MODELLING THE EFFECTIVENESS OF NUTRITIONAL INTERVENTIONS IN CHILDREN UNDER FIVE YEARS IN MANGOCHI, MALAWI.

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Declaration

I Fridah Karimi Mwingirwa declare that this research report is my own independent and original work. It is being submitted in partial fulfilment of requirements for Masters of Science in Epidemiology in the field of Biostatistics degree of the University of the Witwatersrand, South Africa. This work has not been submitted for any other award or degree in this university or other place of learning.

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Dedication

I dedicate this Master's thesis to my lovely husband Calvin Oyengo for always encouraging me and being there for me even when I seemed to despair.

My parents Mr and Mrs Mwingirwa, who ensured that I had a decent education. Thank you for your support and prayers throughout my study.

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Abstract

Background

Malnutrition rates in children under five years remain considerably high, despite many singular interventions to prevent and control undernutrition that have not been successful. Part of the reason for this is, the design of these interventions does not take into consideration whether a singular intervention in a multifactorial caused problem could be effective and that there is need to simulate beforehand what will work before it is implemented. There have been few studies investigating the effectiveness of these interventions in the reduction of the incidence and prevalence of stunting, wasting and underweight in children. The main aim of this study was to develop a simulated mathematical model that informs the effectiveness of nutritional and education interventions for stunting, wasting and underweight in children under five years of age**.**

Methods

The methodology was two-pronged; Firstly, demographic characteristics and prevalence of stunting, underweight and wasting, including risk factors were obtained from secondary analysis of an intervention study conducted in Mangochi, Malawi whereby, 840 children were randomised to receive; micronutrient-fortified lipid-based nutrient supplements(LNSs) with soy protein base, micronutrient-fortified LNSs with milk protein base and micronutrient-fortified corn–soy blend for 12 months. Demographic characteristics were compared using Fisher's exact test and Pearson's Chi square test and risk factors assessed using univariate and multivariable logistic regression models. This analysis provided baseline factors for the simulation analysis.

Secondly, malnutrition rates, recovery rates and supplementary feeding parameters obtained in the first analysis and health education parameters obtained from the literature were used to simulate a deterministic mathematical model. The interventions considered were

supplementary feeding and health education applied singly and when combined. Supplementary feeding coverage was defined by inclusion and by the participant being in the programme for a minimum duration of 12 weeks; health education coverage was defined by intensity and by the participant being in the programme for a minimum duration of 12 weeks; whereas the combined intervention was defined by both inclusion, intensity and by the participant being in the programme for a minimum duration of 12 weeks. Sensitivity analysis was done by varying the model parameters through simulations and associated outputs assessed.

Results

The prevalence of stunting, wasting, underweight and overweight was approximately 37%, 2%, 14% and 7% respectively. Risk factors changed by the type of malnutrition. Maternal education, maternal Mid Upper Arm Circumference (MUAC), mosquito net ownership and sex of the child were associated with stunting. Type of toilet facility, the number of children under five and maternal MUAC were associated with underweight. Our results showed that; female children and children from households with mosquito nets were less likely to be stunted or underweight.

Health education intervention had a significantly larger reduction in incidence and the prevalence of stunting, wasting and underweight compared to supplementary feeding when applied singly. The highest reduction in malnutrition in children under five years was observed after combining supplementary feeding and health education. Malnutrition decreased with an increase in the coverage of the intervention.

Discussion

Health education has a bigger effect on prevention and control of all forms of malnutrition compared to supplementary feeding as a single intervention. Households with their available resources can have improved nutrition statuses without any supplementary feeding, provided that caregivers are educated on improving feeding behaviours, effective child care practices and proper hygiene.

The addition of supplementary feeding to health education (combined intervention) improves the effect size of a single intervention in the reduction of the prevalence and incidence of malnutrition. Therefore, nutritional education interventions should be implemented in combination with affordable supplementary feeding, particularly in middle and low-income countries that are food insecure.

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LIST OF ACRONYMS AND ABBREVIATIONS

AIDS	:	Acquired Immune Deficiency Syndrome
aOR	:	Adjusted Odds Ratio
ART	:	Antiretroviral Therapy
BMI	:	Body Mass Index
CI	:	Confidence Interval
CSB	:	Micronutrient-fortified Corn–soy Blend
DALYs	:	Disability-Adjusted Life Years
DHS	:	Demographic Health Survey
HIV	:	Human Immunodeficiency Virus
LAZ	:	Length for Age Z score
LCNI-5	:	Lungwena Child Nutritional Intervention-5 Study
LNSs	:	Micronutrient-fortified Lipid-based nutrient Supplements
MDGs	:	Millennium Development Goals
MUAC	:	Mid-Upper Arm Circumference
OR	:	Odds Ratio
RTUF	:	Ready to use food
SD	:	Standard Deviation
TB	:	Tuberculosis
UNICEF	:	United Nations Children's Fund
WAZ	:	Weight for Age Z score
WHO	:	World Health Organisation
WLZ	:	Weight for Length Z score

CHAPTER 1

This chapter provides an introduction to the research report by giving the background, literature review, rationale, aim and the specific objectives of the study.

1.1 Background

Malnutrition contributes to about 45% of children's mortality in medium and low-income countries by increasing their susceptibility to common life-threatening infections such as malaria, diarrhoea, measles and pneumonia (1, 2). Moreover, malnutrition also increases the risk of opportunistic non-communicable diseases (3, 4).

The two forms of under-nutrition are specific micronutrients deficiency and protein-energy undernutrition. Specific micronutrients deficiencies are not only common in emergency affected populations but also normally impoverished populations with lots of hidden hunger. Specific micronutrient deficiencies result from insufficient specific micronutrients such as scurvy (vitamin C), goitre (iodine), anaemia (iron) and beriberi (thiamine) (5). Protein energy malnutrition is primarily a deficiency of protein and energy and is assessed by anthropometry measurements and physical examination in public health.

While specific micronutrients and protein-energy deficiencies are more common in these instances, they also do exist in other situations. Furthermore, there is a high likelihood of clustering of problems such that singular deficiencies would be quite rare and a combination of deficiencies more common in populations.

Protein energy malnutrition manifests early in young children between six months and two years compared to the specific micronutrients malnutrition (6). Children suffer from acute malnutrition (wasting/underweight) due to; a combination of recent infections, infestations and inadequate food intake in terms of quantity and quality. Chronic malnutrition (stunting) is as a result of persistent infections and long term food insecurity.

Malnutrition problems are common in countries where there is poverty. The problems limit human potential in both long-term and short-term due to functional consequences (7). Vulnerability to malnutrition is essentially highest among children under five years old and pregnant or lactating women (8). Nutritional problems inherently flourish in utero and the first two years of life which affects nearly a third of young children in low and medium-income countries (7).

According to UNICEF 2017 report; globally, 155 million (23%) of children under five years were stunted in 2016. Stunting decreased by about 39% from the estimated 254 million in 1990 (9). An estimated 51 million (7%) of children under five were wasted globally. This was 11% decrease from 58 million estimated in 1990 (9). An estimated 95 million (14%) children were underweight in 2016, about 40% decrease from the estimated 160 million in 1990 (9). There has been an increasing trend of overweight among children under five in most parts of the world including developing countries. In Africa, the prevalence increased from 4.9% in 1990 to 5.5% in 2016 (9, 10).

Despite malnutrition decreasing globally since 1990, overall progression is still insufficient as millions of children under five years especially in Africa and Asia remain at risk. Approximately 90% of global stunted children live in these two regions (9, 10). In comparison with other regions in the world, Sub-Saharan Africa is furthest behind in achieving the set goal of reducing the burden of stunting by 50% since 1990 (11). This has remained a public health challenge that often goes unnoticed.

Reduction or elimination of malnutrition in children can play a vital role in the realisation of the Millennium Development Goals (MDGs) that focuses on the reduction of infant mortality rate, child mortality rate and the prevalence of malnutrition (12). Supplementary feeding is one of the typical interventions in the management of malnutrition. In a controlled situation, the approach has shown to improve the status of undernourished children (13). Female health education has also shown to work in prevention of malnutrition (13). However, if not reinforced with women empowerment, it may not be effective. Previous research has shown that determinants of malnutrition vary. Therefore, preventive strategies that work in one area may not necessarily work in all settings.

Unfortunately, in Malawi, there have been no changes in children under-five nutritional status since 1992. Malnutrition rates remain considerably high despite numerous interventions. About 21% of children under-five years of age are wasted, 46% are stunted and about 4% underweight. The majority of these malnourished children come from rural areas (10, 14).

The reasons for the lack of progress in Malawi are unclear and complex (15). Firstly, the low maternal education levels and ignorance of standard child care practices and feeding means children do not receive optimal care and nutrition. Secondly, poverty is widespread such that despite some mothers having knowledge of the importance of balanced diet, they do not have resources for recommended quantity and dietary diversification (15).

The main aim of this study is to model the effectiveness of potential interventions to deal with the problem of malnutrition in children under five years of age in Malawi. The study population for this research was a cohort of children in a community based randomised controlled trial done in Mangochi district to determine whether supplementary feeding promoted linear growth and reduced the incidence of stunting in rural Malawian children.

1.2 Literature Review

1.2.1 Malnutrition overview

Children's malnutrition in the form of acute and chronic illness co-exists in the majority of populations in developing countries. Nutrition status in children under-five years of age is among the indicators of a household and the community well-being as it can be used as a determinant of childhood survival later in life (16). Malnutrition accounts for about 3% of Disability-Adjusted Life Years (DALYs) and 2% deaths in children under five years in Sub-

Saharan Africa (17). Poor child nutrition status in the early years has long term effects on their intellectual development, well-being productivity and health later in life (18). This creates inequalities and inequities in health, economic status and other household welfare dimensions.

WHO recommends child malnutrition as a measure of health status for assessing health equity (19) in a country. Stunting is the overall indicator of prolonged dietary inadequacy and the most reliable measure of long-standing childhood malnutrition. The reliability is because, height for age (stunting) has a negligible sensitivity to temporary food shortages. Consequently, wasting is useful in determining the effectiveness of interventions due to weight for height (wasting) being sensitive to short-term dietary changes (16).

Previous research in Ethiopia, Uganda and Jamaica (20, 21) (22) have suggested that both demographic and social economic factors affect the nutritional status of children under five years. Age, the number of children under five years, preceding birth interval, mother's education and household size were associated with stunting (20). Male children and children with recent illness were reported to have a greater risk of acute malnutrition (21, 23, 24). Communicable diseases such as malaria, diarrhoea, pneumonia and HIV/AIDS predispose children to a poor nutritional status that include; chronic ill health, mal-absorption and poor appetite (21).

Malnutrition among children under five years of age is preventable and the prevalence can be reduced even in resource constrained developing countries (25). Prevention and treatment of malnutrition lie in a unique position between public health and clinical medicine (26). Public health measures can be designed to prevent malnutrition with no need for clinical input. For instance, increasing diet quality and quantity as well as health education to care givers (25). However, in case management of malnutrition especially severe cases, the clinical input is important.

Maximum impacts in control and management of malnutrition at the population level can only be achieved if the strategies take into account social economic realities and community needs (26). Therefore, informed strategies are essential in implementing nutrition interventions since different forms of malnutrition exist in various communities (4).

1.2.2 Malnutrition interventions

There are a number of strategies that are in place for prevention and treatment of under nutrition. The interventions range from general interventions directed to a variety of determinants and specific interventions directed to specific determinants. The interventions that have been encapsulated in the United Nations Children's Fund (UNICEF) scaling up nutrition initiative include: increasing income, improving maternal education and nutrition, supporting exclusive breastfeeding, improving water and sanitation, providing therapeutic food and supplementation and child immunisation promotion.

Increasing income at the household level is important in the reduction of malnutrition as it allows families to spend on clean water, food, hygiene and curative and preventive health care (27). Moreover, it allows families to have better childcare practices and more diversified diets. The community level benefits of increased income include improved water and sanitation infrastructure, availability of quality and higher health care and better access to information (27).

Caregivers who are typically women are key in the promotion of the household (28). Women provide the growing child and the family with the care, support and the attention to meet the social, mental and physical needs (29). Care consists of activities that include: appropriate food intake and prenatal visits during pregnancy, exclusive breastfeeding, complementary feeding of young children, child immunisation and health care seeking behaviour, children psychological stimulation, household hygiene practices, appropriate food preparation and storage (30).

Maternal education and women empowerment is vital in improving the nutritional statuses of household members. Nonetheless, women status and ability to make decisions on household spending is a limitation especially in Sub-Saharan Africa (31). Women status and position in the society is informed by cultural beliefs that prohibit them from resource ownership, use and control of finances as well as education and information access (31).

Interventions to improve the quality of water, sanitation and hygiene (WASH) are used to control infectious diseases like diarrhoea and cholera. These diseases predispose children to poor nutritional statuses, therefore, their prevention can be indirectly linked to improving nutrition status in children (32). WASH interventions involve; promoting boiling/treating of drinking water, proper waste disposal, use of improved toilets/latrines and washing of hands with soap before eating, after visiting the toilet and before feeding of the baby.

Consequently, feeding programs have widely been used in the management of malnutrition (33). This typically targets underweight and wasting. The programs are in the form of therapeutic feeding programs and supplementary feeding programs. The targeted feeding programs aim at rehabilitating already malnourished individuals to prevent deterioration by meeting their additional dietary needs (33). In emergency situations, blanket feeding of all the vulnerable populations is used to reduce the incidence of malnutrition (34).

Supplementary feeding with lipid-based nutrient supplements (LNS) has been shown to reduce the incidence of stunting and promote linear growth (35).However, their effectiveness in reducing the prevalence of malnutrition is still questionable. Recent findings from studies in Ghana and Malawi showed improved nutritional statuses of children under LNS supplementations compared to those who did not receive any supplementation (13, 36).

Unfortunately, food supplementation alone has failed to significantly reduce the prevalence of malnutrition in children especially in limited resource environments in the last two decades(37). In Bangladesh, there was no significant difference in the prevalence of severe underweight in children in the integrated nutrition project area and the non-project area (38). Children under feeding programs in Malawi and Ecuador had significant weight gain but not significant linear growth (35, 39).

Previous studies have shown that counselled mothers provide better feeding practices and care for their children which prevent and reduce malnutrition (40).Maternal nutritional counselling reduced the prevalence of wasting in Pakistan (37). However, the study did not consider if the intervention reduced the incidence of wasting. In a community based randomised trial in Bangladesh, the proportion of normal children was higher in the intervention(under health education) group than in the control group (41). Intensive health education significantly improved the statuses in moderately underweight children in Bangladesh, China and India without supplementation (42-44).

Recent research has suggested that food supplementation can be used to manage wasting in the short term in a community setting. However, to reduce stunting in the long term, these specific interventions should be reinforced by the general interventions like education (45). A study in Bangladesh (42) suggested a remarkable improvement in nutritional status among children with combined (health education and supplementary feeding). However, it did not describe the coverage of the intervention for optimal benefits.

Malnutrition intervention strategies that are available can reduce child deaths, micronutrients deficiencies and malnutrition if implemented in an informed manner and sufficient scale. Consequently, they would decrease the Disability-Adjusted Life Years (DALYs) in children by a quarter in a short period (45). Factors that limit supplementary feeding and health education ought to be understood to plan more effective interventions (44) since, despite the numerous uses of these interventions, their efficacy is still questionable (13).

Therefore, this study will investigate supplementary feeding and health education further when applied singly and also in combination through mathematical simulation modelling techniques.

1.2.3 Mathematical modelling

Nutritional interventions just like other disease interventions are complex since they include multiple components that have different targets. They produce nonlinear results hence difficult to predict the overall effect. This complexity calls for robust scientific techniques committed to interconnectedness and holism. Regression models can be used in capturing the interventions theory (46), but despite their sophistication, the qualitative description is not sufficient (47).

The use of mathematical simulated models has had a long and successful history in public health (48). In epidemiology, simulation modelling holds the promise to the future. Furthermore, there have been a growing number of applications of mathematical simulations model in disease epidemic theory over the years (48). The mathematical models come in handy to test the interventions because they are constructed to describe relationships using mathematics and capture the diversity of the settings (47).

The effectiveness of an intervention is defined by the measure of the benefits it brings and the cost incurred when used in a community setting (49). Mathematical models that incorporate the dynamics of a disease that are interrupted by an intervention, are useful tools to unravel the complexities to occur when the intervention is put in nonlinear biological systems (49). There has been an increasing use of Susceptible Infectious and Recovered (SIR) mathematical model for malaria control to weigh alternatives and provide a good decision-making tool to eradicate the disease in Sub-Saharan Africa (50). In cholera prevention and control SIR mathematical models have also been widely used in cost-effective interventions methods in Africa, Asia, Europe and America (51). Transmission dynamical mathematical models were used in England to show that 'MenB' vaccine significantly decreased the incidence of Meningococcal disease (52). The outcome of the study was used to inform policy decision on the introduction of the new vaccine.

The use of mathematical model has grown significantly in modelling cardiovascular diseases and other non-communicable diseases to guide the allocation of resources in the resource constrained developing countries (53). In an effort to reduce the transmission of HIV/AIDS, the mathematical model suggested that although some interventions alone could reduce the incidence, a combination of voluntary HIV testing and instant initiation of Antiretroviral treatment (ART) was more effective (54).

The effectiveness of malaria-vector control interventions was demonstrated in Namawala Tanzania using simulated mathematical modelling techniques (55). The study outcomes were meant to inform malaria control programs on a combination of interventions that were cost-effective and that could give an interruption to malaria transmission compared to when either of interventions was applied singly. Similarly, cost-effectiveness and feasibility of the current malaria control interventions were determined using mathematical simulations in Rachuonyo, Kenya. The results informed the malaria control program in Rachuonyo on considering changing the current malaria control interventions based on the allocated resources by the ministry of health (56).

1.3 Problem statement

There are evidence gaps of nutritional interventions effectiveness and cost effectiveness in developing countries' health systems that require urgent attention. The interventions could be single or integrated to give maximum impact on stunting, wasting and underweight (45). Studies have shown anthropometric benefits of Ready to use food(RTUF) supplementation for already undernourished children however it's not clear on their effectiveness to susceptible younger children (13).

Improved health education enlightens caregivers on preventive and curative health seeking behaviour, breastfeeding, dietary intake, feeding practices and improve overall nutrition in children in areas where food is not a problem (57). Nevertheless, the effect of health education alone is not easily measurable and distinguishable. In the primary study (Lungwena Child Nutritional Intervention-5 study) stunting was identified as the major challenge. However, the aetiology of stunting was found to be unclear. Therefore, future research needs to be done to attempt to explain and investigate the effectiveness of the interventions that are applied singly or as a combination of two or more (13). This particular study is therefore essential as it investigates the effectiveness of nutritional interventions taking into account the dynamics of malnutrition using mathematical modelling techniques.

1.4 Justification for study

Mathematical models have been used to model optimal interventions for diseases like cholera, malaria, HIV and TB. The results of these models have been used to come up with a feasible framework for developing effective measures for disease control with multiple or integrated intervention strategies, therefore, reducing the prevalence and the incidence of these diseases (51).

While the causes of malnutrition are known, it is impractical to implement at large scale all the interventions to deal with the problem. Public health practitioners and policy makers are faced with difficult choices in selecting few very effective interventions and that choice would best be informed by modelling techniques.

Since mathematical models on nutrition dynamics are few, it is, therefore, the intention of this research to formulate and analyse a simulated mathematical nutritional model that informs the effectiveness of nutritional interventions (health education and feeding programs). This research will aim at addressing these knowledge gaps and the results obtained will be helpful in informing policy on a better intervention that should be used.

1.5 Research Question

Are the nutritional interventions against stunting, wasting and underweight among children under five years of age effective?

1.6 Aim of the study

To simulate mathematical nutritional intervention models, that informs the effectiveness of interventions for stunting, wasting and underweight in children under five years of age.

1.7 Objectives of the study

1. To determine the socio-demographic characteristics of children in Lungwena Child Nutritional Intervention-5 Study in Malawi as baseline population and also to provide parameters for simulation.
2. To determine the prevalence of wasting, stunting and underweight and the associated risk factors among children in Lungwena Child Nutritional Intervention-5 Study in Malawi.
3. To develop a deterministic compartmental model of nutritional intervention among children in Lungwena Child Nutritional Intervention-5 study in Malawi.
4. To determine the effectiveness of feeding programs and health education as separate interventions on the prevalence of stunting, wasting and underweight.
5. To determine the effectiveness of a combined intervention of both feeding programs and health education on the prevalence of wasting, stunting and underweight.

CHAPTER 2

This chapter provides a detailed description of various methods used in the study. Because the study was secondary data analysis, methods used in the primary study were also outlined.

2.1 Study design

The data originally collected in a cohort study (Lungwena Child Nutrition Intervention Study-5) was analysed to describe the population and to provide the parameters for developing a mathematical simulation model for optimal nutritional interventions. The children aged 5.5 – 6.5 months in Lungwena and Malindi areas between 28th January 2008 and 25th May 2009 were recruited in the study. These infants formed the cohort that was intensively followed up at three months interval visits until they attained 18 months of age.

2.2 Nutrition Intervention

All the children in Malindi and Lungwena areas in Mangochi district between 5.5 - 6.5 months) were enrolled in the Lungwena Child Nutrition Intervention-5 Study (LCNI-5).

The enrolled children were put in a 12-months supplementation programme in the form of three supplements;

1) Micronutrient-fortified lipid-based nutrient supplements (LNSs) with milk protein base
2) Micronutrient-fortified lipid-based nutrient supplements (LNSs) with soy protein base
3) Micronutrient-fortified corn–soy blend (CSB)

2.2.1 Inclusion criteria

-All children between 5.5 to 6.5 months of age

2.2.2 Exclusion criteria

-Refused informed consent

- Oedema

-Severe illness

-Peanut allergy

- Food intolerance within 30 minutes of consumption

- Children participating in a concurrent trial

2.3 Study site

The primary study sites were Malindi and Lungwena areas, in Mangochi district which is in the southern part of Malawi. Both sites were in the rural community at the shore of the southern part of Lake Malawi (figure 2.1).

The main economic activity in Mangochi is maize farming and fishing. Although there are many crops like cassava, sweet potatoes, vegetables and beans, maize is the staple food.

The population is mainly from the Yao tribe and Islam is the predominant religion. Malindi and Lungwena are catchment areas for Malindi health centre and Lungwena health centre respectively. The health facilities provide free curative and preventive health services like; medical treatment, antenatal care, delivery and vaccinations.

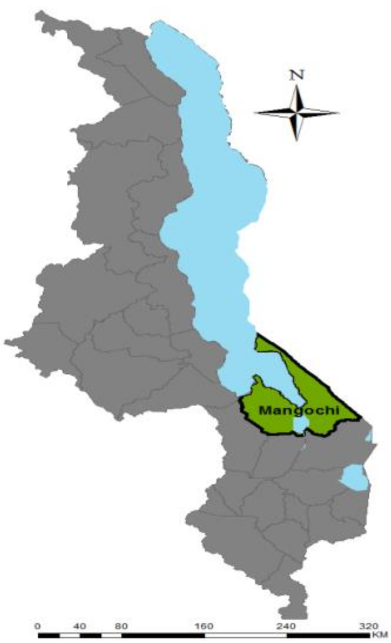


Figure 2.1: Map of the location of the study site in Malawi

2.4 Study population

The study population was 840 children aged between five and a half months to six and a half months in the study areas. The 840 children were randomised into four treatment groups; 1) micronutrient-fortified LNSs with soy protein base; 2) micronutrient-fortified LNSs with milk protein base; 3) micronutrient-fortified corn–soy blend CSB; and 4) control (no supplement) regardless of their nutritional status (figure 2.2).

2.4.1 Randomisation

The study participants were randomised (by a statistician not involved in the implementation of the trial) using computer-generated random number list in blocks of 16 into the four intervention groups. The guardian chose one envelope from the set of identical envelopes in one block that contained the intervention group allocation and the unique identification number.

210 infants received micronutrient-fortified LNSs with soy protein base, 212 children got micronutrient-fortified LNSs with milk protein base, 209 infants were allocated to micronutrient-fortified corn–soy blend CSB and the remaining 209 were in the control group (figure 2.2).

2.4.2 Follow-up of study participants

The cohort was followed up for 12 months, with three months interval visits until they attained 18 months of age. Out of the 840 children that were enrolled into the study; there were 12 deaths and 32 drop outs before the end of 6 months of the study, 13 deaths and 36 drop outs before 12 months of the study. A total of 747 children completed the follow-up period (figure 2.2).

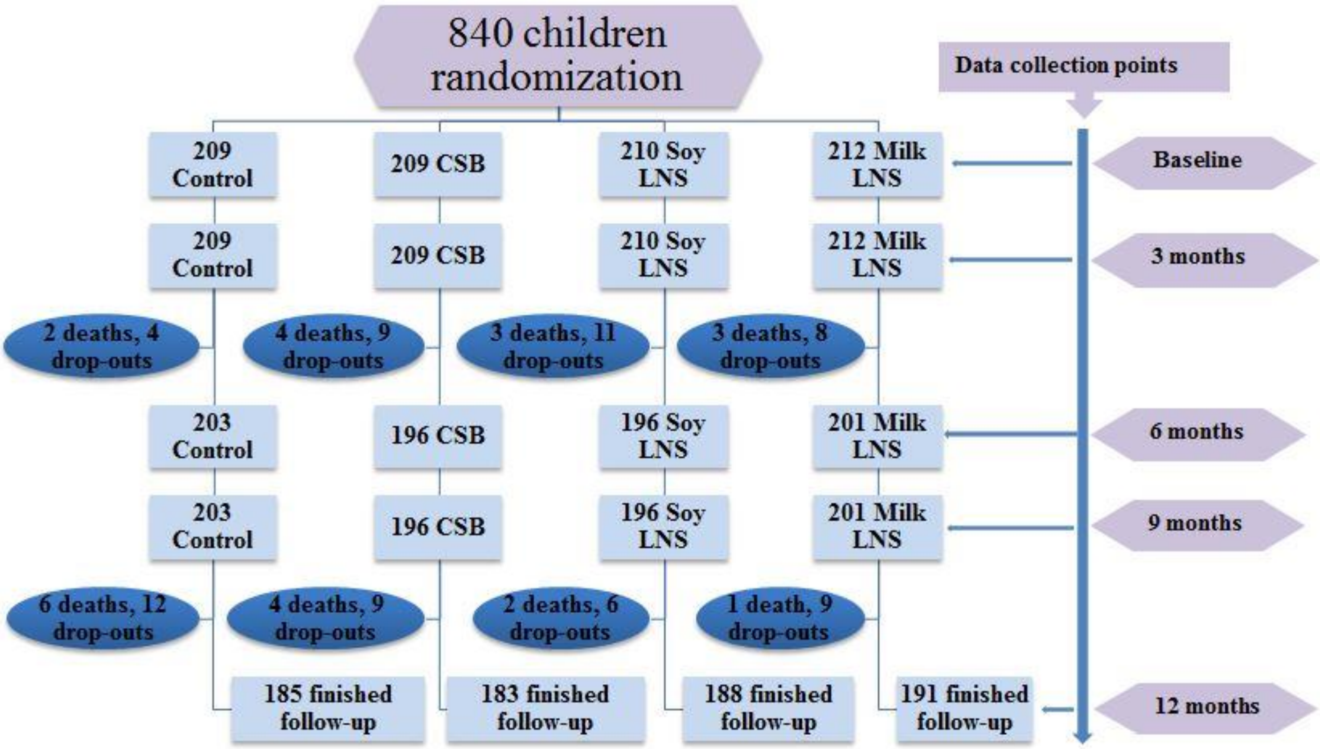


Figure 2.2: Flow diagram of the randomization, data collection points and follow-up of the participants

2.5 Sampling methods

All the participants who satisfied the inclusion criteria in the Lungwena Child Nutritional Intervention-5 Study (LCNI-5) were included in this study.

2.6 Data collection

2.6.1 Primary study

Anthropometry measurements for infants in Lungwena Child Nutrition Intervention-5 Study were done at enrolment. The anthropometry measures were collected using an electronic infant weighing scale for weight and high-quality length board for length on every visit. The socio demographic information and maternal characteristics were collected through personal interviews to care givers using pre-tested questionnaires at enrollment. Delivery of supplements was done every two weeks. Any adverse effects and provided supplements use was also recorded during the visits. Home visits to collect information on anthropometry measurements, feeding practices, vaccination, morbidity and mortality, were done at 12 weeks interval until they attained 18 months of age.

2.6.2 Secondary data analysis

The gate keeper of the data at the University of Malawi, College of Medicine was requested to provide data on relevant variables that helped in answering the research question in this study. Apart from anthropometry data (age, weight, length), interventions variables like supplementary feeding details and health education were obtained. The data also included maternal characteristics and social demographic characteristics.

2.7 Definition of malnutrition outcome

Below are the standard malnutrition indices definitions that were used in the study and as classified by the WHO(58):

1. <u>Stunting</u>: Children with length for age Z scores below -2 standard deviations(SD) from the median of reference population were classified as stunted and length for age Z scores equal to or greater than -2 SD but less than +2 SD classified as normal.
2. <u>Wasting</u>: Children with weight for length Z scores below -2 SD from the median of reference population were classified as wasted and weight for length Z scores equal to or greater than -2 SD but less than +2 SD classified as normal.
3. <u>Underweight</u>: Children with weight for age Z scores below -2 SD from the median of reference population were classified as underweight and weight for age Z scores equal to or greater than -2 SD but less than +2 SD classified as normal.
4. <u>Overweight</u>: Children with weight for length Z scores above -2 SD from the median of reference population were classified as overweight and weight for length Z scores equal to or less than -2 SD classified as normal.

2.8 Independent variables

Table 2.1: List of variables used in the analysis by objective

Descriptive and inferential statistics	**Explanatory variables**		
Objectives	**Continuous**	**Categorical**	**Outcome**
1. To determine the socio-demographic characteristics of children in Lungwena Child Nutritional Intervention-5 Study in Malawi as baseline population and also to provide parameters for simulation 2. To determine the prevalence of wasting, stunting and underweight and the associated risk factors among children in Lungwena Child Nutritional Intervention-5 Study in Malawi.	• Child's age • Child's length • Child's weight • Mother's education years • Mother's BMI • Mother's age • Number of persons in the household • Number of children under five years	• Sex of the child • Dietary diversity • Source of drinking water • Type of toilet facility • Social economic status • Ownership of mosquito nets	• Stunting • Wasting • Underweight • Overweight
Mathematical modelling	**Interventions**	**Outcome**	
3. To develop a deterministic compartmental model of nutritional intervention among children in Lungwena Child Nutritional Intervention-5 study in Malawi.		• Stunting • Wasting • Underweight	
4. To determine the effectiveness of feeding programs and health education as separate interventions on the prevalence of stunting, wasting and underweight.	• Supplementary feeding • Health education	• Stunting • Wasting • Underweight	
5. To determine the effectiveness of a combined intervention of both feeding programs and health education on the prevalence of wasting, stunting and underweight.	• Supplementary feeding • Health education	• Stunting • Wasting • Underweight	

2.9 Data management and analysis

Data management and statistical analysis were performed in STATA 13.0 (StataCorp. College Station, TX) and 95% confidence intervals (CI) were used. Mathematical simulation models were implemented in Berkeley Madonna software and R core team (2013).

2.9.1 Data Management

The variables were correctly labelled using the data dictionary provided and the data description. Comparison of responses for different variables was done to check if they were logical and consistent.

Miscoded, outliers and missing data were identified by the use of frequency tables. The missing data for (weight, length and age) was imputed using mean imputation if the data for the preceding and succeeding visits of the same respondent was available. Last observation carried forward imputation technique was used if data for only preceding visit was available due to the short period between visits. The response in specific variables was regarded as missing if there wasn't any possible way to correct it, for instance, if the participant missed three consecutive visits.

The weight for length Z scores (WLZ), length for age Z scores (LAZ) and weight for age Z scores (WAZ) was computed to match the new WHO 2006 reference population. The outcome variables (stunting, wasting and underweight) were obtained by recoding LAZ, WLZ and WAZ to binary respectively as explained in the definition of outcome. Recoding was done to other variables of interest where necessary for instance, the source of drinking water was collapsed from five to two categories; protected and unprotected.

Principal component analysis with varimax component rotation was used to create social economic status and dietary diversity using 12 household resources ownership variables and 30 household feeding practices variables respectively.

2.9.2 Data analysis

2.9.2.1 Statistical analysis

2.9.2.1.1 Descriptive statistics

Objective 1: To determine the socio-demographic characteristics of children in Lungwena Child Nutritional Intervention-5 Study in Malawi as baseline population and also to provide parameters for simulation.

Frequencies and percentages were generated from cross-tabulation by the intervention arm for categorical variables like; sex of the child, source of drinking water, sanitary facility type, dietary diversity, social economic status and net ownership. Mean and standard deviation by intervention arm was reported for continuous variables like child's age, mother's MUAC, mother's education years and mother's age since the data was normally distributed.

2.9.2.1.2 Inferential statistics

Objective 2: To determine the prevalence of wasting, stunting and underweight and the associated risk factors among children in Lungwena Child Nutritional Intervention-5 Study in Malawi.

Prevalence of stunting, underweight and wasting was obtained by dividing the total number of children who were stunted, underweight and wasted by the total number of children respectively. Prevalence of overweight was computed too although it was not one of the main outcomes. The characteristics of children who were stunted and underweight were compared using Fisher's exact test and Pearson's chi square test. This was done at 5% level of significance. The association between the outcomes and the independent variables was assessed by fitting two different logistic regression models. Risk factor analysis for wasting and overweight was not done because of the small numbers.

A univariate logistic regression analysis was carried out with each of the outcomes (stunting and underweight) and each of the potential risk factors. Multicollinearity among the independent variables was checked using variance inflation factor (VIF) approach before fitting the multivariable model. Multiple logistic regression models were then fitted with all variables that had a p-value of less than 0.2 in the univariate analysis.

Backward elimination stepwise approach was used with a liberal p-value for exclusion of 10% to remove the non-significant (p=>0.5) variables. Before removing the variables, likelihood ratio test was used to reaffirm their significance in the model. Consequently, in addition to the main effects, possible interaction terms were included in the model to further mitigate confounding. This was done at 5% level of significance. Likelihood ratio test was used to determine the most parsimonious model. Hosmer and Lemeshow test was used to test the goodness-of-fit of the final model.

2.9.2.2 Mathematical simulation modelling

Objective 3: To develop a deterministic compartmental model of nutritional intervention among children in Lungwena Child Nutritional Intervention-5 study in Malawi.

A deterministic simulation model was developed using realistic parameters from the analysis in objective 1 and 2. The model utilised ordinary differential equations that took into account the dynamics of malnutrition. The dynamics involve the consideration of four compartments namely; Normal-Stunted/Wasted/Underweight. A child could possibly be in any of the four compartments depending on their nutritional status at a specific time point.

Data analysis of LCNI-5 was used to obtain the parameter values for instance; rates of stunting ʎ, rate of wasting ϕ, rate of underweight ω, rate at which the underweight get wasted σ, rate at which the stunted get wasted ψ, the rate which wasted get stunted Υ, rate at which the wasted became underweight ε, rate of recovery for underweight π, rate of recovery for wasted α and rate of recovery for the stunted β .The mortality rate μ in various compartments was also estimated from the data. Parameters that could not be obtained from LCNI-5 data were sourced from the existing literature in a comparable population (table 2.2). Sensitivity analysis was done by varying the model parameters through simulations and associated outputs assessed.

2.9.2.2.1 Model specification

Derived quantities**: *Ni*= *N*+*S*+*W*+*U***

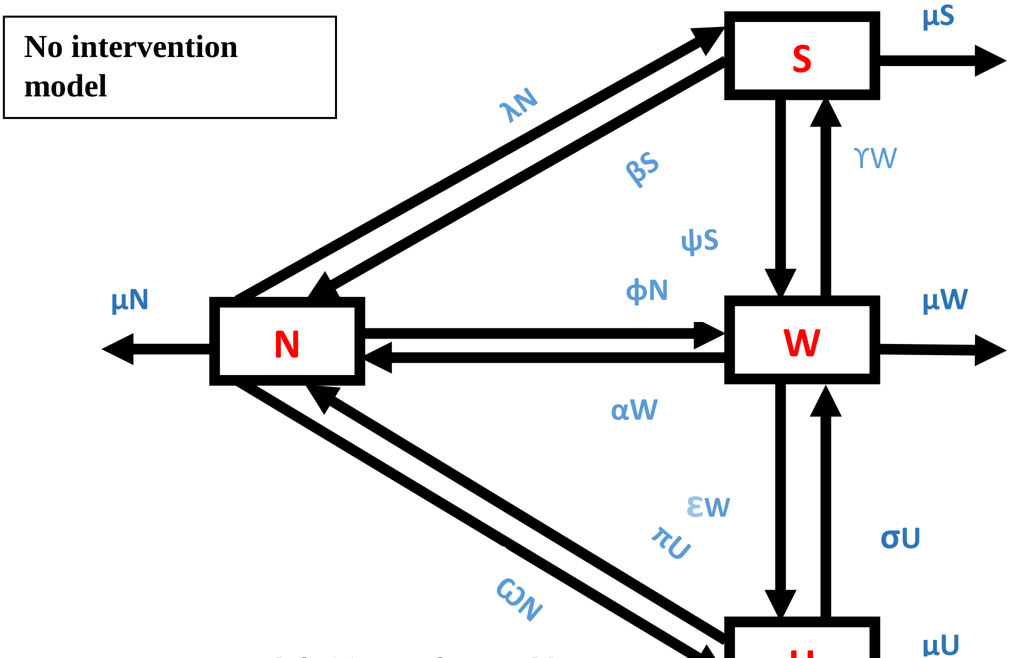
Compartments: N-Normal, **S-**Stunted, **W**-Wasted, **U**-Underweight

Interventions: E- Health Education given to care givers, **F-** Supplementary feeding given to children, **C-** Health Education given to care givers and supplementary feeding given to children

Interventions coverage:

1. **Supplementary feeding –** Coverage defined by inclusion and by the participant being in the programme for a minimum duration of 12 weeks. **100% Coverage;** feeding all the vulnerable population regardless of the nutritional status, **50% coverage**; feeding of half of the population(one enumeration area and the other acts as the control), **38% coverage;** feeding of only the malnourished children (percentage of children with any form of malnutrition in LCNI-5).
2. **Health education –** Coverage defined by intensity and by the participant being in the programme for a minimum duration of 12 weeks. **100% coverage;** Intensive health education to caregivers twice a week, **50% coverage**; intensive health education to caregivers once a week, **25% coverage;** intensive health education to caregivers twice a month.
3. **Combined intervention –**Coverage defined by both inclusion, intensity and by the participant being in the programme for a minimum duration of 12 weeks. **Full coverage;** feeding of all the vulnerable population regardless of the nutritional status and intensive health education to caregivers twice a week, **Medium coverage;** feeding of half of the population and intensive health education to caregivers once a week, **Least coverage;** feeding of only the malnourished children and intensive health

education once a fortnight.

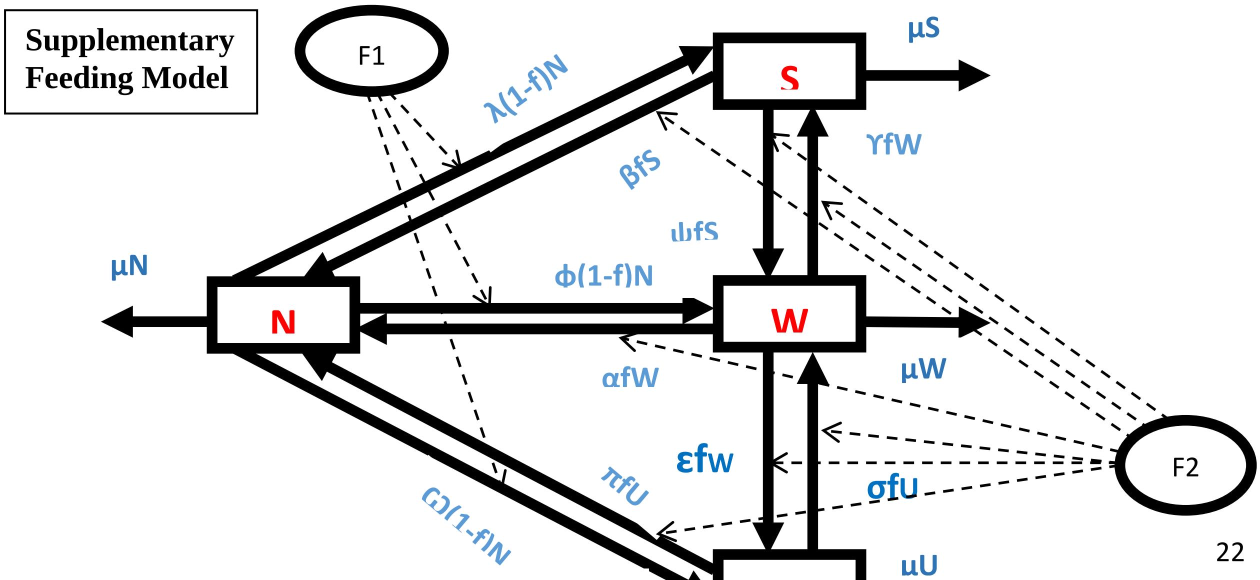


Note: For definitions refer to table 2.2

Figure 2.3: Neutral (no intervention) model

Objective 4: To determine the effectiveness of feeding programs and health education as separate interventions on the prevalence of stunting, wasting and underweight.

The simple model was extended to include the effect of health education to caregivers (E) and supplementary feeding (F) as separate interventions and the associated model output assessed. Additional sensitivity analysis was done by varying the coverage of the separate interventions by simulation to check if there were further changes in the model output. Individual level models incorporating risk factors were also fitted.



Note: For definitions refer to table 2.2

Figure 2. 4: Model with supplementary feeding intervention

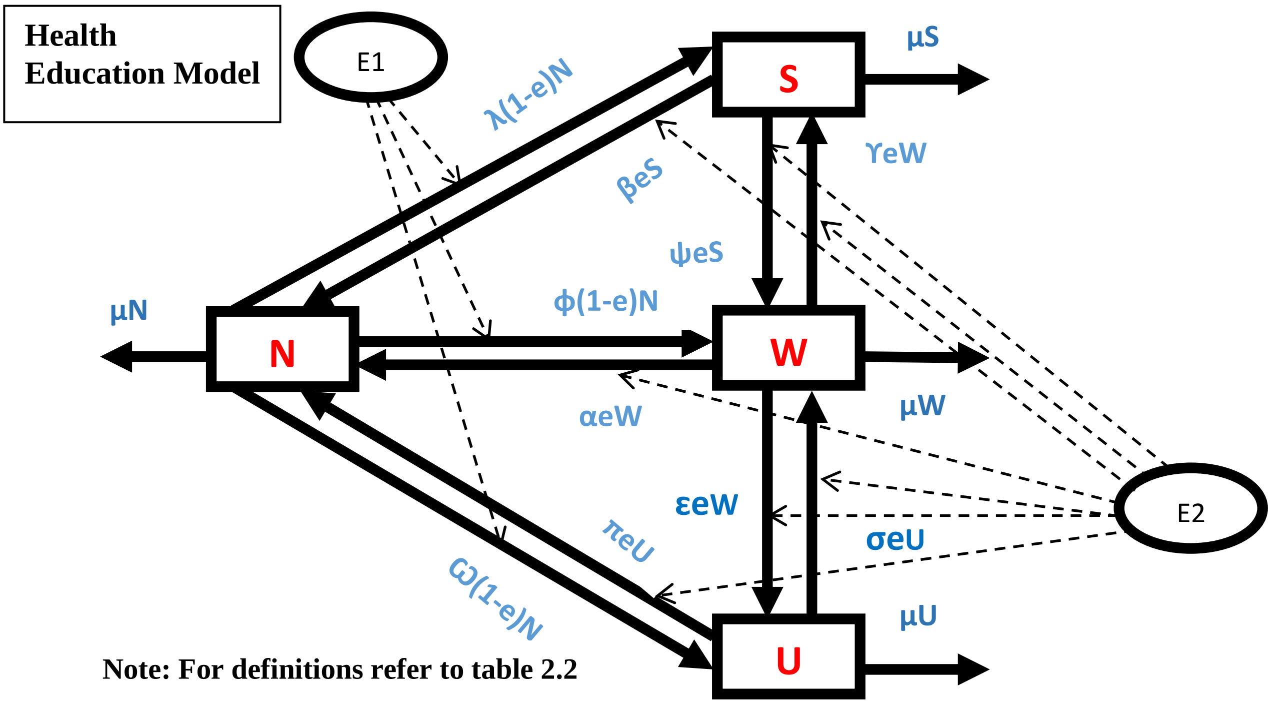


Figure 2.5: Model with health education intervention

Objective 5: To determine the effectiveness of a combined intervention of both feeding programs and health education on the prevalence of wasting, stunting and underweight.

The separate models of supplementary feeding (F) and health education to care givers (E) were then combined to investigate a combined effect (C). Final sensitivity analysis was conducted on the new model by varying coverage of the integrated intervention. The more effective interventions specifically targeting stunting, wasting, underweight or all was evaluated at equilibrium.

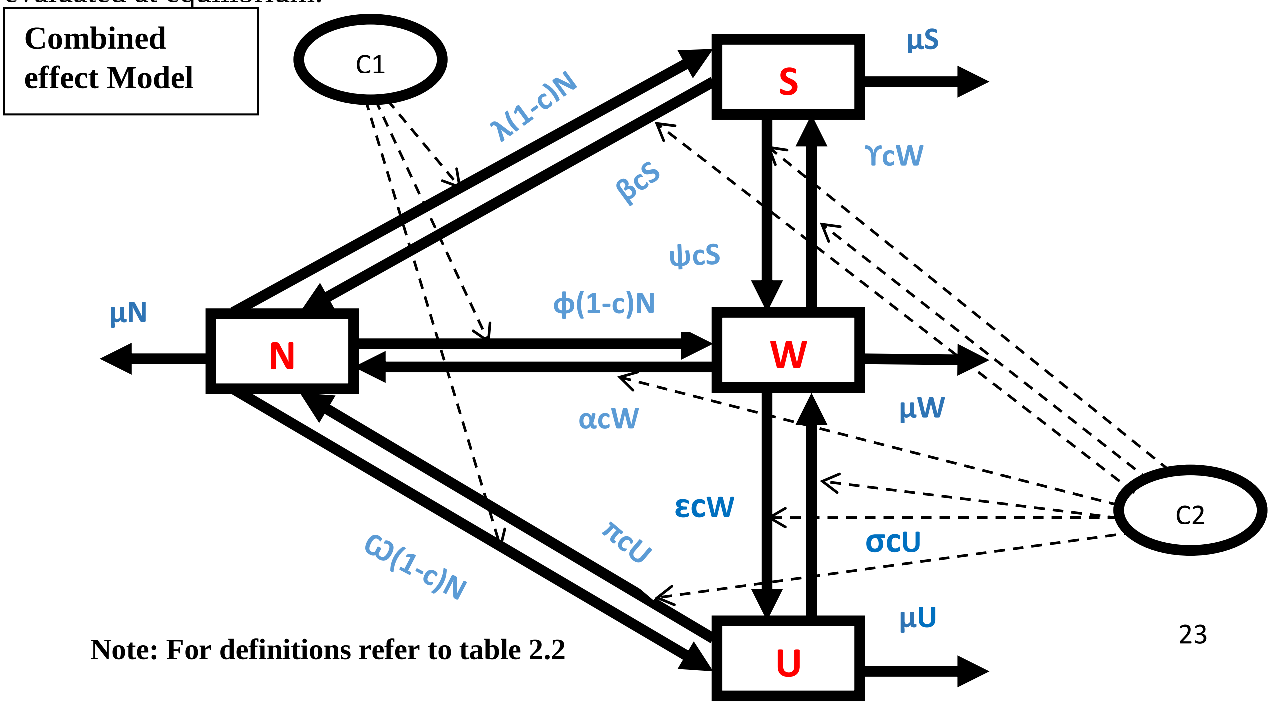


Figure 2.6: Model with supplementary feeding and health education as a combined intervention

2.9.2.2.2 Model assumptions:

- The population is constant- there are no births, immigration or emigration in the population. The only way a child can leave any compartment is by natural death or movement to the next compartment.
- The mortality rate is equal in all compartments i.e. the natural fatality rate is constant
- No disease induced death. The children only die naturally
- The population mixes homogeneously i.e. have the same interactions with one another to the same degree
- All susceptible children had different probabilities of getting malnourished at individual level (micro simulation) analysis. The probability was influenced by the social demographic characteristics like sex and household characteristics. However, at population level (macro simulation) analysis the susceptible children had the same probability of being malnourished.
- The rate of movement to various compartments is the same throughout the year.
- Recovery from malnutrition does not confer lifelong immunity. Recovered children remain susceptible to malnutrition.
- All children were normal at the beginning of the simulation.

2.9.2.2.3 Differential equations

Model 1: Without any intervention

$$\frac{dN}{dt} = -\lambda N - \phi N - \omega N - \mu N + \beta S + \alpha W + \pi U$$
$$\frac{dS}{dt} = \lambda N + \gamma W - \varphi S - \beta S - \mu S$$
$$\frac{dW}{dt} = \phi N + \sigma U + \varphi S - \varepsilon W - \gamma W - \alpha W - \mu W$$
$$\frac{dU}{dt} = \omega N + \varepsilon W - \sigma U - \pi U - \mu U$$

Model 2: With only supplementary feeding

$$\frac{dN}{dt} = -\lambda(1-f)N - \phi(1-f)N - \omega(1-f)N - \mu N + \beta fS + \alpha fW + \pi fU$$
$$\frac{dS}{dt} = \lambda(1-f)N + \gamma fW - \varphi fS - \beta fS - \mu S$$
$$\frac{dW}{dt} = \phi(1-f)N + \sigma fU + \varphi(1-f)S - \varepsilon fW - \gamma fW - \alpha fW - \mu W$$
$$\frac{dU}{dt} = \omega(1-f)N + \varepsilon fW - \sigma fU - \pi fU - \mu U$$

Model 3: With only health education

$$\frac{dN}{dt} = -\lambda(1-e)N - \phi(1-e)N - \omega(1-e)N - \mu N + \beta eS + \alpha eW + \pi eU$$
$$\frac{dS}{dt} = \lambda(1-e)N + \gamma eW - \varphi eS - \beta eS - \mu S$$
$$\frac{dW}{dt} = \phi(1-e)N + \sigma eU + \varphi(1-e)S - \varepsilon eW - \gamma eW - \alpha eW - \mu W$$
$$\frac{dU}{dt} = \omega(1-e)N + \varepsilon eW - \sigma eU - \pi eU - \mu U$$

Model 4: With both education and feeding (combined effect)

$$\frac{dN}{dt} = -\lambda(1-c)N - \phi(1-c)N - \omega(1-c)N - \mu N + \beta cS + \alpha cW + \pi cU$$
$$\frac{dS}{dt} = \lambda(1-c)N + \gamma cW - \varphi cS - \beta cS - \mu S$$
$$\frac{dW}{dt} = \phi(1-c)N + \sigma cU + \varphi(1-c)S - \varepsilon cW - \gamma cW - \alpha cW - \mu W$$
$$\frac{dU}{dt} = \omega(1-c)N + \varepsilon cW - \sigma cU - \pi cU - \mu U$$

2.9.2.2.4 Model parameters

Based on the analysis of the LCNI-5 study and the known literature in comparable populations the following parameters for the mathematical model were used in the simulations.

Table 2.2: Model parameters for simulation

Parameter	Description	Value	Source
μ	Mortality rate	0.03	LCNI-5
ʎ(1-e)N	Stunting rate in children under supplementation	0.28	LCNI-5
Φ(1-e)N	Wasting rate in children under supplementation	0.04	LCNI-5
ω(1-e)N	Underweight rate in children under supplementation	0.10	LCNI-5
σeU	Rate at which underweight get wasted under supplementation	0.18	LCNI-5
ψeS	Rate at which the stunted get wasted under supplementation	0.07	LCNI-5
ϒeW	Rate at which wasted get stunted under supplementation	0.46	LCNI-5
εeW	Rate at which the wasted become underweight under supplementation	0.46	LCNI-5
π eU	Recovery rate for underweight under supplementation	0.36	LCNI-5
A eW	Recovery rate for wasted under supplementation	0.91	LCNI-5
β eS	Recovery rate for stunted under supplementation	0.21	LCNI-5
ʎ(1-e)N	Stunting rate in children of caregivers with health education	0.07	(41)
Φ(1-e)N	Wasting rate in children of caregivers with health education	0.03	(59)
ω(1-e)N	Underweight rate in children of caregivers with health education	0.06	(41)
σeU	Rate at which underweight get wasted with health education	0.15	LCNI-5
ψeS	Rate at which the stunted get wasted with health education	0.07	LCNI-5
ϒeW	Rate at which wasted get stunted with health education	1.00	LCNI-5
εeW	Rate at which the wasted become underweight with health education	0.00	LCNI-5
π eU	Recovery rate for underweight children of caregivers with health education	0.37	(42)
A eW	Recovery rate for wasted children of caregivers with health education	0.34	(60)
β eS	Recovery rate for stunted children of caregivers with health education	0.05	(61)
ʎ(1-c)S	Stunting rate in children under supplementation and caregiver with health education	0.02	LCNI-5, (41)
Φ(1-c)W	Wasting rate in children under supplementation and caregiver with health education	0.01	LCNI-5, (59)
ω(1-c)U	Underweight rate in children under supplementation and caregiver with health education	0.01	LCNI-5, (41)
σcU	Rate at which underweight get wasted under supplementation and caregiver with health education	0.03	LCNI-5
ψcS	Rate at which the stunted get wasted under supplementation and caregiver with health education	0.01	LCNI-5
ϒcW	Rate at which wasted get stunted under supplementation and caregiver with health education	0.46	LCNI-5
εcW	Rate at which the wasted become underweight under supplementation and caregiver with health education	0.01	LCNI-5
πcU	Recovery rate for underweight under supplementation and caregiver with health education	0.13	LCNI-5, (42)
αcW	Recovery rate for wasted under supplementation and caregiver with health education	0.31	LCNI-5, (60)
βcS	Recovery rate for stunted under supplementation and caregiver with health education	0.01	LCNI-5, (61)

2.9.2.2.5 Model validation

The model was verified to ensure the predictions obtained from the model were in line with the model description. Different values of the parameters were explored to validate the models. Repeated random sampling of the population was used to test the model with different sets of dataset. The mathematical models were fitted to realistic data from Lungwena Child Nutrition Intervention (LCNI-5) study and validated by simulation.

2.10 Study ethical considerations

The University of Malawi, College of Medicine Research Ethics Committee and ethical committee of Pirkanmaa Hospital District (Finland) approved the research protocol for the original study; Lungwena Child Nutrition Intervention-5 Study: trial identification number NCT00524446. During the original study, all the 840 parents/guardians were asked to give informed consent for their children to be included in the cohort. Ethical approval to conduct this research was sought from the Human Research Ethics Committee of the University of Witwatersrand: certificate number M161199. Additionally, an official letter of permission to use the data was issued by the principal investigator of the original study.

All the information was kept confidential during analysis. The participants' identity was kept anonymous by separating the identifiers from the dataset. A unique study number was assigned to each participant. The link to the personal identifiers was stored separately on a password controlled computer.

CHAPTER 3

This chapter gives comprehensive results obtained in the study.

3.1 Participants' characteristics

Table 3.1: Characteristics of study participants at baseline by intervention arm

Variable	Level	Milk LNS (n=212)	Soy LNS (n=210)	CSB (n=209)	Control (n=209)	Total (n=840)
Continuous variables, [mean(SD)]						
Infant age, months		6.0 (0.3)	6.0 (0.3)	6.0 (0.2)	6.0 (0.2)	6.0 (0.2)
Infant length, cm		63.2 (2.4)	63.0 (2.4)	62.9 (0.3)	63.2 (2.2)	63.1 (2.3)
Infant weight, Kg		7.1 (1.0)	7.0 (0.9)	7.0 (1.0)	7.0 (0.9)	7.0 (0.9)
Mother's BMI, Kg/m2		20.7 (2.2)	21.0 (2.4)	20.7 (2.4)	20.6 (2.4)	20.7 (2.4)
Mother's education, years		3.9 (3.6)	3.0 (3.1)	3.7 (3.2)	3.6 (3.4)	3.5 (3.3)
Mother's MUAC, cm		25.3 (2.3)	25.3 (2.4)	25.2 (2.3)	25.0 (2.4)	25.2 (2.3)
Household size		5.0 (2.1)	4.9 (1.7)	4.6 (1.6)	4.8 (1.9)	4.8 (1.8)
Household number of under five years		1.6 (0.8)	1.6 (0.7)	1.7 (0.9)	1.6 (0.7)	1.6 (0.8)
Categorical variables, [n (%)]						
Infant gender	Male	107 (50.5)	103 (49.0)	98 (46.9)	111 (53.1)	419 (49.9)
	Female	105	107	111	98	421
Source of drinking water	Unprotected	17 (8.3)	12(5.8)	9 (4.4)	28(13.6)	69 (8.4)
	Protected	188	194	178	188	748
Type of sanitary facility	None	12 (5.9)	13 (6.3)	15 (7.3)	15 (7.5)	55 (6.7)
	Pit latrine	193	192	191	185	761
Mosquito net ownership	No	44 (21.5)	47 (22.8)	54 (26.2)	48 (24.0)	193 (23.6)
	Yes	161	159	152	152	624
Social economic status	Poorest	38 (18.7)	46 (22.5)	42 (20.6)	50 (25.3)	176 (21.8)
	Poorer	38 (18.7)	34 (16.7)	47 (23.0)	29 (14.6)	148 (18.3)
	Poor	41 (20.2)	50 (24.5)	39 (19.1)	44 (22.0)	174 (21.5)
	Rich	42 (20.7)	35 (17.2)	37 (18.1)	36 (18.2)	150 (18.5)
	Richer	44 (21.7)	39 (19.1)	39 (19.1)	39 (19.7)	161 (19.9)
Dietary diversity	No	93 (46.3)	105 (51.5)	107 (52.2)	101 (51.0)	406 (50.2)
	Yes	108	99	98	97	402

Table 3.1 shows infants, maternal and household characteristics at baseline by intervention arm. The intervention arms were similar in most characteristics but slightly differed in some. Infants' mean age, length and weight were similar in all the intervention arms (6 years, 63cm, 7 kg) respectively. There were slightly more female infants in CSB arm 111(53%) and more male infants in the control arm 111(53%). The mean level of maternal education was approximately four years of schooling. The average number of household members in all the four arms was 5 with an average of 2 children under five years. More than 20% of households in all the treatment arms did not own a mosquito net. Approximately 93(46%) of household in Milk LNS arm did not have diversified diet. In Soy LNS, CSB and control arms, a high proportion of more than 50% of the households did not have diversified diets at baseline 105(51.5%), 107(52.2%), 101(51.0%) respectively.

3.2 Prevalence of malnutrition

Table 3.2: Prevalence of stunting, wasting, underweight and overweight by treatment arm at baseline among children under five years in Mangochi.

	Stunting		Wasting		Underweight		Overweight	
Intervention group, n (%)	**Normal**	**Stunted**	**Normal**	**Wasted**	**Normal**	**Underweight**	**Normal**	**overweight**
CSB	126 (60.3)	83 (39.7)	206 (98.6)	3 (1.4)	173 (82.8)	36 (17.2)	192 (91.9)	17 (8.1)
Milk-LNS	140 (66.0)	72 (34.0)	210 (99.1)	2 (0.9)	189 (89.2)	23 (10.9)	195 (92.0)	17 (8.0)
Soy-LNS	128 (61.0)	82 (39.0)	205 (97.6)	5 (2.4)	180 (85.7)	30 (14.3)	195 (92.9)	15 (7.1)
Control	137 (65.5)	72 (34.5)	205 (98.1)	4 (1.9)	182 (87.1)	27 (12.9)	196 (93.8)	13 (6.2)
Overall	531 (63.2)	**309 (36.8)**	826 (98.3)	**14 (1.7)**	724 (86.2)	**116 (13.8)**	778 (92.6)	**62 (7.4)**

Table 3.2 shows that there was a high overall prevalence of stunting 309(36.8%). CSB and Soy LNS arms had apparently slightly higher proportion of the stunted infants 83(39.7%) and 82(39.0%) respectively. Only 14 (1.7%) of the children were wasted at the baseline. Overall the proportion of underweight was higher than overweight 116 (13.8%) and 62(7.4%) respectively. Despite CSB arm having a slightly higher

proportion of underweight children 36(17.2%); it also had a higher prevalence of overweight 17 (8.1%) compared to other groups. Generally, we observed that the prevalence of stunting, wasting and underweight was comparable in all the four intervention arms at baseline.

3.3 Characteristics of children <5 years of age, with stunting and wasting

Table 3.3: Stunting and wasting by explanatory factors at baseline among children under five years in Mangochi.

			Stunting		Wasting	
Factor	**Level**	**n**	**Normal n (%)**	**Stunted n (%)**	**Normal n (%)**	**Wasted n (%)**
Infant gender	Male	419	232 (55.4)	187 (44.6)	412 (98.3)	7 (1.7)
	Female	421	299 (71.3)	122 (28.7)	414 (98.3)	7 (1.7)
Source of drinking water	Unprotected	69	42 (60.9)	27 (39.1)	67 (97.1)	2 (2.9)
	Protected	748	479 (64.0)	269 (36.0)	736 (98.4)	12 (1.6)
Type of sanitary facility	None	55	32 (58.2)	23 (41.8)	54 (98.2)	1 (1.8)
	Pit latrine	761	488 (64.1)	273 (35.9)	748 (98.3)	13 (1.7)
Mosquito net ownership	No	193	112 (58.0)	81 (42.0)	189 (97.9)	4 (2.1)
	Yes	624	409 (65.5)	215 (34.5)	614 (98.4)	10 (1.6)
Social economic status	Poorest	176	105 (59.7)	71 (40.3)	172 (97.7)	4 (2.3)
	Poorer	148	96 (64.9)	52 (35.1)	143 (96.6)	5 (3.4)
	Poor	150	118 (67.8)	56 (32.2)	171 (98.3)	3 (1.7)
	Rich	174	89 (59.3)	61 (40.7)	148 (98.7)	2 (1.3)
	Richer	161	107 (66.5)	54 (33.5)	161 (100,0)	0 (0.0)
Dietary diversity	No	406	251 (61.8)	155 (38.2)	399 (98.3)	7 (1.7)
	Yes	402	256 (63.7)	146 (36.3)	396 (98.5)	6 (1.5)

In table 3.3 above, approximately 45% of males were stunted whereas the prevalence of stunting among females was 29%. Most children from households that did not own mosquito nets were more likely to be stunted compared to those from households that owned mosquito nets (42.0% vs. 34.5%) respectively. Children from households with protected source of drinking water and diverse diets were less likely to be stunted compared to those from households with unprotected source of drinking water and no dietary diversification, (36.0% vs. 39.1%) and (36.3.8% vs. 38.2%) respectively. Households with no toilet facility were more likely to report stunting compared to those with toilet facilities (41.8% vs. 35.9%).

The prevalence of wasting was the similar between male 7(1.7%) and females 7(1.7%); households with toilet facility 13(1.7%) and without toilet facility 1(1.8%); households with diverse diets 6(1.5%) and those without diverse diets 7 (1.7%). The proportion of wasting was higher in poorer households compared to richer households.

3.4 Characteristics of children <5 years of age, with underweight and overweight

Table 3.4: Underweight and overweight by explanatory factors at baseline among children under five years in Mangochi.

			Underweight		Overweight	
Factor	**Level**	**n**	**Normal n (%)**	**Underweight n (%)**	**Normal n (%)**	**Overweight n (%)**
Infant gender	Male	419	346 (82.6)	73 (17.4)	385 (91.9)	34 (8.1)
	Female	421	378 (89.8)	43 (10.2)	393 (93.3)	28 (6.7)
Source of drinking water	Unprotected	69	59 (85.5)	10 (14.5)	61 (88.4)	8 (11.6)
	Protected	748	647 (86.5)	101 (13.5)	697 (93.2)	51 (6.8)
Type of sanitary facility	None	55	43 (78.2)	12 (21.8)	53 (96.4)	2 (3.6)
	Pit latrine	761	662 (87.0)	99 (13.0)	704 (92.5)	57 (7.5)
Mosquito net ownership	No	193	156 (80.8)	37 (19.2)	183 (94.8)	10 (5.2)
	Yes	624	550 (88.1)	74 (11.9)	575 (92.1)	49 (7.9)
Social economic status	Poorest	176	145 (82.4)	31 (17.6)	162 (92.0)	14 (8.0)
	Poorer	148	123 (83.1)	25 (16.9)	136 (93.2)	12 (8.0)
	Poor	178	156 (85.3)	22 (14.7)	162 (93.1)	12 (6.9)
	Rich	144	128 (89.8)	18 (10.2)	134 (92.0)	10 (6.8)
	Richer	161	147 (91.3)	14 (8.7)	150 (93.2)	11 (6.8)
Dietary diversity	No	406	346 (85.2)	60 (14.8)	379 (93.3)	27 (6.7)
	Yes	402	351 (87.3)	51 (12.7)	367 (91.3)	35 (8.7)

Table 3.4 above shows, underweight differed by gender. The proportion of males who were underweight was 73(17.4%) compared to females 43(10.2%). The prevalence of underweight decreased with an increase in social economic status. The proportion of infants that were underweight was similar between the households with protected source of drinking water 101(13.5%) and unprotected source of drinking water 10(14.5%). The proportion of overweight children was lower in the richer households compared to the poorer households. Children from households with diverse diets were more likely to be overweight 35(8.7%) compared to those who came from households without dietary diversification 27(6.7%).

3.5 Factors associated with stunting among children < 5 years of age; univariate and multivariable analysis

Table 3.5 shows factors associated with stunting. Sex was significantly related to stunting; female participants were at reduced odds of stunting (OR= 0.51; 95% CI: 0.38, 0.67). The odds of stunting decreased significantly with 1-year increase in maternal education (OR=0.94; 95% CI: 0.90, 0.98). There was some evidence that children from households that owned mosquito nets were less likely to be stunted (OR=0.73, 95% CI: 0.52, 1.01) compared to children from households that did not own mosquito nets. For a 1-centimetre increase in maternal MUAC the odds of stunting reduced by 12% (OR=0.88, 95% CI; 0.83, 0.94).

Table 3.5: Results of fitting unadjusted and adjusted logistic regression models by stunting

		Unadjusted			Adjusted		
Variable	**Level**	**Odds Ratio**	**95% C.I**	**p-value**	**Odds Ratio**	**95% C.I**	**p-value**
Infant gender	Male	1	Base		1	Base	
	Female	0.51	(0.38;0.67)	**<0.001**	0.51	(0.38;0.68)	**<0.001**
Mosquito net ownership	No	1	Base		1	Base	
	Yes	0.73	(0.52;1.01)	**0.06**	0.72	(0.51;1.01)	**0.06**
Maternal education	Per 1 year increase	0.94	(0.90;0.98)	**0.008**	0.94	(0.90;0.99)	**0.01**
Maternal MUAC	Per 1 cm increase	0.88	(0.83;0.94)	**<0.001**	0.88	(0.82;0.92)	**<0.001**

The multivariable analysis in table 3.5 shows that adjusting for maternal education, maternal MUAC and mosquito net ownership, the odds of stunting among female infants were reduced by half (aOR= 0.51, 95% CI: 0.38,0.68) compared to males. The results show that children from households with mosquito nets were less likely to be stunted (aOR= 0.72, 95% CI: 0.51, 1.01). Children whose mothers/caregivers had higher education (aOR= 0.94, 95% CI: 0.90, 0.99) and higher MUAC (aOR=0.88, 95% CI: 0.82, 0.92) had 6% and 12% reduced odds of stunting respectively. The unadjusted versus adjusted odds ratios were not changing much, but the CI was slightly getting wider in the adjusted model.

3.6 Factors associated with underweight among children < 5 years of age; univariate and multivariable analysis

In table 3.6 below, female children (OR=0.54, 95% CI: 0.36, 0.81) and children from households that owned a mosquito net (OR= 0.57, 95% CI: 0.37, 0.87) were about half less likely to be underweight compared to male children or those who came from households without mosquito nets.

There was some evidence that children from households with a toilet facility (OR=0.53, 95% CI: 0.27, 1.05) had 47% reduced odds of underweight compared to those from households without a toilet facility.

Our results show; for 1-centimetre increase in maternal MUAC, the odds of underweight reduced by 16% (OR=0.84, 95% CI: 0.77, 0.92). The odds of underweight increased by 29% (OR=1.29, 95% CI: 0.99, 1.55), per addition child who is below five years of age in the household. The increase in the risk was marginally significant. The unadjusted versus adjusted odds ratios were not changing much, but the CI was slightly getting wider in the adjusted model.

Table 3.6: Results of fitting unadjusted and adjusted logistic regression models by underweight

		Unadjusted			Adjusted		
Variable	**Level**	**Odds Ratio**	**95% C.I**	**p-value**	**Odds Ratio**	**95% C.I**	**p-value**
Infant gender	Male	1	Base		1	Base	
	Female	0.54	(0.36;0.81)	**0.003**	0.52	(0.34;0.80)	**0.003**
Mosquito net ownership	No	1	Base		1	Base	
	Yes	0.57	(0.37;0.87)	**0.01**	0.58	(0.37;0.92)	**0.02**
Maternal MUAC	Per 1 cm increase	0.84	(0.77;0.92)	**<0.001**	0.84	(0.76;0.92)	**<0.001**
Number of under five	Per 1 person increase	1.29	(0.99;1.55)	**0.06**	1.29	(1.03;1.63)	**0.03**
Type of sanitary facility	None	1	Base		1	Base	
	Pit latrine	0.53	(0.27;1.05)	**0.07**	0.56	(0.28;1.09)	**0.09**

The multivariable analysis in table 3.6 shows that: Underweight was significantly related to mosquito net ownership; participants from households with mosquito nets were at reduced odds of underweight (aOR= 0.58, 95% CI: 0.37, 0.92). There was a strong association between sex and underweight, with the male children more likely to be underweight (aOR=0.52, 95% CI: 0.34, 0.80). There was some evidence that underweight is associated with the availability of toilet facility in the household; children from households with toilet facility risk of underweight was reduced by 44% (aOR= 0.56, 95% CI: 0.28, 1.09) compared to those without toilet facility. Per 1-centimetre increase in maternal MUAC the odds of underweight reduced by 16% (aOR=0.84, 95% CI: 0.76, 0.92) and 1 person increase in the number of children under five, the odds of underweight increased by 29% (aOR=1.29, 95% CI: 1.03, 1.63).

The prior analysis provided parameters for the macro (population level) and micro (individual level) simulation model. In the individual level simulations, the probability of a child getting malnourished varied by social demographic characteristics and the risk factors identified in the above analysis. Sex of the child and the household mosquito nets ownership were associated with both stunting and underweight hence were included the individual level simulations.

3.7 Mathematical model of Malnutrition

Based on the dynamics of malnutrition, the structure of the model was developed as shown in figure 3.1 below. The scenario for the model was based on a closed population of 747 children, parameter values in table 2.2 and all the assumptions stated earlier. The duration of the simulation model was one year; the same duration as the dietary supplementation intervention in the LCNI-5.

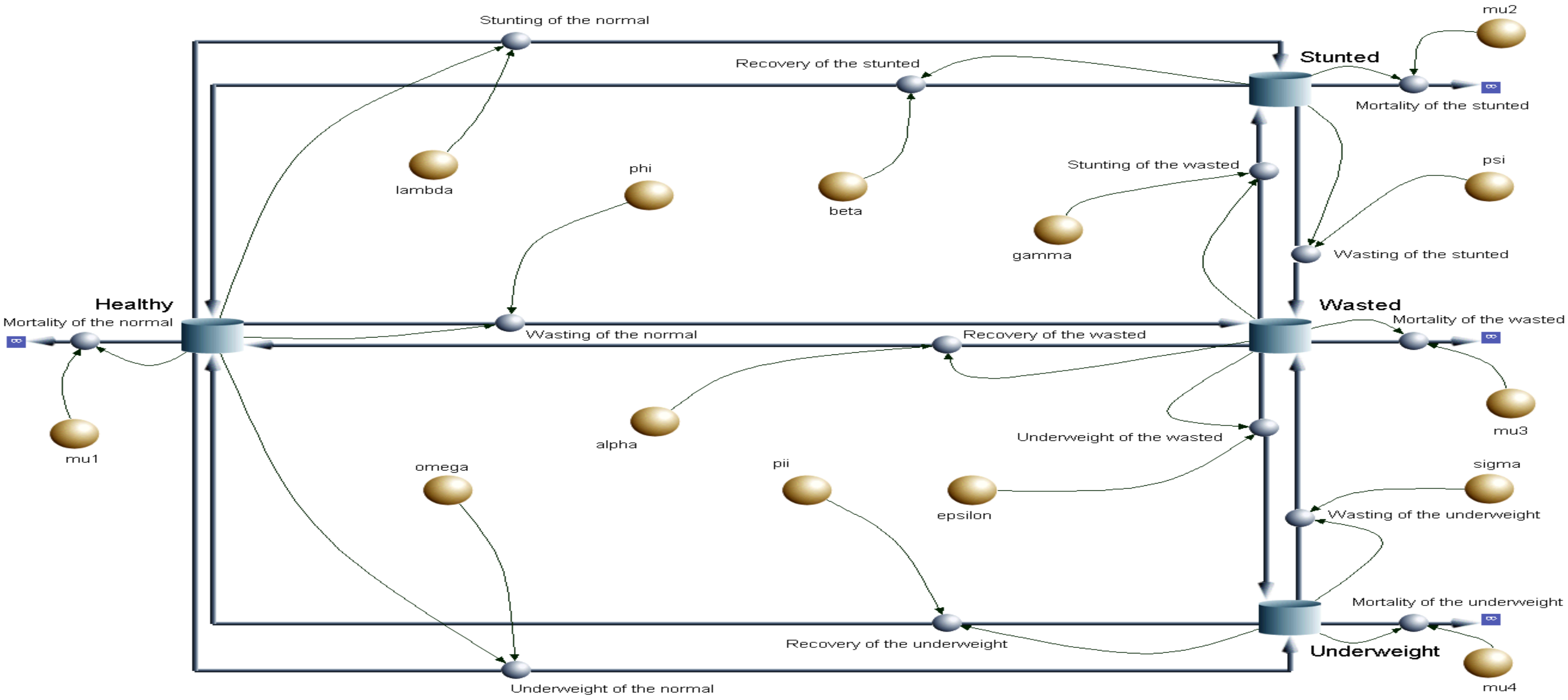


Figure 3.1: Mathematical model structure in Berkeley Madonna

3.7.1 Effects of supplementary feeding

Figure 3.2 below shows that; in milk protein, soy protein and CSB intervention arms, the number of normal children decreased with time. Among the children in the control arm, there was an extreme drop in the number of the normal children and a similar increase in stunting in the first four months. There were more stunted children than normal children from the 4th month onwards. Due to scale limitation, expansion of figure 3.2 (malnutrition without normal group) has been illustrated in figure 3.3.

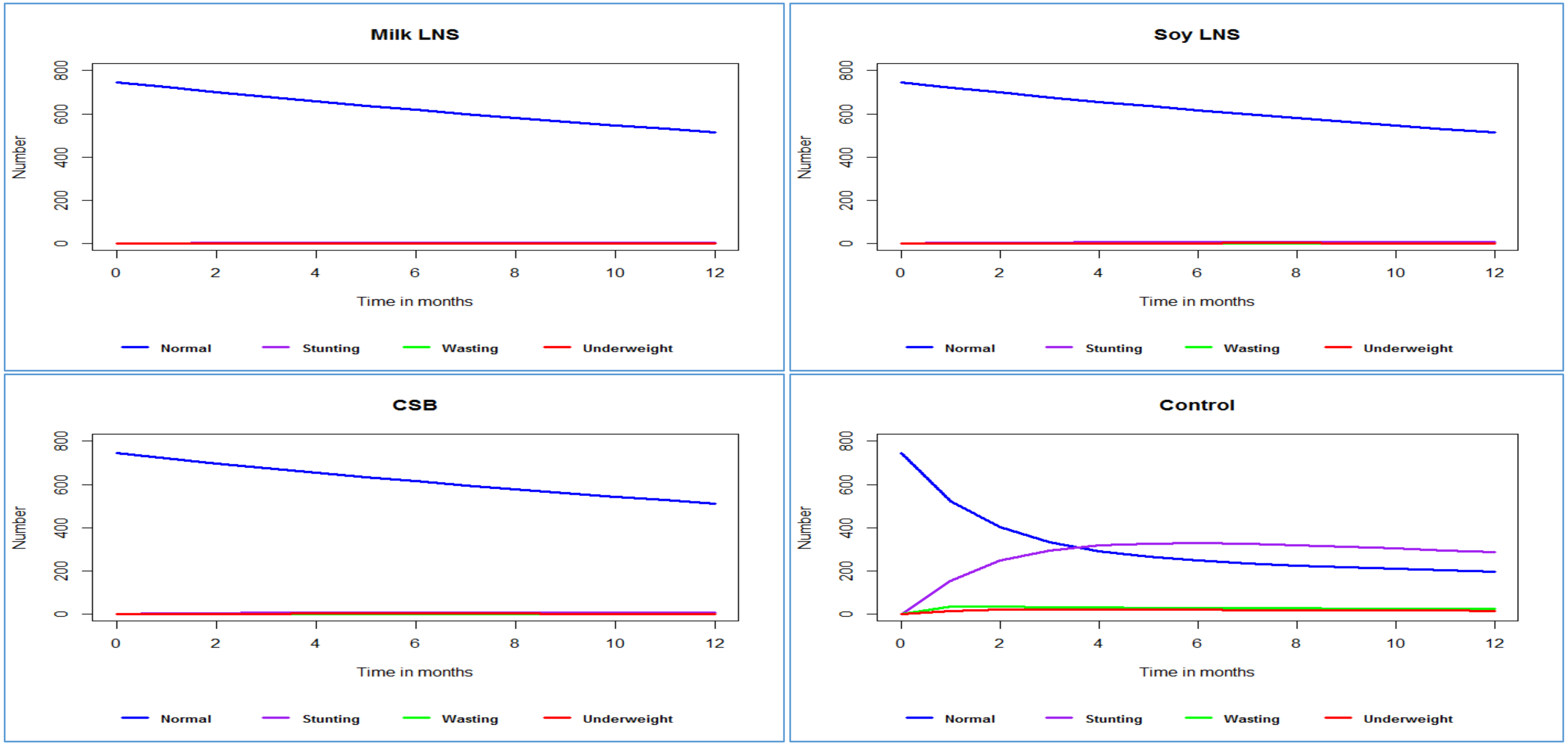


Figure 3.2: Number of normal, stunted, wasted and underweight children by treatment arm

There was an increase in the number of stunted, wasted and underweight children in the entire period in the four arms (figure 3.3). Stunting was the highest form of malnutrition and wasting the least in all the three treatment arms. However, in the control arm, underweight was the least form of malnutrition. Compared to the other arms, there were more malnourished children in the control arm at the end of the 12 months.

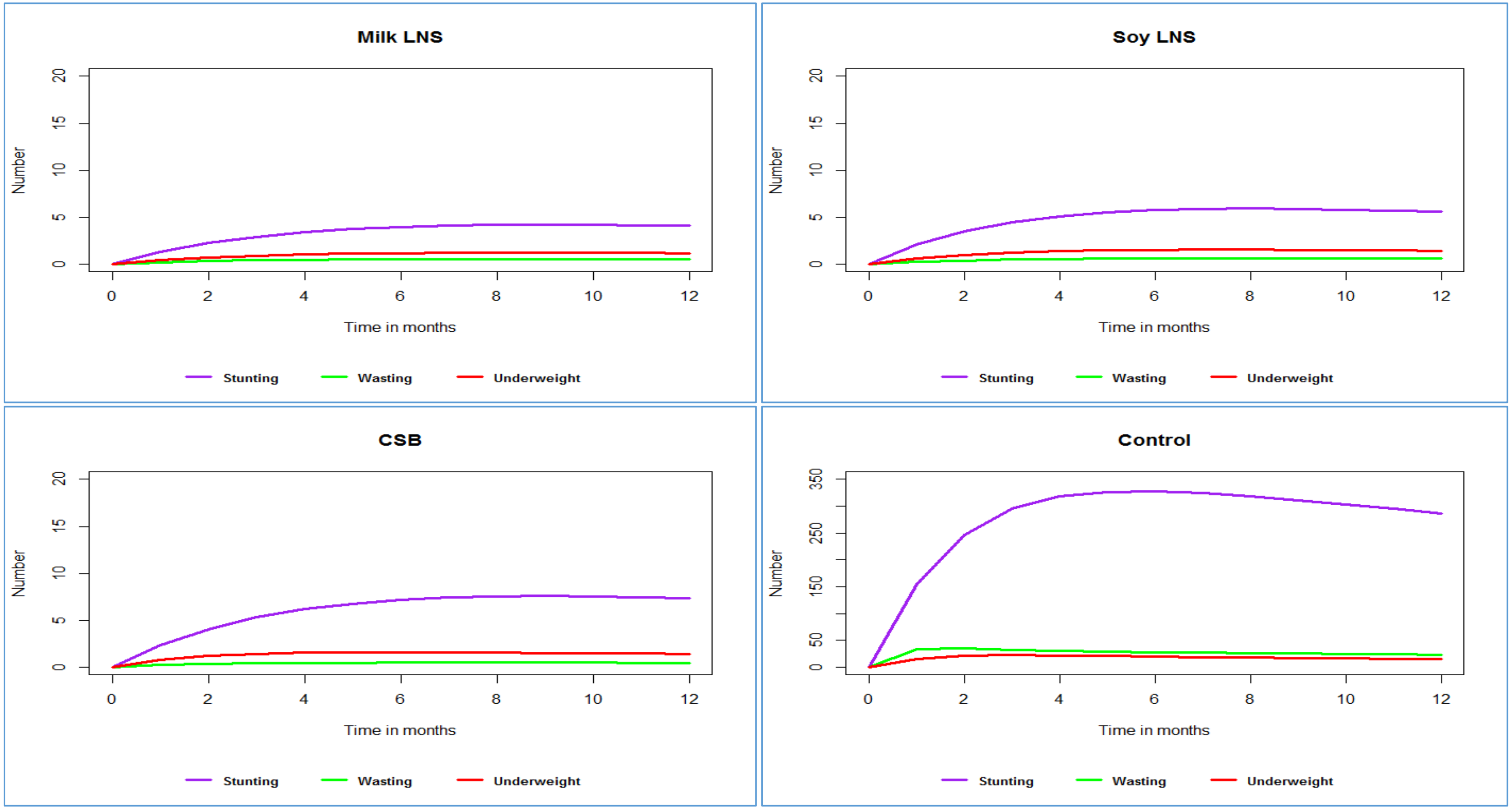


Figure 3.3: Comparison of malnutrition by treatment arm, excluding the normal group

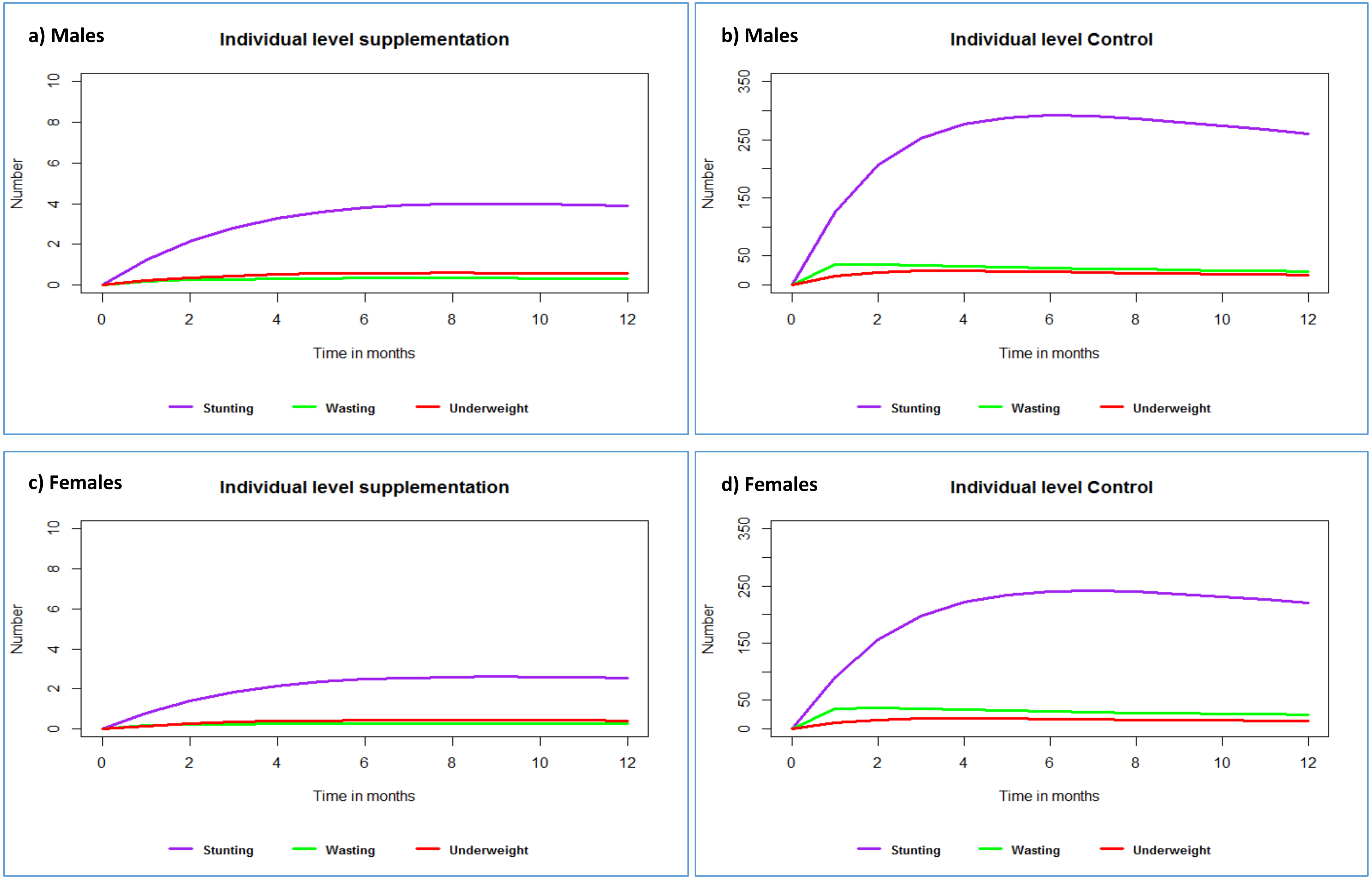


Figure 3.4: Males and female children from households without mosquito nets level of malnutrition

Figure 3.4 above shows individual level analysis (micro simulation. Among males from households without mosquito nets, the number of malnourished boys was more in the control arm compared to the intervention arm at the end of the 12 months (figure 3.4a and figure 3.4b). Stunting was notably higher than wasting and underweight in both the supplementation and the control group. However, this difference was notably higher in the control arm.

The number of malnourished girls was similar between supplementation and the control arms at the start of the intervention (figure 3.4c and figure 3.4d). Nonetheless, at the end of the 12 months, malnutrition was much higher among girls in the control arm than the supplementation arm. While wasting and underweight was stable throughout the 12 months, stunting seemed to increase rapidly up to the 6th months then stabilising after that. There was remarkably higher malnutrition among males than females (figure 3.4) at the end of 12 months intervention.

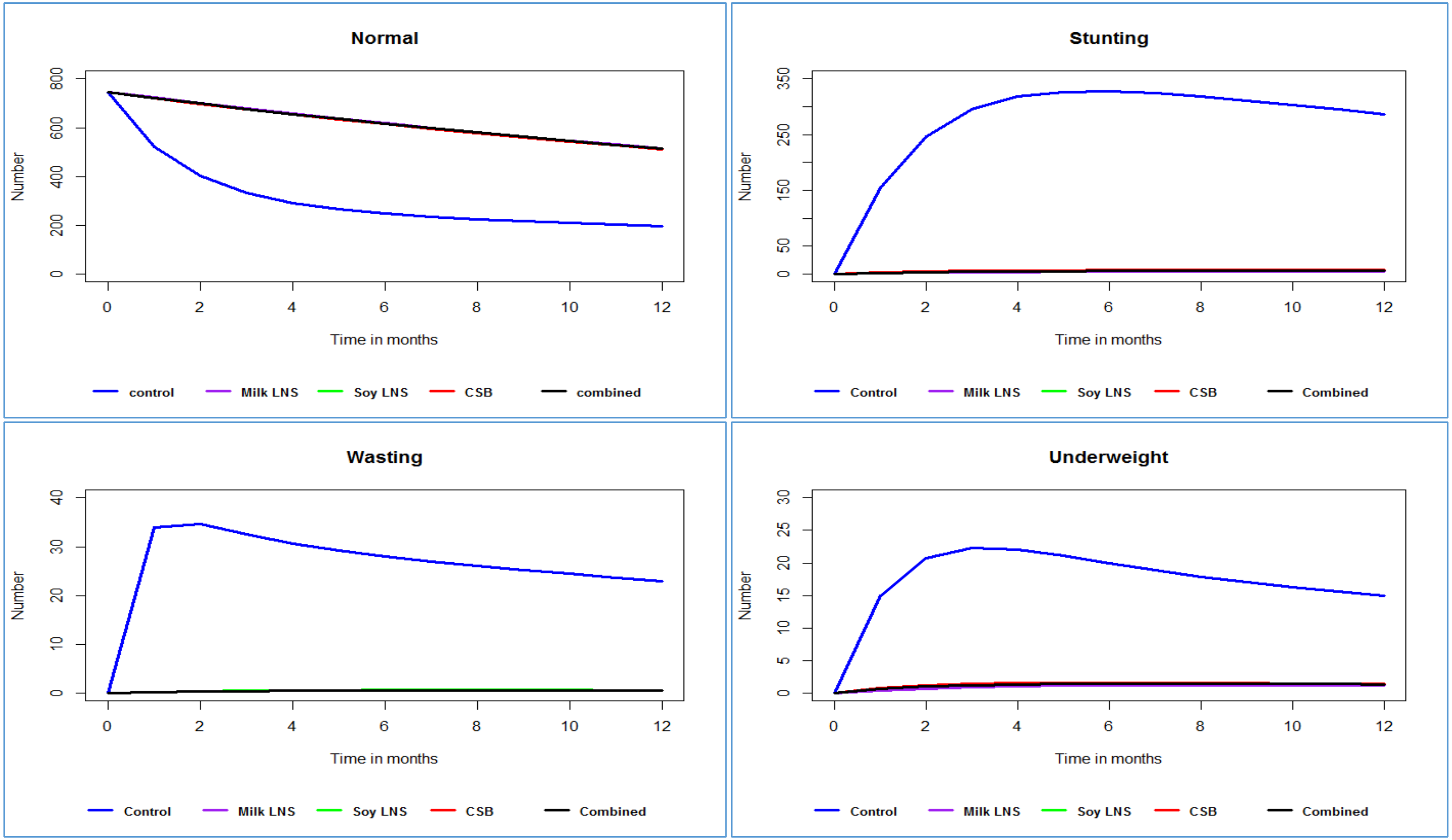


Figure 3.5: Comparison of number of normal, stunted, wasted and underweight by treatment arm with full coverage of supplementation

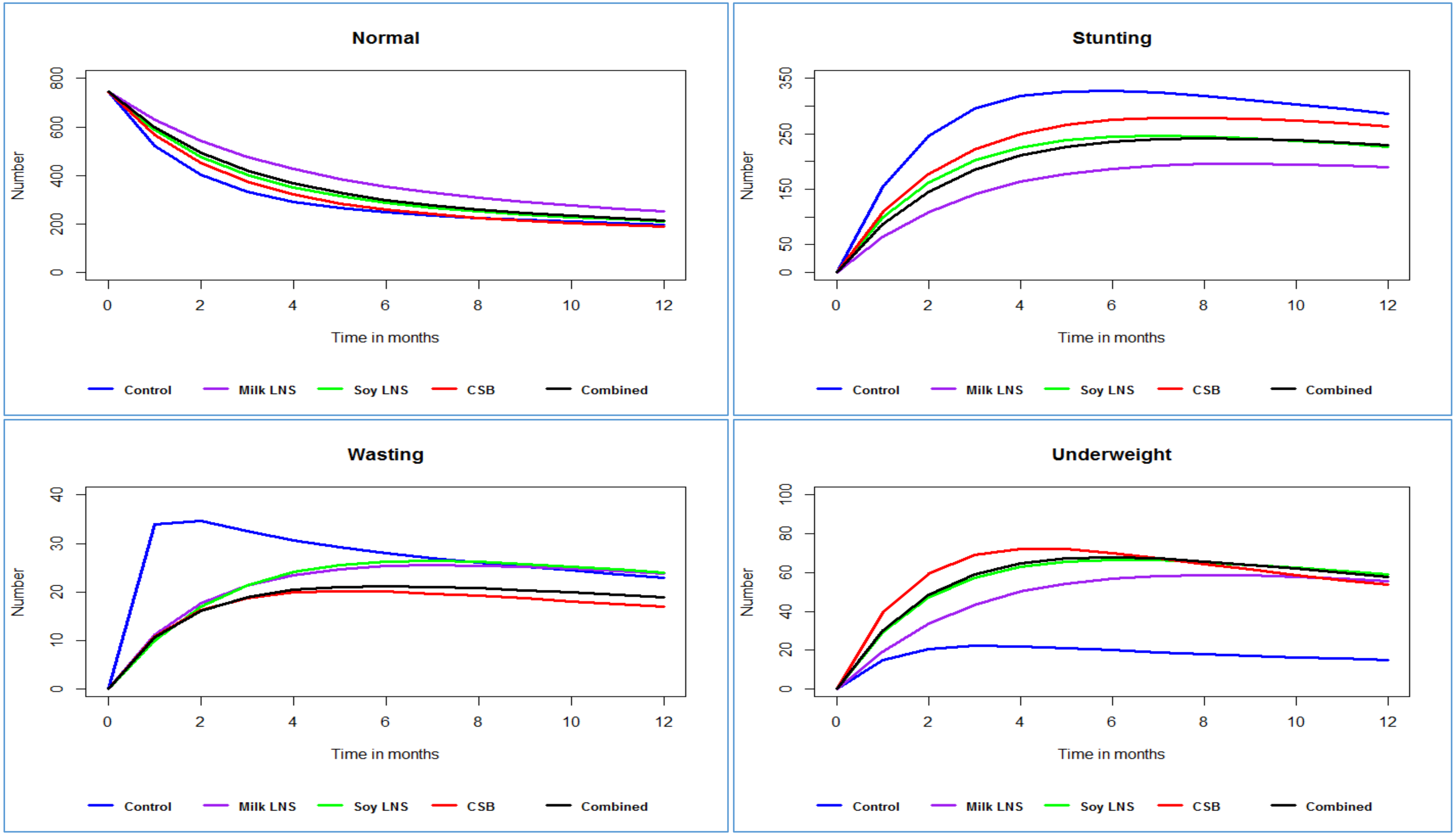


Figure 3.6: Comparison of number of normal, stunted, wasted and underweight by treatment arm with 50% coverage of supplementation

The figure 3.5 above shows; under full coverage (100%) of supplementary feeding, the number of normal children decreased with time. The rate at which the normal children got malnourished was similar for milk protein, soy protein and CSB intervention arms. There was a huge decline the number of normal children in the first six months in the control group. After that, the decline was gradual. There were fewer normal children at the end of the intervention in the control arm compared to the other arms. The number of stunted children increased with time up to the 4th month in the control group then was constant for the rest of the months. There were significantly fewer stunted children in the CSB, soy LNS and milk LNS groups compared to the control arm. Wasting and underweight were very low in all the groups except the control group.

Malnutrition was similar in 50% coverage (half of population supplementation) and 38 % (only malnourished supplementation) as shown in figure 3.6 and 3.7 respectively. Figure 3.7; 38% coverage of food supplementation (malnourished children) shows that the number of normal children decreased rapidly in the first four months then at a much slower rate in the last eight months. There was no much difference in the number of normal children in all the treatment arms. Among the 38% coverage, stunting increased over time. However, CSB group had the highest number of stunted children and milk LNS group had the least number of stunted children at the end of the intervention period. The control group had the highest number of wasted children in the first two months of the supplementation intervention whereas; milk LNS and soy LNS had similar and higher number of wasted children compared to CSB and control at the end of the intervention. The number of underweight children was higher and similar in Milk LNS, soy LNS and CSB compared to control arm. There were fewer malnourished (stunted, wasted and underweight) in the full coverage of intervention scenario compared to 50% and 38% coverage scenario that showed a huge shift of the malnutrition level.

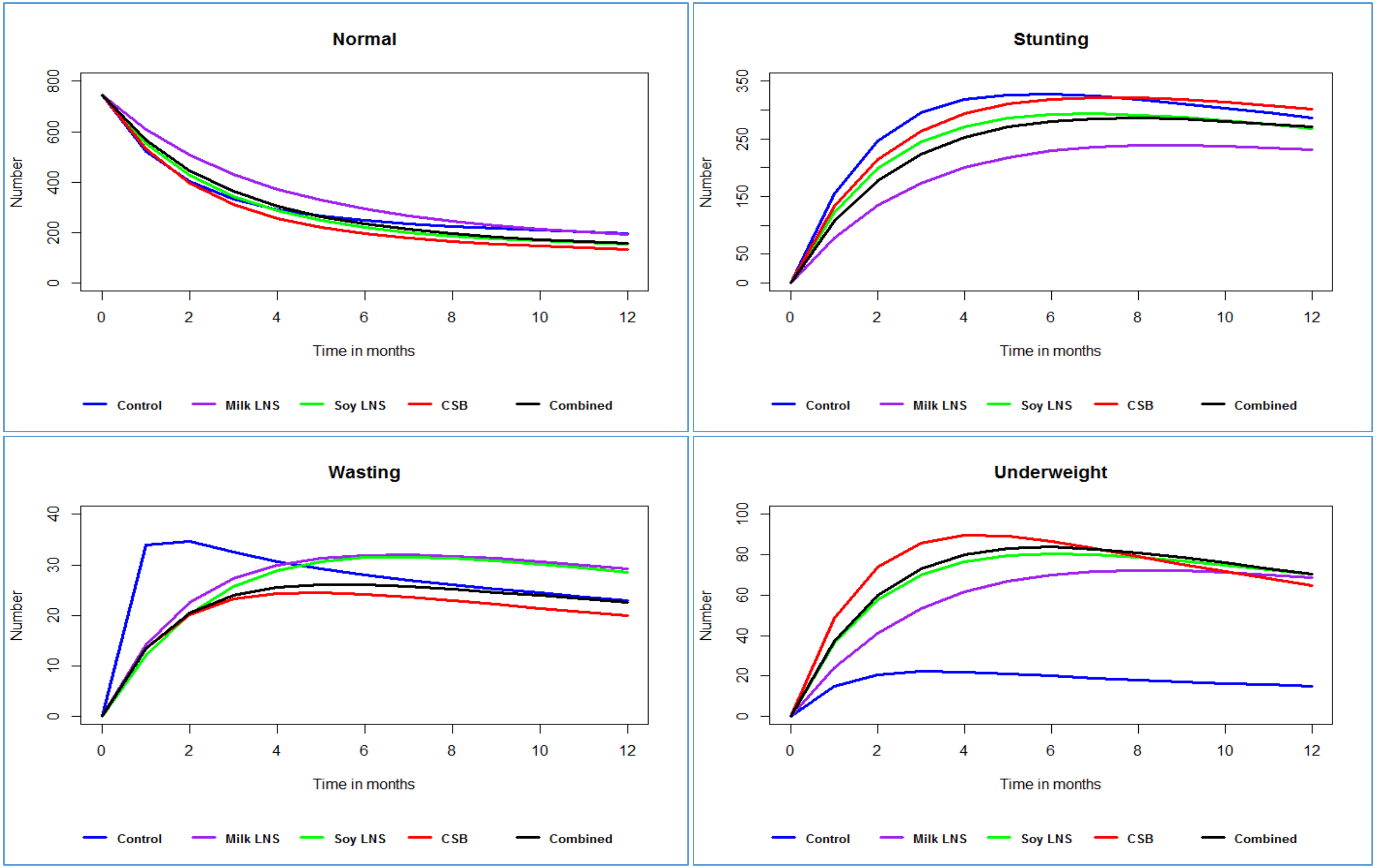


Figure 3.7: Comparison of number of normal, stunted, wasted and underweight by treatment arm with 38% coverage of supplementation

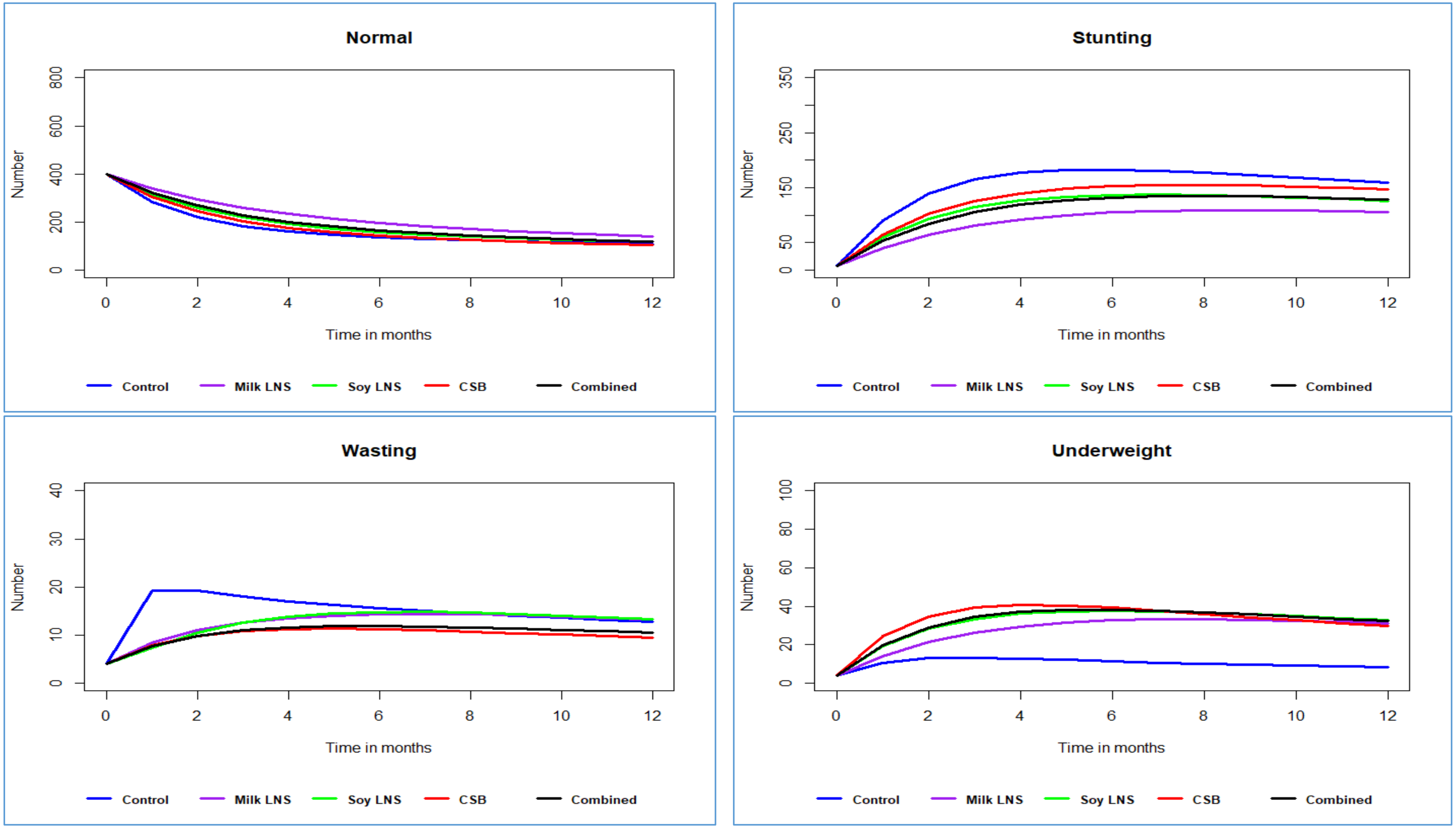


Figure 3.8: Comparison of number of normal, stunted, wasted and underweight by supplementation treatment arm in a randomly sampled population of 400 children

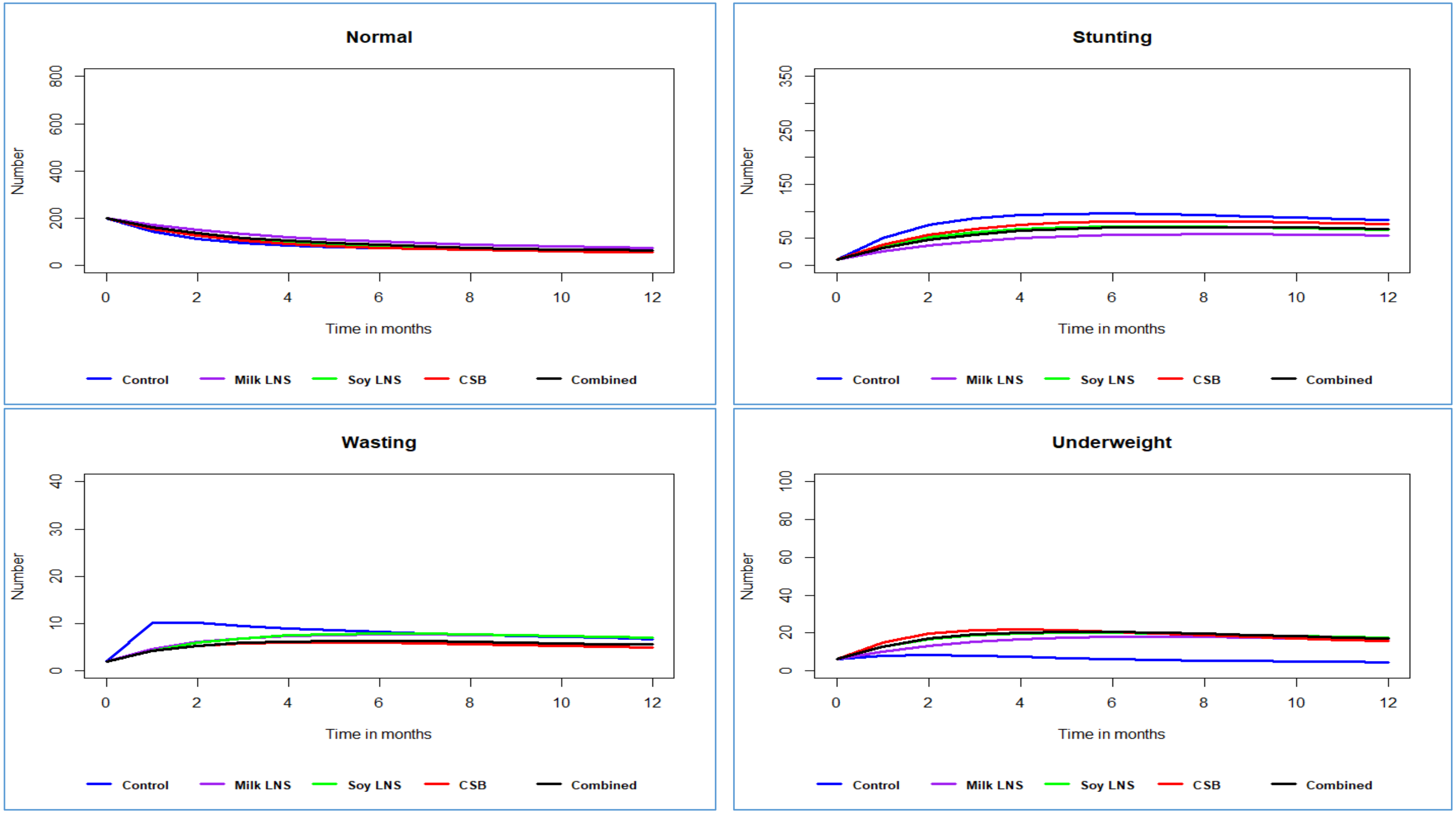


Figure 3.9: Comparison of number of normal, stunted, wasted and underweight by supplementation treatment arm in a randomly sampled population of 200 children

Figure 3.8 and figure 3.9 shows the effect of supplementary feeding on sampled population of 400 and 200 children. Same as in the entire dataset, stunting was the highest form of malnutrition and wasting the least. Children in the control group had higher malnutrition than others.

3.7.2 Effect of maternal health education

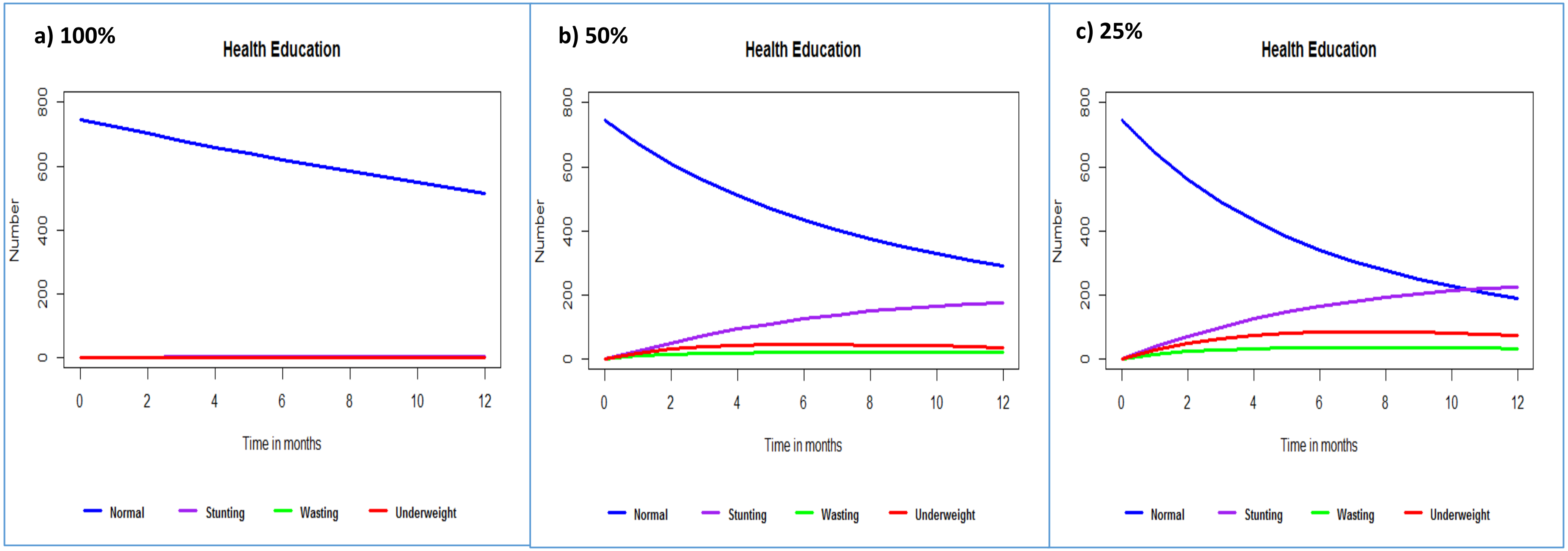


Figure 3.10: Comparison of the level of malnutrition on full coverage (100%), 50% and 25% health education coverage respectively

In figure 3.10, the number of normal children in 100% coverage (education twice a week) decreased at a slow pace over the twelve months period. Whereas, there was a sharp decline in the first 6th months of supplementation then slow pace of decline for the last six months in 50% coverage (education one a week) and 25% coverage (education once a fortnight). The number of children who were stunted, wasted and underweight was low and stable up to month six, then slightly increased in the last six months of the intervention in 100% health education coverage scenario. In 50% and 25% coverage setups, the number of malnourished children was significantly higher at the beginning of the intervention compared to the full coverage. At the 12th month of the intervention, the number of stunted children was more than the number of the normal children in 25% coverage of intervention. The number of the wasted and underweight children was stable in the last six months of supplementation in 100%, 50% and 25% coverage. The number of malnourished children decreased with an increase in the coverage of health education.

Figure 3.11 and 3.12 shows the performance of the health education intervention on sampled population of 400 and 200 children respectively. The number of stunted, wasted and underweight increased in a similar manor in the two sampled populations. However, the increase stabilized towards the 12 month of the intervention. The results from the models fitted in sampled population was comparable to the results from the actual data.

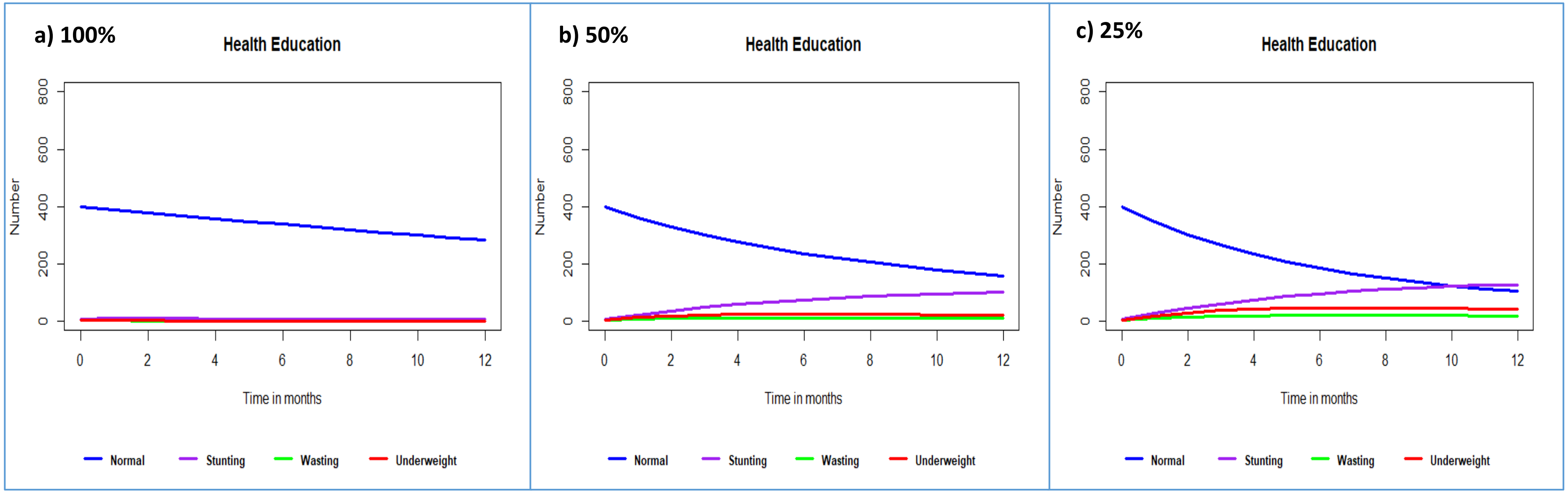


Figure 3.11: Comparison of the level of malnutrition on full coverage (100%), 50% and 25% health education coverage respectively in a randomly sampled population of 400 children

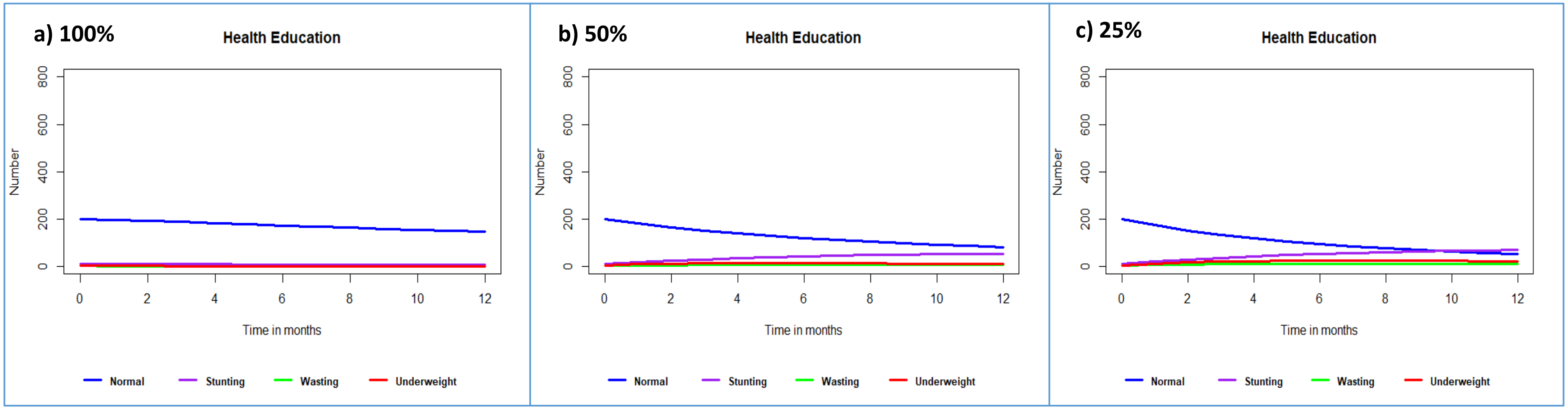
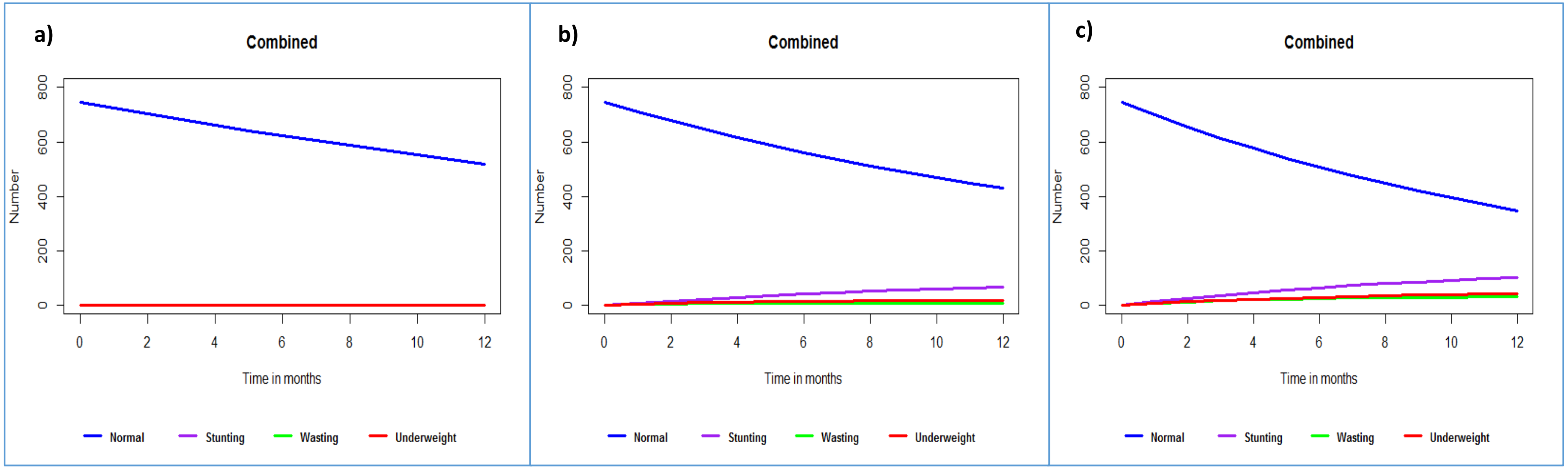


Figure 3.12: Comparison of the level of malnutrition on full coverage (100%), 50% and 25% health education coverage respectively in a randomly sampled population of 200 children

3.7.3 Effect of combined intervention of supplementary feeding and health education

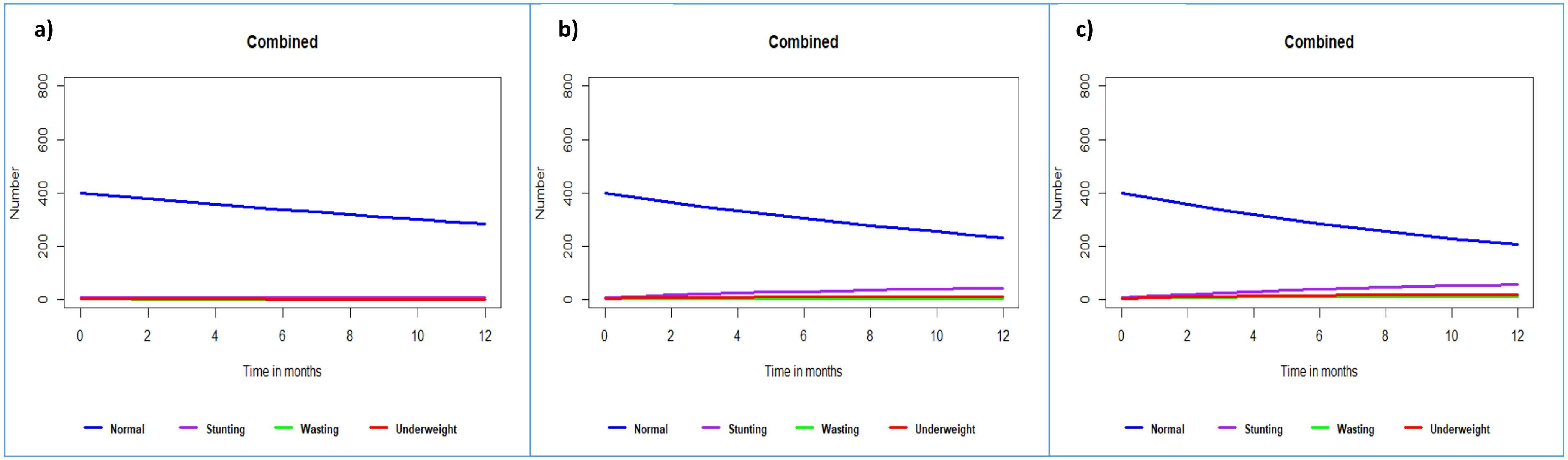


a) Feeding of all the vulnerable population and health education twice a week. **b)** Feeding of half the vulnerable population and health education once a week**. c)** Feeding of only the malnourished children and health education once a fortnight.

Figure 3.13: Combined supplementation and health education with full, medium and least coverage respectively

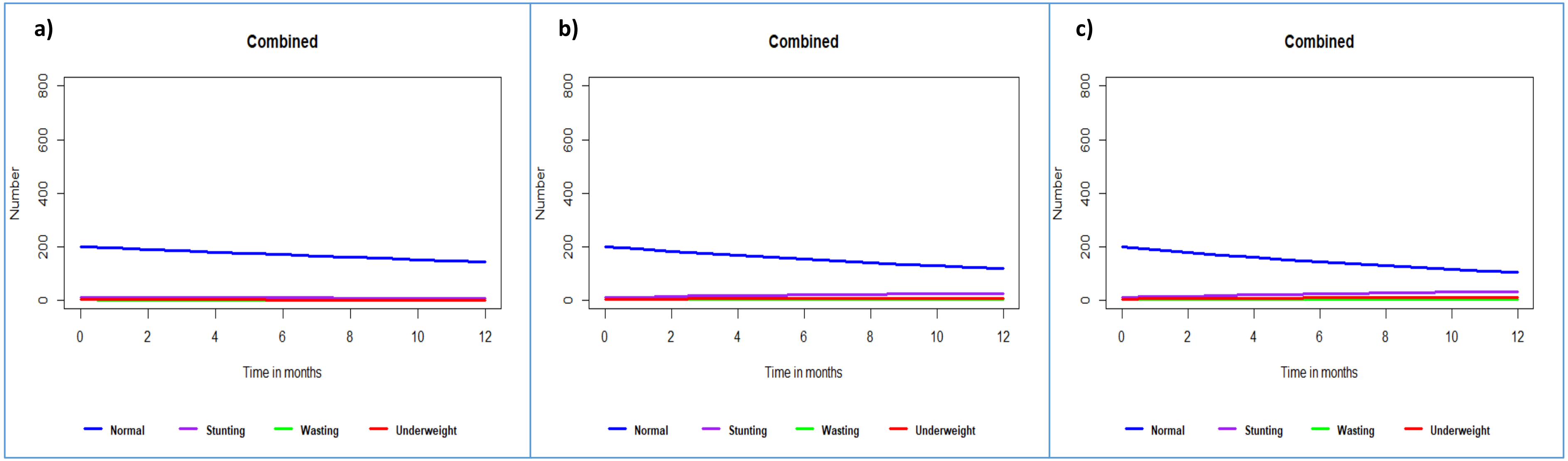
Figure 3.13 above shows the effect of full coverage of combined intervention and partial coverage. The normal children under full coverage (figure 3.13a) of the intervention reduced at a slower rate compared to those under partial coverage (figure 3.13b and 3.13c) of interventions. The number of stunted, wasted and underweight was constant over time in full intervention coverage scenario.

At 12 months of intervention, the number of stunted children was highest compared to wasting and underweight. The number of malnourished children was similar in the full coverage and partial coverage at the beginning of the intervention. However, there were a notably higher number of malnourished children in partial intervention coverage scenarios compared to the full coverage at the end of the intervention.



a) Feeding of all the vulnerable population and health education twice a week. **b)** Feeding of half the vulnerable population and health education once a week**. c)** Feeding of only the malnourished children and health education once a fortnight.

Figure 3.14: Combined supplementation and health education with full, medium and least coverage respectively in 400 randomly sampled children



a) Feeding of all the vulnerable population and health education twice a week. **b)** Feeding of half the vulnerable population and health education once a week**. c)** Feeding of only the malnourished children and health education once a fortnight.

Figure 3.15: Combined supplementation and health education with full, medium and least coverage respectively in 200 randomly sampled children

Figure 3.14 and figure 3.15 shows the change in the number of normal, stunted, wasted and underweight as a result of combined intervention (supplementary feeding and health education) in sampled populations of 400 and 200 children respectively. The rate of malnutrition was comparable in both the sampled population and the whole dataset.

CHAPTER 4

This chapter gives the discussion, limitations, strengths, recommendations and conclusions of our study.

4.1 Study findings summary

In this study, we investigated the effectiveness of nutritional interventions for stunting wasting and underweight in children under five years of age. Our results showed that; the prevalence of stunting wasting underweight and overweight was approximately 37%, 2%, 14% and 7% respectively. Risk factors changed by the type of malnutrition. Maternal education, maternal MUAC, mosquito net ownership and sex of the child were associated with stunting. Type of toilet facility, sex of the child, the number of children under five years and maternal MUAC were associated with underweight.

Health education intervention had a significantly larger reduction in incidence and the prevalence of stunting, wasting and underweight compared to supplementary feeding when applied singly. The highest reduction in malnutrition in children under five years was observed after combining supplementary feeding and health education. Malnutrition decreased with an increase in the coverage of the interventions.

4.2 Characteristics of participants

The results from our study revealed that at six months children in Mangochi were lighter (7kg) and shorter (63cm) compared to WHO reference population where the average weight and length of a normal six months old is 7.3kg and 66cm respectively (62). The finding was coherent to previous research in the same area as concluded by Maleta et al. (63). Low weight and height could be attributed to sub-optimal weaning from exclusive breastfeeding, frequent infections, low birth weight and size as a result of intra-uterine growth retardation and inherent shortness or thinness from the familial path. Similar conclusions were made in three different studies in Malawi (63, 64) (65).

Maternal education was considerably low in Mangochi. On average, women had only four years of schooling. Low maternal education was also reported in other studies in rural Malawi (15) and was similar to what was observed in Mangochi. This could partly be attributed to early marriages, early pregnancies and discrimination on the allocation of household resources to cater for education compared to their male siblings. However, women empowerment has been on the rise in recent years in Malawi like many other African countries and more girls are going to school as reported in Malawi Demographic Health Survey (DHS) 2010 (66).

4.3 Prevalence of malnutrition

The findings from our study show that childhood under-nutrition was very common in Mangochi. At six months of age; 37% of children were stunted, 14% underweight, and 2% wasted. Although the prevalence of malnutrition was still high, it had reduced by almost half compared to previous studies in the same area by Maleta et al. (67) that reported 70% stunting,40% underweight and 6% wasting in 2003. Similar results were reported in Malawi Demographic Health Survey (DHS) in 2010 (66) and WHO malnutrition estimates in 2012 (10).

Malawi DHS 2010 (66) reported a decreasing trend in malnutrition in Malawi over the years. Our findings indicated a decline in the prevalence of malnutrition in Mangochi in 2008 compared to 2003 findings by Maleta et al. in the same area (67) which is consistent with the DHS finding. This could be explained by improved health services, promotion of breastfeeding practices, education on appropriate complementary foods based on the child's nutritional needs, timely vaccinations and improved way of life. Despite a remarkable decrease in under-nutrition since 1992, Malawi DHS 2010 found that overweight which is a sign of over-nutrition has been reported (66). Our results were similar to such findings with 7% of the children in Mangochi being overweight. Other studies have also reported a rise of overweight/obesity in under-developed and developing countries including Malawi (68, 69). This nutrition transition could be attributed to; improved social-economic status, adoption of energy-dense diets that are highly saturated in sugar, fats and refined foods, a lifestyle change that includes reduced physical activities (68, 69).

4.4 Factors associated with stunting and underweight among children < 5 years of age

We found that boys were more likely to be malnourished compared to girls. This was consistent with findings of comparable populations from studies in Uganda, Kenya and Vietnam (21, 70-72). The cause of the difference in the risk of malnutrition by sex is not well established in the existing literature. However, it is believed that environmental stress that manifests as increased morbidity and mortality affects boys than girls (71, 73). Another possible explanation for increased risk of malnutrition among boys could be; boys tend to be more active, running and playing in the neighbourhood that makes them rare at home. Girls, on the other hand, are always at home with their mothers and probably eat whatever small foods their mothers have (21, 24).

Our analysis showed that children from households without mosquito nets were more likely to be malnourished. Studies that have looked at mosquito net use claim that, mosquito nets protect children from mosquito bites that prevent malaria transmission. Young children with persistent episodes of malaria have an acute reduction in weight due to; dehydration caused by diarrhoea and poor appetite, vomiting, tachypnea, hypoglycemia, and inability to breastfeed and/or feed normally (74). A study in Uganda by Olwedo et al. found that communicable disease infection such as diarrhoea, pneumonia fever(malaria) in children is associated with malnutrition (21).

Maternal factors such as education level and MUAC were also significantly associated with child's malnutrition status. These findings were consistent with other studies done in Vietnam and Pakistan (71, 75, 76). In this study, children with more educated mothers were less likely to be stunted. Mother/care giver education level is linked with better utilisation of health care services that are available, effective management of household resources, greater household health promoting behaviours, family planning and efficient child care practices. Moreover, educated mothers are more likely to get better jobs hence can have resources to have better health care services for their children.

Our results revealed that mother's MUAC has a strong link with the child's nutrition status. Similar results were obtained in a study in Bangladesh (77). The risk of malnutrition in children decreases with an increase in maternal nutrition. Maternal malnutrition is common and complex in Malawi with several underlying causes (65). Poverty is the direct cause of girls getting malnourished in childhood through adolescence. The status does not improve even after marriage. Discrimination in food distribution, early marriages, a short spacing between births also partly contributes to poor maternal nutrition. Undernourished mothers mostly give birth to babies with low birth weight and cannot adequately breastfeed their children. This affects the children nutrition status.

The number of children who are less than five years in a family was found to be an important factor related to underweight. Children from households with three or more children who are under five years of age are more likely to be underweight compared to children from households with two or fewer under-fives. This is because caregivers with many children have divided attention and little time to devote to each child's needs compared to those with fewer children. Moreover, there could be competition for the available resources when a family has more children. The finding was similar to the studies in Vietnam (23, 71).

Children from households without a toilet facility were at a higher risk of underweight. The same results were obtained in studies in Brazil and Lebanon(23, 78). Lack of toilet facility might mean inappropriate sewage disposal. This leads to contamination of water sources which in turn increases the risk of infectious diseases like cholera and diarrhoea. These diseases, in turn, lead to malnutrition. Our results were consistent since children from households with protected source of drinking water were less likely to be malnourished although this was not statistically significant in our study.

One difference between the results obtained in this study and other studies is that no association was found between maternal age and stunting or underweight. A previous study by Vanessa et al. in Indonesia and Bangladesh (79) found that younger mothers are more likely to have malnourished children. Younger mothers are mostly not ready to take care of the child and have limited resources compared to older women. Another difference between results of this study and other studies is that we found no statistical association between the household social economic status and malnutrition although there was a similar apparent trend. Earlier research in Peru, Senegal and Kenya (80-82) reported that the risk of malnutrition is lower in richer households. Rich households have access to better health care; have more diversified diets and better child care practices.

4.5 Effects of supplementary feeding

Between group differences in the intervention arms, were small except in the control arm. The number of normal children decreased over the 12 months period. The reduction was due to malnutrition either in the form of stunting, wasting or underweight and natural deaths. The prevalence of malnutrition increased at a slow rate as a result of the intervention. Our findings show that there was similar prevalence of malnutrition in the three arms which was consistent to another different study in Malawi (83). The study suggested that the recovery rates for stunting, wasting and underweight were similar among children who received milk

LNS, soy LNS and CSB as a form of dietary supplementation. However, among the children who did not receive any supplementation, there were more stunted children than the normal after four months which is a clear indication of the need for supplementary feeding especially in emergency situations (36, 84).

At the end of the 12 months, there were slightly fewer cases of stunting and other forms of malnutrition in the milk LNS group compared to other groups. There were biological plausibility and inherent consistency on this finding with earlier studies in Malawi and Ghana (35, 36, 85) that suggested moderate improvement of growth as a result of milk protein intervention.

Our results show that there were more cases of stunting, wasting and underweight in 50% and 38% coverage of supplementation compared to the full coverage (100%) of supplementation. The full coverage of supplementary feeding was informed by blanket feeding supplementary programme that entails feeding of the entire vulnerable population consisting of; all children under five years, elderly people, pregnant or lactating women, medically or socially needy people in a household (34). The 50% coverage was informed by feeding of half the vulnerable population where, one enumeration area would be given the intervention while the other acts as the control. The 38% coverage of supplementation was informed by targeted supplementary feeding programme that focussed on only the malnourished children in the household (34). The high prevalence of malnutrition in 38% coverage of supplementation could be caused by sharing of the portion that was intended for the sick child with the other members of the household. Also, food insecurity in the household might have forced the mother to withdraw other foods given to the child and instead give only the supplement, or there could be the diversion of the supply by selling or trading off the supply with other goods (13).

The sharp increase in the number of stunted, wasted and underweight children in the first two months of supplementation was due to weight loss as a result of transitioning of children from exclusive breastfeeding to complementary feeding. Regardless of full coverage (blanket feeding) being more effective in reducing malnutrition, it may not be sustainable due to high costs for human and material resources involved in its implementation. Targeted supplementation (38% coverage) is more feasible as it requires fewer staff and materials as suggested by Collins et al. (86).

4.6 Effects of maternal health education

Based on our findings, health education significantly reduced malnutrition. More children from caregivers who received full coverage (intensive health education twice a week) remained healthy compared to children, whose care givers received less intensive health education (once a week and once a fortnight). Intensive health education entailed training on the importance of breastfeeding, care practices, disease control, personal hygiene, food security and nutritional properties of different foods twice per week. The middle intensive education training was done one per week on the same issues and least intensive training twice a month.

The low prevalence of malnutrition in full coverage of health education scenario could be due to; increased perception of child feeding practices, changes in child care behaviour and improved health care seeking practices highly motivated by frequent and comprehensive education.

Nevertheless, there were still few cases of stunting, wasting and underweight even in full coverage of health education. Since food security is an issue of concern in Malawi according to UNICEF 2009 (15), the finding could be as a result of some families incapability to afford the nutritious foods, or the women were forced to work hence had very little time to take care of their children. Moreover, the position of women does not allow them to decide on the allocation of resources for food in the household as this is perceived as the responsibility of the husband (31).

In less intensive maternal education (50% and 25% coverage), our findings were; there was a rapid drop in the number of normal children in the first six months. This could be explained by the increase in malnutrition over the same period. The highest cases of stunting were reported at the 12th month as a result of accrued cases of stunting which is difficult to recover (3, 87). Also, the deteriorated cases of wasting and underweight and relapse of stunting might have contributed to the high prevalence of stunting.

Our findings were biologically plausible and coherent with previous research in Pakistan and Sub-Saharan Africa countries like Malawi and Ghana (36, 37, 41, 42) that claimed a reduction in the prevalence of malnutrition by introducing maternal health education. Improved nutrition as a result of health education intervention was also reported even in developed countries like China and India(43, 44). However, another study in India by Bhandari et al. suggested that health education applied alone cannot improve nutrition status (88). Our study suggests that the intensity of maternal education is essential in designing of the intervention for a more desirable effectiveness.

4.7 Effects of combined intervention of supplementary feeding and health education

Our results showed that intensive nutritional education combined with supplementary feeding targeting all the vulnerable population (full coverage) were highly effective as most children remained normal. However, the number of normal children at the end of the 12 months was less than at the beginning probably due to natural deaths. This finding is clear indications that participants in the full coverage of combined intervention were highly motivated to adopt and apply proper child care practices. The provision of feeding to all vulnerable groups reduced the diversion of the supplements to other members of the household with adequate nutritional value.

Although the prevalence of malnutrition in the less intensive health education and supplementary feeding targeting only malnourished children was also low, some children had developed malnutrition by the end of the intervention. This could be as a result of not adequate education that would impact behaviour change and sharing of the supplement with the unintended beneficiary. A similar study in Bangladesh showed that combined intervention improved mother's perception on child feeding and care practices (42). This finding was consistent with our results.

4.8 Limitations

The study had several limitations mainly as a result of secondary data analysis. Firstly, some of the variables like child's HIV status, oedema and the household's food security that might have been potential confounders for malnutrition were not collected in the primary study. Secondly, due to small numbers of wasted children, it was not possible to do risk factors analysis for this form of malnutrition.

The participants in the primary study were enrolled at six months where growth decelerates as children transition from the wholesome breast feeding to suboptimal complementary feeding. This might have diluted the potential effects of the supplementary feeding intervention. Lastly, our study's definition of being malnourished was categorical. Hence, it did not take into consideration the distance to becoming malnourished.

However, despite these limitations, our study has shown that intervention on supplementation does work even when combined with health education. Our study population consisted of children of the same age group in different intervention arms. This allowed us to compare age specific malnutrition rates, and also examine changes in prevalence of stunting, wasting and underweight over some months.

The model was fitted using LCNI-5 study parameters and parameters from existing literature from a comparable population; therefore the results are generalizable in different low and middle-income countries. Finally, this study adds important information on the effectiveness of interventions using a mathematical modelling approach.

4.9 Conclusions

Although supplementary feeding was effective in reducing the prevalence of malnutrition, our results suggest that; households within their available resources can have improved nutrition status without any supplementary feeding, provided that caregivers are educated on improving feeding behaviours, effective child care practices and proper hygiene. Maternal health education interventions have great potential in improving the nutritional status of children under five years of age in developing countries. Therefore, nutritional education interventions should be implemented in combination with affordable supplementary feeding, particularly in middle and low-income countries that are food insecure.

4.10 Recommendations

It should be noted that to address the issue of malnutrition, supplementary feeding or health education interventions alone can't change the underlying factors like sanitation and poor health systems that play a role in poor child growth. There is need to implement the intervention in conjunction with larger strategies like better and affordable health care and improved water and sanitation.

To guide future nutrition investments, further research should be done to compare the cost-effectiveness of alternative intervention strategies like supplementary feeding, health education or both in combating malnutrition.

Health education as a means of reducing malnutrition in children under five years of age should be applied at the community level as preventive and management strategy. This could be a significant step to have culturally-based skills at the community level for long term goals and sustainability.

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APPENDICES

APPENDIX 1: Plagiarism Declaration Form

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

FACULTY OF HEALTH SCIENCES

PLAGIARISM DECLARATION TO BE SIGNED BY ALL HIGHER DEGREE STUDENTS

SENATE PLAGIARISM POLICY: APPENDIX ONE

I **Fridah Karimi Mwingirwa** (Student number: **1476298**) am a student registered for the degree of **MSc. Epidemiology in the field of Biostatistics** in the academic year **2017**.

I hereby declare the following:

- I am aware that plagiarism (the use of someone else's work without their permission and/or without acknowledging the original source) is wrong.
- I confirm that the work submitted for assessment for the above degree is my own unaided work except where I have explicitly indicated otherwise.
- I have followed the required conventions in referencing the thoughts and ideas of others.
- I understand that the University of the Witwatersrand may take disciplinary action against me if there is a belief that this is not my own unaided work or that I have failed to acknowledge the source of the ideas or words in my writing.

Signature: .... Date: 28th January 2018

APPENDIX 2: Ethics Clearance Certificate

R14/49 Miss Fridah Mwingirwa

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M161199

NAME: (Principal Investigator)	Miss Fridah Mwingirwa
DEPARTMENT:	School of Public Health University of the Witwatersrand
PROJECT TITLE:	Modelling the Effectiveness of Nutritional Interventions in Children under Five in Lungwena, Malawi
DATE CONSIDERED:	25/11/2016
DECISION:	Approved uncondtionally
CONDITIONS:	
SUPERVISOR:	Prof Tobias Chirwa
APPROVED BY:	Professor P. Cleaton-Jones, Chairperson, HREC (Medical)
DATE OF APPROVAL:	20/03/2017

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary in Room 10004,10th floor, Senate House/2nd floor, Phillip Tobias Building, Parktown, University of the Witwatersrand. I/We fully understand the the conditions under which I am/we are authorised to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit to the Committee. **I agree to submit a yearly progress report**. The date for annual re-certification will be one year after the date of convened meeting where the study was initially reviewed. in this case, the study was initially review in November and will therefore be due in the month of November each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature

Date 23/03/2017

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES