (No poverty), CSDG 8 (Decent work and economic growth), CSDG 9 (Industry, innovation and infrastructure) as well as CSDG 11 (Sustainable cities and communities). These, in turn, had a restricting impact on CSDG 15 (Life on land), leading to the indirect negative influence of promoting child health. The impressive growth in many economic sectors throughout Cambodia has been coupled with an expansion of different industries, while rural economic growth is often driven by land being transformed from forest into agricultural fields.[115,116] There are also widespread deforestation practices even in protected areas, severely impacting vulnerable ecosystems and biodiversity.[117] Climate change is set to exacerbate these conditions further with increased floods and storms in the country.[118–120] While the direct and indirect negative impacts of improving child health on CSDG 15 (Life on land) are likely minor, the tension between increased economic growth, human capital and environmental related goals is evident and will with climate change become ever more prominent.

5.1.3 Multisectoral collaboration for child health in Cambodia – a valuable option?

Multisectoral collaborations are complex processes, often taking substantial resources and efforts from the included stakeholders. There must be a significant advantage of engaging in the collaboration in order to make it worthwhile,[121] as described in **Study II**, and it is likely that the adoption of the CSDGs assisted in framing and explicitly providing a framework for multisectoral collaboration. The participants in **Study II** expressed a desired linear stepwise approach to conducting multisectoral collaborations for child health. As originally theoretically proposed by Dewy,[122] each step in the process is objectively evaluated until a decision is made and the next step can take place. The desire of funders, be it government or international funders, often put a strong emphasis on clear project management and monitoring of deliverables which might further strengthen the desire of collaborators to have this kind of rational stepwise approach to the collaboration.[123] The process or project-oriented view on the multisectoral collaboration was favored by the participants, yet according to their description of the multisectoral collaborations they were not carried out in this way or had to adapt to unforeseen circumstances. Shyama et al.[89] proposed a more dynamic model of multisectoral collaboration, whereby the collaboration is equally driven by relationships and power dynamics between the stakeholders as the desire to fulfill implementation plans or reach a set of objectives. As evident from the descriptions by the participants in **Study II**, this model seems to be more representative of the realities of conducting multisectoral collaborations for child health in Cambodia.

Importantly, participants detailed a set of success factors and obstacles in relation to the multisectoral collaboration. The primary success factor, or obstacle in its absence, was funding. Providing incentives for multisectoral collaborations and sustaining funding through different organizations can be a cumbersome process, and many funders might be hesitant to provide such funding due to the perceived lack of monitoring and accountability.[124] Crucially, having control of the funding was one of the major sources of power in the collaboration, together with being part of the government or having a close connection to a government ministry. Distorted power dynamics, territory feelings, and lack of leadership were often cited as obstacles to successful multisectoral collaborations. This has been extensively studied in other forms of collaborations, with mutual relationship building, shared ownership and accountability of the collaboration being key counterweights.[125,126] Cambodia has made multisectoral collaboration a cornerstone of its child health plans, providing sustainable financing schemes, an enabling environment for multisectoral collaboration that is built on networks, shared ownership and accountability holds promise to leveraging synergies and handling trade-offs found in **Study I** to accelerate child health improvements in the country.

5.1.4 The importance of maternal and household determinants for child mortality and morbidity from infectious diseases

From the quantitative analysis of the latest DHS in Cambodia (**Study III**), it is evident under-five mortality was associated with two key maternal determinants: contraceptive use of the mother and the birth order of the child. There is an established relationship between contraceptive use and lower under-five mortality, and in the study of the 2014 CDHS Um and Heng also found contraceptive use to be associated with under-five mortality.[72] In Cambodia, contraceptive use is closely linked to increased status of the mother in the household,[127] similarly higher education of the mother greatly increases the probability of a woman using contraceptives.[128] There are still cultural and practical barriers to accessing modern contraceptive options for women in Cambodia.[129] Empowering women to make their own reproductive choices leads to fewer unwanted pregnancies and has been shown to reduce infant mortality rates.[130] Given the lack of data on health service seeking patterns in our model, contraceptive use might also be indicative of health literacy and health seeking behavior[128] among mothers which could serve as a protective factor against under-five mortality. The importance of birth order, specifically being born fourth or later leading to an increased odds of under-five mortality has not been previously shown in Cambodia.[71,72] The finding might reflect a growing child health inequality whereby poor households have more children that are at higher risk of under-five mortality, but this warrants further investigation. In other settings, there is an established relationship between having a high birth order and under-five mortality[98,131] while also being a key risk factor for undernutrition.[132,133]

For morbidity burden from infectious diseases (**Study III**), we found three household-related determinants: having an improved water source or being in the middle, richer, or richest wealth quintile seemed to protect children, while households in the Great lake and Coastal regions had a higher risk of infectious disease. Having access to clean water is a fundamental determinant of infectious diseases in children, particularly food and water-borne diseases, and the relationship has been established in many similar settings.[134] In the analysis by Vong et al.[76] of the 2014 CDHS also demonstrated a higher risk of diarrhea among children living in households with unimproved water sources. There was a marked reduced risk of infectious disease if the child lived in a household that was in the middle, rich or richest wealth quintile. There is ample evidence of the growing inequality in child health in Cambodia, with infectious diseases primarily affecting children living in poor and vulnerable households.[73,135–137] We also found that children living in the Great lake (Banteay Meanchey, Battambang, Kampong Chhnang, Kampong Thom, Pursat and Siemreap) or Coastal (Kampot, Kep, Koh Kong and Preah Sihanouk) regions had an increased risk of infectious disease, not previously detailed. Living in other regions outside of Phnom Penh also had a tendency to be associated with increased risk, albeit not statistically significant. It might be that these regions (Great lake and Coastal) are home to large water bodies that lead to a higher risk of exposure to infectious diseases,[138] and that they are more prone to climate change related flooding and cyclones that can further intensify transmission.[139]

5.1.5 Child health in Cambodia: a story of two tales?

While Cambodia has made impressive advancements in the MDG era and seems to be continuing the reduction in under-five mortality, the findings from this thesis illustrate the double nature of child health in the country. On one hand, there is a need to focus on the unfinished goal of reducing preventable child mortality and protecting children living in poorer households in vulnerable geographies from infectious diseases (**Study III**). This could be achieved through leveraging synergies between the CSDGs (**Study I**) and multisectoral collaborations, if done right, could spearhead such efforts (**Study II**). The ID-Poor program, encompassing both the focus on vulnerable households and being a connection point for multisectoral collaboration is one such example.[66] On the other hand, the CSDGs have an ambition for children to not only survive but to thrive and transform their communities. An increased focus on limiting the burden of communicable and non-communicable morbidity, education and gender equality will be necessary to fully achieve the CSDGs. Here, the synergies and trade-offs identified (**Study I**) and the perceptions and understanding of the CSDGs and the potential of multisectoral collaboration are key (**Study II**). Although significant advances have been made, much remains to be accomplished.

5.2 A global perspective of the determinants of under-five mortality and infectious disease morbidity

Providing a global perspective, **Study IV** showcases a more complex pattern when it comes to the determinants of under-five mortality and morbidity from infectious diseases in LMICs.

5.2.1 Under-five mortality

Child-specific determinants found to be associated with under-five mortality included the sex of the child, if it was a twin, birth order and interval. Using similar datasets from LMICs, male sex has been found to be associated with increased risk of under-five mortality, and there is a clear gender division across the determinants of under-five mortality.[140] It is well-known that twins both in high[141] and low-income settings[142] have more dire health outcomes due to the higher likelihood of complications during pregnancy, delivery and perinatal period. They are also often underweight and preterm,[143] which in turn are risk factors for neonatal and under-five mortality. We found that not being first born reduced the odds of under-five mortality, while shorter birth interval was associated with an increase in odds of under-five mortality. This is similar to other studies based on data from a more narrow set of countries that have showcased an increased risk of under-five mortality with having a short birth interval[98,131] possibly through an increased risk of undernutrition being associated with short birth intervals.[132,133]

Maternal-related determinants found to reduce the odds of under-five mortality were higher age, educational attainment and contraceptive use (similar to **Study III**) as well as the health facility delivery. Higher age and educational attainment are known protective factors of children in all settings, while contraceptive use and having the delivery in a health facility might reflect overall healthcare utilization and socioeconomic status.[144] However, the link between health facility delivery and reduced mortality rates is complex and the quality of the care in the facility has been shown to have the strongest influence on whether or not health facility delivery can improve outcomes.[145]

Household characteristics such as access to electricity, using electricity or gas as cooking fuel and being in the higher wealth quintiles were also associated with lower odds of under-five mortality. Interestingly, taking these variables into consideration, the place of the household (rural or urban), water source, or sanitation facility were not independently associated with under-five mortality. There is a well-known rural-urban divide in child mortality, however this divide has become narrower over time in many LMICs.[146,147] It might be that other socioeconomic determinants, such as household wealth, have become a relatively more important determinant of child mortality independent of whether a household is in a rural or urban setting.

5.2.2 Infectious disease morbidity

Child-specific determinants that were associated with infectious disease morbidity included sex of the child, birth order and birth interval. While being second in birth order and not being first-born was associated with reduced odds, being born fourth or later was associated with slightly increased odds of infectious disease. This might reflect an increased risk of infectious diseases with larger household size, which has previously been shown to be a risk factor for untreated infectious diseases.[148]

Maternal determinants such as higher age and level of education were associated with reduced odds. Interestingly, non-health professionals assisting at delivery were also associated with increased odds, which might reflect the possibility of access and desire to seek out health care when needed. In general, seeking health care for infectious diseases for their children is more prevalent in mothers who are older and have higher levels of education[149] similar to effectively implementing preventive health measures to limit the spread of infectious disease.[150]

Household determinants, including having access to improved sanitation facilities, electricity, and using gas or electricity as cooking fuel, were also associated with lower odds. There is a well-known relationship between household air pollution from charcoal or wood and the risk of acute respiratory infections[151] while improved sanitation facility (toilet or latrine connected with sewage or septic tanks) lowers the likelihood of children in the household suffering from diarrheal diseases.[134] Rural households led to increased odds of infectious disease, which has been found in other studies.[152] The relation between the state of the household and risk of infectious disease among children is complex, and often varies depending on the country or sub-country region of measurement.[153,154]

5.3 Methodological considerations

5.3.1 SDG Synergies approach

The SDG Synergies approach provides a methodological middle road between qualitative and quantitative research, explicitly incorporating subjectivity and biases of how stakeholders perceive and understand interactions into a concrete framework. As such, the approach allows for a more realistic and context-specific framing of interactions compared with purely quantitative methods.[155,156] The SDG Synergies approach applied in Cambodia and focused on child health (**Study I**) takes several methodological decisions that impact the interpretation of the findings. First, having the analysis at the country and goal level allows for larger generalizability. However, the broad description of the CSDGs can be interpreted in different ways, and most likely, the results would be different if the analysis had been made for a specific region. Secondly, a different mix of stakeholders scoring the interactions could have impacted the results. Our implementation of a double-scoring validation system for each interaction was an attempt to provide relatively unbiased scores. Thirdly, on a more technical note, there is a possibility to go beyond the second-order interactions to summarize the impact of how one interaction ripples through the network by use of supermatrices, which could provide a fuller picture of the effects of child health on the CSDGs and vice versa.[157] Moreover, the approach has been expanded to incorporate health overall in low-income and fragile settings including the Democratic Republic of Congo,[158] Somalia[159] and Uganda. In general, the SDG Synergies approach requires substantial contextualization. By accompanying the findings with available child health indicators, a fuller picture of the interactions between child health and the CSDGs can be formed.

5.3.2 Qualitative research reflections

The qualitative research was guided by information power[87] and the feasibility of conducting the study during the COVID-19 pandemic. A sample size of 30 participants (out of which we reached 29) was deemed sufficient given the broad research questions, specific knowledge of the topic, high-quality dialogue, and established use of frameworks and theories. Our sample, purposefully recruited, however, was unbalanced in terms of gender and experience of different SDGs (**Supplementary Material Table S1**). Additionally, there is a risk of positive recall bias, which in this study seems negligible given the participant's frank and critical responses when discussing multisectoral collaborations. A difficulty in assessing the multisectoral collaborations came from the complexity of the multisectoral collaborations being both at the national and sub-national level, having a more focused interview on either the national or sub-national level could have been beneficial. Mindful of existing tensions between government and non-government stakeholders, the interviews were conducted by country team members representing neutral academic institutions with in-depth knowledge of the evolving landscape and qualitative methods, leading participants to express their opinions and views freely.

Being explicit about how I and the research team may influence the study and its findings,[160] it is important to note that given the limitations of travel due to the COVID-19 pandemic my understanding of the Cambodian society and the findings is at a superficial level. Country team members were heavily engaged and provided crucial insights and input to every step of the research process.

5.3.3 Demographic health survey data and machine learning

While the DHS provide a unique data source on maternal and child health, there are some important methodological considerations. Across the surveys, the participating women might have recall, omission or desirability bias when answering the questions.[161] Additionally, in many DHS (including the CDHS used in **Study III**) variables concerning the prenatal, delivery and postnatal period are only collected for children below three years limiting the possibility of including these variables in models to understand the determinants of under-five mortality or infectious disease. It is also important to note that the secondary outcome of infectious disease in **Study III** and **Study IV** is narrowly defined as the child having symptoms of infection (fever, diarrhea or signs of respiratory infection) any time in the two weeks preceding the interview and hence does not detail the severity of disease or underlying infectious pathogen. Although the DHS are standardized across countries, there are differences in some variables that must be accounted for such as if the variable is available for all children under-five years or only a sub-group and a de-normalization process of survey weights when combining the datasets (as in **Study IV**). The surveys were not weighted at a country level as any specific weighting method would be an arbitrary choice, leading to the combined dataset used having a substantial portion of children from larger countries such as India and Nigeria. Further, 75% of the children included in **Study IV** lived in rural households compared to the average of 50% in LMICs,[162] raising questions around the generalizability of the findings.

Regarding the statistical analyses applied in **Study III** and **Study IV**, the random forest machine learning algorithm results should be interpreted as complementing the logistic regression. The two approaches rest on different sets of statistical assumptions and rationales, and comparison of the performance or accuracy of the models along with their statistical underpinnings were not the in the scope of this thesis. For the same reasons and ease of reproducibility, we did not tune the algorithm's hyperparameters but applied it using its standard settings. In a pure machine learning approach where the goal is prediction, tuning hyperparameters after the specific underlying data structure is one of the critical steps to improve performance.[163] Given the aim of understanding the underlying determinants of the defined outcomes, random forest model interpretability through permutation importance was used. However, this variable importance measure can only indicate the relative importance or unimportance of the variable in question for the algorithm, not if the association indicates a reduced or increased odds of the outcome as the odds ratio from the logistic regression provides.

To overcome this difficulty, Lundberg and Lee[164] have proposed a framework for interpreting predictions made by machine learning algorithms through Shapley Additive Explanations Values that have become an important way to compare variable importance across different machine learning algorithms and enhance interpretability of associations using a game-theory approach. There are, however, limited practical applications developed to adapt this approach to complex surveys, and the calculations require substantial computational capacity, making it unfeasible to use in **Study III** and **Study IV**. Overall, machine learning algorithms such as random forest hold promise to provide complementary insights to complex associations, but significant methodological developments are needed for increased usability of these methods.[165]

6 Conclusions

In order to improve child health in Cambodia, there is a need to capitalize on the synergies between the SDGs while carefully handle potential trade-offs. The adoption of the SDGs promoted an aspirational perspective on child health allowing for multisectoral collaborations to be effective if implemented in a grounded context. Nevertheless, fundamental child, maternal and household characteristics still determine vulnerabilities of children and drive worse child health outcomes in Cambodia and globally. A focus on the most vulnerable children and a holistic approach to designing interventions should be considered to accelerate improvements in child health in Cambodia and globally.

7 Points of perspective

7.1 Research implications

This thesis yielded several potential future avenues of research.

- Understanding the interactions between the CSDGs at a sub-country level in Cambodia could provide more contextually relevant findings.
- Extending the SDG Synergies analysis to understand how the interactions ripple through the entire network might provide additional insights.
- Investigating the role of power and hierarchies will be vital to develop the theory underlying multisectoral collaborations for child health.
- Exploring different funding schemes and how they impact the performance of multisectoral collaborations could remove key obstacles to implementation.
- It is necessary to compare the performance and develop the usability of different machine learning algorithms for analyzing global child health data.

7.2 Policy implications

A number of policy implications can be derived from this thesis.

- Understanding the interactions between different goals or targets is vital to identify synergies to leverage and trade-offs to consider in order to accelerate child health improvements in Cambodia and other LMICs.
- Ensuring the realization of CSDG 16 (Peace, justice and strong institutions) likely has the most synergetic potential for child health in Cambodia, while environmental related CSDGs such as CSDG 15 (Life on land) could be negatively impacted by improvements in child health.
- The Cambodian government and civil society's adoption and continued support of the SDGs are important to ensure higher ambition for and multisectoral action on child health.
- Multisectoral collaborations, if allowed sustainable funding and conducted in a grounded, realistic manner, have the potential to exploit synergies, manage trade-offs, and improve child health determinants.
- Improving the conditions of vulnerable households as well as empowering women will be key to accelerating further reductions in child mortality and the burden of infectious diseases in LMICs.
- At a global level, acting on the fundamental child, maternal and household determinants remains essential to reduce child mortality and infectious disease morbidity in the SDG era.
- Beyond the SDGs, this thesis showcases how the next sustainable development agenda must balance the need to focus on the most vulnerable children to reduce preventable child mortality and morbidity while ensuring that children can thrive and transform societies.

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10 Supplementary Material

Table S1. Participant characteristics

Nr	Sex	Years worked	Organization	Work sector experience according to Cambodian Sustainable Development Goals
1	Male	6-14	Governmental	7, 13, 14, 15
2	Female	>15	Governmental	3, 5, 6
3	Female	>15	Governmental	5, 17
4	Male	>15	Governmental	1, 3
5	Male	>15	Governmental	3, 4, 17
6	Female	1-5	Governmental	3, 16
7	Male	>15	Governmental	3, 4
8	Male	>15	Governmental	1, 2, 3, 4, 5, 6, 7, 10, 11, 12, 16, 17
9	Male	>15	Governmental	3, 4, 5, 16
10	Male	>15	Governmental	4, 17, 18
11	Male	>15	Governmental	4, 17, 18
12	Male	6-14	Governmental	1, 2, 3, 6, 16
13	Female	6-14	Governmental	1, 3, 17
14	Male	6-14	Governmental	17, 18
15	Male	6-14	Non-governmental	2, 3, 4, 6, 13
16	Male	>15	Non-governmental	2, 3
17	Male	>15	Non-governmental	5, 10, 16, 17
18	Male	6-14	Non-governmental	2, 3
19	Female	1-5	Non-governmental	1, 3, 4
20	Male	>15	Non-governmental	2, 4, 8

21	Male	>15	Non-governmental	16, 17
22	Female	>15	Non-governmental	2, 3, 4, 6
23	Male	>15	Non-governmental	3, 4, 5, 6
24	Female	>15	Non-governmental	2, 3, 5, 6
25	Male	>15	Non-governmental	1,2,3, 4, 6
26	Male	>15	Non-governmental	2, 3
27	Male	6-14	International	2, 3, 17
28	Female	6-14	International	1, 2, 3, 16, 17
29	Male	>15	International	2, 3, 4, 6, 17