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The Relationship between Climate Variability, Household Food Security, and Child Nutrition in a Rural Social-Ecological System

by

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Abstract

Climate change is expected to impact livelihoods and human well-being, with rural areas potentially most at risk. The potential impacts of climate change on food security and nutrition in rural communities are particularly worrying. The socioeconomic disparities that exist in South Africa also drive disparities in food insecurity and undernutrition, with some people being affected more than others. Climate change is believed to threaten food security and nutrition, but only a limited number of studies in South Africa have evaluated the impact of climate change on changing household food security and, hence, the nutritional status of children under five years over time. Therefore, this study evaluated how climate variability (a proxy for climate change because of data limitations), specifically changes in precipitation, affected household food security and the nutritional status of children under five years between 2010 and 2021 in a rural social-ecological system in Mpumalanga Province, South Africa. It is the first of its kind to assess the impact of climate variability on the changes in household dietary diversity, the experience of hunger and the prevalence of child undernutrition while considering the impact of household socioeconomic characteristics in the context of a rural social-ecological system. This study is part of the SUCSES (Sustainability in Communal Social-ecological Systems) study, which aims to examine household livelihood and socioeconomic characteristics and how this influences child nutrition. SUCSES is nested within the MRC/Wits Agincourt Health and Sociodemographic Surveillance System site, which consists of 31 villages with households that rely on remittances and government social assistance as their main livelihood strategies. SUCSES, however, comprised 590 households at baseline in 2010.

The children's ages (months), heights (cm) and weights (kg) were available for each household. These measurements were used to calculate the children's weight-for-height, weight-for-age, and height-for-age, respectively, and to categorise the number of children who were wasted, underweight, or stunted according to the United Nations Children's Fund's nutritional standards. These numbers were then used to determine the prevalence and severity of wasting, underweightness and stunting. The household dietary diversity score (HDDS) and the household food insecurity access scale (HFIAS) are two food security indices developed using data from the SUCSES household survey questionnaires. These indices were used to quantify changes and trends in household food security status over time, while household socioeconomic characteristics, such as employment, asset ownership and household head, among others, were assessed as potential drivers of these households' food security status. Then, utilising these food security and nutrition indices, the association between food security and child nutrition was examined. Seasonal precipitation trends were also quantified after converting rainfall averages to precipitation anomalies. The effects of precipitation were then assessed by comparing the variations in precipitation to indicators of food security and nutrition.

Between 2010 and 2021, there was a significant rise in the prevalence and severity of wasting. Similar variations over time were seen in the prevalence and severity of underweightness (low weight-for-age). Stunting (low height-for-age) exhibited the highest mean prevalence and severity compared to wasting and underweightness, which fluctuated over time. The prevalence of stunting had no directional trend over the years, but the severity of stunting has increased dramatically, raising concerns because chronic poverty is a proxy for long-term undernutrition (e.g., stunting). Although the experience of hunger did not change, these households experienced a decrease in the diversity of diets over time. The diversity of diets was only associated with weight-for-height and weight-for-age in girls under five, despite popular research suggesting that food security is a significant contributor to nutrition. Therefore, households with less varied diets reported more wasted and underweight girls. Generally, rainfall stayed above normal between 2010 and 2014 while falling below average in the following years. However, the statistical analysis used in this study did not find evidence to support a downward or upward trend in precipitation over time. Changes in precipitation had little effect on the households' experiences of hunger or how diverse their diets have been over time, but these precipitation patterns were associated with weight-for-height, with wasting (low weight-for-height) being more prevalent in below-average rainfall years.

The study's findings highlight the potential influence of climate change on nutritional status, regardless of changes in household food security, but the study's low sample size may have limited this. Future studies need to build on this research, considering this study's limitations, to gain a deeper understanding of the relationship between climate change, food security and child nutrition.

Keywords

Food Security, Climate Variability, Undernutrition, Rural Areas, Social-Ecological System

Dedication

Ndiyacamagusha kwizinyanya nezihlweli zam. I dedicate this to my ancestors and God, as They are my ultimate source of strength.

I would also like to dedicate this to my parents, Mhlangabezi and Tankiso Xuba; I literally would not be here without them. Not forgetting a dedication to my siblings and best friends, Mandisa and Miliswa Xuba. And last but not certainly least, I would like to dedicate this to my main man, my boy, Yonda Sintu Xuba.

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To be here and complete my thesis, I had to survive a life-threatening condition where I was hospitalised in the ICU at the Life Vincent Palloti Hospital for most of 2020. I am thankful for the doctors, nurses, physical and mental therapists, and other staff who ensured that I live to tell the tale. I trusted those people with my life, and their efforts to make sure that I am alive, as well as their words of hope and encouragement, are the reason I am here today. I really appreciate them. When I left the hospital, I also struggled with physical strength, and I needed to use a wheelchair to move around as I was unable to walk. I was admitted to the Life Vincent Palloti Rehabilitation Unit, where a team of doctors and therapists helped me become independent again, and for this, I will always be grateful.

Throughout all of this, I have had support from friends and family who have been instrumental in my recovery from illness, while some helped me integrate back into society and consequently back to working on my thesis. From the beginning to the end, my parents, two sisters, and my nephew were always there for me when I needed them. The level of gratitude I have for being blessed with my family is unmatched, and fighting for my life, as well as finishing my degree, would not be possible without them.

And last but certainly not least, I give thanks to God and my ancestors, in that order. Ndibulela kuwe wena Qamata, wena wathi “ixesha lakho alikafiki” wandithuma emhlabeni ukuba ndiyokudumisa igama Lakho, ndiyabulela Mdali. Ndibulela namandla othe wanika izinyanya nezihlwele zam ukuba zindikhusele. Mandibuye ndicamagushe kuni zinyanya zam, nina maMpemvu, kuni nina booJali, ooNgciva, ooJuda, ooMngqub’aw’pheli. Ndibulele nakubuhlwele bakulo mama, amaBhele, ooLangalokulunga, ooNtshangase, ooKhuboni. Ngalamazwi andizigatyi kwaye andizilibelanga ezinye izihlwele ezisegazini. Camagu!!

List of Acronyms

AHDSS	Agincourt Health and Demographic Surveillance System
FAO	Food and Agriculture Organization
HDDS	Household Dietary Diversity Score
HFIAS	Household Food Insecurity Access Score
IPC	Integrated Food Security Phase Classification
IPCC	Intergovernmental Panel on Climate Change
MRC	Medical Research Council
SGD	Sustainable Development Goal
SUCSES	Sustainability in Communal Social-ecological Systems
UNICEF	United Nations Children's Fund
WHO	World Health Organisation
WITS	University of the Witwatersrand

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CHAPTER 1
INTRODUCTION

1.1 Research Background

There has been an unprecedented rate of global climate change over the past century, with an increase in global surface temperatures at an average of 0.16℃ to 0.18℃ per decade since the 1970s and an average increase of 1.1℃ from 1900 to 2020 (Caminade *et al*., 2019; Ray *et al*., 2019; IPCC, 2022). The 2010 to 2019 decade was one of the hottest since the beginning of industrial time, with some record-breaking extreme weather events because of anthropogenic activities, causing production effects on the natural environment and its finite resources (Pandy & Rogerson, 2021; IPCC, 2022). Africa has contributed the least to anthropogenic climate change, but it is most vulnerable to its effects because of its low level of adaptability and high vulnerability, which are partly caused by poverty, weak institutional support and the growing population (Connolly-Boutin & Smit, 2016; Caminade *et al*., 2019).

In South Africa, temperatures have increased over the last century, while trends in precipitation have become more variable across the country, with most of the north-easterly parts of the country showing a decrease in precipitation and the number of rainy days (Kruger & Nxumalo, 2017; IPCC, 2022). Although there is uncertainty, projections for the future show a decrease in precipitation and the number of rainy days, with a subsequent increase in rainfall intensity, which would be detrimental to South Africa and its population, considering that the country is already water-stressed (Engelbrecht *et al*., 2015; Pandy & Rogerson, 2021). Climate change presents a problem for human livelihood and health, both directly and indirectly, as it could potentially affect South Africa's water resources, food systems, health, infrastructure and agricultural productivity (Ziervogel *et al*., 2014; Kruger & Nxumalo, 2017). Because of the socioeconomic status and needs of South Africa's population, adaptive responses that reduce vulnerability and sensitivity to climate change are important (Ziervogel *et al*., 2014; Shayegh *et al*., 2021). For example, the historic trends of increasing temperatures have caused increased incidences of heat stress because of the increased number of 'hot days' and the frequency and intensity of heat waves (Ziervogel *et al*., 2014; Scholes & Englebrecht, 2021; IPCC, 2022). These trends are projected to increase, causing more heat-related illnesses and hospital admissions over the coming decades (Ziervogel *et al*., 2014). Vector-borne diseases are also projected to increase in likelihood and severity because of climate change, with linkages to poor infrastructure and quality of public health services (Caminade *et al.*, 2019).

For South Africa, certain barriers to climate change adaptation exist, such as a limited capacity of people and expertise regarding the understanding of climate-related issues, poor intra and inter-departmental communication regarding climate issues, and because climate change has been considered an environmental issue rather than a national development imperative (Ziervogel *et al*., 2014). One of the greatest threats of climate change is the effect on agriculture and food systems. Our ability to meet our food and nutrition needs is dependent on agriculture, and climate change might affect food systems severely; this is a common theme for rural economies in Africa (Dube & Phiri, 2013; Ofoegbu *et al.*, 2017; Fanzo *et al.*, 2018). Climate change will, for example, affect the quality and price of food globally through effects on food production and market conditions. Therefore, access to sufficient, safe and nutritious food will be reduced, especially in low-income countries, thus negatively affecting the nutritional status of the population (Fanzo *et al*., 2018). Climate change will also increase energy costs and reduce water availability, exerting further strain on South Africa's food systems, causing increased food prices and, hence, greater levels of food insecurity (Fanzo *et al*., 2018; Senyolo *et al*., 2018).

In provinces such as Mpumalanga and Limpopo, drought is common, presenting a problem to an agriculture system that is largely rain-fed (Senyolo *et al.*, 2018). About 65% of the total water available in South Africa is used for agriculture, and further decreases in rainfall over the coming decades would, in addition to South Africa's socioeconomic and environmental issues, impact the population's food security status (Dube & Phiri, 2013; Senyolo *et al*., 2018). Coupled with these stresses, the impacts of 'load shedding' where energy sources are severely constrained will further compound the commercial agricultural sectors across scales **(**Punt, 2008; Walsh *et al*., 2021). Agriculture is the backbone of rural economies because it presents a huge economic opportunity for the population, bringing income to many (Diao *et al*., 2010; Dube & Phiri, 2013). In Africa, small-holder farming is an important part of rural economies and livelihoods; however, there has been poor investment in rural agriculture, making it underperform (Dovie *et al*., 2003; Diao *et al*., 2010). This is worrying because small-holder farming could reduce food insecurity in poor rural households because it increases the food supply while decreasing dependence on purchased foods and promoting agro-ecological options beneficial to biodiversity and humans (Baiphethi & Jacobs, 2009; Diao *et al*., 2010; IPBES, 2019).

South Africa's current poverty and unemployment rates are other key factors affecting food security because the loss of employment leads to a reduced standard of living and the inability to purchase food (Masipa, 2017). South Africa is currently food secure, but because of inequalities, 60 to 70% of households experience some sort of food insecurity (Masipa, 2017). By 2080, 9.0 to 21% of agricultural productivity will be lost in South Africa, and with the prospect of drought and lack of rainfall in the future, South Africa will struggle to maintain an adequate supply of food, thus potentially being food insecure at the national level (IPCC, 2007; Masipa, 2017; Myers *et al.*, 2017). Poverty and food insecurity affect the development of children under five, and such effects need not be great to affect child development. As mentioned, food insecurity and subsequent undernutrition are strongly linked to poverty-inducing socioeconomic inequality in South Africa. Child development is largely affected by their nutritional status, which, in turn, is affected by prevailing poverty and food insecurity (Chilton *et al.*, 2007). In South Africa, chronic malnutrition in the form of stunting is a bigger problem than acute malnutrition, such as wasting and underweightness, but these also persist, especially in under-resourced areas (Chakona & Shackleton, 2018; Modjadji & Mashishi, 2020). All forms of malnutrition increase children's mortality risk, hinder cognitive development and lead to poor socioeconomic status in adulthood, thus maintaining the intergenerational transmission of poverty and poor nutrition (Modjadji & Mashishi, 2020).

Meeting global food and nutrition needs is hindered by climate variability and change effects, such as variable rainfall patterns, frequent drought spells and periodic flooding (Fanzo *et al.*, 2018; Senyolo *et al.*, 2018). This is especially true in South Africa's agricultural industry, which consists of largely rain-fed commercial and small-scale farms, and in already-vulnerable rural communities where high levels of poverty, high temperatures and low precipitation limit adaptation capacity (Dube & Phiri, 2013; Senyolo *et al.*, 2018). A significant portion of South Africa's population resides in rural areas with poor infrastructure and a lack of access to basic needs and public services; thus, communities in these areas are highly dependent on forest resources for income and subsistence (Dovie *et al.*, 2003; Ofoegbu *et al.*, 2017).

Nutritional status is considered a vitally important indicator of national development because a healthy and well-nourished population induces a productive labour force, which is crucial for a nation's economic and social development (Vorster, 2010; Chakona & Shackleton, 2018). Every child has the right to good nutrition because early childhood nutrition influences a child's growth, development and survival (World Health Organization, 2020b). Therefore, since the nutritional status of a child under five indicates a household's health and nutritional status, child nutrition must be monitored for the sake of the child, the household and the nation at large (Chakona & Shackleton, 2018). Undernutrition is one of the world's most serious but least addressed problems, and in South Africa, it is heavily linked to the burden of social and economic disparity (Tirado *et al*., 2013; Monyeki *et al*., 2015). Current rates of undernutrition in children indicate that efforts to realise Sustainable Development Goal (SDG) targets and goals to reduce child stunting, underweightness and wasting have not been sufficient. National and subnational data and information systems must be strengthened, ensuring that government obtains timely and good-quality data for nutrition-related policies and interventions (World Health Organization, 2020b).

A limited number of studies in South Africa, such as Monyeki *et al*. (2015), Madiba *et al*. (2019) and Modjadji and Madiba (2019) have assessed the prevalence of child undernutrition. However, only a few have evaluated the prevalence and intensity of child wasting, underweightness and stunting in rural South Africa. Furthermore, Chakona and Shackleton (2018) argued that no study had explored the relationship between household food insecurity, household dietary diversity and child nutritional status in South Africa's mid-size towns, which are characterised by high poverty levels. The current study aimed to add to this limited research, providing such an analysis and the data in the context of a rural social-ecological system. In recent years, several studies, such as Tirado *et al*. (2013), Phalkey *et al*. (2015), Bahru *et al*. (2019) and Drysdale *et al*. (2021), have explored the connection between climate change or variability and its impact on the nutrition of children. Although the number of studies in this field is limited, their findings have highlighted a significant relationship between climate-related factors and child nutrition, particularly in terms of stunting and wasting (Phalkey *et al*., 2015). However, the current study provides greater analysis and insights into the impact of precipitation trends on food security and nutritional statuses over time. The World Health Organisation (WHO) and the Intergovernmental Panel on Climate Change (IPCC) have identified malnutrition as one of the major health consequences of climate change, emphasising its prominence among the top five impacts (IPCC, 2014; IPCC, 2022). This recognition underscores the importance of understanding and addressing the effects of climate change on child nutrition.

Specifically, the study conducted by Drysdale *et al*. (2021) stands out as one of the few research efforts in South Africa that examines the relationship between climate change, droughts and child nutrition. Drysdale *et al*. (2021) shed light on the consequences of droughts on the nutritional status of children in South Africa, contributing to the growing body of evidence linking climate variables to child malnutrition. Overall, while the available studies on climate change and child nutrition are limited, they collectively suggest a strong association between weather variables and nutritional outcomes in children, particularly in terms of stunting and wasting. These findings align with the viewpoints of reputable organisations, such as the WHO and the IPCC, which recognise malnutrition as a significant health impact of climate change.

Phalkey *et al*. (2015) state that there could be a complex set of causal mechanisms that affect the relationship between climate variability and the levels and patterns of child nutrition, but only a few data-driven analyses have been conducted to date. Variable patterns in temperature and precipitation are also known to affect agricultural activities, affecting food production and access, dietary diversity, and, thus, nutritional status. However, variability and trends in climate and the impacts on household food access and the prevalence of undernutrition in children have not been evaluated, especially in rural social-ecological systems. Therefore, in this study, the nutritional outcomes for children under the age of five in relation to household food security and climate variability were described in the context of a South African rural social-ecological system.

1.2 Aim

Given the background outlined above, this study aimed to examine the relationship between climate variability, food security and child nutrition in a rural social-ecological system in Mpumalanga Province, South Africa.

1.3 Objectives, Key Questions and Hypotheses

The following objectives were set out. They are linked to the key research questions and their relevant hypotheses:

1. To quantify the patterns and trends in child wasting, underweightness and stunting in a rural social-ecological system from 2010 to 2021.
    - Was there an increase or decrease in the prevalence and intensity of wasting, underweightness and stunting?
        - ⇒ The nutritional status of children is expected to improve over the years.
2. To examine the relationships between household food security and child undernutrition in these rural households.

- What are the relationships between household food security (i.e., dietary diversity and experience of hunger) and child undernutrition (i.e., wasting, underweightness and stunting)?
    - ⇒ Undernutrition is expected to decrease with an improvement in the food security status of households.

3. To examine the relationships between precipitation variability, household food security and undernutrition in children.
    - What impact does precipitation variability have on household food security status?
        - ⇒ The status of food security is expected to be better in years of above-average rainfall.
    - How does undernutrition change with changing precipitation?
        - ⇒ Undernutrition is expected to be less in years of above-average rainfall.

1.4 Literature Review

1.4.1 Livelihoods in Rural Social-Ecological Systems

There are several framings that can be drawn on to help situate this research. The Sustainable Livelihoods Framework, Social-Ecological Systems, Ecosystem Services and various poverty and agricultural framings can be used when exploring the complex links between nature, climate variability and change, and food security (Adato & Meinzen-Dick, 2002; Turner & Daily, 2008; Preiser *et al*., 2018). A social-ecological system, for example, is a complex system that can be used to examine the relationship between society and ecosystems and their feedback within the system. Long-term management of these systems is critical for the health of humans and the natural environment; therefore, this is important for household food security and the nutrition of children (Everard, 2020). Food systems are symbolic of social-ecological systems because wild foods, for example, which are an important part of poor households' diets, are produced by natural ecosystems. The feedback between the socioeconomic, such as income and assets owned, and the natural phenomena, such as precipitation, within these food systems could encourage unsustainable reliance on these social-ecological systems because households tend to rely on natural resources for coping and adaptation purposes (Golden *et al.*, 2021). Since this current study is undertaken from a rural social-ecological system perspective, it is crucial to comprehend the characteristics of social-ecological systems when attempting to understand rural livelihoods.

Understanding rural communities and the local environment as social-ecological systems provides a framework for exploring relationships between climate variability, agriculture, livelihoods, sociocultural dynamics and ecosystem services (Everard, 2020). This viewpoint must be taken into consideration when assessing how climate variability affects household food security and child nutrition since it illustrates the interconnection and distinctive dynamics of rural communities (Everard, 2020).

Viewing this study using a social-ecological lens, households can be seen as users of ecosystems' services like provisioning services, which include food, fuel, and cultural services such as spiritual fulfilment, among others (Millennium Ecosystem Assessment, 2005; Paumgarten & Shackleton, 2011; Ragie *et al.*, 2020). A sizeable fraction of these households rely on these resources for coping with shocks and hazards and are, therefore, vulnerable to any threats to the sustainability of these systems (Hunter *et al.*, 2011; Paumgarten & Shackleton, 2011). Because the natural resources produced from these ecological systems depend on the health of these ecosystems, which has an impact on people's quality of life, humans need to coexist sustainably with and within these systems (Herrero-Jáuregui *et al.*, 2018). Ecosystem services either contribute to overall livelihood through provisioning ecosystem services or provide opportunities for income generation, aiding in poverty reduction (Hunter *et al.*, 2010; Paumgarten & Shackleton, 2011). In cases of either socioeconomic or biophysical stress (e.g. extreme drought), ecosystem services can be used as coping mechanisms in some places, such as the villages of Bushbuckridge, and, as such, natural resources play a significant role in their livelihoods (Giannecchini *et al.*, 2007; Herrero-Jáuregui *et al.*, 2018). Most households in South Africa's rural areas do not rely extensively on natural resources because remittances from migrant workers and state pensions for the elderly are their main livelihood strategies (Giannecchini *et al.*, 2007; Hunter *et al.*, 2011; Ragie *et al.*, 2020). Environmental resources nonetheless play a significant role in people's lives despite having a lower income share than other livelihood strategies (Hunter *et al.*, 2011). Due to poverty, population expansion and a lack of traditional authorities' control over these resources, among others, some people overuse these resources for commercial purposes, which jeopardises the security of those resources and leads to unsustainable harvest patterns (Giannecchini *et al.*, 2007).

These communities typically have inadequate infrastructure and limited access to public services like water and sanitation, which are essential for child development and for expectant mothers who want to deliver healthy babies (Kahn *et al.*, 2012; Kavosi *et al.*, 2014; Hunter *et al.*, 2021). Ironically, children may get sick where they are supposed to receive medical care because hospitals lack sufficient facilities and hygiene. A large majority of individuals living in these rural areas are black, and disparities and apartheid legacies have not been satisfactorily addressed even decades after apartheid (Turok, 2018; Hunter *et al*., 2021; Pillay, 2021). Due to issues like rising unemployment and load shedding, rural livelihoods would have to rely more on these natural resources (Hunter *et al*., 2011; Mabhaudhi *et al*., 2016). This raises serious concerns since it influences levels of food security, nutrition and healthcare in these areas (Musemwa *et al*., 2015).

Livelihoods and well-being in rural areas are threatened by climate variability through various factors, mainly linked to their ecosystems and ability to produce goods and services (Kronenberg, 2014). The residents of rural Mpumalanga Province claim that soil erosion brought on by deforestation, water scarcity, air and water pollution, and bushfires that may spread faster due to rising temperatures are the most frequent environmental problems in the area. People in the area are very concerned since their environment is connected to their ability to support themselves financially and their general well-being (Hunter et al., 2010). The impacts of climate variability may also affect rural livelihoods through reduced precipitation and increased temperature on small-holder farmer production, which would affect household food consumption and or income generation (Shisana *et al*., 2013; IPCC, 2022).

1.4.2 Climate Variability

According to Serdeczny *et al.* (2017) and the IPCC (2022), Africa is one region of the world most impacted by climate change. Climate change has affected food and water security, and according to climate change projections, Sub-Saharan Africa, particularly, is warming, becoming drier, and experiencing more extreme heat waves and variable precipitation patterns (Serdeczny *et al*., 2017; IPCC, 2022). South Africa is increasingly vulnerable to aridity, which has already affected some areas, such as Cape Town, which already has water resource issues (Filatova & Pohill, 2012; Calverley & Walther, 2022). In low-income rural households where food- and water-borne diseases have increased due to climate change, this exposure has affected food utilisation, an important pillar of food security, thus potentially affecting the nutritional status of people in the households (IPC Global Partners, 2021; IPCC, 2022). However, the greatest pathway through which climate change affects food security is through effects on food availability, where reduced rainfall and increased temperatures and pests plus diseases will reduce food production, thereby reducing food consumption (IPC Global Partners, 2021).

Climate projections in South Africa indicate a rise in temperatures, an increase in the number of days with heat waves, an increase in the severity of extreme weather events, erratic precipitation patterns and fewer wet days in rural regions (Pohl et al., 2017; IPCC, 2022). The erratic nature of the rainfall reduces agricultural productivity because the soil poorly captures the water, while the increased runoff causes soil erosion and, thus, crop damage (Oyebande, 2001; Gandure *et al*., 2013; Nuwagira & Yasin, 2022). Due to their inadequate infrastructure, these areas also have little or no collecting systems for rainwater (Baiyegunhi *et al*., 2015). At the national level, the agricultural sector, which already relies heavily on rainfall, is impacted by changes in rainfall and temperature patterns because many of the crops farmed are vulnerable to temperature rises, especially during the growing season (Mongi *et al*., 2010; Meza *et al*., 2021). This hinders attempts to alleviate poverty and eliminate hunger since food production is reduced, and there will be an increased reliance on coping techniques in these rural communities, threatening resilience to risk (Mongi *et al*., 2010; Hunter *et al*., 2011).

South Africa has a semi-arid climate with frequent dry spells that have significant consequences for food systems and negatively influence lives in all dimensions that will be aggravated by climate change (Masunungure & Shackleton, 2018; Calverley & Walther, 2022; IPCC, 2022). High inequality, as well as other social, economic and governance concerns, jeopardise the country's ability to adapt to future dangers that will arise from climate change (Shackleton *et al*., 2015; Tanner *et al*., 2015; Calverley & Walther, 2022). This would result in an ongoing cycle of generational poverty, impeding the country's progress (Tanner *et al*., 2015). The possible increase in extreme weather events threatens the country's inadequate and unreliable infrastructure, particularly in rural areas (Mpandeli *et al*., 2015). Healthcare infrastructure may be harmed, reducing hospitals' capacity to care for the sick, affecting their health and, thus, nutritional condition (Levy *et al*., 2016; Freeman *et al*., 2017; Satterthwaite *et al*., 2020). Weather-related damage to the nation's transportation infrastructure might impede key industries like tourism, retail and agriculture, which employ a large section of the population (Rogerson & Rogerson, 2015; Satterthwaite *et al*., 2020). This would impact revenue, impacting food security and nutrition (Mugambiwa & Tirivangasi, 2017). Increases in temperature and decreases in rainfall can also hasten the spread of cardiovascular disorders, heat stroke and vector-borne diseases, which directly impact the general populace and, in the case of breadwinners, the entire household (Mugambiwa & Tirivangasi, 2017; Satterthwaite *et al*., 2020; Foggit, 2021).

Southern African food systems, including those in South Africa, are very vulnerable to climate change (IPCC, 2022). Changes in rainfall and temperature could impact livestock survival and agricultural growth, while environmental changes could create the ideal setting for pests to thrive in addition to decreasing water availability (Henry *et al*., 2018; Shahzad *et al*., 2021; IPCC, 2022). These have an overall effect on food production, endangering the stability of the nation's food security (Mugambiwa & Tirivangasi, 2017; Shahzad *et al*., 2021). Damage to transportation infrastructure may make it more difficult to access food markets, and rising population density and climate change may make it easier for diseases to spread. When these factors come together, the nation could face a food security crisis (Fanzo *et al*., 2018).

1.4.3 Food Security

A household, community or nation is considered food secure when all people always have physical and financial access to enough safe and nutritious food that satisfies their dietary needs and preferences for an active and healthy life, according to the 1996 World Food Summit (cited in Mohamed, 2017). According to the United Nations FAO's Integrated Food Security Phase Classification (IPC) division, food security's four elements are food availability, access, utilisation and stability. Food availability is the presence of sufficient quantities and necessary types of food (Ziervogel & Ericksen, 2010). Food access refers to a household or individual's ability to obtain food by methods of production or purchase. Food utilisation refers to the nutritional benefits gained from the food ingested, as well as effective food processing, storage practices, adequate nutrition knowledge, and the availability of adequate health and sanitation services (Mohamed, 2017). The stability of these three dimensions against shocks, such as politics, climate and the economy, is food stability (Department of Social Development & Department of Agriculture, Forestry and Fisheries, 2014; Mohamed, 2017).

Several factors affect food security, and in South Africa, the most prominent ones include the country's growing population and rising unemployment rates, urbanisation and poverty (Akinboade *et al*., 2016). Food insecurity is also exacerbated by health-related problems, with the COVID-19 pandemic's effect on the economy and directly on people's health status serving as a prime example (De Villiers *et al*., 2020; Barrett *et al*., 2022; Ngarava, 2022). South Africa's food insecurity is a serious problem since it is not distributed equitably across the nation because there is food security at the national level but food insecurity at the community or household level (Akinboade *et al*., 2016). According to the General Household Survey of 2021, household food insecurity is common in South Africa. Over 20% of households, primarily in rural areas, had insufficient access to food in 2021 (Statistics South Africa, 2021). Food insecurity occurs when people are unable to manage reduced food availability, access and utilisation and when food stability suffers severely (Ingram, 2011; Myers *et al.*, 2017). In South Africa, inequality has created a spectrum of food security status, with some households experiencing insecurity in short but extreme periods caused by shocks, while others are subjected to chronic insecurity, where food insecurity occurs over longer periods and because of chronic poverty (Akinboade *et al.*, 2016). South Africa continues to battle poverty, as has been clear for decades, so hunger will persist (The Government of the Republic of South Africa, 2019).

Food availability is not the only important factor in food security because households' lack of access to food is South Africa's biggest obstacle to reaching 100% food security (Devereux *et al.*, 2020). Due to their reliance on store-bought food, these households are more susceptible to inflation and rising food costs, which do so at a rate faster than their income growth over time (Schipanski *et al.*, 2016; Pawlak & Kołodziejczak, 2020). Social grants may have been implemented to combat poverty and hunger, but they are insufficient for everyone to purchase adequate food (Mugambiwa & Tirivangasi, 2017). Due to transportation costs when food is brought to rural markets, the rural poor pay more for identically sized food baskets and have less access to a variety of wholesome foods than in urban areas (Pereira, 2014). Because of this, research on food security interventions stresses the significance of local production for raising food affordability. Increasing the number of small-holder farmers will improve access, availability and stability while giving more people a sense of independence (Pawlak & Kołodziejczak, 2020; Sambo *et al*., 2022). In addition to reducing the level of food security in Africa's rural areas, the reduction in small-holder farming over time has led to social, economic and resilience problems, as well as increased vulnerability to social conflicts (Clapp & Moseley, 2020).

The relationship between health, food and nutrition is such that those who experience hunger suffer negative health effects because food is the body's energy source (Shisana *et al.*, 2013). The health and nutrition of children during the early stages of development, when growth is rapid and immune systems are underdeveloped, are also expected to be strongly correlated with food security (Govender *et al*., 2017; Myers *et al.*, 2017). Any compromise caused by food insecurity, poor nutrition and other factors results in poor nutrient absorption, which, in turn, causes serious long-term health issues (Levy *et al*., 2016; IPC Global Partners, 2021).

1.4.4 Child Nutritional Status

According to Section 28 (1) (C) of the Bill of Rights, every child in South Africa has the right to a nutritious diet. Nutrition is essential for a healthy life since there can be no growth or survival without it. The foundation of good health and well-being is good nutritional status, which is crucial from the earliest stages of foetal development onward (World Health Organization, 2020a). However, poor maternal and, consequently, foetal health is common in many communities in southern Africa's rural areas, which compromises the child's physical, mental and cognitive growth and development from birth (Tomlinson *et al*., 2015; Bush *et al*., 2017; Tshotetsi *et al*., 2019). In many low- and middle-income nations, the prevalence of malnutrition has increased, and in around 30% of these nations, one form of malnutrition is highly prevalent (World Health Organization, 2000a; Seferidi *et al*., 2022). Because malnutrition has been associated with greater rates of death, it is harmful, especially to young children under the age of five (Tshotetsi *et al*., 2019).

Despite regulations and programmes pertaining to nutrition in African nations, notably South Africa, there is still a high prevalence of undernutrition among children under the age of five (Shisana *et al*., 2013). Undernutrition is a major source of concern for individuals and countries, and the three major indicators used to define undernutrition are wasting, underweightness and stunting, which are represented as low weight-for-height, low weight-for-age, and low height-for-age, respectively (Madiba *et al*., 2019). Children are considered wasted when their weight-for-height is less than −2.0 standard deviations from the sex-specific reference median, and they are considered underweight or stunted when their weight or height is less than −2.0 standard deviations from the reference median of the same age and sex (Onyango, 2003). A high prevalence of undernutrition indicates a less healthy country and, as a result, a slower rate of economic development. Madiba *et al*. (2019) discovered a very high frequency of stunting (35.8%), underweightness (20.5%) and wasting (17.2%) in South African children under the age of five in impoverished communities. Stunting, in particular, is a problem since it indicates persistent poverty and is the most common form of malnutrition in South Africa (Kimani-Murage *et al*., 2010; Shisana *et al*., 2013). Although South Africa has made significant progress in eliminating undernutrition in recent decades, the prevalence remains high for an upper-middle-class country (Shisana *et al*., 2013; The Government of the Republic of South Africa, 2019; Siddiqui *et al*., 2020).

Child nutrition and health status trends in South Africa reveal the country's levels of food security, which are characterised by less nutritious and diversified diets, a proxy for poverty (Siddiqui *et al*., 2020). Although South Africa has a double burden of malnutrition, the consumption of fats and processed animal meat, which is the major cause of overweightness and obesity, are more prevalent in metropolitan areas (Kimani-Murage *et al*., 2010; Sartorius *et al*., 2015). Rural communities are characterised by low-diversity diets consisting of high amounts of traditional staple foods and a lack of protein and healthy fats, which are essential for their health and well-being. Reduced small-holder farming also results in less consumption of fresh produce, which lowers micronutrient intake (Chakona & Shackleton, 2017; Govender *et al*., 2017). Another contributing factor is poor feeding practices. For instance, in some households, infants receive insufficient amounts of breastmilk and nutrient-poor meals, which are insufficient for their nutritional requirements (Chakona, 2020). Education levels, health, socioeconomic conditions and water availability have all been linked to undernutrition, and in rural South Africa, HIV is another factor that has an impact on children's nutritional status both directly and indirectly through illness or the loss of the primary breadwinner (Kimani-Murage *et al*., 2011; Kahn *et al*., 2012; Chakona & Shackleton, 2017).

The South African Constitution and several other government documents and reports state that the welfare of children is a national priority (Barbarin, 2003; Schmid & Patel, 2016). Several national policies and programmes of action have been enacted since the end of apartheid, such as the National Programme of Action for Children in South Africa that was launched in 1996, emphasising the need for good child nutrition, healthcare and early childhood development (Barbarin, 2003). Since then, major policies, such as The National Policy on Food and Nutrition Security (2013) and the Roadmap for Nutrition in South Africa (2013-2017), have been enacted with the purpose of ensuring national- and household-level reduction of food insecurity and malnutrition, mostly for children. Objectives of these policies include introducing or increasing agriculture investments, nutrition education and the integration of departments and policies to improve mortality-inducing nutritional levels.

1.5 Study Approach

In this study, a social-ecological system lens was used to examine child nutrition-environment relationships. These communal rural areas are approached as social-ecological systems characterised by feedback between the biophysical and social components that regularly interact sustainably, and this interaction affects the availability of critical resources (Everard, 2020). A social-ecological system lens can be used to gain important insights into the relationships between human societies and their ecosystems, assisting in creating more efficient policies and initiatives to support environmental sustainability and child nutrition.

This study integrated climatic and sociodemographic data for a rural region of Mpumalanga Province. It used a pre-existing longitudinal rural household dataset that includes household socioeconomic and food security data, as well as child anthropometrics. Undernutrition metrics such as wasting, underweightness and stunting were assessed to infer child nutrition patterns and trends. Child anthropometric measures, particularly weight (in kilograms), height (in centimetres) and age (in months), were used to compute each child's weight-for-height, weight-for-age and height-for-age ratios. These ratios were assessed against the United Nations Children's Fund's (UNICEF's) child nutrition standards to quantify wasted, underweight or stunted children. Household dietary patterns were used to develop food security indicators, such as the dietary diversity score, which accounts for the different food groups consumed in the household, while the food insecurity access scale was developed according to the patterns of hunger in the household. Using these two indicators, changes over time were quantified and trends were evaluated. These food security indicators were then compared to the child nutrition indicators to assess the association. In investigating the effects of climate change on food security and child nutrition, precipitation variability was used to infer climate change in the absence of long-term rainfall data and other climate-related features. The study used a quantitative analysis approach because all data, from anthropometric measurements to household dietary diversity and food insecurity, as well as the rainfall data, are numerical.

1.6 Structure

This dissertation comprises six chapters, with three key data chapters (three to five) that correspond to the study's objectives. Chapter 1 describes the study's background and importance, reviews literature relating to the study's key topics, and outlines the aim, objectives, research questions and hypotheses. Chapter 2 describes the study site and methodology. The first data chapter (Chapter 3) investigates the patterns and trends in the prevalence and severity of undernutrition (i.e., wasting, underweightness and stunting) between 2010 and 2019. Chapter 4 assessed the changes in household food security status (dietary diversity and the experience of hunger) and how household socioeconomic characteristics such as employment affect these changes. The chapter also evaluates the relationship between food security and undernutrition. Chapter 5 examines the extent of the variability in rainfall and the impact of this variability on household food security and the undernutrition in children. The last chapter (Chapter 6) presents the overall discussion and conclusions, while providing future research recommendations.

CHAPTER 2
STUDY SITE AND GENERAL METHODS

2.1 Study Site

2.1.1 Geography

The study was undertaken at the well-established Agincourt Health and Demographic Surveillance System (AHDSS) site, which is managed by the MRC/Wits Rural Public Health and Health Transitions Research Unit (Agincourt Unit) of the Medical Research Council (MRC) and the University of the Witwatersrand (Wits) (Kahn *et al*., 2012). The AHDSS is in the resource-poor local municipality of Bushbuckridge in the Mpumalanga Province of South Africa (Figure 2.1), 500 km from the city of Johannesburg and close to the Mozambique border (Kabudula *et al*., 2017; Watkins *et al*., 2019). The study area (Figure 2.2) is about 450 km^2, consisting of 31 villages with over 22 000 households and over 110 1000 residents (Kahn *et al*., 2012).

The AHDSS site is in a former homeland area of the apartheid era, where black people were forcibly moved, resulting in high human density, increasing pressure on the natural environment and its resources (Ragie *et al*., 2020). Although the villages of Bushbuckridge are scattered throughout the landscape, the resettlement that occurred during apartheid is still evident (Ragie *et al*., 2020; Hunter *et al*., 2021). Villages in Bushbuckridge consist of homesteads and are surrounded by communal rangelands (Ragie *et al*., 2020). Homesteads typically include dwellings, animal pens or kraals, and home gardens where subsistence farming is practised, while the rangelands are where grazing of livestock and foraging for environmental products occurs, as well as cultivation by households with not enough space for subsistence farming (Ragie *et al*., 2020).

Figure 2.1 Geographical location of MRC/Wits Agincourt Health and Demographic Surveillance System study site in Mpumalanga Province, South Africa

[Source: https://www.agincourt.co.za/?page_id=1896#PrettyPhoto[1896]/0/]

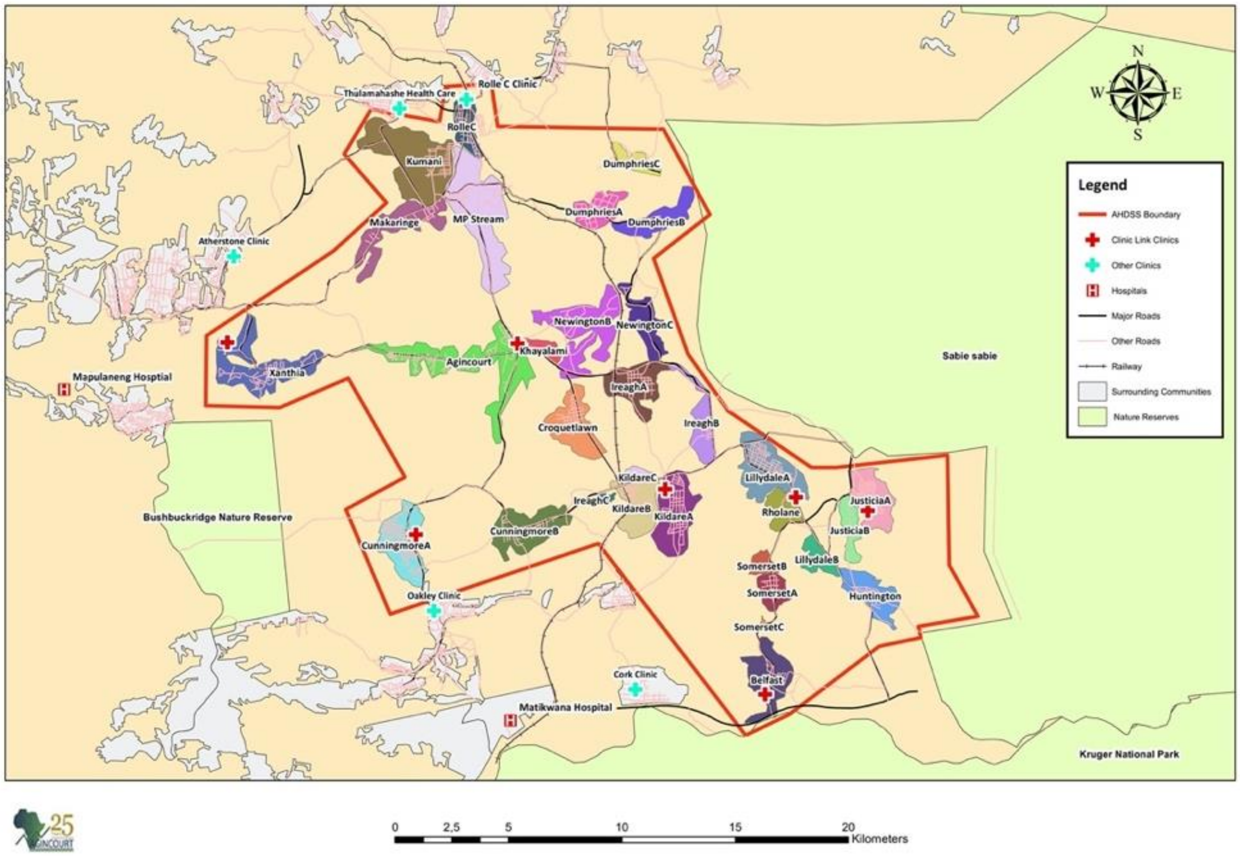


Figure 2.2 Villages within the MRC/Wits Agincourt Health and Demographic Surveillance System study site boundary

[Source: https://www.agincourt.co.za/?page_id=1896#PrettyPhoto[1896]/0/]

2.1.2 Climate and Vegetation

The region is dry with an annual rainfall of 550 to 800 mm per annum and a rainfall gradient from east to west; the west with an average of 800 mm while the east receives around 550 mm, resulting in the variation of vegetation density and natural resource availability across this site (Giannecchini *et al*., 2007; Hunter *et al.*, 2021; Ragie *et al*., 2020). The site has a mean annual temperature of approximately 22°C and below-average sunlight during summer for a savanna biome (Hunter *et al*., 2021; Manyuchi *et al*., 2022). The area is relatively dry in winter (May to October), characterised by summer (October to May) rainfall with high humidity, and it has an overall semi-arid climate suitable for game farming rather than agriculture (Kahn *et al*., 2012; Ragie *et al.*, 2020; Manyuchi *et al*., 2022). The area also has mild short-term and localised storms and strong winds that account for over 10% of crop failure in the area (Tibesigwa *et al*., 2016).

The area has experienced rising temperatures since 1916, with temperatures increasing by 0.5℃ per decade and marked increases in the minimum temperatures during the summer and autumn months (Manyuchi *et al*., 2022). There has also been an increase in the number of hot days and hot nights, as well as daily temperatures that have risen by 1.5℃ between 1992 and 2013, while the rainfall continues to be highly variable (Manyuchi *et al*., 2022; Rusere *et al*., 2023). The area has an altitude of less than 600 m above sea level and is characterised by a terrain that is shallowly undulating (Mbiba *et al*., 2019). The soil in the area is infertile with deeper duplex soils in the base of the catena, but shallow sandy lithosols generally everywhere else, suitable for game rather than agricultural use (Kahn *et al*., 2012; Mbiba *et al*., 2019). Vegetation is typically broad-leaf savanna woodland characterised by three vegetation types, namely, granite lowveld, which is the most common, gabbro grassy bushveld and legogote sour bushveld (Mbiba *et al*., 2019).

2.1.3 Socioeconomic Characteristics

The AHDSS site is characteristic of all rural areas in South Africa, with high population densities, high poverty, poor infrastructure and limited access to public services (Kahn *et al*., 2012). While the community relies on piped water from boreholes or local dams and streams for domestic use, agriculture in the area is largely rain-fed (Kimani-Murage *et al*., 2010; Pereira *et al*., 2014). Socioeconomically, it is characterised by high reliance on remittance from adults who are migrant workers, and a substantial portion of the households depend on government social support such as old-age pensions and child grants (Hunter *et al*., 2020). Unemployment rates remain high, and households engage in an array of informal livelihood strategies, such as arable agriculture, home gardens, livestock husbandry, collection of natural resources for sale and consumption, small-scale enterprises and migrant labour (Madubansi & Shackleton, 2007). Residents use the natural environment for a range of purposes, and although subsistence farming is an important livelihood strategy, it is only a secondary livelihood strategy (Hunter *et al*., 2020; Ragie *et al*., 2020). Households in the area are dependent on rain-fed agriculture and have low adaptive capacity because of their low economic resources; thus, any weather-related events with negative effects because of climate variability would likely exacerbate food insecurity and, hence, poverty (Tibesigwa *et al*., 2016; Masipa, 2017). It comes as no surprise that the health care system and the health status of the people in these areas are low, considering the low socioeconomic status and prevailing poverty (Tibesigwa *et al*., 2016; Burger & Christian, 2020).

2.1.4 Land Tenure

Land tenure in the study site is communal. These communal lands are characteristic of many in South Africa where land is used for agriculture, grazing and resource harvesting, which is shared by the community but are managed by traditional leaders or authorities who also play a significant role in the transfer and disposal of land (Adams *et al*., 1999; Weinberg, 2015). Land dispute is inevitable, as traditional authorities complain about being undermined by the local government in terms of land rights, while councillors complain that development is halted by traditional leaders who want to retain land for themselves (Adams *et al*., 1999; Findlay & Twine, 2018). This conflict ignores the view of the poor citizens that have occupied the land for decades, and inequality has existed between and within sexes as women were not permitted to own land, as 'customary' rules were maintained with men as heads of households being responsible for decision-making concerning land (Weinberg, 2015). For most people living in rural areas like Bushbuckridge, their land rights are uncertain and vulnerable. Over two decades post-apartheid, the government has failed to carry out widespread tenure reform, although the right to security of tenure is expressed in Section 25(6) of the Constitution (Cousins, 2015; Weinberg, 2015). However, land tenure reform has been expressed as one of the three main objectives of the South African government's land reform programme (Cousins, 2015; Weinberg, 2015).

2.1.5 Food Systems

Households in the site rely on several food sources, ranging from purchased to cultivated to wild harvested. These homestead plots have small gardens that are not big enough to support subsistence agriculture, but crops such as maize (staple crop), vegetables, ground nuts and fruits are cultivated (Hunter *et al*., 2007; Pereira *et al*., 2014; Ragie *et al*., 2020) About 96.8% of households in the study site cultivate traditional crops such as maize and vegetables because these have greater resilience to the local environmental conditions, and any deviation would increase vulnerability to food insecurity (Hunter *et al*., 2007; Pereira *et al*., 2014; Ragie *et al*., 2020). Agricultural practices in the area are largely reliant on the area's inconsistent rainfall, with many households making use of communal land of poor granitic soils to grow enough food for consumption and sales (Pereira *et al*., 2014; Ragie *et al*., 2020). Households also own cattle, goats, and pigs, where these commonly graze on communal rangelands (Ragie *et al*., 2020). Grains, sweets, and vegetables are the most consumed food, while chickens are the most consumed meat since they are kept and bred by many households (Pereira *et al*., 2014; Ragie *et al*., 2020).

Households that produce their own food are believed to be more resilient to shocks that affect food security such as the effects of the 2008 food crisis because they produce their own food and are not vulnerable to changes in purchasing power because of said shocks (Nawrotzki *et al.*, 2014; Béné, 2020).

Maize, rice, and bread are the commonly bought staple foods, and while villagers have the option of travelling to urban and peri-urban centres to purchase food, supply is also mediated through local entrepreneurs (Pereira *et al.*, 2014). These include spaza shops, general dealer stores, and local street vendors who sell fresh produce (Pereira *et al.*, 2014). This substantial reliance on purchased food makes this population vulnerable to food insecurity and consequent undernutrition (Kimani-Murage *et al.*, 2010). Food production in the area has been reduced, mainly because of the reduced land and water availability, reduced cattle for ploughing and a general disinterest in agriculture (Giannecchini *et al.*, 2007; Pereira *et al.*, 2014).

A few households rely on agriculture as their main food source, while many rely on purchased food, although they have low purchasing power (Kimani-Murage *et al.*, 2010; Twine & Hunter, 2011). When households cannot meet their food security needs, such as households that cannot grow or buy their own food, they rely on their neighbours for support, in addition to the use of natural resources (Twine & Hunter, 2011; Pereira *et al.*, 2014; Mbiba *et al.*, 2019). Households may also supplement the food grown with natural resources, such as wild fruits, indigenous spinach and insects, which is common in food-insecure households (Pereira *et al.*, 2014; dos Santos *et al.*, 2019). However, the use of natural resources as a coping strategy in areas of high population density and poverty, such as Bushbuckridge, is a threat to sustainability. The expected increase in climate variability could mean that households that practice small-scale subsistence farming may be compelled to rely more on natural resources (Tibesigwa *et al.*, 2016).

2.2 Data Collection

2.2.1 The SUCSES Household Panel Study

This study is part of the SUCSES (Sustainability in Communal Social-ecological Systems) study, which aims to examine household livelihood and socioeconomic characteristics and how this influences child nutrition, in the AHDSS site. The SUCSES study analyses the relationship between the environment and society at the individual, household and village levels. The objectives of this household panel study are to investigate the drivers of household reliance on natural resilience for their livelihoods and the importance of environmental resources as coping or adaptation strategies during times of livelihood shock and to evaluate the links between human well-being, household use of natural resource and the natural environment. This study helps identify, understand and respond to threats against and opportunities for well-being and ecological sustainability, which is necessary for informing policy.

The SUCSES livelihoods panel study consists of a random sample of 590 households. The sample was drawn from 12 census villages in 2010 across nine settlements spanning the range in village size and the west-to-east rainfall gradient on the AHDSS site. Data collection is through surveys designed in detail, collecting data on livelihood strategies capital, the experience of shocks to livelihoods and how these households respond to such. In addition to this, an environmental monitoring system is also being developed to complement the household livelihood data collected. The household survey includes a roster that collects data on the status of health and education, age and gender, and the contribution to the household income of each household member, whether they are temporary or permanent migrants. Finally, food and nutrition security measurements are recorded for the household survey. This includes the number of meals per day, dietary diversity, the experience of hunger and coping strategies.

In the first round of the survey (2010), each household was assigned a unique SUCSES code (001-600). The household survey was done annually from 2010 to 2014 and again in 2019 and 2021. The survey interviews are conducted annually from April to June at the end of the agricultural and vegetation growing season, which is the crucial period for the livelihood perspective of the rural areas. Informed consent was obtained before conducting the survey interview, and as far as possible, the interview was conducted with the person in charge of overseeing day-to-day household activities, such as resource collection, cooking and shopping. The interviews were conducted in Shangaan, but the questionnaires were filled out in English.

After each interview, every child in the house who was at least 12 months but younger than five years of age on the 15th of June of the relevant year was measured and weighed. Height was measured in centimetres (cm) to the nearest centimetre using a portable stadiometer. Two height measurements were taken, and certainty was established that the two height measurements were not more than 2.0 cm apart. Weight was measured in kilograms (kg) to the nearest 0.1kg using a digital bathroom weight scale. Measurement order was as follows: height1; weight; height2. To maximise the availability of children for taking measurements, this part of the survey was conducted in the afternoon so that school-going children were catered for.

All data were entered using a purpose-built front-end on Microsoft Excel, and to ensure low input error, a double-entry system was used. The Excel file was then imported into a Microsoft Access database to archive the data. Starting in 2019, data has been collected using a tablet, checked, and then integrated into the existing data.

2.2.2 Climate Data

Rainfall data were collected from Newington Gate (24°55’ S, 31°29’ W) located in the Sabi Sand Game Reserve, approximately 40 km away from Agincourt village. The data made available were rainfall data dating back to 1989 until 2020. Although the anomalies described in Chapter 3 were calculated using the long-run average from 1989 to 2020, for the sake of this project, only data from 2008/2009 up until the 2020/2021 rainfall season was used to assess precipitation patterns because this corresponds to the timeline of the food security and nutrition data. As such, in the current study, climate variability was used as a proxy for climate change because the dataset does not fulfil the 30 years of rainfall needed for any climate change trend analysis, according to the World Meteorological Organization (Shevchenko *et al*., 2020).

2.3 Data Preparation

Upon acquiring the anthropometrics, food security and climate data, the data were cleaned and sorted to eliminate any inconsistencies that could compromise the accuracy of the results, such as incomplete data points for each individual or household used in the study. Anthropometric data of children over 60 months was removed because the study focused on statistics for children 60 months or younger because the nutritional stats of these children are a proxy for households’ access to food and the development of a country. This reduced the sample size, but enough data was maintained for most of the years, i.e., 2010 (140), 2011 (226), 2013 (132), 2014 (120) and 2021 (110), with 2019 (35) having a relatively small sample size. The household survey included data from 2010 to 2014 and 2019, and all data from 2012 was removed because no anthropometric data were available for those years. Additionally, only household survey data from households with anthropometric data were selected; the rest were removed. All the data was collected using Microsoft Excel, while analysis was done on R Studio. The data analysis methods are described in the relevant data chapters (Chapters 3 to 5).

2.3.1 Child Nutrition

Using the data collected during the household survey, child anthropometric data, i.e., child height (cm), weight (kg) and age (months), were extracted to evaluate the extent and trends in child wasting, underweightness and stunting among children aged five and younger between 2010 and 2021. The study consisted of an average of 127 children per year over six years. The largest sample size was in 2011, with 226 total children, while the smallest was in 2019, with 35 children. The youngest female child participant was 12 months old, the youngest male participant was nine months old, and the oldest for both genders was almost 60 months old.

Weight-for-height ratios for the children were calculated to compare them to the WHO's child growth standards for wasted, normal and overweight children. Wasted children have a weight-to-height ratio below 2.0 standard deviations from the sex-specific median, while overweight children have a ratio above 2.0 standard deviations (see Appendices 1 & 2, and Appendices 3 & 4). According to the WHO's child growth standards, underweight children have a weight-for-age ratio below 2.0 standard deviations from the same-sex median, while overweight children have a ratio above 2.0 standard deviations, concluding on the statistics for underweight, normal and overweight children (see Appendices 5 & 6). Lastly, the proportion of normal, stunted or overgrown children was evaluated. A stunted child has a height-for-age ratio below 2.0 standard deviations from the sex-specific median height for a given age, while overgrown children have said ratio of above 2.0 standard deviations from the median.

2.3.2 Food Security

Two food security indices were developed. In this case, the indices represent food consumption, an integral part of food security that has direct relevance to nutrition. The first index is the Household Dietary Diversity Score (HDDS), which represents the qualitative consumption of food in households, reflecting the household's access to various food groups consumed in the last 24 hours before the interview. This consists of 13 food groups; thus a maximum score of 13 would mean all food groups were consumed, and 0 being none. The second index is the Household Food Insecurity Access Score (HFIAS), which represents the experience of hunger. This index considers three measures of food shortage in a 30-day period, i.e., the lack of access to food because there was no money to buy food, going to bed on an empty stomach and going the whole day without any food. Each measure has a score from 0 to 3, 0 being never and 3 being quite often (indices). The maximum HFIAS would be 9, meaning the highest level of experience of hunger. Households with no children as participants in the anthropometric surveys were removed from the food security analysis, and only the relevant households' HDDS and HFIAS were extracted, ensuring that the datasets were congruent.

2.3.3 Climate Variability

In this study, we had to give priority to the rainfall data due to the limited availability of temperature data. We were able to identify variations from the typical or predicted rainfall patterns by concentrating on rainfall anomalies, which are frequently more relevant for comprehending how climatic variability affects food security and nutrition (Niles & Brown, 2017). The results might have been different in a few ways if rainfall had been a continuous variable. Extreme weather events, such droughts or floods, can have a significant impact on agricultural output and food security, but they may not be sufficiently captured by continuous rainfall data. Through our emphasis on rainfall anomalies, we were able to draw attention to these deviations from the norm, which has allowed us to gain a more comprehensive understanding of the connection between climate variability and the consequences related to food security and nutrition. Annual seasonal years (July to June) were used to capture the rainfall of the full growing season (October to March) before each survey round. Rather than using raw annual rainfall data, annual metrics were quantified as rainfall anomalies, which represent the variability of rainfall relative to the long-term mean, using the equation:

$$Z = ((xi - x\text{-}i))/s,$$

Where 'Z' is the standardised rainfall, 'xi' is the seasonal mean rainfall, 'x-i' is a long-term mean seasonal rainfall over a period of observation and 's' is the standard deviation of seasonal rainfall over the period of observation.

The anomalies were calculated using the seasonal rainfall data from 1989/90 to the 2020/21 season, and thus, the rainfall anomaly scores represent the rainfall variability from 1989/90 to 2020/21. A negative rainfall anomaly represents decreased mean seasonal precipitation relative to the long-term average, while a positive anomaly represents an increase.

This chapter has provided an in-depth review of the study site and the main research procedures used in the well-established AHDSS in rural South Africa. The AHDSS is operated by the MRC/Wits Rural Public Health and Health Transitions Research Unit and is in the resource-poor municipality of Bushbuckridge in Mpumalanga Province. It covers around 450 km^2 and comprises 31 communities with over 22 000 houses and over 110 000 persons. The climate of the region is semi-arid with irregular rainfall, making agriculture difficult. High poverty rates, restricted access to public facilities and dependency on remittances and government assistance are typical socioeconomic characteristics. Food systems comprise a mix of purchased, farmed and wild-harvested commodities, and land tenure is communal and prone to dispute. The chapter also discussed data gathering methods, such as the SUCSES Household Panel Study, climate data collection and data preparation, establishing the framework for later chapters' analyses of child nutrition, food security and climate variability.

CHAPTER 3

TRENDS IN THE PREVALENCE AND SEVERITY OF CHILDHOOD UNDERNUTRITION

3.1 Abstract

The nutritional status of children has been an important topic of discussion internationally as undernutrition persists even after the efforts through the Millennium Development Goals and, subsequently, the Sustainable Development Goals thus far. Undernutrition has impacts on the health of children under the age of five, weakening their immune systems and making them more susceptible to infections and diseases. However, trends in the prevalence and severity of child undernutrition have not been thoroughly assessed in South Africa. Therefore, this study aimed to quantify the patterns and trends in the prevalence and severity of undernutrition in children under the age of five in Bushbuckridge, Mpumalanga Province. The analysis was conducted using anthropometric data from 2010 to 2021, using metrics guided by the World Health Organization and United Nations Children's Fund, i.e., wasting (low weight-for-height), underweightness (low weight-for-age) and stunting (low height-for-age). Chi-squared tests were used to assess the changes in undernutrition, while Mann-Kendall tests were conducted to assess the trends in the prevalence and severity of the resulting changes in undernutrition over the years. Significant variations in the state of children's nutrition were found, with increasing trends in the prevalence and severity of wasting and underweightness in children in Bushbuckridge. Although the prevalence of stunting has not increased over the years, there has been an increase in the severity of stunting. The increasing severity of stunting in the area is indicative of the chronic poverty which persists, raising concerns about the physical and cognitive development of these children.

Keywords

Undernutrition, Wasting, Underweightness, Stunting, Prevalence, Severity

3.2 Introduction

Nutrition is an important part of the 2030 SDG because SDGs 2 and 3 strongly emphasise evaluating nutritional status at the individual level when assessing progress towards goals. SDG 2 is targeted at ending hunger, achieving food security and improved nutrition, and promoting sustainable agriculture, while SDG 3 aims to ensure healthy lives and promote well-being for all at all ages (Le Blanc, 2015). It is presumed that nutritional status is affected by the rising number of people who experience hunger, particularly in Africa. According to estimates, 670 million people worldwide will be undernourished by 2030, which is the same proportion of people as when the SDGs were introduced in 2015, and a substantial portion of these individuals will be children under the age of five (FAO *et al.*, 2023). In South Africa's rural areas, where undernutrition (wasting, underweightness and stunting) continues to be a common factor linked to fatalities in children under five, the prevalence of undernutrition is high for an upper-middle-class country (Shisana *et al*., 2013; FAO *et al.*, 2023).

According to the South African National Food and Nutrition Security Plan (Department of Health, 2013), high levels of household and individual food insecurity persist and consequently, undernutrition. High levels of undernutrition raise concerns for individual and country development; hence, it is necessary to build evidence regarding the prevalence of undernutrition, especially in rural areas where the risks and vulnerabilities are deemed greatest. Considering the range of drivers of undernutrition and the outcomes across temporal and spatial scales, it is crucial to understand the importance of the intersection between nutrition and development (Shisana *et al*., 2013). This includes but is not limited to economic progress, health, longevity and overall well-being of the child.

Because of apartheid, black people's rights were denied, causing many young children to live a life of hunger, poor healthcare and severe malnutrition. Currently, black children have some of the highest prevalence of wasting, underweight and stunting at 2.6%, 4.9% and 15.15%, respectively (Atmore, 2013; Shisana *et al*., 2013). Notwithstanding some interventions, there has not been any significant change in the levels of undernutrition in South Africa since the early 2000s with stunting, for example, increasing from 23.4% to 26.5% in children three years and younger, and current levels are synonymous with those of low-income countries despite our higher GDP per capita (Department of Health, 2013; Shisana *et al*., 2013). In low- and middle-income countries, undernutrition is associated with at least 45% of deaths in children under the age of five

(Madiba *et al*., 2019). Madiba *et al*. (2019) argue that undernutrition is a result of insufficient food and infectious diseases, with chronic undernutrition or stunting being the most prevalent, especially among rural black people (Modjadji & Madiba, 2019).

One outcome of the nutritional status of children is their development, where malnutrition results in poor child development, with children in the rural areas of South Africa being the most vulnerable (Barbarin, 2003; Jimoh *et al*., 2018). Undernutrition has, for example, been associated with poor development in children under five years because early childhood is the most critical period where significant learning, growth and development occurs (Pérez-Escamilla & Hall Moran, 2016). The prevalence of stunting in South Africa is a cause for concern because chronic undernutrition adversely affects cognitive development and educational attainment in children, with children in developing countries having fewer achievements than those in developed countries of the same age (Grantham-McGregor *et al*., 2007; Madiba *et al*., 2019).

The impacts of undernutrition are not static and can be long-lived. UNICEF, for example, has recognised South Africa as one of 24 high-burdened countries regarding stunting, and like poverty, undernutrition can be passed from one generation to the next; therefore, interventions like Early Childhood Development programmes are a necessity (Madiba *et al*., 2019; Modjadji & Madiba, 2019). These generational curses are problematic because poor nutrition and development of children in low- to middle-income countries lead to poor labour health and reduced economic productivity. This is because these children become less productive individuals as they do not reach their full development potential (Grantham-McGregor *et al*., 2007; Atmore, 2013; Ssentongo *et al*., 2021).

The scale of the impacts of undernutrition is not only inter-generational but can also be socioeconomic. When a significant number of children are affected by undernutrition such that it impacts development, national development is also significantly affected (Grantham-McGregor *et al*., 2007). Early childhood development has been recognised as one of the important predictors of a nation's future development regarding social capital because proper early childhood development results in better intellectual skills and well-being needed for healthy and productive adulthood (Black *et al*., 2017; Jimoh *et al*., 2018). A significant portion of children in South Africa is at risk of not reaching their full potential, mainly because of poverty, social exclusion and, importantly, undernutrition (Jimoh *et al*., 2018). Therefore, many can argue that the prevalence and intensity of undernutrition are not just a proxy indicator for access to food but also the development potential of a country because healthier and well-nourished populations usually have lower morbidity and mortality rates and higher labour productivity (Hunt, 2005; Department of Social Development & Department of Agriculture, Forestry and Fisheries, 2013). This would lead to better investment in education and employment opportunities, encouraging a cycle of better socioeconomic status and poverty reduction (Hunt, 2005).

According to UNICEF's nutrition brief on South Africa (2020), the country is on course to reduce levels of wasting in children, while it's far off-course in efforts to reduce stunting expression. Additionally, in 2018, an estimated 59% of all children in South Africa lived below the poverty line, with most coming from rural areas (Mkhize & Sibanda, 2020). The prevalence of undernutrition in the rural population differs from the national population; therefore, the trends in child nutritional status displayed at the national level might not reflect the actual trends in rural settings (Novignon *et al*., 2015; Mkhize & Sibanda, 2020).

To date, no study has explored the trends in the prevalence and severity of child undernutrition in rural South Africa. An assessment of this kind is important because trends in the prevalence of undernutrition could indicate potential long-term consequences on child health and development, which extend into adulthood, while trends in severity allow for assessing the conditions of those already undernourished. The current study not only addresses the abovementioned but also adds to the growing knowledge around the nutritional status of children in rural areas and gives insights on trends in the prevalence and severity of undernutrition, which has implications for trends in rural economic and health status, policy and the overall progress for achieving the SDGs in rural communities (Zere & McIntyre, 2003; Mkhize & Sibanda, 2020).

This chapter explores the prevalence and intensity of undernutrition at the AHDSS site, and an analysis was conducted to establish whether there was a trend between 2010 and 2019. This is important because these children's nutritional status depicts the household's health (Shisana *et al*., 2013). Short- and long-term undernutrition trends were investigated, including what these could mean, while the potential explanation for why these trends exist is evaluated in Chapters 4 and 5.

3.3 Methods

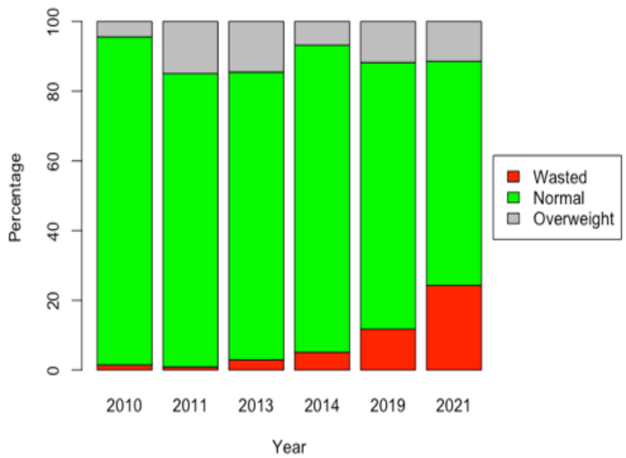
The details of the study site and general methods are given in Chapter 2. Each child's malnutrition metric (i.e., wasting, underweight and stunting) has three possible outcomes per the WHO's standards of normal nutrition status. In the case of wasting, for example, a child can either be wasted, normal or overweight. Using these three outcomes, the resultant frequencies per outcome were used to conduct a chi-square test to test whether these results are due to chance or if there is a relationship between the undernutrition metrics and the year.

To assess changes in the prevalence of undernutrition, the percentages of children in each malnutrition metric were quantified (i.e., wasting, underweight and stunted) per year. The highest, lowest and mean percentage prevalence over the years were recorded, and using these percentages, three Mann-Kendall tests were conducted to assess the trends in child malnutrition from 2010 to 2021 for all, male and female children. For every wasted, underweight and stunted child, the deviation from the WHO's standard of normal nutritional status was quantified to determine the severity of the undernutrition. After averages for each year were calculated, a Mann-Kendall test was conducted to investigate changes in the severity of undernutrition over time and any resultant monotonic trend.

3.4 Results

3.4.1 Wasting

The prevalence of wasting (low weight-for-height) in children relative to normal and overweight children differed significantly between years ($X^2 = 72.58$; df = 10; $p < 0.001$). This pattern applied to both males ($X^2 = 67.51$; df = 10; $p < 0.001$) and females ($X^2 = 97.77$; df = 10; $p < 0.001$) (Figure 3.1). The prevalence of wasting increased exponentially from 0.72% in 2010 to 20.91% in 2021 for the overall group of children, with a mean prevalence over the years of 7.13%. Male children had a mean prevalence of wasting of 7.72% over the years, with the highest prevalence in 2021 (24.29%), while the lowest was in 2011 (0.88%). Compared to the opposite sex, the mean prevalence of wasting in females was lower at 6.09%, with the highest prevalence of wasting in females also lower, at 16.67% in 2019, with no recorded incidences of wasting in 2010 and 2014. This positive trend in the prevalence of wasted children over time was significant ($z = 2.25$; $n = 6$; $p < 0.05$). The increasing trend was significant over the years for males ($z = 2.25$; $n = 6$; $p < 0.05$) but not statistically significant for females ($z = 1.34$; $n = 6$; $p = 0.09$). The positive trend in the mean severity of wasting (Figure 3.2) also increased significantly over time ($z = 2.12$; $n = 39$; $p < 0.05$).



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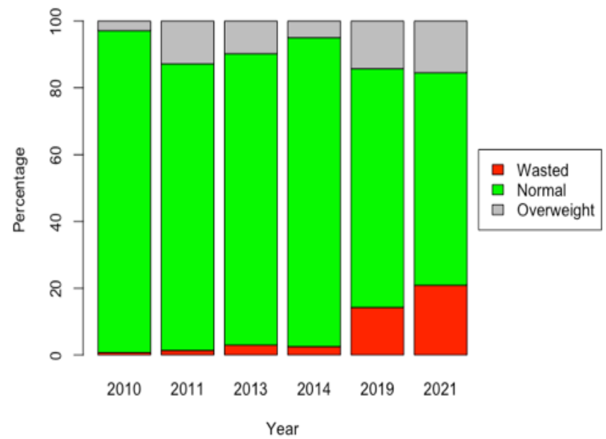

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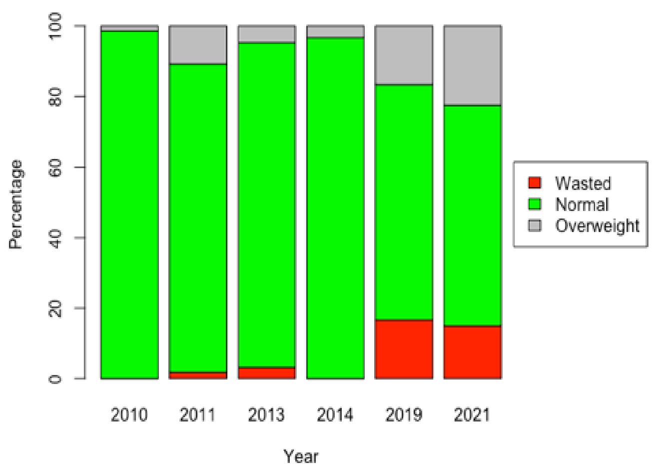

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Figure 3.1 The prevalence of wasting in male (A), female (B) and all (C) children.

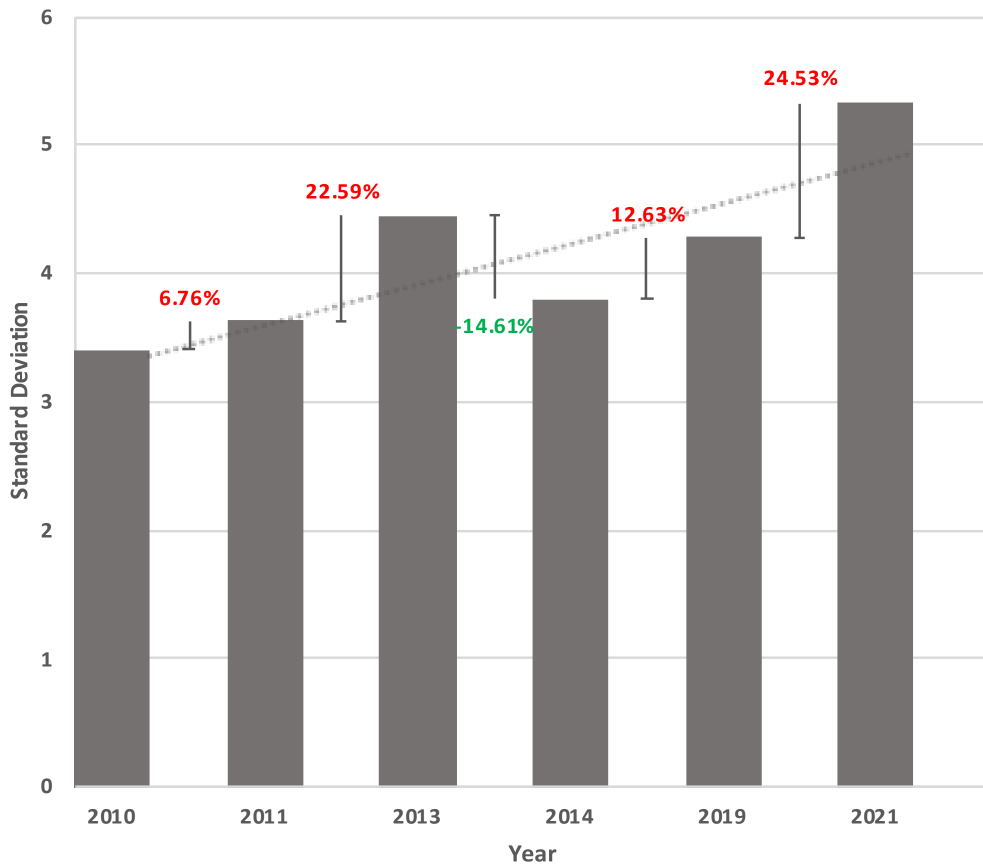
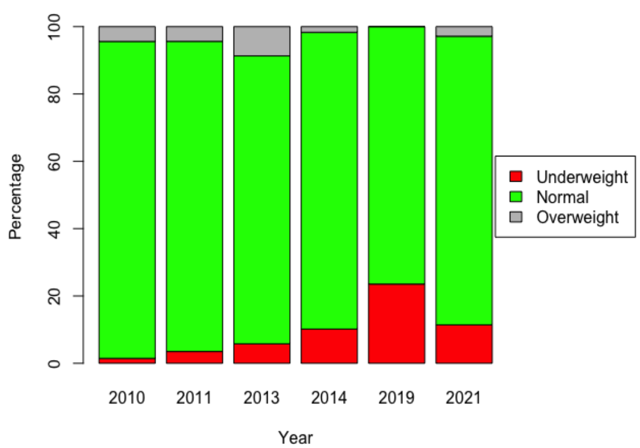


Figure 3.2 The severity of wasting among wasted rural children over the study years, classified by the deviation from the standard of healthy/normal children per UNICEF's growth standards.

3.4.2 Underweight

The prevalence of underweightness (low weight-for-age) in children relative to normal weight and overweight children differed significantly between the years ($X^2 = 38.35$; df = 10; $p < 0.001$). The same applies to males ($X^2 = 48.08$; df = 10; $p < 0.05$) and females ($X^2 = 67.39$; df = 10; $p < 0.05$) (Figure 3.3). The prevalence of underweightness in all children increased from the lowest prevalence in 2010 (0.72%) to the highest in 2019 (20%), with a mean prevalence of underweightness 7.822% of the overall group of children. The prevalence of underweight male children increased from the lowest in 2010 (1.47%) to the highest in 2019 (23.53%), with a mean prevalence of 9.32% over the years. There were no recorded underweight female children in 2010 and 2014, while the highest prevalence of 16.67% was in 2019, with a lower mean prevalence of underweightness of 6.22% compared to male children. The changes in underweightness over the years resulted in a positive trend that was statistically significant ($z = 1.88$, $n = 6$, $p < 0.05$). The increasing trend in underweightness was also statistically significant for males ($z = 2.25$, $n = 6$, $p < 0.05$) but not for females ($z = 0.96$, $n = 6$, $p = 0.17$). Additionally, there was a significant increase ($z = 2.60$, $n = 44$, $p < 0.05$) in the mean intensity of underweight children in the pooled data (Figure 3.4).



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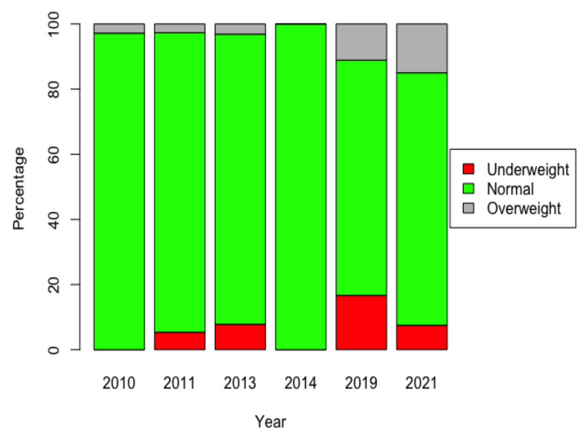

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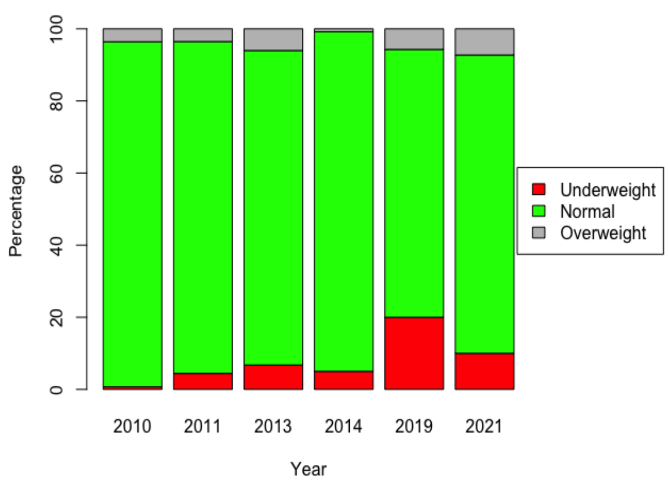

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Figure 3.3 The prevalence of underweight male (A), female (B) and all (C) children.

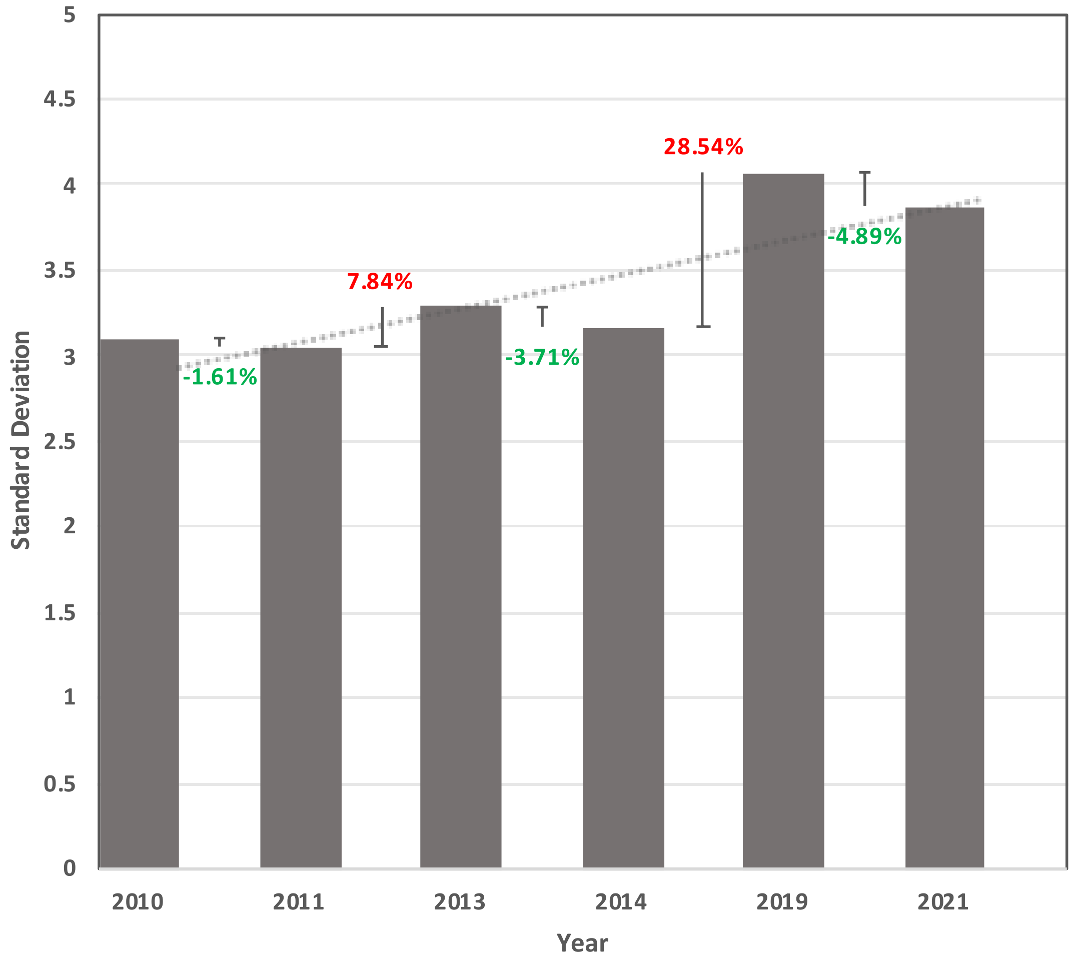
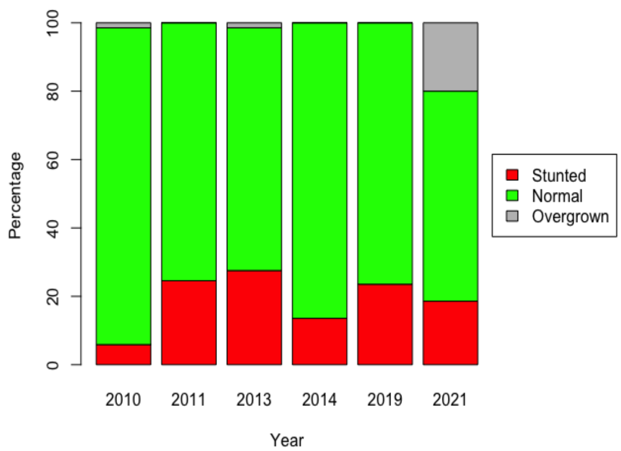


Figure 3.4 The intensity of underweightness among underweight rural children, classified by the deviation from the standard of healthy/normal children as per UNICEF's growth standards.

3.4.3 Stunting

The prevalence of stunting (low height-for-age) in children differed significantly ($X^2 = 100.34$; df = 10; $p < 0.001$) from normal height and overgrown children (Figure 3.5). The same applies to males ($X^2 = 108.09$; df = 10; $p < 0.001$) and females ($X^2 = 97.77$; df = 10; $p < 0.001$). The lowest prevalence of stunted children was in 2010 (3.6%), while the greatest was in 2011 (24.78%), with a mean prevalence of 15.34% over the years. For male children, the lowest prevalence of stunting was in 2010 (5.88%), while the greatest was in 2013 (27.54%), with a mean prevalence of 18.94% over the years. Female children had the lowest prevalence of stunting in 2010 (1.41%), the highest in 2011 (25%) and a mean prevalence of 11.97% over the years. Although there was variability, the changes in the prevalence of stunting did not show a significant trend for all ($z = 0$, $n = 6$, $p = 0.5$), male ($z = 0$, $n = 6$, $p = 0.5$) and female ($z = 0.38$, $n = 6$, $p = 0.35$) children. Surprisingly, the has been a significant ($z = 2.74$, $n = 126$, $p < 0.01$) increase in the intensity of stunting (Figure 3.6) in children over the years.



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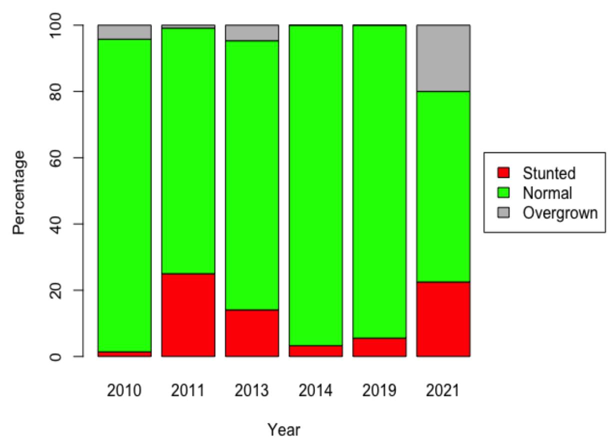

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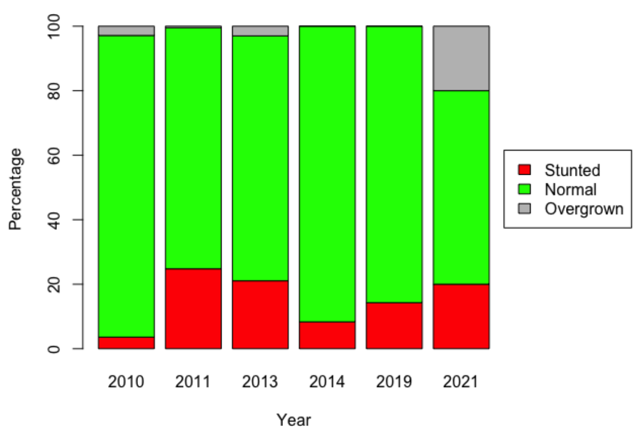

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Figure 3.5 The prevalence of stunting in male (A), female (B) and all (C) children.

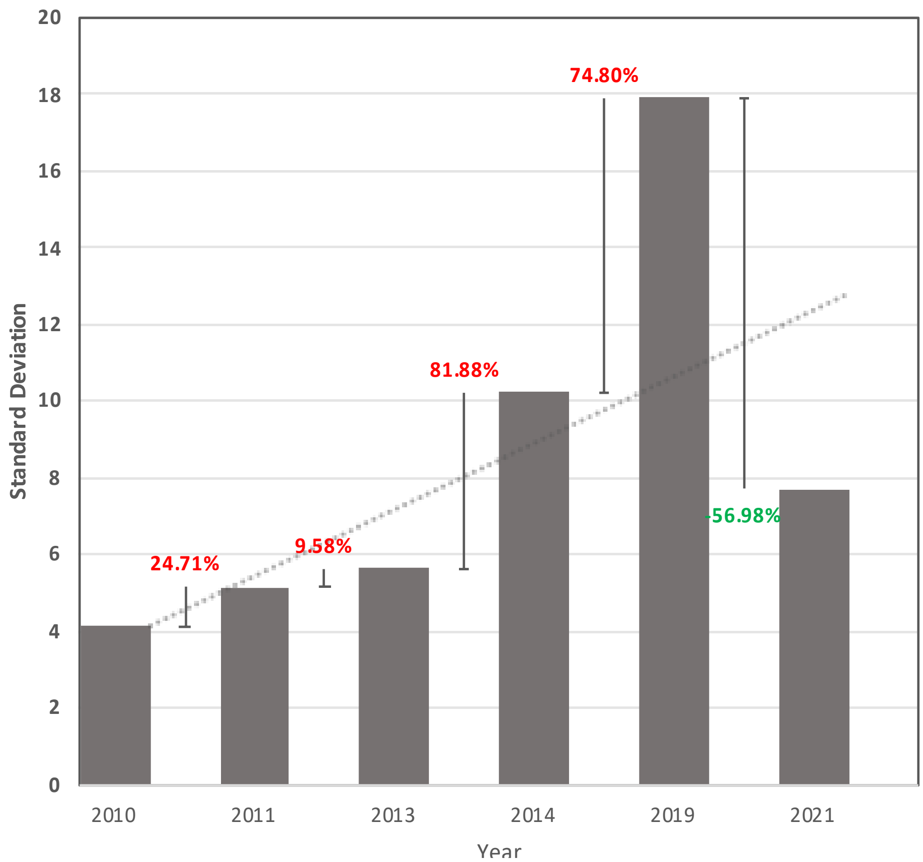

Figure 3.6 The intensity of stunting among stunted rural children, classified by the deviation from the standard of healthy/normal children as per UNICEF's growth standards.

3.5 Discussion

This chapter examined the prevalence and intensity of undernutrition in children under five but older than one year. Wasting (low weight-for-height), underweightness (low weight-for-age) and stunting (low height-for-age) were the undernutrition metrics used to evaluate trends for the years 2010, 2011, 2013, 2014, 2019 and 2021. The findings suggest that the nutritional status of these children has declined over the years, with the prevalence and severity of wasting and underweight increasing over the years. However, the trends in stunting prevalence were inconclusive, although severity has increased.

3.5.1 Wasting

The study found an overall increase in the prevalence and severity of wasting in children five years and younger. With averages in prevalence at about 6.0 to 7.0% of children, as well as increases to above 20%, wasting levels in the AHDSS site are higher than national levels (from 2.2% in 2010 to 3.3% in 2016), according to the South African National Food and Security Plan (The Government of the Republic of South Africa, 2019). The levels of wasting found in this study are similar to what Bloss *et al.* (2004), Kimani-Murage *et al.* (2011), Kimani-Murage (2013) and Sartorius *et al.* (2020) found on the prevalence of wasting in rural areas of developing countries. Mean wasting levels in the study were higher than national averages because this study was conducted in a rural setting where the general prevalence of malnutrition is higher than in urban areas, and thus national levels because the spatial distribution of malnutrition is subject to socioeconomic inequalities, with rural areas being victims (Bloss *et al.*, 2004; Benson & Shekar, 2006; Shisana *et al.*, 2013 Sartorius *et al.*, 2020). According to the National Food and Security Plan (2018-2023), national averages in child wasting have increased slightly. Therefore, the trends in the AHDSS site are similar to national trends in that wasting has increased over the years, although more pronounced in the study site. These results are contrary to Tzioumis *et al.* (2016) and Sartorius *et al.* (2020), who found that the prevalence of wasted children in South Africa decreased from 6.5% (2008) to 3.5% (2017) after increasing from 2008 to 2012. However, a certain level of congruency has been maintained because their reported levels of wasting are above national levels, similar to this study.

According to UNICEF, maternal malnutrition, low birth weight, poverty, poor feeding practices and food insecurity are some of the many contributing factors to child acute undernutrition (Ahmed *et al.*, 2013; Akombi *et al.*, 2017). Coupled with an increasing population and high cost of living, these could lead to an increase in the prevalence of wasting, as seen in this study (Darnton-Hill & Cogill, 2010; Schönfeldt *et al.*, 2010; Akombi *et al.*, 2017). However, wasting is the consequence of recent illness and weight loss (Bloss *et al.*, 2004). The second highest prevalence of wasting was in 2021, just over a year after the onset of the COVID-19 pandemic in South Africa. During the pandemic period, there could have been an increase in child illness and increased weight loss because of a decline in food availability (Smith & Wesselbaum, 2020). While the direct mortality impact of COVID-19 on children remained low, the pandemic's ripple effects on child health, development, and success were significant (Spaull & van der Berg, 2020). Disruptions to essential health services, including childhood vaccinations and treatment for chronic conditions, posed grave risks, potentially resulting in increased mortality from preventable diseases like pneumonia, diarrhea, and HIV/AIDS (Spaull & van der Berg, 2020; Jansen *et al.*, 2021). Declines in clinic attendance and hospital admissions for checkups signalled a concerning trend in child health services utilization. Moreover, fear of contracting COVID-19 significantly influenced health-seeking behavior, particularly in areas already plagued by limited access to healthcare services (Jansen et al., 2021).

Hunger was a result of reduced household income, a consequence of the strict lockdown conditions which led to many households, especially low-income households, finding it difficult to purchase sufficient food (Devereux *et al*., 2020; Inegbedion *et al*., 2021; Simon & Khambule, 2022). Nwosu and Oyenubi (2021) found a decline of over 46% in household income in South Africa, while Kansiime *et al*. (2021) found an increase of 38% and 44% in the proportion of food-insecure people in Kenya and Uganda during the COVID-19, respectively. Some studies found an increase in mental distress among mothers because of the pandemic, which could result in disrupted food practices, thus affecting the nutritional status of children (Russell *et al*., 2020).

3.5.2 Underweight

The levels of underweightness found in this study were higher than the South African national prevalence of underweightness in children under the age of six years at 5.1%, 6.8% and 3.4% for all, male and female children, respectively (Shisana *et al*., 2013). Like wasting, the prevalence of underweightness is usually higher in rural than urban areas and, thus, than national levels because of increased hunger, caloric deficiencies and prolonged ill-health in rural areas (Shisana *et al*., 2013; Monyeki *et al*., 2015; Akombi *et al*., 2017).

The study found a significantly increasing trend in the prevalence of underweight children. Not many studies have explored the prevalence of underweightness over time, but studies such as de Onis *et al*. (2004) and Rachmi *et al*. (2016 reported a decrease in the prevalence of underweight children over the years in Sub-Sharan Africa and South Africa. However, Mkhize and Sibanda (2020) noted an increase in the prevalence of underweight children in their review of selected studies on factors associated with undernutrition in South Africa. They also stated that underweightness in South Africa is not as severe as in other developing countries; however, the prevalence is greater than in other upper-middle-income countries (Akombi *et al*., 2017; Ssentongo *et al*., 2019; Emerson *et al*., 2020; Ssentongo *et al*., 2021).

3.5.3 Stunting

The average prevalence of stunting in the study was 15.34%, 18.94% and 11.97% for all, male and female children. This prevalence was lower than in other communities in rural areas of South Africa, according to Lesiapeto *et al*. (2010) and Madiba *et al*. (2019), and lower than in rural areas of other low- and middle-income countries, according to Akombi *et al*. (2017), Ssentongo *et al*. (2021) and Gausman *et al*. (2022). However, this study found the prevalence of stunting to be the same at the provincial level but higher than at the national level (7.0 to 11%), according to Monyeki *et al*. (2015) and Sartorius *et al*. (2020). This is because rural areas tend to have a higher degree of undernutrition than urban areas and higher than national averages because of socioeconomic differences, poverty and lack of resources (Shisana *et al*., 2013; Ntenda, 2019; Sartorius *et al*., 2020).

There was no specific trend in the prevalence of stunting over the years, although stunting was more prevalent in 2011 (>20%), while the severity of stunting has increased over the years. Stunting is also permanent, so a young child will still be stunted even in the next year of the survey, regardless of the changes in contributing factors (Bloss *et al*., 2004). However, many studies, such as Armstrong *et al*. (2011), Said-Mohamed *et al*. (2015), Jonah *et al*. (2018), and Sartorius *et al*. (2020) found a decrease in the prevalence of stunting over time, while El Kishawi *et al*. (2017) and Drysdale *et al*. (2021) found the contrary.

3.6 Conclusion

Based on the IPC's acute malnutrition classification, the data presented in this chapter paints a concerning picture for the AHDDS site in Bushbuckridge (IPC Global Partners, 2021). The prevalence of wasting and underweightness, averaging 7.82% and 7.13%, respectively, signals alert levels of undernutrition (phase 2), while the average prevalence of stunting at 15.34% falls into the critical category of undernutrition (phase 4). These elevated levels of undernutrition not only indicate a growing trend but also heightened severity, which is cause for concern. It is essential to underscore the potential consequences of these findings. Children facing undernutrition experience deficiencies in essential vitamins and minerals, making it difficult for them to fight off life-threatening conditions, such as HIV/AIDS, pneumonia and diarrhoea, as highlighted by Madiba *et al*. (2019). Furthermore, these findings shed light on the challenges in achieving SDGs related to hunger eradication (SDG 2) and better health (SDG 3) in South Africa's rural social-ecological systems. While progress was anticipated, the persistence of high levels of undernutrition underscores the need for targeted interventions and policy adjustments to ensure the well-being and prospects of the Bushbuckridge community. Addressing these issues is imperative to advance not only the health of the population but also the broader goals of the region's sustainable development. These findings highlight the complex interplay within a social-ecological system where biological, social, and environmental factors converge to influence child health outcomes. In rural settings, socioeconomic inequalities exacerbate malnutrition, with factors such as maternal malnutrition, poverty, and food insecurity playing significant roles.

CHAPTER 4
THE RELATIONSHIP BETWEEN FOOD SECURITY AND CHILD NUTRITION

4.1 Abstract

Food insecurity is common in rural areas, where one of the driving factors is a lack of income. According to some research, the consequent food insecurity may contribute to children's low nutritional status. However, few studies have examined the impacts of household food access on the prevalence of wasting, underweightness and stunting in children while accounting for socioeconomic factors. Therefore, this part of the study aimed to assess the food security status of households in Bushbuckridge and whether this can be used to explain the changes in the nutritional status of children under the age of five over time explored in Chapter 3. Changes in food security between 2010 and 2019 were assessed using food consumption metrics, i.e., dietary diversity (HDDS) and the experience of hunger (HFIAS). Household socioeconomic characteristics, such as employment ratio, dependency ratio, household size, etc. were used to assess whether they can explain the change in household food security status over the years. The relationships between food security and undernutrition metrics were then examined. There was a significant decrease in the dietary diversity of households over the years, with no changes in the experience of hunger. Households' food security statuses can be explained by socioeconomic characteristics, with households having a better status of food security when they were led by a male, when there was a greater ratio of employment and a smaller ratio of dependents, and when households had more high-value assets. The status of food security had no impact on the nutritional status of the overall group of children, but there is an association between the diversity of diets in households and the prevalence of wasting and underweightness in female children. The results of this chapter illustrate the importance of socioeconomic interventions that aim to improve financial support and reduce inequalities when addressing food security and nutrition-related problems. It can also be noted that there was a poor association between household food security and the nutrition of children under five years.

Keywords

Dietary Diversity, Hunger, Socioeconomic Characteristics, Undernutrition

4.2 Introduction

Although the country is food secure, millions of people in South Africa go to bed hungry because many households have poor access to food (Ndlovu & Masuku, 2021). This occurs mainly in rural areas which have high unemployment rates, poor education, poverty and increasing populations, making them vulnerable to hunger, malnutrition and other socioeconomic challenges (Makiwane *et al*., 2012; Mashile *et al*., 2019; Ndlovu & Masuku, 2021). In the previous chapter, levels of child undernutrition, especially wasting and underweightness, were found to vary between years. This chapter explores the extent to which this variability can be explained by variability in household food security levels, which, in some cases, can be influenced by household socioeconomic conditions. This chapter explores these contributing factors, such as household socioeconomic conditions, which affect household dietary diversity and the experience of hunger. Other factors, such as climate conditions, are assessed in the next chapter.

The unemployment rate in South Africa is above 30%, and because it is generally higher in rural areas, many have adopted multiple livelihood strategies to cope with these disparities (Makiwane *et al*., 2012; Paumgarten *et al*., 2020; Hlatshwayo *et al*., 2021). Social assistance, wages, remittance and farming are some of the most common sources of income, with tourism worth mentioning when it comes to rural Mpumalanga (Makiwane *et al*., 2012; Nduna & Van Zyl, 2017). Small-holder agriculture is dominant and provides about 70% of employment in rural areas; however, the barriers to this livelihood strategy mean that it has not reached its full potential. The agricultural sector has a proven potential to reduce poverty in rural South Africa and improve food security and livelihoods and, consequently, the nutrition status of adults and children (Hlatshwayo *et al*., 2021; Ndlovu & Masuku, 2021). Small-holder farming would not only provide food but also income through surplus sold, and the prevalence of food insecurity in Mpumalanga necessitates the prioritisation of agricultural improvement because households that engage in farming are better off than wage-dependent households (Kanayo, 2021; Ndlovu & Masuku, 2021).

However, in most rural areas of South Africa, households rely on food purchases to a much greater degree than their own production, making them vulnerable to variable food prices, hence food insecurity (Chakona & Shackleton, 2018). After spending most of their income on food purchases, little to none is left as a safety net (Makiwane *et al*., 2012). Therefore, during shocks, these households depend on unsustainable coping strategies that severely affect their livelihoods, which has been linked to poor nutrition in children (Musemwa *et al*., 2015; Amoah & Simatele, 2021). These are households of poor socioeconomic status where the burden of food insecurity and undernutrition affects many (Chakona & Shackleton, 2018). It is important to understand the socioeconomic status and resources of households when evaluating their food security because many studies have found a relationship between food security and household socioeconomic factors, such as income, ownership of assets, family size and gender of household head, to name a few (Sekhampu, 2017; Chakona & Shackleton, 2018; IPC Global Partners, 2021). These households are characterised by low income, consumption of low-quality monotonous diets and low education, which is associated with poor child feeding and caregiving, ultimately affecting food security (Chakona & Shackleton, 2018; IPC Global Partners, 2021). Low socioeconomic households are also heavily impacted by mortality, especially of breadwinners, because this affects income, and they are slow when recovering (Twine & Hunter, 2011; Sekhampu, 2017).

Even with normal national food production, rural areas are largely food insecure because availability does not translate to better access to food (FAO, 2018; Jamieson & Van Blerk, 2022). Besides volatile food prices, low income and economic opportunities mean the rural poor have low purchasing power and, hence, poor access to food (Makiwane *et al*., 2012; The World Bank, 2018). These households struggle with physical access to food, such as being far from markets, declining subsistence farming and financial access like low purchasing power and poor credit access (Makiwane *et al*., 2012; Chakona & Shackleton, 2017). However, these areas tend to have better social access because of their social networks, kinship and family support (Musemwa *et al*., 2015; Paumgarten *et al*., 2020). Poor education and knowledge about food and nutrition also mean that food utilisation is low in rural areas, predisposing them to poor food storage and preparation techniques, thereby not maximising nutrients from the food they eat, which affects nutrient intake, compromising nutrition status. Additionally, the stability of the food security/systems in these areas is threatened because these areas are characterised by larger vulnerabilities and low resilience to shocks affecting food security and nutrition status (IPC Global Partners, 2021).

Along with non-food-related factors, such as poor health care, inadequate food consumption (e.g., low dietary diversity and increased experience of hunger) can result in increased malnutrition (e.g., wasting, underweightness and stunting) (IPC Global Partners, 2021). These effects at the household level have been made a global priority under the United Nations SDGs, and adequate food has been considered a human right according to the WHO and the South African Constitution (Maxwell, 1990; Shisana *et al*., 2013; Dunga, 2020). Household food security and nutrition status are more important than national food security because national food security alludes to food availability, while household food security reflects food access and affordability (Dunga, 2020). Hunger is detrimental to the population, physically and socially, and the use of food security and nutritional indicators is a convenient way to measure the change in poverty (Maxwell, 1990; Shisana *et al*., 2013).

Food insecurity is regarded as a proxy for poverty and an indicator of compromised human health, nutrition and well-being, resulting in pronounced malnutrition (e.g., wasting, underweightness and stunting) in children under five years (Maxwell, 1990; Shisana *et al*., 2013; Govender *et al*., 2017). Nutritional status is regarded as a proxy for national development because it affects the country's development, while a child's nutritional status is a key indicator of a household's health and nutritional status (Chakona & Shackleton, 2018; Omotayo *et al*., 2018). A focus on food security, as well as its effects on nutrition, ensures that the needs of the poor are not neglected in policy formation (Maxwell, 1990; Chakona & Shackleton, 2018). However, there is a lack of data regarding household food security and child nutritional status in rural social-ecological systems in South Africa, making it difficult for government to respond with sensible policies, plans and initiatives (Schmeer & Piperata, 2017; Chakona & Shackleton, 2018; UNICEF, 2019). At the national level, developing countries track and monitor information on wasting, underweightness and stunting in children under five years. However, this is not the case at the local level, where data are crucial because they can reveal inequalities that influence local policy implementation (UNICEF, 2019).

Numerous studies investigating the relationship between child nutrition and food security highlight the need for more research investigating the factors influencing nutrition, particularly child nutrition (Nakabo-Ssewanyana, 2003; Schmeer & Piperata, 2017; Chakona & Shackleton, 2018). Additionally, the South African National Policy on Food and Nutrition Security (2014) highlights a lack of appropriate, timely and relevant data as one of the country's difficulties in terms of food security implications (Department of Agriculture, Forestry and Fisheries, 2014). This study examined the relationship between food security and nutrition, considering the gap identified by this Policy and the Statistics South Africa 2019 Food Security Report to inform government actions aimed at reducing food insecurity and undernutrition in the country at the household level (Statistics South Africa, 2019). In this chapter, the relationship between food security and child nutrition was examined. To do so, the relationship between household food consumption and undernutrition in children was assessed, while considering the impact of household socioeconomic factors.

4.3 Methods

Chapter 2 describes the study site and general methods. To establish whether there was significant variability in the food security status of households between years, one-way ANOVA was used to compare mean dietary diversity and mean food insecurity between years. Mann-Kendall tests were then run on two food consumption indices to identify if there is a significant monotonic trend in the mean value for each index across time, i.e., 2010, 2011, 2013, 2014 and 2019, with food security data for 2021 unavailable. Multiple regression analyses were then conducted to test whether a household's dietary diversity and experience of hunger can be predicted by the year and household characteristics, i.e. employment ratio (the number of employed adults divided by the total number of adults in the household), grants value (the total value of social grants received by the household), high-value assets (the number of high-value assets owned by the household, such as cars, motorbikes, tractors, carts, etc.), household size (the number of members in the household), the dependency ratio (the number of children under 15 and elderly over 64 years divided by the number of economically active age members), temporary migration ratio (the number of temporary migrants divided by the number of adults in the household) and whether the household head is male or female.

The prevalence of undernutrition was then compared to that of food security. Using the annual aggregated percentages in child undernutrition and mean food security indices, Pearson's correlation tests were performed between the different indicators of child undernutrition and those of food security to evaluate the connection between food security and child nutrition at the area level. Lastly, logistic regression analyses assessed the relationship between food security (HDDS and HFIAS) and child undernutrition (wasting, underweightness and stunting). The households that had at least one wasted, underweight or stunted child were assigned a score of 1 while the rest were given 0. Because the analysis was conducted on a dataset with non-consecutive years, a year dummy variable was created, with 2010 as the reference year. Three logistic regressions were conducted with HDDS and HFIAS serving as the predictor variables; the year and the household characteristics were controlled for as the confounding variables while wasting, underweightness and stunting were the binary outcome variables in each logistic model. Because the sample size was too low for some study years, this analysis was only conducted for the pooled data and not for each gender.

4.4 Results

4.4.1 Household Food Security

The lowest HDSS was in 2019 at 6.30, the highest was in 2014 at 7.78, and the mean over the years was 7.13 ± 0.604. The lowest HFIAS was 0.197 in 2014, the highest was in 2010 at 0.835, and the mean over the study years was 0.457 ± 0.263. Differences in mean household dietary diversity were observed between the years, and these differences were statistically significant [$F(1, 1561) = 42.24$, $p < 0.001$]. The decreasing trend in household dietary diversity was statistically significant ($z = -4.970$, $n = 1563$, $p < 0.05$). However, the same cannot be said about households' experience of hunger. No significant variation was found in the households' food insecurity (experience of hunger) over the years [$F(1, 1561) = 0.675$, $p = 0.411$. Furthermore, there was no significance in the decreasing trend in households' experience of hunger ($z = -0.188$, $n = 1563$, $p = 0.425$).

Table 4.1 The mean household food security scores over the study years.

	Mean Household Dietary Diversity Score (HDDS)	Mean Household Food Insecurity Access Score (HFIAS)
2010	7.31 ± 2.13^{a}	0.82 ± 1.53^{a}
2011	7.51 ± 2.02^{ab}	0.36 ± 0.99^{b}
2013	6.71 ± 2.10^{c}	0.28 ± 0.94^{b}
2014	7.78 ± 1.91^{b}	0.19 ± 0.78^{b}
2019	6.30 ± 2.19^{c}	0.62 ± 1.15^{a}

4.4.2 The Effect of Household Characteristics on Food Security

The regression model predicting the effect of household characteristics on household dietary diversity was statistically significant ($R^2 = 0.079$, $F(8, 1554) = 17.63$, $p < 0.001$). The employment ratio, amount of high-value assets, dependency ratio, household head and year were found to be significant predictors of HDDS (Table 4.2). The HDDS increased with employment and asset score, decreased with dependency ratio, and was higher in male-headed households.

Table 4.2 The relationship between household characteristics and dietary diversity.

Household Characteristics (*Coefficients*)	ß	p
Employment Ratio	1.222	< **0.05**
Grants Value	~0.000	0.328
High-Value Assets	0.608	< **0.05**
Household Size	0.020	0.197
Dependency Ratio	-0.300	< **0.05**
Temporary Migration Ratio	-0.292	0.203
Male Head	0.231	< **0.05**
Year	-0.221	< **0.05**
Intercept	242.6	< **0.05**

The regression model predicting the effect of household characteristics on the experience of hunger was also significant ($R^2 = 0.035$, $F(8, 1554) = 8.112$, $p < 0.001$). The employment ratio, high-value assets, dependency ratio and household head were the only factors found to be significant predictors of a household's experience of hunger (Table 4.3). The HFIAS decreased with increased employment, asset score and dependency ratio, and it was higher in households headed by females.

Table 4.3 The relationship between household characteristics and the experience of hunger.

Household Characteristics (*Coefficients*)	ß	p
Employment Ratio	-0.488	**< 0.05**
Grants Value	~0.000	0.060
High-Value Assets	-0.196	**< 0.05**
Household Size	-0.001	0.864
Dependency Ratio	-0.112	**< 0.05**
Temporary Migration Ratio	-0.229	0.068
Male Head	-0.141	**< 0.05**
Year	-0.004	0.641
Intercept	9.814	0.610

4.4.3 The Relationship Between Child Anthropometrics and Household Food Security

4.4.3.1 Population-level Association Between Food Security and Child Undernutrition

4.4.3.1.1 Household Dietary Diversity Score (HDDS)

There was a strong negative correlation ($r = -0.774$) between the annual prevalence of wasting and the mean annual dietary diversity score (Figure 4.1.), but this relationship was not significant ($p = 0.062$). Regarding the specific genders, the prevalence of wasted male children had a non-significant ($p = 0.126$) moderate negative correlation ($r = -0.634$) with dietary diversity, while there was a statistically significant ($p < 0.05$) negative correlation ($r = -0.830$) between household dietary diversity and the prevalence of wasted female children. Therefore, evidence suggests that female children have a better nutritional status when household diets are more diverse.

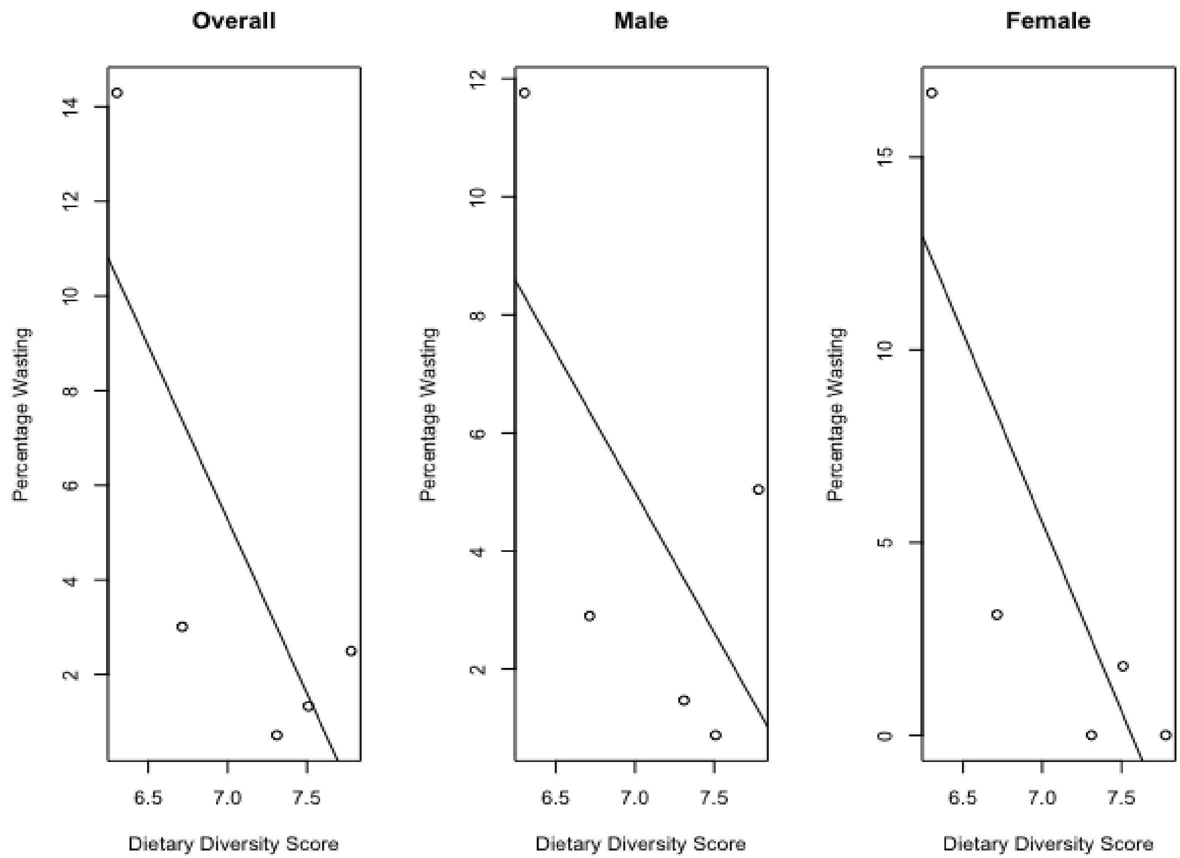

Figure 4.1 The correlation between mean dietary diversity and the prevalence of wasted children.

From 2010 to 2019, there was a non-significant ($p = 0.060$) strong negative correlation ($r = -0.779$) between dietary diversity and the prevalence of underweight children (Figure 4.2). Similarly, a non-significant ($p = 0.135$) moderate negative correlation was found between the prevalence of underweight male children and dietary diversity, while the correlation between the prevalence of underweight female children and dietary diversity was strongly negative ($r = -0.889$) and statistically significant ($p = < 0.05$). Therefore, evidence suggests that female children have fewer cases of underweightness when household diets are more diverse.

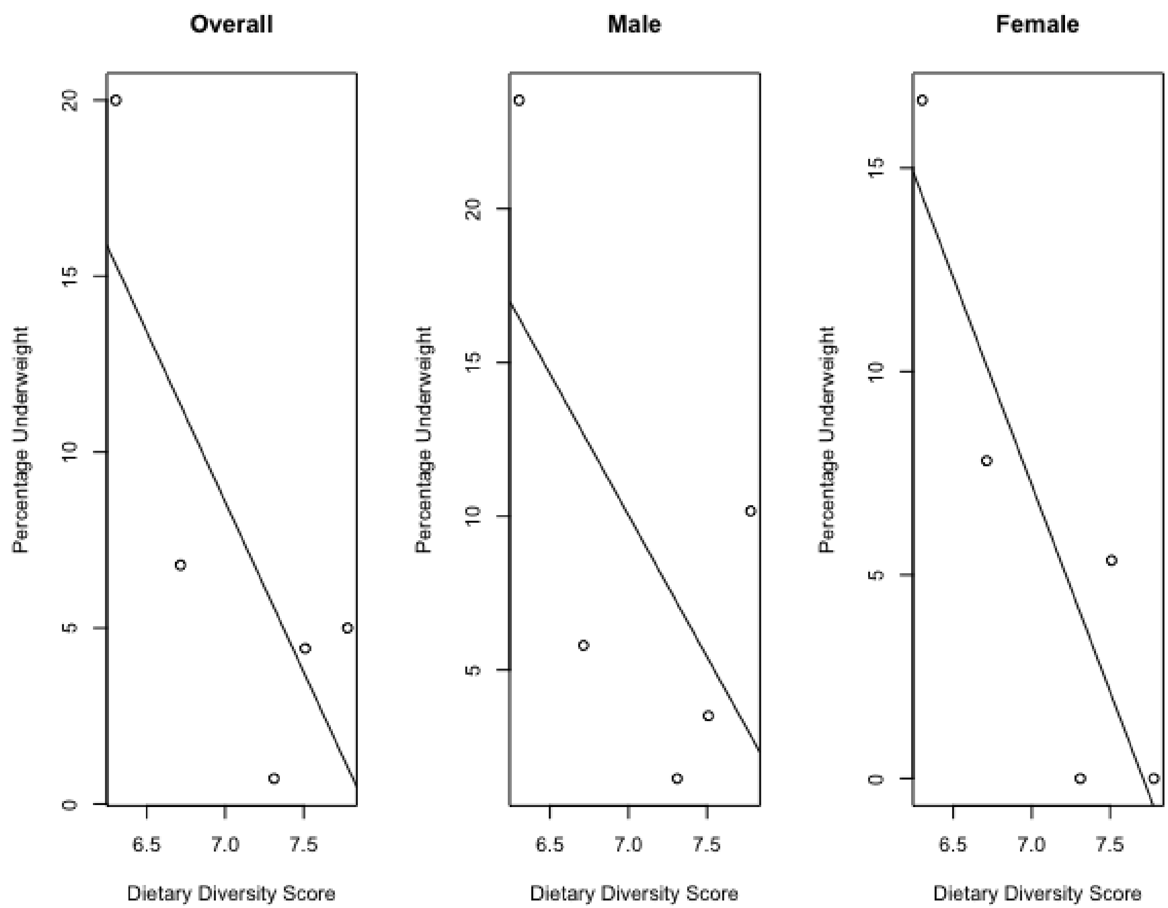

Figure 4.2 The correlation between dietary diversity and the prevalence of underweightness in children.

The correlation between the mean prevalence of stunted children and mean household dietary diversity (Figure 4.3) was non-significant ($p = 0.350$) and weakly negative ($r = -0.237$). Similarly, there was a non-significant ($p = 0.183$) and weakly negative correlation ($r = -0.524$) between the mean prevalence of stunted male children and the mean household dietary diversity. However, there was a non-significant ($p = 0.464$) weak positive correlation ($r = 0.057$) between the prevalence of stunted female children and mean household dietary diversity. Therefore, there is no evidence suggesting an association between household dietary diversity and stunting in children.

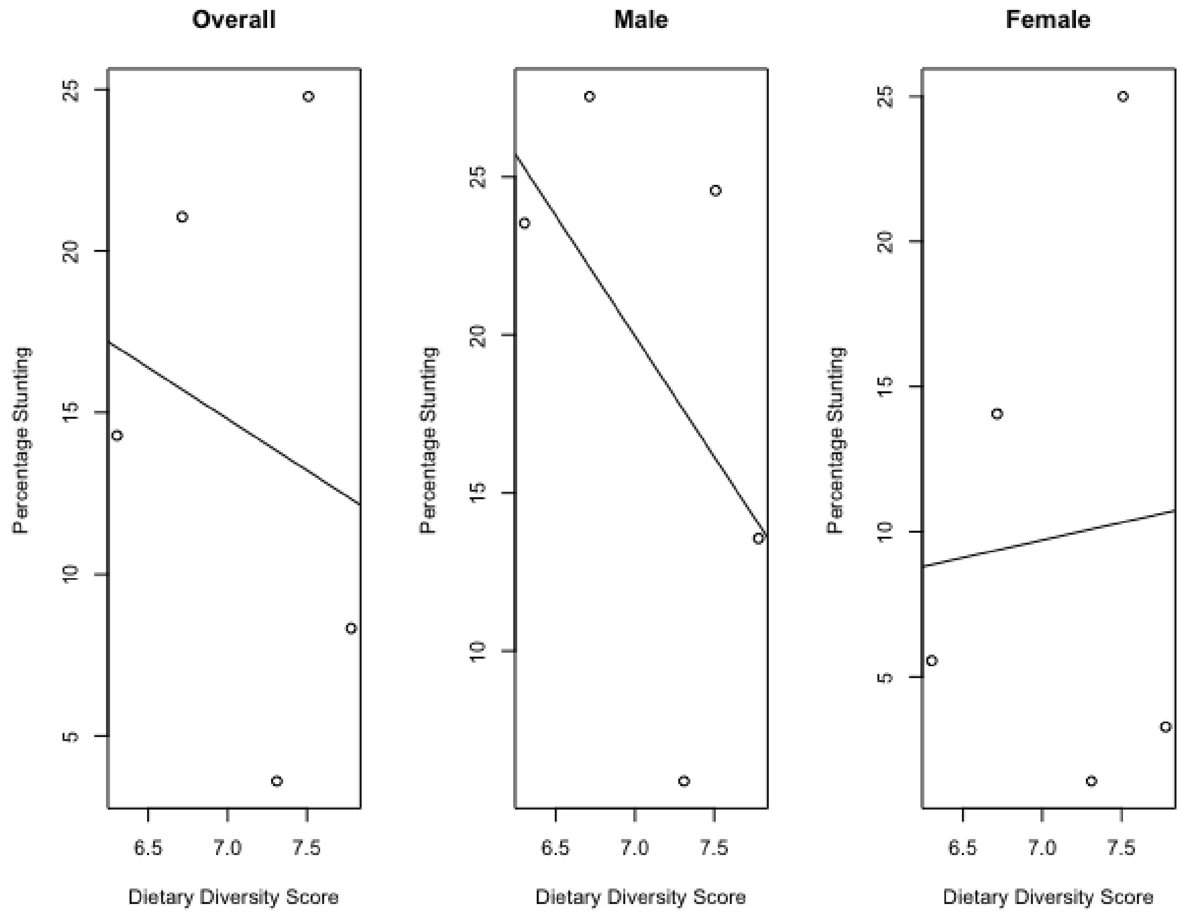

Figure 4.3 The correlation between dietary diversity and the prevalence of stunted children.

4.4.3.1.2 Household Food Insecurity Access Score

There was a non-significant ($p = 0.374$) weak positive correlation ($r = 0.200$) between the mean prevalence of wasted children and food insecurity (Figure 4.4). Similarly, the prevalence of wasted male children was weakly positive ($r = 0.101$) and statistically insignificantly ($p = 0.436$) correlated to the mean household experience of hunger. There was also a non-significant ($p = 0.341$) weak positive correlation ($r = 0.253$) between the mean prevalence of wasted females and the mean household experience of hunger. Therefore, there is no evidence suggesting that children were more wasted when their households experienced more hunger.

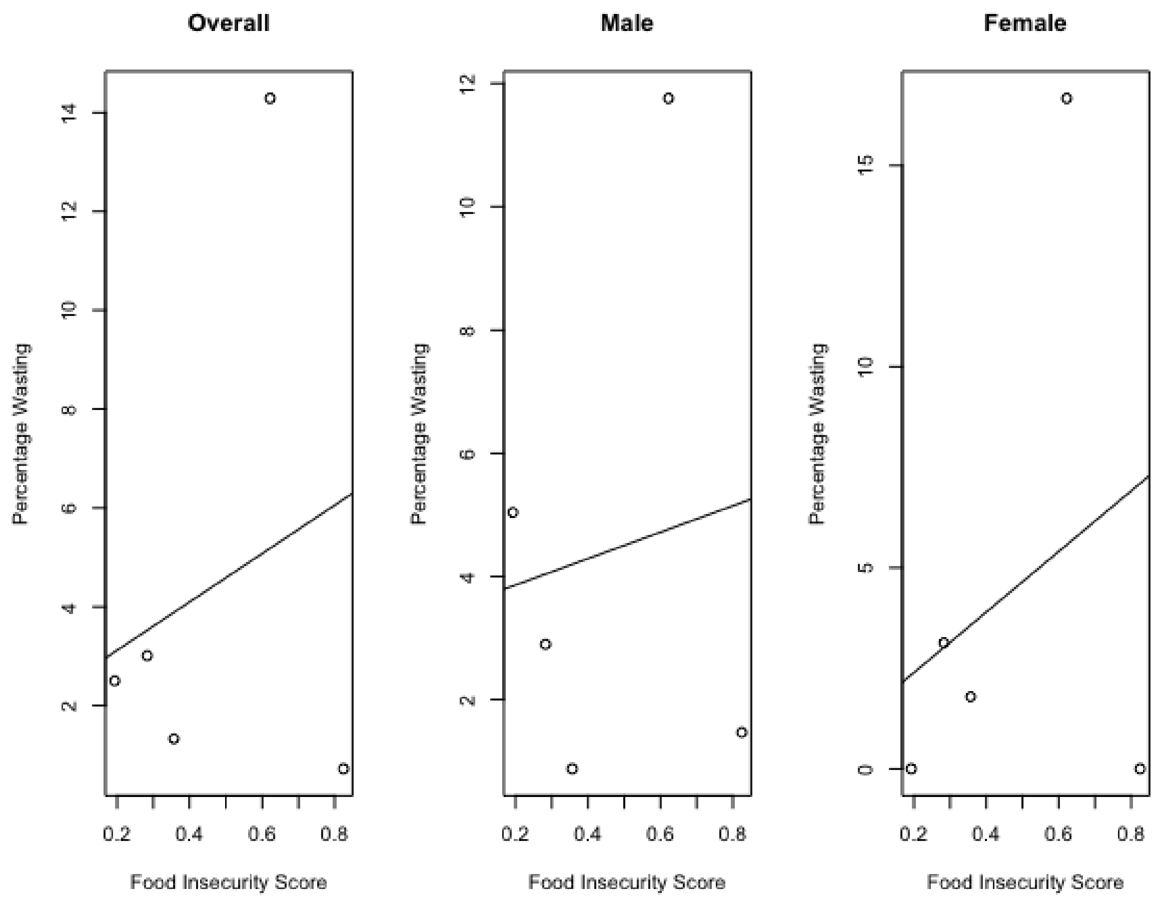

Figure 4.4 The correlation between the experience of hunger and the prevalence of wasted children.

There was a non-significant ($p = 0.463$) very weak positive correlation ($r = 0.058$) between the mean prevalence of underweight children and the mean household experience of hunger (Figure 4.5). The mean prevalence of underweight male children had a non-significant ($p = 0.486$) weak positive correlation ($r = 0.022$) to mean household food insecurity. Similarly, there was a weak positive ($r = 0.095$) statistically insignificant ($p = 0.440$) correlation between the mean prevalence of stunted female children and the household experience of hunger. Therefore, there is no evidence suggesting that underweightness is greater when there is more hunger.

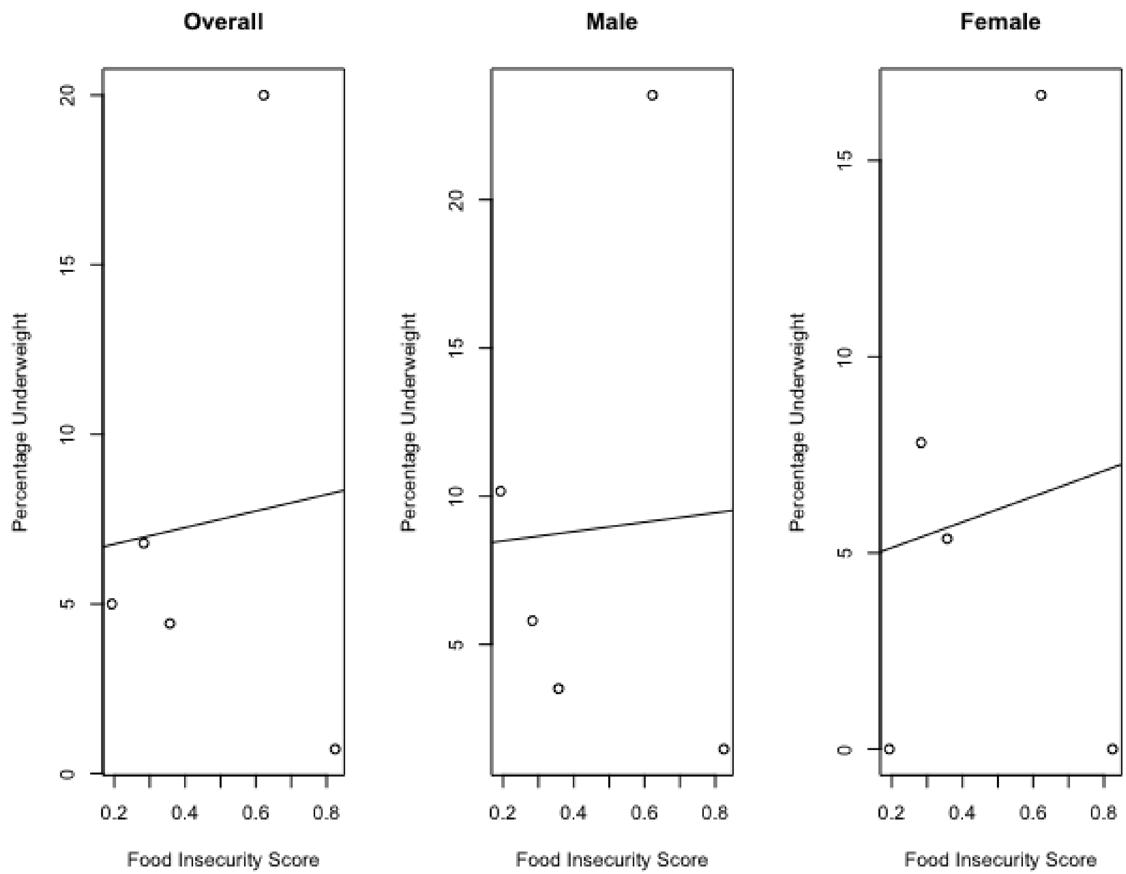

Figure 4.5 The correlation between the experience of hunger and the prevalence of underweight children.

There was a statistically insignificant (p = 0.191) and moderate negative correlation (r = -0.509) between the mean prevalence of stunted children and mean household food insecurity (Figure 4.6). Similarly, there was a non-significant (p = 0.187) moderately negative correlation (r = -0.516) between the mean prevalence of stunted male children and household food insecurity, while the prevalence of stunted female children was also not statistically significantly correlated (p = 0.241) with the household's experience of hunger, with a moderately negative correlation (r = -0.420). Therefore, there is no evidence suggesting more cases of stunting when there is more hunger.

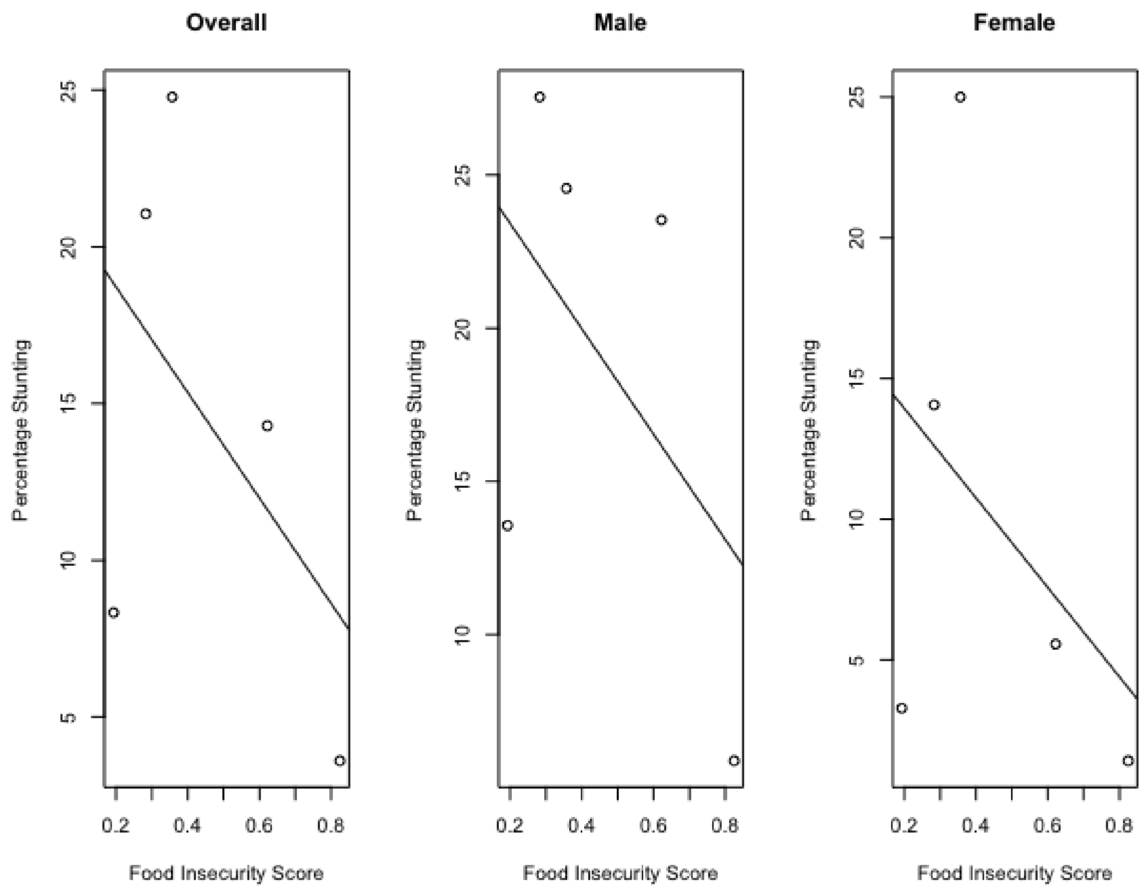

Figure 4.6 The correlation between the household experience of hunger and the prevalence of stunting.

4.4.3.2 Household-level Food Insecurity Impact on Child Undernutrition

After controlling for household characteristics, household dietary diversity and experience of hunger did not significantly influence the likelihood of a household having a child experiencing any form of undernutrition, i.e., wasting, underweightness or stunting (Tables 4.3, 4.4 and 4.5). It is worth mentioning that the variable 'year' was a significant predictor for both wasting and underweightness in children but not for stunting. This was similar to the results found in Chapter 3, where only trends were found in the prevalence of wasting and underweightness between 2010 and 2021 and not for the prevalence of stunting.

Table 4.4 The relationship between food security and wasting in children.

Covariates	Coefficients	95% CI	p-value
HDDS	0.265	-0.072, 0.723	0.137
HFIAS	0.350	-0.203, 1.286	0.264
Employment Ratio	0.158	-0.688, 3.301	0.826
Grants Value	~0.000	~0.000, 0.001	0.061
High-Value Assets	-0.431	-0.856, 1.253	0.422
Household Size	-0.102	-0.235, 0.054	0.188
Dependency Ratio	-0.502	-0.807, 0.289	0.151
Temporary Migration Ratio	0.843	-0.527, 6.182	0.379
Male Head	-0.243	-0.758, 1.366	0.632
Year	**0.407**	**0.169, 0.694**	**< 0.05**
Intercept	**~0.000**	**~0.000, ~0.000**	**<0.05**

HDDS: Household Dietary Diversity Score; HFIAS: Household Food Insecurity Access Score

Table 4.5 The impact of food security on underweight children.

Covariates	Coefficients	95% CI	p-value
HDDS	0.153	-0.065, 0.422	0.183
HFIAS	0.275	-0.114, 0.836	0.191
Employment Ratio	0.671	-0.274, 2.848	0.227
Grants Value	**0.001**	**~0.000, 0.001**	**<0.05**
High-Value Assets	-0.564	-0.839, 0.179	0.102
Household Size	**-0.106**	**-0.198, -0.003**	**<0.05**
Dependency Ratio	-0.357	-0.650, 0.182	0.155
Temporary Migration Ratio	-0.515	-0.849, 0.553	0.223
Male Head	0.704	-0.238, 2.810	0.195
Year	**0.272**	**0.113, 0.455**	**< 0.05**
Intercept	**~0.000**	**0.000, ~0.000**	**<0.05**

HDDS: Household Dietary Diversity Score; HFIAS: Household Food Insecurity Access Score

Table 4.6 The effect of food security on stunting in children.

Covariates	Coefficients	95% CI	p-value
HDDS	0.071	-0.048, 0.205	0.254
HFIAS	0.094	-0.027, 0.231	0.436
Employment Ratio	0.272	-0.219, 1.071	0.411
Grants Value	~0.000	~0.000, ~0.000	0.240
High-Value Assets	-0.214	-0.511, 0.264	0.320
Household Size	-0.040	-0.455, 0.693	0.160
Dependency Ratio	0.026	-0.266, 0.436	0.879
Temporary Migration Ratio	-0.141	-0.520, 0.538	0.609
Male Head	0.496	-0.158, 1.660	0.093
Year	0.001	-0.905, 0.079	0.980
Intercept	0.007	~0.000, ~0.000	0.962

HDDS: Household Dietary Diversity Score; HFIAS: Household Food Insecurity Access Score

4.5 Discussion

4.5.1 Household Food Security Status

Households had a decreasing trend in dietary diversity and a low experience of hunger that remained unchanged over the study years, suggesting that these households can meet their food and non-food essential needs without engaging in unsustainable coping and adaptation strategies to access food and income (Grobler, 2014; Musemwa *et al.*, 2015; IPC Global Partners, 2021). The results of this study are, however, contrary to the National Food Consumption Survey – Fortification Baseline, where nationally, a high 52% of households experienced hunger while a further 28% were at risk (cited in Labadarios *et al.*, 2005). The General Household Survey (2015) found that the percentage of people in South Africa who experience hunger and food insecurity decreased between 2002 and 2015, from 29.3% to 13.1%, with Mpumalanga Province prevailing at a high 31.7% in 2015 (Labadarios *et al.*, 2011; Statistics South Africa, 2015). However, in some parts of the country, both malnutrition and food insecurity have increased (Mthethwa & Wale, 2020). Certain characteristics of households, economic and social, are also responsible for the level and changes in food security. Food security is not only determined by the availability of food but also by household-specific socioeconomic factors, which play a significant role in determining the household's access to food continuously (Zhou *et al*., 2019).

4.5.2 The Effect of Household Characteristics on Food Security

The current study found that the diversity of diets increased, and the experience of hunger was lower when the employment ratio was higher. Studies such as D'Souza & Jolliffe (2012), Clements and Si (2018), Desta *et al*. (2019) and Obayelu and Osho (2020), also found dietary diversity increases and the experience of hunger decreases with employment as food baskets increase in both quantity and quality. These studies also refer to Engel's Law, which states that as household income increases, the percentage of money spent on food purchases decreases. However, Fraval *et al*. (2019) believe that employment may not necessarily result in a more diverse diet. The working poor who rely on part-time, temporary, low-wage and informal jobs do not earn enough to afford a good-quality diet and are thus at risk of food poverty (Bublitz *et al*., 2019; Fraval *et al*., 2019).

Some households rely on social assistance to meet their food and energy requirements; however, in this study, there was no evidence suggesting that an increase in grant value will increase dietary diversity while decreasing the experience of hunger (Shisana *et al*., 2013; Uhunamare *et al*., 2017). The South African General Household Survey (GHS) indicates that there was an increase in the percentage of households receiving social assistance from 45% in 2009 to 45.5% in 2019, increasing markedly to above 50% in 2021 because of the COVID-19 pandemic (cited in Statistics South Africa, 2021). The survey reports that in 2021, the percentage of households receiving social assistance in Mpumalanga Province increased to over 65%. Koswana (2019) found that although social grants are a key feature in South Africa's attempt to reduce poverty and food security, they are not sufficient because their value increase is slower than the increase in food prices as households also spend their income on non-food basic needs and investments (Neves *et al*., 2009; Koswana, 2019). South Africa spends more on social grants than most countries, and this has created a large dependence on social assistance among its citizens (Saunders, 2002; Triegaardt, 2006; Bähre, 2011; De Villiers *et al*., 2020; Visagie & Turok, 2021). However, the current study found no evidence that social grants have an impact on food security. Although social assistance increases accessibility and availability to quality food, Chakona and Shackleton (2019) found that households receiving social grants were more food insecure, and the focus should be on increasing employment opportunities and promoting small-holder farming to increase food availability and purchasing power.

This current study also found that households with more high-value assets had more diverse diets, and they experienced less hunger. Households with assets tend to have a higher socioeconomic status, which is positively related to health and nutrition outcomes because asset ownership and dwelling characteristics can be used as a proxy for long-term income using the 'asset index' (Sheppard *et al*., 2009; Pereira *et al*., 2014; Kabudula *et al*., 2017). Hjelm *et al*. (2016) conducted a food security analysis using indicators such as consumption score, energy deficiency and caloric content and found that households with more assets were more likely to be food secure. Like this current study, Guo (2011) found a relationship between ownership of assets and food-secure households, stating that an income's effect on food security decreases when there is ownership of assets because assets provide safety nets in the event of loss of income. Therefore, asset ownership, particularly agriculture-related, can reduce vulnerability to food insecurity (Beyene & Muche, 2010). Demeke *et al*. (2011) and Mango *et al*. (2014) found that livestock ownership was a significant predictor of food security, resulting in increased dietary diversity and a reduced experience of hunger, similar to what was found in the current study.

Larger family sizes are characteristic of poor areas because household income per capita decreases as the household size increases (Omotayo *et al*., 2018; Semenya & Machete, 2019). Meyer and Nishimwe-Niyimbanira (2016) evaluated the impact of household size on poverty in low-income areas of South Africa. They found that about 74% of households live below the poverty line, and these households had more family members than those living above the poverty line. Studies in South Africa, such as Sekhampu (2017) and Oduniyi and Chagizwa (2022), also found a relationship between household size and food security, with larger households being more food insecure. However, in this current study, there was no evidence suggesting that larger households experience more hunger and have less diverse diets.

This current study found that an increase in the number of dependents in a household decreases the diversity of diets but, surprisingly, decreases the experience of hunger as well. Houle *et al*. (2013) found that an increase in dependents, especially children, can result in food insecurity because of lowered household average income. Fisher and Lewin (2013) suggest that adding only one child to a household increases the probability of being food insecure by about 25%. Studies, such as Altman and Ngandu (2010), Sharaunga *et al*. (2015), Akinboade and Adeyefa (2016), David and Grobler (2020) and Kent *et al*. (2022), found that households with more dependents, especially children, are more food insecure, with greater expenses per capita, lower household savings and less income. The child support grant does not contribute to the food security status of households because the grant (~R500) is considerably less than the food poverty line of ~R700 (Jamieson & Blerk, 2022).

Temporary migration was investigated as a potential determinant of food security because it is another factor influencing household income through migrant labour remittances. In this study, temporary migration did not affect dietary diversity and the experience of hunger. However, many studies report that migration reduces household size while remittances from migrants increase the total household income, thus improving the household's food security status (Crush & Caesar, 2017; Waidler & Devereux, 2019). Studies like Kuuire *et al*. (2013), Generoso (2015), Kangmennaang *et al*. (2018) and Zhou *et al*. (2019) found that households that receive remittance from migrant members are more food secure, and the remittance can sometimes be in forms other than cash. While most studies report a positive effect of migration and remittances on food security, Atuoye *et al*. (2017) found that remittances did not significantly reduce prevailing food insecurities in rural households. Although migration has been widely accepted as a tool to improve rural food security, this has increased urban informal settlements of poor housing, infrastructure, water and sanitation, causing increased numbers of food-insecure households in urban areas (Frayne *et al*., 2010; Van der Merwe, 2011).

The current study also found that male-headed households were more food secure, with greater diet diversity and a lower experience of hunger. Most relevant literature, for example, Selepe *et al*. (2015) and Ningi *et al*. (2022), state that this is related to rural culture and the lack of land ownership by females and their limited access to broader economic activities. Women are previously disadvantaged and more vulnerable; however, interventions to reduce food insecurities have thus far favoured male-headed households (Selepe *et al*., 2015). Tibesigwa *et al*. (2015) and the FAO *et al*. (2017) also found that male-headed households enjoy greater food consumption than female-headed households. A compelling argument was made by Maziya *et al*. (2017) when they found that male-headed households were more food insecure, stating that their presence in the households means they are unemployed since they have not migrated to the urban areas for work.

When examining the impact of household socioeconomic features on food security in the context of a social-ecological system, a complex web of interactions between economic, social, and environmental elements emerges. The findings offered light on how employment ratios affect food diversity and hunger levels, indicating both economic prosperity and environmental sustainability within the system. While higher household employment ratios are associated with greater dietary diversity and lower hunger, notably through increased food access, the study emphasises the importance of investigating the quality and security of employment. For example, despite the overall favourable relationship between employment and food security, unstable job situations among the working poor show the system's socioeconomic vulnerabilities, which have the potential to undermine long-term food security outcomes.

Furthermore, the study's findings on the role of social assistance programmes provide important insights into the system's social dynamics. While social handouts aim to alleviate poverty and improve food access, their impact on the social-ecological system is multifaceted. The study's findings call into doubt the ability of social assistance programmes to alleviate food insecurity on their own, emphasising the significance of taking into account broader socioeconomic and environmental conditions. Interventions within the socio-ecological system can promote resilience and equality in food systems by acknowledging the interdependence of social protection measures, livelihood opportunities, and environmental sustainability. Thus, a holistic approach that incorporates economic development, social welfare, and environmental stewardship is required to provide long-term food security results within the changing social-ecological systems.

4.5.3 Food Security and Child Nutrition

4.5.3.1 Wasting

The current study found a correlation between the annual prevalence of wasted female children and mean household dietary diversity. However, at the household level, the likelihood of households having a wasted child was not significantly related to household dietary diversity or the experience of hunger. While some studies, such as Motbainor *et al.* (2015), Chakona and Shackleton (2018) and Belayneh *et al.* (2021), have found a relationship between food security and wasting in children, with indicators such as dietary diversity and food insecurity decreasing and increasing the prevalence of wasting, respectively, many other studies concur with the current study’s results. Studies such as Betebo *et al.* (2017), M’Kaibi *et al.* (2017), Ogechi and Chilezie

(2017) and Drysdale *et al*. (2021) found no relationship between food insecurity, access or dietary diversity and wasting in children under the age of five. This is because food security is not the only contributing factor to child nutrition; other factors include the health status of the child and mother, feeding practices and environmental health (IPC Global Partners, 2021). Other basic causes include livelihood strategies, low birth weight, low fertility and maternal malnutrition (Ekesa *et al*., 2011; IPC Global Partners, 2021).

Wasting is a consequence of poor dietary diversity and repeated exposure to micronutrient deficiencies. Micronutrient deficiency causes compromised immunity and neurological function, anaemia and susceptibility to infections, which are common in these rural poor settings (Chowdhury *et al*., 2019). Child illness and metabolic disorders are also contributing factors to their nutritional status, especially their weight-for-height, while poor nutrition also predisposes children to sickness (Mkhize & Sibanda, 2020). Studies such as Betebo *et al*. (2017), Mkhize and Sibanda (2020) and Belayneh *et al*. (2021) found a relationship between the prevalence of wasting in children and recent illness in the form of flu, diarrhoea and vomiting. Drysdale *et al*. (2021) found an increase in the number of children experiencing these illnesses, a potential explanation for the resultant trend in wasting found in the current study.

Illnesses such as diarrhoea and vomiting can be a result of consuming impurified and unsanitary water, and generally, poor food storage, preparation and feeding practices causing undernutrition (Darapheak *et al*., 2013; Motbainor *et al*., 2015; Mkhize & Sibanda, 2020). Poor infrastructure, sanitation and access to water are common in these rural settings, and climate change is expected to exacerbate these conditions, leading to greater negative effects on child nutrition (Smith *et al*., 2005; Momberg *et al.*, 2020; Drysdale *et al.*, 2021). Belayneh *et al*. (2021) also found that wasting was higher in households with uneducated parents because education is believed to improve childcare, feeding practices and, therefore, nutritional status. Furthermore, literacy is associated with better socioeconomic status, therefore, higher income and thus food security through improved access to food (Smith *et al.*, 2005; Twine & Hunter, 2011; Belayneh *et al*., 2021).

4.5.3.2 Underweight

The aggregate analysis results report a negative correlation between underweightness in females and dietary diversity. Further, the results suggest that dietary diversity and the experience of hunger were not good predictors of underweightness in children under the age of five. Also, larger households have a lower probability of having an underweight child. This is contrary to some studies, for example, Saha *et al*. (2009), Betebo *et al*. (2017) and Chakona and Shackleton (2018), who found that food security is related to inadequate intake of food and thus underweightness, also stating that food-insecure households have underweight children compared to their food-secure counterparts. In their review of South Africa's national food security surveys, Labadarios *et al*. (2011) also state that dietary diversity is strongly associated with a child's weight-for-age.

Several studies, such as Bukania *et al*. (2014), Motbainor *et al*. (2015), M'Kaibi *et al*. (2017) and Drysdale *et al*. (2021), found results similar to the current study, with food security indicators such as HFIAS and dietary diversity being non-predictors of underweightness. However, Motbainor *et al*. (2015) found that although dietary diversity was not a predictor of underweightness, the number of meals eaten by a child or the food consumption score was a significant predictor. Therefore, it is also important to improve dietary quantity to reduce underweightness in children (Chakona & Shackleton, 2018). Darapheak *et al*. (2013) found that introducing animal-source foods rich in vitamins and minerals not found in plant-based food is linked to reduced underweightness.

Like wasting, underweightness can result from poor mother or child health, and illness during pregnancy could affect the mother's health and nutrition, resulting in low birth weight and thus underweightness (Chopra, 2003; Kimani-Murage, 2013; Betebo *et al*., 2017). Other factors believed to cause underweightness are single-headed households, poor public health services and poor sanitation, causing water-borne diseases (Chopra, 2003; Mkhize & Sibanda, 2020). Mkhize and Sibanda (2020) also found that low parental education, leading to poor feeding and hygiene practices, and little knowledge of nutritious and balanced diets contribute to underweightness, similar to wasting.

4.5.3.3 Stunting

This study found no correlation between stunting and food security, and according to the results, dietary diversity and the experience of hunger are not good predictors of stunting in children under the age of five. Stunting remains high in South Africa, for a middle-income country, and many studies, such as Bukania *et al*. (2014), Betebo *et al*. (2017), M'Kaibi *et al*. (2017), Chakona & Shackleton (2018) and Drysdale *et al*. (2021), found that food security indicators such as dietary diversity and the food insecurity score are great predictors of stunting in children, contrary to the current study. However, like this study, Ekesa *et al*. (2011) and Motbainor *et al.* (2015) found no significant relationship between food security and stunting in children.

While wasting and underweightness are a result of short-term inadequate quality and quantity of food and infectious diseases, stunting is caused by chronic exposure to undernutrition, where chronically undernourished parents have a higher probability of giving birth to stunted children, resulting in an intergenerational cycle of poverty and hunger (Chowdhury *et al*., 2019; Momberg *et al.*, 2020). Therefore, short-term changes in food security do not cause stunting because stunting is a consequence of long-term deprivation and exposure (Chopra, 2003; Belayneh *et al*., 2021). Stunting is strongly associated with long-term poor socioeconomic status, low parental education and poor access to public services and facilities, which affect the health and nutrition of children through reduced access to food, low birth weight and chronic illness (Smith *et al*., 2005; Kimani-Murage, 2013; Ogechi & Chilezie, 2017; Belayneh *et al*., 2021; Drysdale *et al*., 2021). Chronic malnutrition is a bigger problem than acute malnutrition in South Africa, and apart from the physical effects, stunting is associated with impaired cognitive function, resulting in a workforce that has low mental capacity, less productivity and thus lower overall development (Ekesa *et al*., 2011; Chakona & Shackleton, 2018). Therefore, it is important to monitor and reduce chronic malnutrition because of its nationwide effects.

4.6 Conclusion

In conclusion, this chapter's findings highlight the need for a nuanced understanding of the complex relationship between food security and undernutrition. While the established view emphasises food security as a primary driver of undernutrition, this research suggests that this relationship may not hold when food security is assessed solely at the household level and limited to only two dimensions. Moreover, it is essential to recognise that undernutrition is a multifaceted issue influenced by a myriad of factors, including dietary diversity, climate conditions and health status. These interconnected elements underscore the complexity of the challenge at hand.

Within the context of the study site, certain factors have been identified as positively affecting food security, including greater employment opportunities, asset ownership, smaller household sizes and male-headed households. These findings underscore the importance of addressing gender inequality and promoting education and employment opportunities as integral components of South Africa's strategy to reduce food insecurity. Furthermore, the looming threat of climate change, as discussed in the following chapter, necessitates a comprehensive approach to food security policy interventions. Government must consider these multifaceted dynamics and strive for holistic solutions to ensure the well-being of its citizens in the face of evolving challenges.

CHAPTER 5
THE IMPACT OF CLIMATE VARIABILITY ON FOOD SECURITY AND CHILD NUTRITION

5.1 Abstract

Climate change poses a substantial threat to food security and nutrition by changing precipitation patterns, rising temperatures and increased drought, potentially leading to reduced agricultural yields and adverse effects on household food security. Despite the critical importance of this issue, there has been a limited exploration of the long-term impacts of climate variability on food security and nutrition. The primary aim of this part of the study was to assess the influence of precipitation variability on household food security and the nutritional status of children under the age of five. To achieve this, a comprehensive analysis of precipitation trends from 2010 to 2021 was conducted, employing precipitation anomalies and the Mann-Kendall test as quantification tools. Correlation tests were then conducted between precipitation anomalies and the food security and undernutrition metrics introduced in the preceding chapters. Due to data constraints, climate variability was employed as a proxy for climate change throughout this chapter. Consequently, the analysis revealed no discernible trend in precipitation fluctuations over the study period. Moreover, no significant association with precipitation was found when examining changes in food security over the years. The findings suggest that precipitation variability is a relatively weak predictor of undernutrition. Specifically, the prevalence of wasting in children exhibited a negative correlation with rainfall anomalies, but no such association was identified for underweightness or stunting. Recognising that stunting may be influenced by long-term changes in contributing factors, potential delayed effects of precipitation on stunting were explored, yet the results failed to indicate any correlation. It is crucial to acknowledge that data availability emerged as a prominent limitation, potentially contributing to the absence of significant associations. Consequently, a more comprehensive investigation with robust data coverage over an extended timeframe is warranted to gain a deeper understanding of the intricate relationship between precipitation variability and food security, as well as child nutrition.

Keywords

Climate Variability, Precipitation, Food Security, Undernutrition, Correlation

5.2 Introduction

In low- and middle-income countries, undernutrition is a serious development issue that affects the health and productivity of populations (Phalkey *et al.*, 2015). Undernutrition is also viewed as one of the five greatest consequences of climate change, mainly through effects on food security, especially dietary diversity (Phalkey *et al.*, 2015; Niles *et al.*, 2021). Climate change will affect South Africa's food availability, access, utilisation, and stability, thereby increasing the risk of hunger and, therefore, affecting the nutritional status of many, including children (IPC Global Partners, 2021). Therefore, this part of the study evaluated the effect of climate variability in the form of precipitation changes in the Bushbuckridge region of Mpumalanga Province. This is crucial since rainfall greatly impacts South Africa's food systems and people's livelihoods (IPC Global Partners, 2021; IPCC, 2022). This chapter builds on Chapters 3 and 4 by examining whether local precipitation changes may account for ongoing patterns in child undernourishment and household food security. As a result, the primary goal of this chapter was to evaluate how precipitation variability affects household food security and undernutrition in young children in a rural population, and because there were not enough time series data to investigate climate change impacts, climate variability was used as a proxy.

Climate variability, in the form of precipitation change, can affect nutrition mainly through two pathways: 1) increasing the prevalence and spread of diseases, and 2) effects on food consumption (Hagos *et al.*, 2014; Phalkey *et al.*, 2015; Thiede & Gray, 2020; Niles *et al.*, 2021; Mank, 2022). This also happens when climate variability affects food utilisation, such that reduced rainfall causes less water available for the proper caring and feeding practices necessary for good child nutrition (Tfwala *et al.*, 2018; Thiede & Gray, 2020; Niles *et al.*, 2021). Ziervogel *et al.* (2006) also believe that adequate food utilisation is achieved when good techniques for processing, storing and consuming food are followed, and there is adequate knowledge and implementation of proper caring and nutrition techniques, which are affected by precipitation and temperature variability. A variable climate may also increase transmission of water-borne diseases such as malaria, a disease that signifies poverty as it is common in areas of low income and poor housing, water and sanitation, which is widespread in South Africa's low altitude areas, i.e., Mpumalanga and Limpopo (Adeola *et al.*, 2019a; Thiede & Gray, 2020). When these happen, they affect a child's health and thus their nutrient intake and absorption ability, causing mild to severe undernutrition (Le & Nguyen, 2021).

Arguably, the greatest pathway through which climate variability affects nutrition is its effects on food consumption because of changes in food availability and access (Wossen *et al*., 2018; Niles *et al*., 2021). This happens because climate variability, in the form of precipitation and temperature changes, as well as the likelihood of droughts, floods and other extreme weather events, affects the availability and access to food for consumption (Ziervogel *et al*., 2006; Cooper *et al*., 2019; Kinda & Badolo, 2019). The United Nations Food and Agriculture Organization (FAO) also states that countries that rely on rain-fed agriculture are at the highest risk of hunger; therefore, South Africa needs to properly assess their vulnerabilities towards climate change and its effects, such as reduced rainfall, to reduce the impact on food security and nutrition (cited in FAO, 2018; Botai *et al*., 2018; Kinda & Badolo *et al*., 2019). South Africa is a water-stressed semi-arid country with high climate variability both spatially and temporally, which affects a country that is already dependent on rain-fed agriculture and has minimal financial and technical resources, thus a low adaptive capacity, making it vulnerable to climate shocks (Kotir, 2011; Moylan, 2012; Ghosh-Jerath *et al*., 2021; Masingi & Maposa, 2021). Small-holder farming, which has the potential to improve food security and nutrition through increased food consumption and income, has already declined in South Africa (Hoddinott, 2012; Ghosh-Jerath *et al*., 2021). Those who still engage in this type of farming have cited reduced agricultural output, which could be worsened by climate change (Ghosh-Jerath *et al*., 2021). Climate change may have other impacts, such as decreased national food production, increased fuel, water and electricity prices, and reduced access to food markets. These would cause further increases in the price of food, affecting household purchasing power and, therefore, reducing food consumption and, consequently, the nutritional status of children in the household (Cooper *et al*., 2019).

While climate change threatens to affect the world, some regions like Sub-Saharan Africa are expected to be affected more than others (Thiede & Gray, 2020; Masingi & Maposa, 2021). South Africa is not exempted from these effects, and with prevailing inequalities in the country, these effects differ between socioeconomic classes as poor black children, such as those in rural Mpumalanga Province, are affected the most (Du Plessis & Mestry, 2019; Le & Nguyen, 2021; Mank, 2022). Climate change offsets economic development and undermines national and regional interventions to alleviate food insecurity and malnutrition in children, resulting in poor child development, thereby rendering the country stuck in a poverty cycle (Nhemachena *et al*., 2020; Niles *et al*., 2021). The United Nations FAO states that climate change is one of the greatest threats to food systems; therefore, South African national policy should consider climate adaptation, especially in marginalised and already-vulnerable groups who need improved government assistance, when evaluating hunger eradication (Moylan, 2012; cited in FAO, 2018; Ghosh-Jerath *et al*., 2021).

South Africa is currently not on track to meet SDG nutrition targets relating to SDGs 2 and 3 on hunger and health partly because the impact of climate change and variability, among other things, has not been accounted for in policy interventions (Moylan, 2012; Cooper *et al*., 2019; Niles *et al*., 2021). Cooper *et al*. (2019) also believe that changes in precipitation patterns and their effects on food security and nutrition are underexplored. There is currently little evidence on the effects of climate variability on food security and nutrition at the household and community levels; therefore, this study sought to extend the empirical evidence that literature has failed to provide about climate impacts on food security and nutritional status (Phalkey *et al*., 2015; Wossen *et al*., 2018; Cooper *et al*., 2019; Thiede & Gray, 2020). Therefore, the aim of this part of the study was to evaluate the effects of precipitation variability on food security and nutrition. To do so, the changes in precipitation between 2010 and 2021 and how these affect household dietary diversity, the experience of hunger and the prevalence of undernutrition in children were assessed.

5.3 Methods

Chapter 2 describes the study site and general methods. A Mann-Kendall test was conducted to assess the precipitation pattern trend over the study years (2010 to 2021) using the previously calculated seasonal anomalies. Pearson correlation analysis tests were then performed to compare mean HDDSs and HFIASs against annual rainfall anomaly scores. The same analysis was conducted to compare the aggregated mean for the percentage of wasted, underweight and stunted children per year versus the seasonal rainfall anomaly scores. For stunting, potential medium-term impacts of rainfall were also assessed using the Pearson correlation test, comparing the association between stunting in children and rainfall after several time lags, i.e., one, two, three, four and five years.

5.4 Results

5.4.1 Precipitation Patterns

Considering only the years included in the study, the average anomaly score was 0.14, the greatest being 0.934 in 2013, while the greatest reduction in rainfall relative to the mean was in 2019 at -

0.678. Although rainfall in the earlier years of the study was above average while those in the latter years were generally below average, there was no statistically significant ($z = -0.376$, $n = 6$, $p = 0.707$) in the monotonic decrease in precipitation (Figure 5.1). Figure 5.2 displays precipitation changes that have no apparent trend.

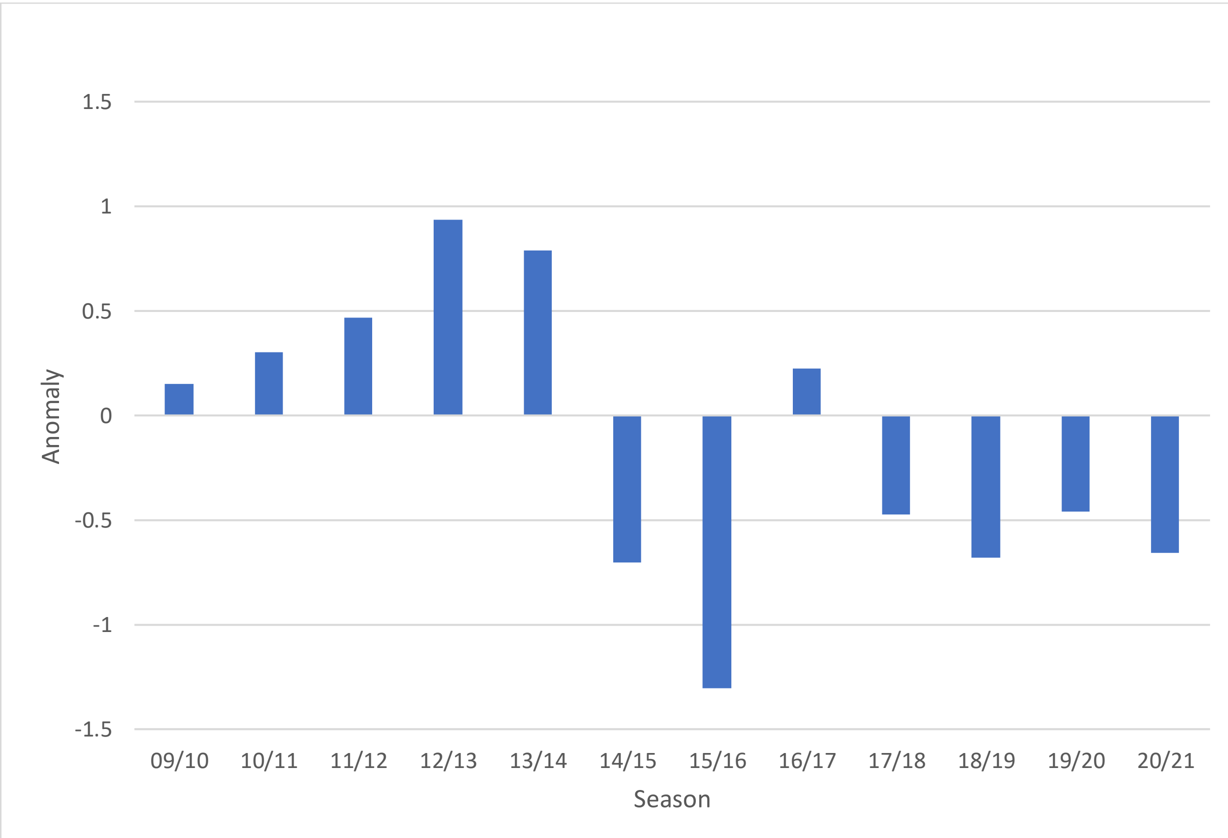

Figure 5.1 Variability of rainfall in the years relevant to the study presented as anomalies.

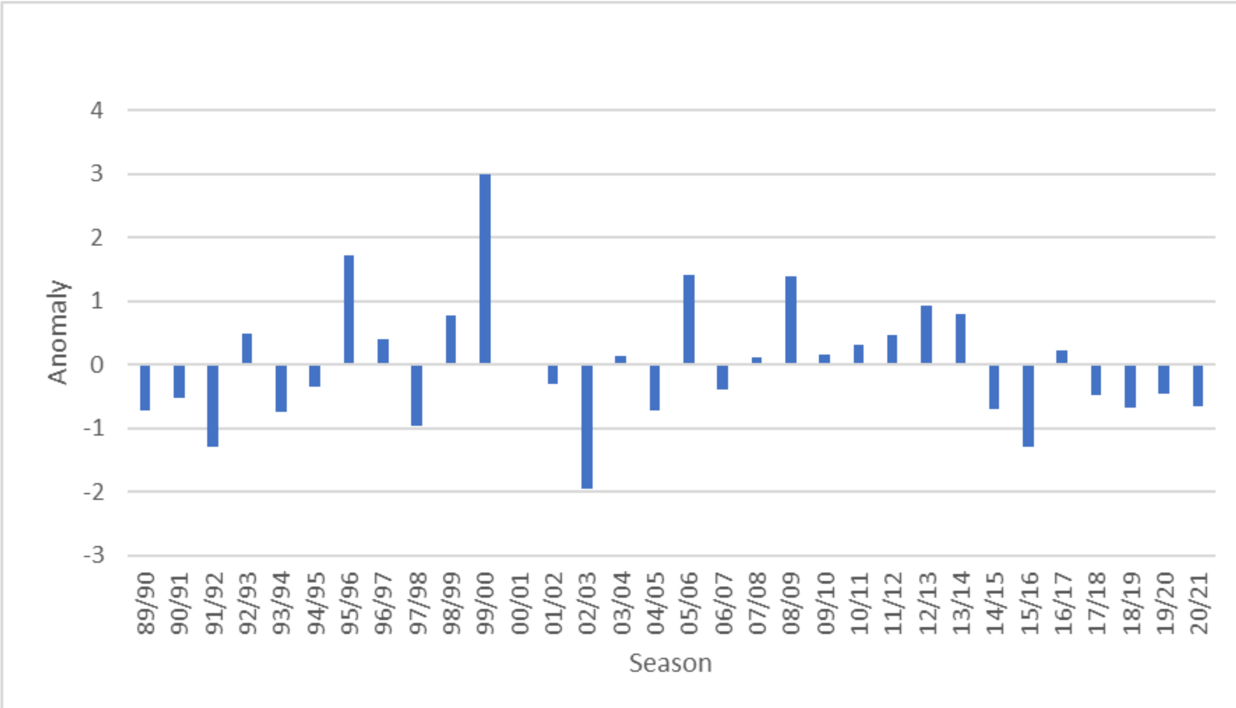

Figure 5.2 Anomalies representing the rainfall variability throughout the years used for the long-run average.

5.4.2 The Impact of Rainfall on Household Food Security

There was a non-significant (p = 0.342) moderate positive correlation (r = 0.527) between rainfall and mean annual dietary diversity (Figure 5.3). The lowest mean dietary diversity scores were in the years with the lowest and highest rainfall, respectively. Similarly, there was a non-significant (p = 0.200) but moderate negative correlation (r = -0.675) between rainfall and the experience of hunger. Although dietary diversity tended to be higher and food insecurity access lower in above-average range for years, these relationships were not statistically significant.

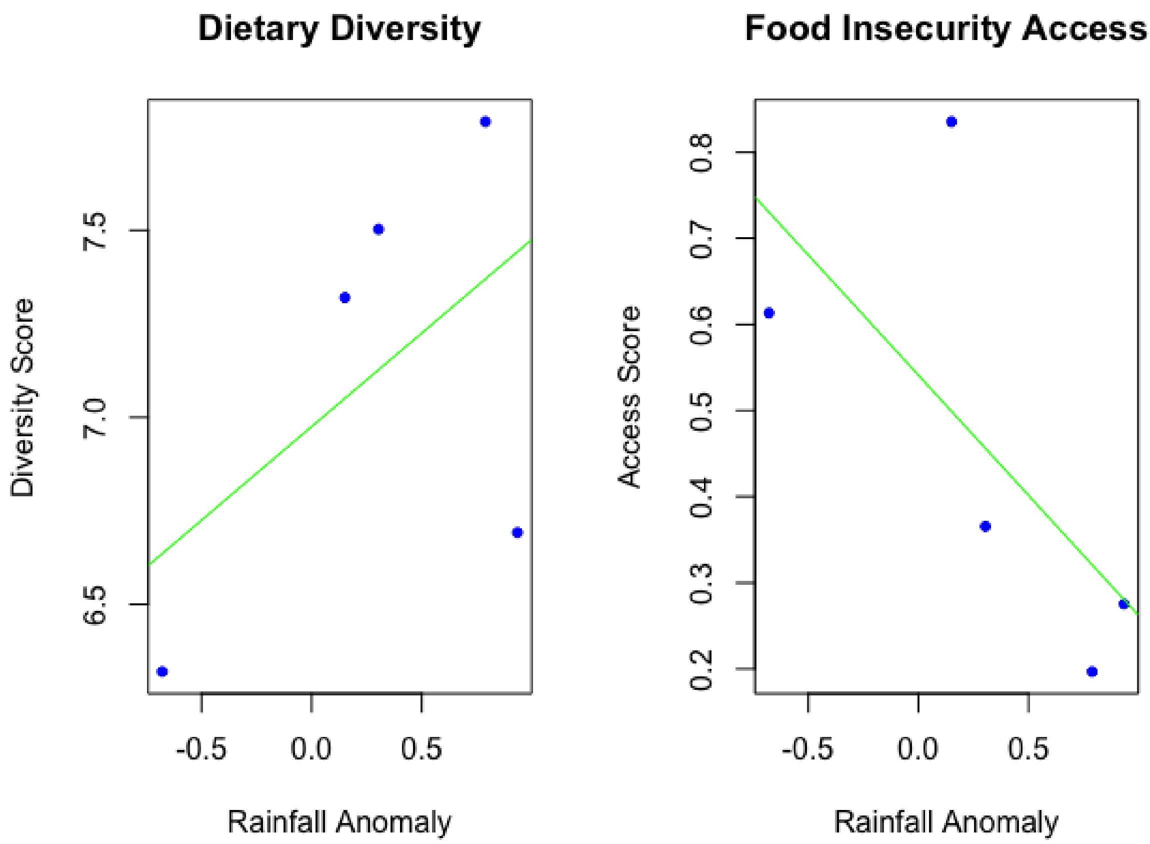

Figure 5.3 Household food access as represented by the household dietary diversity score and the household food insecurity access score recorded at different rainfall variabilities.

5.4.3 The Impact of Rainfall on Child Undernutrition

5.4.3.1 Wasting

The prevalence of wasting was generally higher during below-average rainfall periods (Figure 5.4). The tests found a statistically significant ($p < 0.05$) strong and negative correlation ($r = -0.831$) between rainfall anomaly and the prevalence of wasting in children. The correlation between wasting in male children and rainfall patterns was strongly negative ($r = -0.747$) and statistically significant ($p < 0.05$). Female children had an even stronger negative correlation ($r = -0.864$) to rainfall patterns, which was also statistically significant ($p < 0.05$). This evidence suggests that wasting in children is more prevalent in years of below-average rainfall.

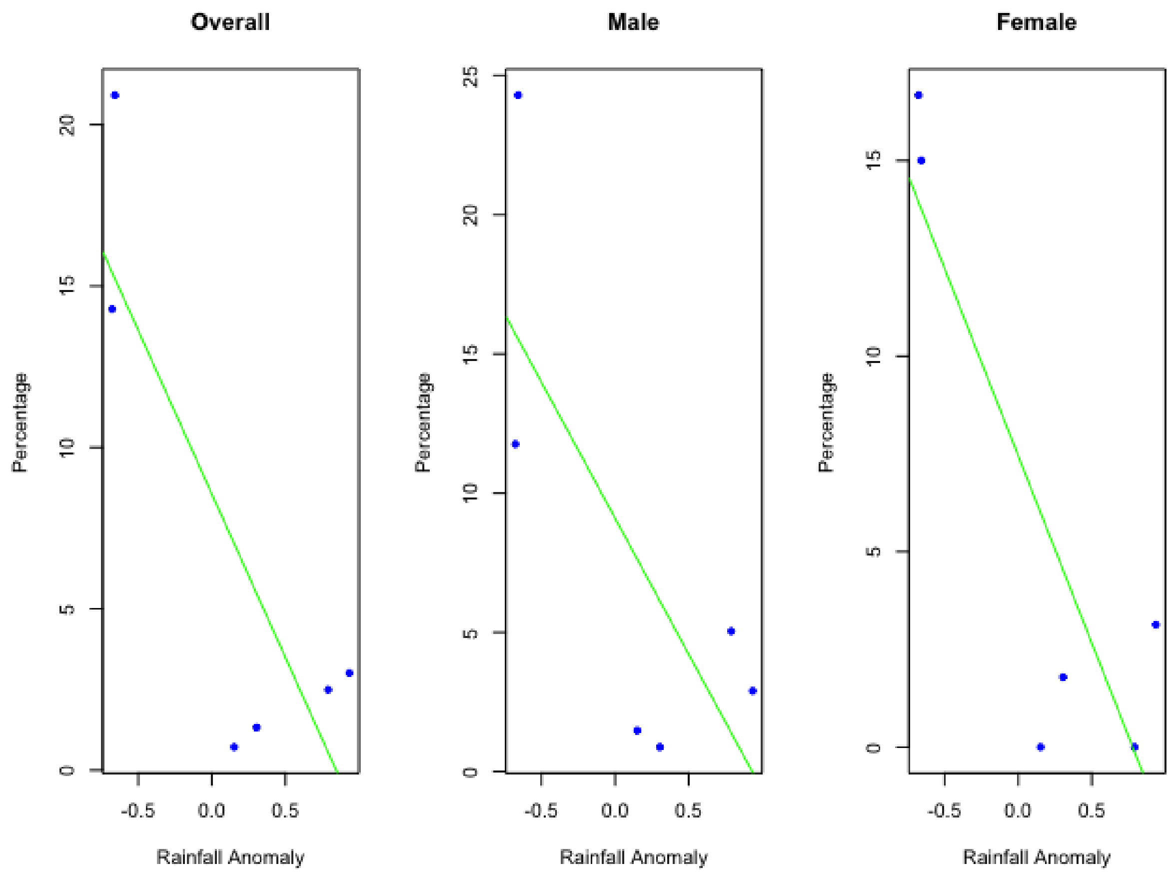

Figure 5.4 The prevalence of child wasting in relation to the amount of rainfall available in the area.

5.4.3.2 Underweight

There was a moderate negative correlation (r = -0.648) between rainfall and underweightness in children, although not statistically significant (p = 0.082) (Figure 5.5). Similarly, the was a non-significant (p = 0.101) moderate negative correlation (r = -0.605) between rainfall and the prevalence of underweight male children. The correlation between rainfall and the prevalence of underweight female children was not significant (p = 0.110) and moderately negative (r = -0.587). Thus, there is no evidence that underweightness is influenced by rainfall.

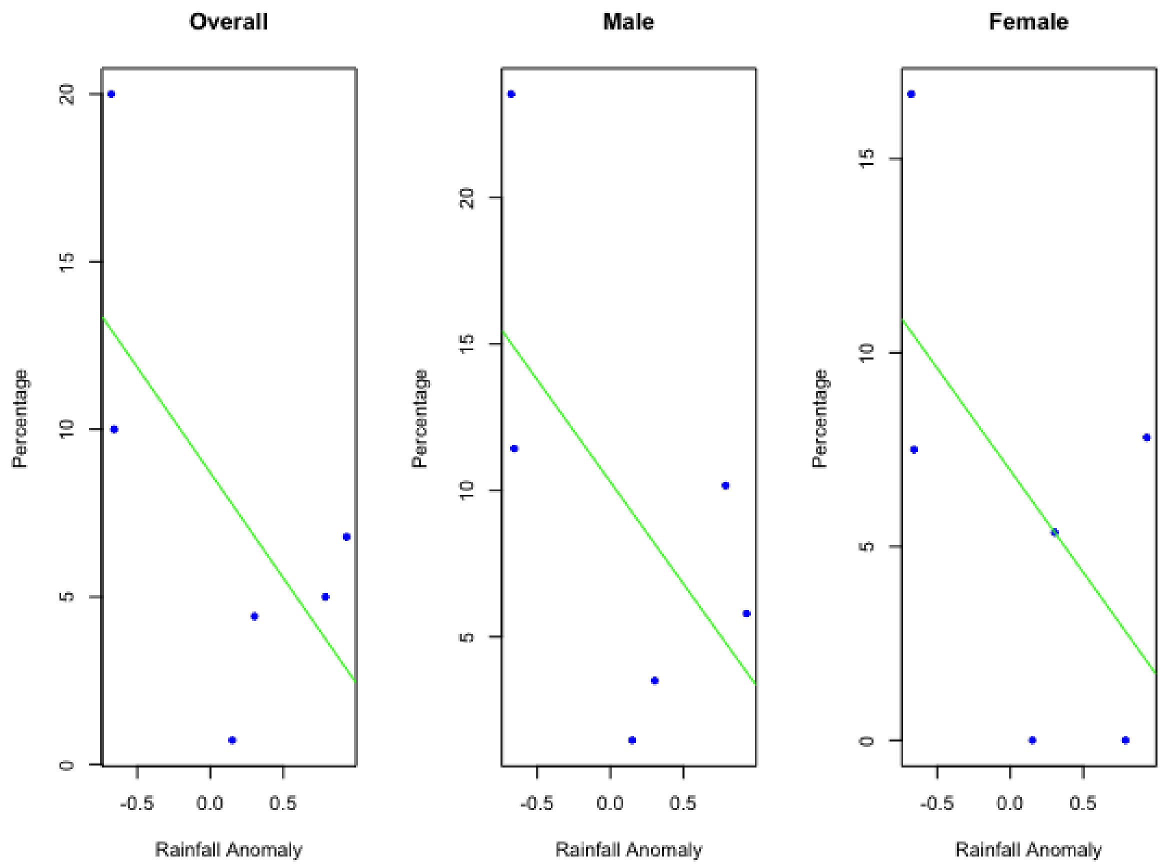

Figure 5.5 The prevalence of underweight children at different variabilities of rainfall.

5.4.3.3 Stunting

There was a non-significant (p = 0.461) and very weak negative correlation (r = -0.052) between rainfall and the prevalence of stunted children (Figure 5.6). The correlation between rainfall patterns and the prevalence of stunting in male children was weak and positive (r = 0.023) and not statistically significant (p = 0.518). Similarly, there was no statistical significance (p = 0.391) in the weak and negative correlation (r = -0.146) between rainfall patterns and stunting in female children. There was a stronger negative association between rainfall and stunting in children a year later compared to other time periods (i.e., two, three, four and five years). However, none of these correlations were statistically significant (Table 5.1). Therefore, there is no evidence that rainfall impacts stunting in children.

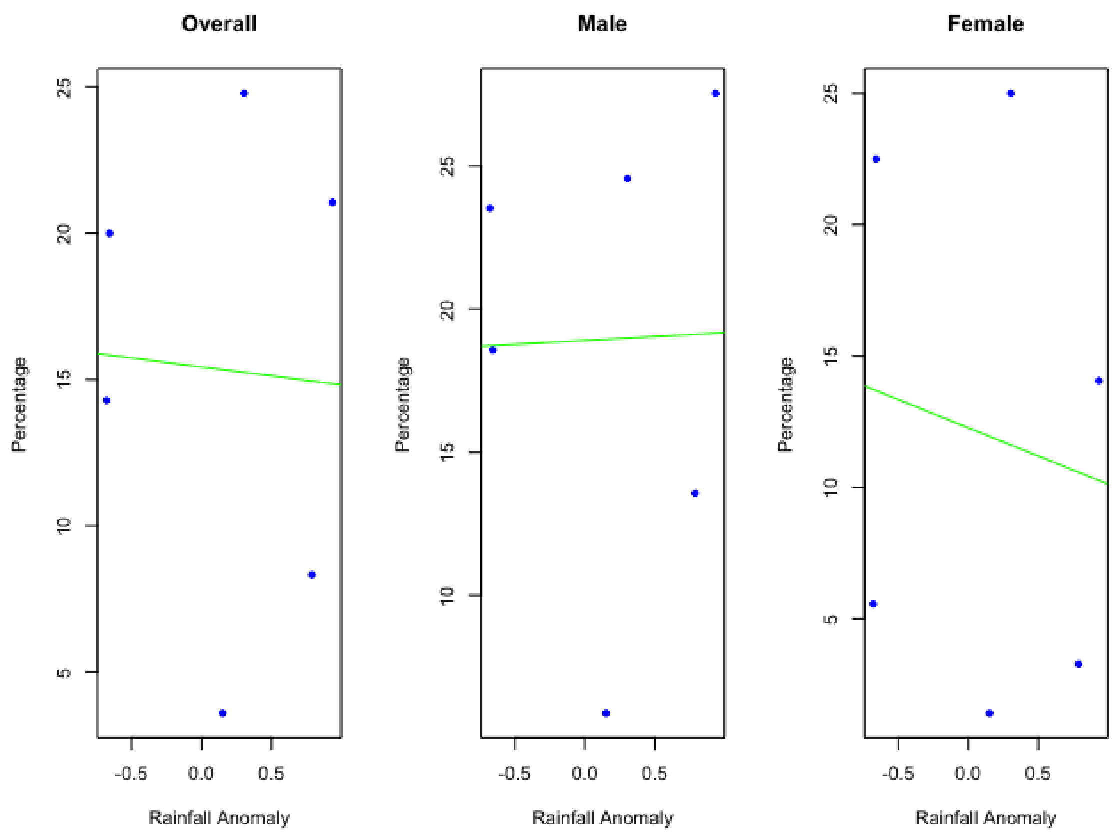

Figure 5.6 The prevalence of stunting in children correlated to rainfall variability.

Table 5.1 The association between children's stunting and precipitation patterns that were collected in the years prior to the collection of anthropometric measures.

Years before collection	Stunting	Correlation (r)	p-value
1	Overall	-0.670	0.073
	Male	-0.672	0.072
	Female	-0.570	0.119
2	Overall	0.256	0.688
	Male	0.289	0.711
	Female	0.149	0.611
3	Overall	0.144	0.607
	Male	-0.018	0.486
	Female	0.217	0.661
4	Overall	-0.321	0.267
	Male	-0.356	0.244
	Female	-0.257	0.311
5	Overall	0.124	0.593
	Male	0.327	0.859
	Female	-0.082	0.438

5.5 Discussion

This study found no significant trend in seasonal precipitation. However, it should be noted that a longer period is always recommended for assessing trends, according to the World Meteorological Organization's Technical Regulations (cited in Shevchenko *et al*., 2020). Similar to this study, Masingi and Maposa (2021) found that the decrease in rainfall from 1900 to 2017 in Mpumalanga did not observe a statistically significant monotonic trend. These findings are contrary to several studies, such as Lakhraj-Govender and Grab (2019), Mahlalela *et al*. (2020) and Nhemachena *et al*. (2020), which found a decline in rainfall from 1980 to 2018 in South Africa, stating that the reduction is mainly due to a reduction in the number of rainy days, which can be detrimental in social-ecological systems where precipitation greatly affects food systems. More importantly, studies such as MacKellar *et al*. (2014) and Adeola *et al*. (2019a) found statistically significant decreases and variability in rainfall over the northeastern region of South Africa, such as Mpumalanga and Limpopo Provinces.

Although there were apparent trends in the relationship between precipitation and the food security indices, the low sample size (six years) could explain why these relationships were not statistically significant. Therefore, in the current study, there was no strong evidence suggesting that rainfall affects dietary diversity and experience of hunger in the study site. Niles *et al*. (2021) found a 12-month delayed effect caused by rainfall on food security, as child dietary diversity increases 12 months after rainfall increases. Changes in precipitation might take time to manifest effects on food production, access and, therefore, consumption, resulting in a lack of statistical relationship as found in the current study. Additionally, the effects of food insecurity are exacerbated in children more than adults because children are at a sensitive development stage (Thiede & Gray, 2020). Impacts on food security can also be underwhelming as a result of high dependence on store-bought food, within these social-ecological systems (Boatemaa *et al*., 2018). However, according to Phalkey *et al*. (2015) and Niles *et al*. (2021), most literature has found an association between climate variability and food security. This can be seen in studies by Moylan (2012) and Wossen *et al*. (2018), who found that precipitation variability influenced food produced and the price of food, and thus is an expression of households' vulnerability to such shocks through decreased diversity of diets (Ziervogel *et al*., 2006). Nhemachena *et al*. (2020) believe that variability could reduce food production by up to 50% by the end of the century. Kotir (2011) also believes that food insecurity in Africa will worsen over the coming decades, with the number and potentially the percentage of food-insecure people expected to increase.

This chapter revealed a statistically significant association between wasting in children and precipitation, suggesting more incidences of wasted children in years of below-average rainfall. There was, however, no significant evidence for an association between precipitation and stunting or underweightness in children. Like this study, Cooper *et al*. (2019) found a significant association between short-term changes in rainfall and wasting in children in Ghana. This supports claims that wasting is short-term undernutrition, which responds to short-term changes in its defining factors while stunting results from long-term exposure (Le & Nguyen, 2021). Le and Nguyen (2021) also found that climate variability can affect children in the utero stage, causing strongly apparent consequences in the first few years of life and affecting their anthropometric status. This delayed effect can be seen in the study's finding of a strong correlation between precipitation patterns and stunting in children, where there was a 12-month delayed effect, but the lack of statistical significance of this association could be the small sample size. However, this was not the case in the current study because an assessment of rainfall on stunting between longer periods revealed that stunting in children was not affected by rainfall changes that occurred in the five years before the collection of the relevant anthropometric measures.

Similar to the current study, Niles *et al*. (2021) found that in Rwanda, Eswatini and Kenya, child undernutrition was strongly associated with reduced rainfall. Hagos *et al*. (2014) was one of the select studies that found a strong statistical significance between stunting in children and reduced rainfall while failing to find any association between reduced rainfall and the prevalence of wasting and underweightness in children. They believe that short-term undernutrition because of a change in precipitation can be 'fixed' by modified coping and or adaptation strategies. However, evidence that quantifies these impacts and subsequent coping strategies enough to inform policy decisions is still limited (Phalkey *et al*., 2015). Although limited studies have been conducted to evaluate the impact of precipitation on child nutrition, additional studies such as Le and Nguyen (2021) and Mank (2022) have found contrasting evidence of the association. As expressed by Hagos *et al*. (2014) and Mank (2022), it is clear that socioeconomic factors play a significant role in mediating the association between precipitation and undernutrition in children. Improved socioeconomic status acts as a safeguard against climate change and variability impacts, which, for example, seek to reduce agricultural activity and increase food prices and purchasing power. With greater socioeconomic status, households are resilient to such effects (Al *et al*., 2008; Connolly-Boutin & Smit, 2016; IPCC, 2022).

Climate variability poses significant challenges to agricultural productivity, affecting crop yields, livestock health, and overall food production. The unpredictability of weather patterns, including changes in precipitation, temperature extremes, and the frequency of extreme events like droughts and floods, disrupts agricultural systems, leading to yield losses and income shocks for farming households. While climate variability can have immediate impacts on agricultural production, the broader trends associated with climate change introduce additional complexities, necessitating long-term adaptation strategies, greater than the commonly used coping strategies such as use of wild foods, in these local social-ecological systems (Golden et al., 2021). Therefore, it is crucial to explore not only the direct effects of climate variability but also the cumulative impacts of ongoing climate change on agricultural systems and their implications for household food security.

While agricultural output is inextricably related to food security, it is critical to recognise that other socioeconomic factors influence nutritional results, particularly among disadvantaged people (Phalkey *et al*., 2015, Mabhaudhi et al., 2016; Chakona & Shackleton, 2019). Access to food, income inequality, healthcare, and education all have a significant impact on household food security and nutrition (Shisana *et al*., 2013; Statistics South Africa, 2015). Neglecting these issues might oversimplify the complex dynamics that drive malnutrition, undermining efforts to effectively address its core causes. As a result, a thorough investigation of the interplay between climate change, food security, and malnutrition should include a broader range of variables in order to inform holistic interventions and policy suggestions targeted at developing resilient food systems in the face of climate change, promoting production within local social-ecological systems.

Climate variability and its effects on agricultural productivity have far-reaching consequences for the global food chain, impacting food prices and trade patterns (Chen et al., 2017). Variable weather patterns can cause fluctuations in crop yields and livestock productivity, resulting in supply shortages and rising food prices, particularly for essential goods. Price increases, exacerbated by climate-related shocks such as droughts or floods, disproportionately affect vulnerable groups, aggravating food poverty and malnutrition (Phalkey et al., 2015; Chen et al., 2017). Furthermore, disruptions in local food supply might increase reliance on imported items, putting further strain on global food markets and worsening price fluctuations (Hamilton et al., 2020). Therefore, although populations are increasingly reliant on market food produced outside of their social-ecological systems, food access can be affected because of reliance on other systems which are being impacted by their own shocks (Golden *et al*., 2021).

Global trade has a significant impact on food security and nutrition outcomes, particularly in regions where domestic supply alone cannot meet demand (Myers et al., 2017; Hamilton *et al.*, 2020). However, the global food system's interdependence makes it vulnerable to a variety of threats, including climate-induced supply disruptions and price volatility (Hamilton *et al.*, 2020). Countries that rely on imported food are more vulnerable to worldwide market changes, which have a negative impact on food security and nutrition, at the local level (Myers et al., 2017). Furthermore, trade regulations, taxes, and subsidies can alter market dynamics, impacting the affordability and availability of nutritious food for vulnerable groups (Maestre et al., 2017).

5.6 Conclusion

The findings presented in this chapter underscore the complex nature of the relationship between precipitation, food security and nutrition. While the analysis revealed no significant monotonic trend in precipitation over the years, it was not observed that precipitation variability exerts a substantial impact on the food security status of households. This lack of influence could be attributed to the prevailing reliance on store-bought food, which remains largely unaffected by local rainfall fluctuations or the low sample size. Furthermore, the chapter's exploration illuminated the intricate interplay between climate, food security and nutrition. Notably, reductions in rainfall were associated with an increased prevalence of wasting, indicating a potential link to reduced weight-for-height ratios. This underscores the importance of recognising that improving food security solely might not suffice to alleviate undernutrition, as other factors like climate variability may also be significant contributors. Given these findings, adopting a holistic approach when addressing undernutrition, considering multifaceted factors beyond food security alone, is imperative. By acknowledging the complexity of the climate-food-nutrition nexus, we can develop more effective strategies to combat undernutrition and enhance the resilience of vulnerable populations in the face of changing climatic conditions.

CHAPTER 6
SYNTHESIS AND CONCLUSION

6.1 Introduction

In South Africa, where commercial farms produce most of the nation's food and account for 90% of all agricultural output, it is imperative to view the country's rain-fed agricultural industry through a social-ecological lens. This perspective highlights the interconnectedness between the natural environment and human society and the potential impacts on food security and nutrition. The expected effects of climate change and variability pose a significant threat to South Africa's agricultural sector from a social-ecological standpoint (Calzadilla *et al*., 2014). This could result in higher food costs and reduced purchasing power for many people, exacerbating food insecurity. Moreover, at the local level, reduced precipitation due to climate change and variability directly affects small-holder agriculture and household food security (Shisana *et al*., 2013; IPCC, 2022). These effects on food systems, when viewed through a social-ecological lens, underscore the intricate relationship between environmental changes and societal well-being. Climate change could increase nutrition-related mortality, particularly among children under the age of five (IPC Global Partners, 2021), emphasising the critical intersection of ecological factors and human health.

Food security and nutrition, as seen through a social-ecological perspective, are essential aspects of livelihoods deeply entwined with multiple drivers, including climate change. Poverty and inequality, which are major food security challenges in South Africa, contribute to food insecurity in various regions (Shisana *et al*., 2013). The social-economic lens highlights how rising unemployment and income inequality limit food purchasing power, leading to increased food insecurity and undernutrition when coupled with rising food prices (Cousins, 2015; Haini *et al*., 2023). Access to land and land reform also play a pivotal role in addressing disparities, as they affect food availability within a social-ecological framework (Shisana *et al*., 2013; Cousins, 2015). South Africa's semi-arid nature and water constraints in numerous areas further underscore the social-ecological dimension of food security. Climate change and the increasing likelihood of droughts exacerbate water scarcity issues, impacting agricultural productivity, health and nutrition (Rusere *et al*., 2019; IPCC, 2022). Poor nutrition, as viewed through a social-ecological lens, has cascading effects on health and economic productivity, particularly in rural areas (IPC Global Partners, 2021).

Although not a dominant part of their livelihoods, these populations use agricultural, fishery, forestry or other natural resources to improve their livelihoods. Reduced rainfall and increased temperatures affect the health of their livestock and shorten or disrupt the crop-growing season (Thomas & Twyman, 2005; Connolly-Boutin & Smit, 2016). Droughts and water scarcity, which are believed to accompany climate change, will influence pastoralists to change water regimes, but the lack of credit is a major adaptation barrier for many farmers in South Africa (Connolly-Boutin & Smit, 2016; IPCC, 2022). In these rural areas, climate change interacts with unemployment, poor healthcare and inadequate infrastructure to increase vulnerability (Connolly-Boutin & Smit, 2016). This threatens Bushbuckridge's socioeconomic future because this can compromise the well-being of the future workforce because of inadequate nutrition, which results in low productivity, low cognitive development and high disease susceptibility.

This study aimed to examine the impact of climate variability on household food security and the nutritional status of children under the age of five years in Bushbuckridge. To fulfil this aim, the objectives were to quantify the trends in child undernutrition; assess the changes in households' food security status and evaluate the relationship between household food security and the children's nutritional status; and assess the impact that changes in precipitation have on food security and child nutrition. It is important to monitor food security and nutrition because these are proxies for the level of poverty and the country's development potential. As stated by the National Food and Security Plan 2018-2023 of South Africa, timely and accurate data are important when assessing and monitoring the status of food and nutrition security, especially in rural areas where status differs at the national level (The Republic of South Africa, 2017). As such, this study assessed the trend in short- and long-term undernutrition from 2010 to 2021 to determine whether nutritional status is improving, as this is important for addressing national and global targets of reducing child malnutrition (Chapter 3). The contributing factors to undernutrition were then assessed in Chapters 4 and 5, evaluating whether household food security and or precipitation changes have any impact on nutrition. The changes in food security status from 2010 to 2019 were also quantified in Chapter 4 before assessing the impact that household characteristics, such as employment and household size, have on a household's food security status. In Chapter 5, the trends in precipitation were evaluated to begin to examine the impact of climate change on household food security and child nutrition.

6.2 The Nutritional Statuses of Children in Bushbuckridge

It is clear from Chapter 3 that both the prevalence and severity of short-term undernutrition (wasting and underweightness) have increased and that although the prevalence of stunting has not changed, its severity has. Therefore, it may be assumed that nutritional status in children under the age of five in Bushbuckridge will have long-term effects on their growth and development. This also implies that there are inequalities within the region, with some children's long-term nutritional status possibly improving while others are deteriorating. The findings of this study, which revealed that short-term undernutrition (wasting and underweightness) has been increasing in the Agincourt study site, are an exaggeration of the findings in the South African National Food and Nutrition Security Plan 2018-2023, which show a slight increase in the prevalence of short-term undernutrition. Due to inadequate socioeconomic development, increasing undernutrition has negative effects on a child's health and well-being, including a higher risk of mortality and the prospect of diminished productivity in later life, encouraging a cycle of poverty (Black *et al.*, 2015; Daelmans *et al.*, 2017).

The SDGs are explicit about reducing poverty and hunger, but rising undernutrition undercuts attempts to achieve SDG 2, which aims to eradicate hunger and enhance food security and nutrition. Nutrition is related to other development difficulties facing South Africa, such as those stated in the National Development Plan 2030, including poverty, inadequate health care, poor education, inequalities and, of course, food security. If these underlying issues are not addressed, undernutrition will persist in these regions and, given the growing threat posed by other variables like climate change, there will be an increase in undernutrition, threatening the health and well-being of children under the age of five (IPCC, 2022). Given that undernutrition trends in Bushbuckridge differ slightly from those at the national level, as the National Food and Security Plan found small increases in short-term undernutrition, which were projected to decrease, compared to this study's significant increases, illustrates the disparities and inequalities in the nation because there are regional factors that impact nutrition outcomes like those listed above. If undernutrition increases at the national level but is significantly greater at the rural level, this also shows the inequality within the impacts of negative change. This is similar to how climate change affects the poor more than the rest (IPCC, 2022).

The COVID-19 pandemic has exerted a multifaceted impact on child nutrition, especially in regions like South Africa, where pre-existing socio-economic disparities intersect with the disruptions caused by the virus (Jensen *et al*., 2021; Alaba *et al*., 2022). The National Income Dynamics Study-Coronavirus Rapid Mobile Survey (NIDS-CRAM WAVES 1-5) conducted during the pandemic highlighted stark realities. Child hunger fluctuated across the waves, with the highest levels recorded during the initial phase, predominantly affecting urban children and poorer households (Alaba *et al*., 2022). This period exacerbated pro-poor inequalities, where factors like race and socioeconomic status played pivotal roles in determining access to adequate nutrition, but this was more pronounced in urban children, hence the probable lack of impact on the children in this study (Spaull & van der Berg, 2020; Alaba et al., 2022). South Africa's stringent lockdown measures aimed at curbing the spread of the virus led to widespread loss of employment and a significant decrease in disposable income, particularly impacting the secondary economy reliant on informal daily wage jobs (Alaba *et al*., 2022). Restricted mobility and access to farms further disrupted food systems, exacerbating food insecurity, while the closure of schools deprived vulnerable children of essential meals provided through feeding schemes, compounding nutritional challenges (Spaull & van der Berg, 2020; Alaba *et al*., 2022). However, this impact is mainly on primary school attending-children over the age of 6 years, dissimilar to the children used in this study (Alaba *et al*., 2022).

This study also found that boys were more undernutritioned than girls under the age of five years, with girls being more affected by food security status than boys. Differences in nutritional status and food security between boys and girls can be influenced by a variety of biological, cultural, and socioeconomic factors (Thurstans *et al*., 2020). Boys and girls have differing metabolic rates and dietary needs, with boys often requiring more energy and being more commonly affected by weight-loss inducing illness (Thurstans *et al*., 2020). Cultural and societal biases in feeding habits may exist, with boys receiving more or higher quality food than girls, resulting in girls being more affected by decreased food security (Haddad *et al*., 1996; Akseer *et al*., 2017). Parental nutrition education and awareness may also differ in how it is applied to boys and girls, with some parents assuming that boys require more nutrition for growth or strength, while neglecting girls' nutritional needs (Haddad *et al*., 1996; Akseer *et al*., 2017). To address these difficulties, nutrition programmes should take gender variations into account and provide nutritional supplementation and information suited to girls' specific needs. More research is needed to understand the precise cultural behaviours and socioeconomic factors that contribute to these discrepancies. This will enable the development of more effective dietary treatments and policies, resulting in improved health outcomes for both boys and girls under the age of five.

6.3 The Impact of Food Security on Nutritional Status

Building on the findings of Chapter 3, which explored the trends in nutritional status, Chapter 4 explored the potential household drivers of the observed nutrition patterns. Chapter 4 also assessed the role of socioeconomic characteristics as drivers of household food security and, thus, nutrition. The observed decrease in the diversity of diets (Chapter 4**)** indicates a narrowing of diets and, hence, fewer nutrients consumed over the study decade. Nutritional deficits in children, notably undernutrition, are brought on by the decrease in the types of nutrients, vitamins and minerals ingested (Chakona & Shackleton, 2018; Muzhinji & Ntuli, 2020). Because of this, it is expected that undernutrition will rise. However, only weight-for-height for young girls was associated with household dietary diversity, suggesting increases in short-term undernutrition when diets were less diverse. Therefore, these results suggest that food security affects female children under five years more so than males, even under low sample sizes and other study limitations. Should these limitations underestimate the effects of food security on nutrition, this suggests that future studies that remove such limitations could show greater effects on the nutrition of young girls, therefore, portraying the gender inequality that already exists in South Africa.

In Chapter 4, the effects of socioeconomic characteristics on food security status were also examined. Expectedly, employment had a positive impact on food security, increasing diet diversity while reducing hunger. As a country that has a high unemployment rate, this presents a problem to the country's overall food security status, potentially explaining the decrease in household dietary diversity in Bushbuckridge (Ngubane et al. 2023). Households that were led by men were also more food secure, which speaks to the gender inequality that persists in the country. Households with more assets also had a better food security status. These households are less vulnerable to shocks that affect food security and nutrition because they could sell assets as a temporary adaptation strategy, and with increasing unemployment, this seems likely. The number of dependents in a household also affects households' dietary diversity, with households having less diverse diets when there are more dependents.

Although the literature highlights that the issue in South Africa is the population's purchasing power has affected child nutrition status due to less food available for consumption, it is important to understand that this relationship is extremely complex, with several intersectional drivers and contributing factors (Chakona & Shackleton, 2018). The country has, for example, enacted several policy programmes, such as the school feeding programme and child support grants, but as seen in Chapter 3, undernutrition (wasting and underweightness) continues to increase, regardless. Food insecurity and malnutrition increased further during the COVID-19 pandemic, with millions more people slipping into hunger (FAO *et al*., 2022).

There are many reasons for the general lack of association between food security and undernutrition in these homes, as found in Chapter 4. It is crucial to realise that nutrition is complicated and that it can be impacted by various other factors, including poverty, cultural practices and food preferences, health and education, which can have an impact on nutrition independent from food security (Fanzo *et al*., 2015; IPC Global Partners, 2021). As seen in Chapters 4 and 5, food security did not impact the nutrition status of the overall group of children, while the prevalence of wasting in these children was correlated to reduced rainfall. Acute illness, infectious disease and insufficient nutritional intake are the main causes of short-term undernutrition, such as wasting and underweightness. The findings in Chapter 5 suggest that rainfall impacts children's nutritional status, which is independent of food security, and thus, a thorough assessment of the health conditions of these children, such as recent illness, would show whether rainfall indeed affects health and, consequently, weight-for-height.

The sample size of this research was another significant limitation; the number of children and households, as well as the years needed to perform the analysis, was not enough; therefore, the absence of a relationship between food security and nutrition can be explained by the dearth of data available for analysis. Low sample size may decrease generalisability and statistical power, increasing sampling error and not being representative of the larger population. When evaluating the long-term impact of food security on nutrition, it is important to consider cumulative effects and the delayed impact of food security on undernutrition because it may take some time for the body to exhaust its nutrient reserves and for the consequences of inadequate nutrition to become apparent.

6.4 Climate Variability Impacts on Food Insecurity and Undernutrition

Although no monotonic trend was found for precipitation between 2010 and 2021 in this study, other studies, including those by Lakhraj-Govender and Grab (2019), Mahlalela *et al*. (2020), and the IPCC (2022), have reported declining trends in rainfall from 1980 to 2020 over some regions of South Africa. This study assessed the potential answer to the changes in food security of these households over the years, particularly their dietary diversity and the trends in child nutrition where food security failed in Chapters 5 and 4, respectively. The results of this study should not underestimate the effects of precipitation on food security because a growing literature is showing the effects of reduced precipitation on food availability and access and, hence, food consumption (IPCC, 2022). The lack of a correlation between precipitation changes and the food security indices in Chapter 5 may have been due to the data limitations mentioned in the previous section. Because there are other contributing elements, such as socioeconomic status, cultural norms and access to food markets, precipitation patterns alone may not be sufficient to predict food security, making the complexity of food systems one of the most crucial factors to consider. The impacts of precipitation on food security can have a temporal lag, similar to what was mentioned in the preceding section, as changes in precipitation may take some time to manifest as real effects on food security.

Even though food security was unaffected, the rise in the prevalence of wasting among all the children during periods of lesser rainfall illustrates how complex undernutrition is and how it is influenced by various factors, not only food security. In this case, undernutrition may be linked to how climate change affects infrastructure and sanitation, maternal and childcare practices, access to clean water and health care, and other factors. This study (Chapter 5) found that children were more likely to be wasted in years when rainfall was below average. This represents a potential pathway through sickness because wasting is regarded as undernutrition caused by recent illness because the body's ability to absorb nutrients is compromised, and in the AHDSS site, precipitation reduction may have caused illnesses such as cholera, thus reducing child weight-for-height. Considering the country's burden of diseases like TB and HIV, common in children in rural areas such as the AHDSS site, the added burdens of environmental stresses may aggravate other development challenges in the area (Ataguba *et al*., 2015; Chersich *et al*., 2018).

6.5 Study Limitations

The major limitation of this study was the number of years used to compare the trends using the Mann-Kendall test, and there were gaps between in the 11-year timestamp of the study. Six years were used, which was insufficient to produce an accurate analysis model and a reliable conclusion regarding the trends in undernutrition over time. The number of children per year was also a limitation, with a sample of only 35 children in 2019. Similar to the anthropometric analyses in Chapter 3, the sample size for analysis was small in terms of the number of years and children.

The Mann-Kendall and Pearson's correlation tests performed to find the trends in food security indicators over the years and the association between food security and malnutrition indicators, respectively, had a small sample size of five years.

The small sample size was also not enough to assess the relationship between food security and stunting because changes in food security need to be over more time to exhibit changes in stunting (Momberg *et al.*, 2020). In the effort to assess the association between precipitation and food security or nutrition, the study had a small sample size in terms of the number of children and years, and there was no consideration of any confounding factors. This could have underestimated or overestimated the effect of precipitation on food (in)security and nutrition, and as mentioned by Cooper *et al*. (2019), the lack of confounding factors in an association analysis could result in a Type I error in the study. Therefore, future studies should consider conducting the association over more years to increase the sample size and, hence, the validity, as well as adding key confounding variables. Future studies should also quantify these impacts at the level of the individual and household. This will be crucial for policy because policy interventions that respond to effects based on averages may increase inequalities (Wossen *et al.*, 2018).

The study compared food security to undernutrition measures, across five non-consecutive years with a modest number of participants each year. The small sample size intensifies the impact of each data point, resulting in outlier data points having greater influence on the slope of the correlation. These outliers appear to have a greater impact on observations than they should. Figures 4.1 and 4.2, for example, exhibit outliers indicating greater wasting and underweightness as dietary diversity increased. These outliers may represent a unique example in which, despite adequate dietary diversity, factors such as disease or metabolic problems are contributing to the participant's nutritional status. Given our limited sample size, it is critical to interpret these outliers with caution, acknowledging that one outlier may just be a single data point that needs to be part of a larger data sample, in order to properly represent the population dynamics.

This study used only two indicators of food security to assess the impact of child nutrition, which could have also been a factor that affected the results because multiple indicators of food security need to be used to reflect the true food security status of a population (IPC Global Partners, 2021). Future studies should consider using multiple indicators of food security, such as the Food Consumption Score, reduced Coping Strategies Index and Livelihood Coping Strategies, in conjunction with the indicators used in this study. Chapter 5 also only used one rainfall metric, which did not capture the complexity of the effect of rainfall on food production. For example, the rainfall totals do not account for the rainfall spread throughout the season because some months might experience light rainfall throughout the month, while other months might have erratic, heavy rainfall, but both months might have the same total rainfall. This complexity creates a spectrum of different effects on food security and nutrition, although total rainfall is the same. Therefore, this should be another consideration in future studies.

6.6 Food and Nutritional Security Policy Environment

Global and national policies emphasise climate change's effect on food security and nutrition through increased likelihood of droughts, especially in rural areas dependent on rain-fed agriculture (Department of Agriculture, Forestry and Fisheries, 2014; IPCC, 2022). Because the link between precipitation and food security was not observed in this study, the association found between climate variability and acute undernutrition alludes to effects through food utilisation (Department of Agriculture, Forestry and Fisheries, 2014). This happens through infectious and non-communicable illnesses caused or exacerbated by climate change (IPCC, 2022). However, there are gaps in national and global policies relating to the availability of data that shows climate-driven water-related diseases' burden on the population and children under five years, especially their nutritional status (Ziervogel & Ericksen, 2010; Department of Environmental Affairs, 2019; IPCC, 2022; Zembe *et al*., 2022).

National development policies in South Africa, such as the National Development Plan 2030, also poorly address food security and nutrition, especially for children under five years. In the social protection section, food security and nutrition are outlined as important issues, especially relating to the HIV/AIDS prevalence in rural communities, although little to no association is made to the effect of climate change (National Planning Commission, 2012). However, South Africa has food security and nutrition policies, such as the previous National Policy on Food and Nutrition Security (2014), which emphasised the importance of food production and access and less on food utilisation (Boatemaa *et al.*, 2018; Kushitor et al., 2022). The Policy did not explore climate change as a threat to food security and nutrition thoroughly, but the effect on food consumption is understood, and the policy called for a more comprehensive policy on food security and nutrition (Department of Agriculture, Forestry & Fisheries, 2014). The subsequent National Food Security and Nutrition Plan (2018-2023) was enacted in 2017, with explicit targets of 20% reductions in the prevalence of stunting and wasting by 2020 in children under five years (The Republic of South

Africa, 2017). The effects of drought and rainfall variability on food security and nutrition were explored in this policy better than in the previous one. However, considering the results of the current study and trends in wasting and stunting in the South African National Health and Nutrition Examination Survey (SANHANES-1), nutrition interventions have failed to meet their intended goals of reducing malnutrition (Shisana *et al*., 2013; Boatemaa *et al*., 2018).

Climate health policies, such as the South African National Climate Change Adaptation Strategy (2019), mention the effects of climate change on food security and health; however, the consequences of ill-health on nutrition are not explored (Department of Environmental Affairs, 2019). Therefore, it is easy to see that climate change is a known threat to food security and nutrition; however, the complexity of this relationship still needs to be researched as gaps persist, notably on the climate-health-nutrition nexus, where collaboration with environmental sectors is needed (Kushitor *et al*., 2022). This would add to the data on the underlying causes of malnutrition in the country, thereby informing policies and their interventions.

6.7 Implications of the Current Study's Findings on Food Security and Nutrition Policy

Food security strategies frequently focus on expanding food production, with many authors, including Baiphethi and Jacobs (2009), Pandey *et al*. (2016), Fan and Rue (2020) and Myeni *et al*. (2021), arguing that increasing small-holder farming is a viable solution. They also suggest increasing access by increasing purchasing power through social grants and pensions (Boatemaa *et al*., 2018). However, because so many complex elements affect nutrition, policies and interventions must be more comprehensive and use integrated methodologies, considering how factors like climate directly affect children (Ziervogel & Ericksen, 2010; de Onis *et al*., 2013). These include but are not limited to nutrition-specific interventions, such as promoting breastfeeding, improving nutritional intake and encouraging interest in education, as well as interventions that focus on nutrition-related issues, such as access to clean water, sanitised food, healthcare and education.

While Chapter 5 did not provide evidence of a direct link between climate change and food security, common literature sources like Phalkey *et al*. (2015), Niles *et al*. (2021) and IPCC (2022) suggest this connection. Therefore, adopting climate-smart agricultural methods could benefit small-holder farmers, ultimately improving food access and availability, potentially enhancing nutrition (Beuchelt & Badstue, 2013). Implementing early warning systems to alert communities of impending climate shocks and assist them in planning and implementing coping strategies would be invaluable in rural areas. Given the findings of this study, which underscore the importance of locally tailored policy responses, it is essential to reinforce data systems, particularly at the community level. National-level policies may not effectively address the unique challenges faced by different regions (Boatemaa *et al.*, 2018). Therefore, interventions must be customised through data-driven targeting.

This study reveals a complex relationship between climate variability, household food security and undernutrition in children under five years. While socioeconomic factors play a significant role, governance issues can also hinder efforts to improve food security, nutrition and overall livelihoods. The increasing prevalence and severity of undernutrition found in this study highlights the need for a comprehensive re-evaluation of current food security and nutrition policies. This calls for policy changes addressing root causes, enhancing diet quality, bolstering climate change resilience, promoting intersectoral coordination and strengthening monitoring and evaluation procedures. Policymakers should recognise and address these gaps to respond to evolving undernutrition challenges and enhance the nutritional health of the population better.

6.8 Future Recommendations

Given this study's limitations and the knowledge acquired from it, it is recommended that future research take the following into account:

- Conducting a comprehensive analysis of nutritional status necessitates employing a substantial and consecutive sample size across multiple years. Ensuring the absence of gaps in the dataset is crucial for gaining an in-depth understanding of nutritional trends over time.
- Studies must delve into the escalating prevalence and severity of undernutrition, exploring its implications on cognitive development and related aspects.
- Broaden the spectrum of food security indices beyond the two employed in the current study and incorporate indices that delve into food availability and utilisation within the specified research area.
- Expand the sample size for food security analysis, encompassing consecutive years without data gaps. This approach could ensure a more robust and nuanced examination of the dynamics of food security over time.

- Factor in individual-level food consumption patterns, recognising the diversity of habits within households. This refinement aims to enhance the precision of assessing the relationship between food consumption and the nutritional status of children.
- Consistently analyse the same child over the five-year period to track changes in nutritional status to provide a nuanced understanding of how children's health evolves longitudinally.
- Extend the assessment of climate change variables over a more extensive timeframe, moving beyond a single metric such as precipitation change. This approach aims to capture a comprehensive understanding of climate trends and their impact on the research area, especially considering the correlation analyses conducted in the current study.
- Evaluate climate impacts specifically on households engaged in small-holder farming. Quantify the effects on food production and relevant food consumption indicators to comprehend the intricate relationship between climate change, food consumption and nutritional status.
- Investigate the correlation between climate variability and nutritional status; if the identified link involves health effects, thoroughly examine relevant health metrics connecting climate change and nutritional outcomes.
- Exploring the complex interactions between climate change and its indirect effects on nutrition outcomes could be an exciting direction for future research. There is still a vast knowledge gap about the cumulative effects of climate change on nutritional status, even if previous research has frequently concentrated on the primary causes of undernutrition, such as food insecurity or insufficient dietary intake. Recognising climate change as an indirect driver will allow us to examine its complex effects on food systems, ecological dynamics, and agricultural productivity—all of which have an impact on nutritional outcomes. This kind of research project might aid in the creation of evidence-based guidelines and programs that improve resilience and lessen the negative nutritional effects of climate change on the world's most vulnerable communities.

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APPENDICES

Appendix 1

Boys' weight-for-height z-scores

Weight-for-length BOYS

Birth to 2 years (z-scores)

				Z-scores (weight in kg)						
Length (cm)	**L**	**M**	**S**	**-3 SD**	**-2 SD**	**-1 SD**	**Median**	**1 SD**	**2 SD**	**3 SD**
45.0	-0.3521	2.4410	0.09182	1.9	2.0	2.2	2.4	2.7	3.0	3.3
45.5	-0.3521	2.5244	0.09153	1.9	2.1	2.3	2.5	2.8	3.1	3.4
46.0	-0.3521	2.6077	0.09124	2.0	2.2	2.4	2.6	2.9	3.1	3.5
46.5	-0.3521	2.6913	0.09094	2.1	2.3	2.5	2.7	3.0	3.2	3.6
47.0	-0.3521	2.7755	0.09065	2.1	2.3	2.5	2.8	3.0	3.3	3.7
47.5	-0.3521	2.8609	0.09036	2.2	2.4	2.6	2.9	3.1	3.4	3.8
48.0	-0.3521	2.9480	0.09007	2.3	2.5	2.7	2.9	3.2	3.6	3.9
48.5	-0.3521	3.0377	0.08977	2.3	2.6	2.8	3.0	3.3	3.7	4.0
49.0	-0.3521	3.1308	0.08948	2.4	2.6	2.9	3.1	3.4	3.8	4.2
49.5	-0.3521	3.2276	0.08919	2.5	2.7	3.0	3.2	3.5	3.9	4.3
50.0	-0.3521	3.3278	0.08890	2.6	2.8	3.0	3.3	3.6	4.0	4.4
50.5	-0.3521	3.4311	0.08861	2.7	2.9	3.1	3.4	3.8	4.1	4.5
51.0	-0.3521	3.5376	0.08831	2.7	3.0	3.2	3.5	3.9	4.2	4.7
51.5	-0.3521	3.6477	0.08801	2.8	3.1	3.3	3.6	4.0	4.4	4.8
52.0	-0.3521	3.7620	0.08771	2.9	3.2	3.5	3.8	4.1	4.5	5.0
52.5	-0.3521	3.8814	0.08741	3.0	3.3	3.6	3.9	4.2	4.6	5.1
53.0	-0.3521	4.0060	0.08711	3.1	3.4	3.7	4.0	4.4	4.8	5.3
53.5	-0.3521	4.1354	0.08681	3.2	3.5	3.8	4.1	4.5	4.9	5.4
54.0	-0.3521	4.2693	0.08651	3.3	3.6	3.9	4.3	4.7	5.1	5.6
54.5	-0.3521	4.4066	0.08621	3.4	3.7	4.0	4.4	4.8	5.3	5.8
55.0	-0.3521	4.5467	0.08592	3.6	3.8	4.2	4.5	5.0	5.4	6.0
55.5	-0.3521	4.6892	0.08563	3.7	4.0	4.3	4.7	5.1	5.6	6.1
56.0	-0.3521	4.8338	0.08535	3.8	4.1	4.4	4.8	5.3	5.8	6.3
56.5	-0.3521	4.9796	0.08507	3.9	4.2	4.6	5.0	5.4	5.9	6.5

WHO Child Growth Standards

Weight-for-length BOYS

Birth to 2 years (z-scores)

				Z-scores (weight in kg)						
Length (cm)	**L**	**M**	**S**	**-3 SD**	**-2 SD**	**-1 SD**	**Median**	**1 SD**	**2 SD**	**3 SD**
57.0	-0.3521	5.1259	0.08481	4.0	4.3	4.7	5.1	5.6	6.1	6.7
57.5	-0.3521	5.2721	0.08455	4.1	4.5	4.9	5.3	5.7	6.3	6.9
58.0	-0.3521	5.4180	0.08430	4.3	4.6	5.0	5.4	5.9	6.4	7.1
58.5	-0.3521	5.5632	0.08406	4.4	4.7	5.1	5.6	6.1	6.6	7.2
59.0	-0.3521	5.7074	0.08383	4.5	4.8	5.3	5.7	6.2	6.8	7.4
59.5	-0.3521	5.8501	0.08362	4.6	5.0	5.4	5.9	6.4	7.0	7.6
60.0	-0.3521	5.9907	0.08342	4.7	5.1	5.5	6.0	6.5	7.1	7.8
60.5	-0.3521	6.1284	0.08324	4.8	5.2	5.6	6.1	6.7	7.3	8.0
61.0	-0.3521	6.2632	0.08308	4.9	5.3	5.8	6.3	6.8	7.4	8.1
61.5	-0.3521	6.3954	0.08292	5.0	5.4	5.9	6.4	7.0	7.6	8.3
62.0	-0.3521	6.5251	0.08279	5.1	5.6	6.0	6.5	7.1	7.7	8.5
62.5	-0.3521	6.6527	0.08266	5.2	5.7	6.1	6.7	7.2	7.9	8.6
63.0	-0.3521	6.7786	0.08255	5.3	5.8	6.2	6.8	7.4	8.0	8.8
63.5	-0.3521	6.9028	0.08245	5.4	5.9	6.4	6.9	7.5	8.2	8.9
64.0	-0.3521	7.0255	0.08236	5.5	6.0	6.5	7.0	7.6	8.3	9.1
64.5	-0.3521	7.1467	0.08229	5.6	6.1	6.6	7.1	7.8	8.5	9.3
65.0	-0.3521	7.2666	0.08223	5.7	6.2	6.7	7.3	7.9	8.6	9.4
65.5	-0.3521	7.3854	0.08218	5.8	6.3	6.8	7.4	8.0	8.7	9.6
66.0	-0.3521	7.5034	0.08215	5.9	6.4	6.9	7.5	8.2	8.9	9.7
66.5	-0.3521	7.6206	0.08213	6.0	6.5	7.0	7.6	8.3	9.0	9.9
67.0	-0.3521	7.7370	0.08212	6.1	6.6	7.1	7.7	8.4	9.2	10.0
67.5	-0.3521	7.8526	0.08212	6.2	6.7	7.2	7.9	8.5	9.3	10.2
68.0	-0.3521	7.9674	0.08214	6.3	6.8	7.3	8.0	8.7	9.4	10.3
68.5	-0.3521	8.0816	0.08216	6.4	6.9	7.5	8.1	8.8	9.6	10.5

WHO Child Growth Standards

Weight-for-height BOYS

2 to 5 years (z-scores)

World Health Organization

				Z-scores (weight in kg)						
Height (cm)	**L**	**M**	**S**	**-3 SD**	**-2 SD**	**-1 SD**	**Median**	**1 SD**	**2 SD**	**3 SD**
65.0	-0.3521	7.4327	0.08217	5.9	6.3	6.9	7.4	8.1	8.8	9.6
65.5	-0.3521	7.5504	0.08214	6.0	6.4	7.0	7.6	8.2	8.9	9.8
66.0	-0.3521	7.6673	0.08212	6.1	6.5	7.1	7.7	8.3	9.1	9.9
66.5	-0.3521	7.7834	0.08212	6.1	6.6	7.2	7.8	8.5	9.2	10.1
67.0	-0.3521	7.8986	0.08213	6.2	6.7	7.3	7.9	8.6	9.4	10.2
67.5	-0.3521	8.0132	0.08214	6.3	6.8	7.4	8.0	8.7	9.5	10.4
68.0	-0.3521	8.1272	0.08217	6.4	6.9	7.5	8.1	8.8	9.6	10.5
68.5	-0.3521	8.2410	0.08221	6.5	7.0	7.6	8.2	9.0	9.8	10.7
69.0	-0.3521	8.3547	0.08226	6.6	7.1	7.7	8.4	9.1	9.9	10.8
69.5	-0.3521	8.4680	0.08231	6.7	7.2	7.8	8.5	9.2	10.0	11.0
70.0	-0.3521	8.5808	0.08237	6.8	7.3	7.9	8.6	9.3	10.2	11.1
70.5	-0.3521	8.6927	0.08243	6.9	7.4	8.0	8.7	9.5	10.3	11.3
71.0	-0.3521	8.8036	0.08250	6.9	7.5	8.1	8.8	9.6	10.4	11.4
71.5	-0.3521	8.9135	0.08257	7.0	7.6	8.2	8.9	9.7	10.6	11.6
72.0	-0.3521	9.0221	0.08264	7.1	7.7	8.3	9.0	9.8	10.7	11.7
72.5	-0.3521	9.1292	0.08272	7.2	7.8	8.4	9.1	9.9	10.8	11.8
73.0	-0.3521	9.2347	0.08278	7.3	7.9	8.5	9.2	10.0	11.0	12.0
73.5	-0.3521	9.3390	0.08285	7.4	7.9	8.6	9.3	10.2	11.1	12.1
74.0	-0.3521	9.4420	0.08292	7.4	8.0	8.7	9.4	10.3	11.2	12.2
74.5	-0.3521	9.5438	0.08298	7.5	8.1	8.8	9.5	10.4	11.3	12.4
75.0	-0.3521	9.6440	0.08303	7.6	8.2	8.9	9.6	10.5	11.4	12.5
75.5	-0.3521	9.7425	0.08308	7.7	8.3	9.0	9.7	10.6	11.6	12.6
76.0	-0.3521	9.8392	0.08312	7.7	8.4	9.1	9.8	10.7	11.7	12.8
76.5	-0.3521	9.9341	0.08315	7.8	8.5	9.2	9.9	10.8	11.8	12.9

WHO Child Growth Standards

Weight-for-height BOYS

2 to 5 years (z-scores)

World Health Organization

				Z-scores (weight in kg)						
Height (cm)	**L**	**M**	**S**	**-3 SD**	**-2 SD**	**-1 SD**	**Median**	**1 SD**	**2 SD**	**3 SD**
77.0	-0.3521	10.0274	0.08317	7.9	8.5	9.2	10.0	10.9	11.9	13.0
77.5	-0.3521	10.1194	0.08318	8.0	8.6	9.3	10.1	11.0	12.0	13.1
78.0	-0.3521	10.2105	0.08317	8.0	8.7	9.4	10.2	11.1	12.1	13.3
78.5	-0.3521	10.3012	0.08315	8.1	8.8	9.5	10.3	11.2	12.2	13.4
79.0	-0.3521	10.3923	0.08311	8.2	8.8	9.6	10.4	11.3	12.3	13.5
79.5	-0.3521	10.4845	0.08305	8.3	8.9	9.7	10.5	11.4	12.4	13.6
80.0	-0.3521	10.5781	0.08298	8.3	9.0	9.7	10.6	11.5	12.6	13.7
80.5	-0.3521	10.6737	0.08290	8.4	9.1	9.8	10.7	11.6	12.7	13.8
81.0	-0.3521	10.7718	0.08279	8.5	9.2	9.9	10.8	11.7	12.8	14.0
81.5	-0.3521	10.8728	0.08268	8.6	9.3	10.0	10.9	11.8	12.9	14.1
82.0	-0.3521	10.9772	0.08255	8.7	9.3	10.1	11.0	11.9	13.0	14.2
82.5	-0.3521	11.0851	0.08241	8.7	9.4	10.2	11.1	12.1	13.1	14.4
83.0	-0.3521	11.1966	0.08225	8.8	9.5	10.3	11.2	12.2	13.3	14.5
83.5	-0.3521	11.3114	0.08209	8.9	9.6	10.4	11.3	12.3	13.4	14.6
84.0	-0.3521	11.4290	0.08191	9.0	9.7	10.5	11.4	12.4	13.5	14.8
84.5	-0.3521	11.5490	0.08174	9.1	9.9	10.7	11.5	12.5	13.7	14.9
85.0	-0.3521	11.6707	0.08156	9.2	10.0	10.8	11.7	12.7	13.8	15.1
85.5	-0.3521	11.7937	0.08138	9.3	10.1	10.9	11.8	12.8	13.9	15.2
86.0	-0.3521	11.9173	0.08121	9.4	10.2	11.0	11.9	12.9	14.1	15.4
86.5	-0.3521	12.0411	0.08105	9.5	10.3	11.1	12.0	13.1	14.2	15.5
87.0	-0.3521	12.1645	0.08090	9.6	10.4	11.2	12.2	13.2	14.4	15.7
87.5	-0.3521	12.2871	0.08076	9.7	10.5	11.3	12.3	13.3	14.5	15.8
88.0	-0.3521	12.4089	0.08064	9.8	10.6	11.5	12.4	13.5	14.7	16.0
88.5	-0.3521	12.5298	0.08054	9.9	10.7	11.6	12.5	13.6	14.8	16.1

WHO Child Growth Standards

Weight-for-height BOYS

2 to 5 years (z-scores)

World Health Organization

Height (cm)	L	M	S	-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
				Z-scores (weight in kg)						
89.0	-0.3521	12.6495	0.08045	10.0	10.8	11.7	12.6	13.7	14.9	16.3
89.5	-0.3521	12.7683	0.08038	10.1	10.9	11.8	12.8	13.9	15.1	16.4
90.0	-0.3521	12.8864	0.08032	10.2	11.0	11.9	12.9	14.0	15.2	16.6
90.5	-0.3521	13.0038	0.08028	10.3	11.1	12.0	13.0	14.1	15.3	16.7
91.0	-0.3521	13.1209	0.08025	10.4	11.2	12.1	13.1	14.2	15.5	16.9
91.5	-0.3521	13.2376	0.08024	10.5	11.3	12.2	13.2	14.4	15.6	17.0
92.0	-0.3521	13.3541	0.08025	10.6	11.4	12.3	13.4	14.5	15.8	17.2
92.5	-0.3521	13.4705	0.08027	10.7	11.5	12.4	13.5	14.6	15.9	17.3
93.0	-0.3521	13.5870	0.08031	10.8	11.6	12.6	13.6	14.7	16.0	17.5
93.5	-0.3521	13.7041	0.08036	10.9	11.7	12.7	13.7	14.9	16.2	17.6
94.0	-0.3521	13.8217	0.08043	11.0	11.8	12.8	13.8	15.0	16.3	17.8
94.5	-0.3521	13.9403	0.08051	11.1	11.9	12.9	13.9	15.1	16.5	17.9
95.0	-0.3521	14.0600	0.08060	11.1	12.0	13.0	14.1	15.3	16.6	18.1
95.5	-0.3521	14.1811	0.08071	11.2	12.1	13.1	14.2	15.4	16.7	18.3
96.0	-0.3521	14.3037	0.08083	11.3	12.2	13.2	14.3	15.5	16.9	18.4
96.5	-0.3521	14.4282	0.08097	11.4	12.3	13.3	14.4	15.7	17.0	18.6
97.0	-0.3521	14.5547	0.08112	11.5	12.4	13.4	14.6	15.8	17.2	18.8
97.5	-0.3521	14.6832	0.08129	11.6	12.5	13.6	14.7	15.9	17.4	18.9
98.0	-0.3521	14.8140	0.08146	11.7	12.6	13.7	14.8	16.1	17.5	19.1
98.5	-0.3521	14.9468	0.08165	11.8	12.8	13.8	14.9	16.2	17.7	19.3
99.0	-0.3521	15.0818	0.08185	11.9	12.9	13.9	15.1	16.4	17.9	19.5
99.5	-0.3521	15.2187	0.08206	12.0	13.0	14.0	15.2	16.5	18.0	19.7
100.0	-0.3521	15.3576	0.08229	12.1	13.1	14.2	15.4	16.7	18.2	19.9
100.5	-0.3521	15.4985	0.08252	12.2	13.2	14.3	15.5	16.9	18.4	20.1

WHO Child Growth Standards

Weight-for-height BOYS

2 to 5 years (z-scores)

World Health Organization

Height (cm)	L	M	S	-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
				Z-scores (weight in kg)						
101.0	-0.3521	15.6412	0.08277	12.3	13.3	14.4	15.6	17.0	18.5	20.3
101.5	-0.3521	15.7857	0.08302	12.4	13.4	14.5	15.8	17.2	18.7	20.5
102.0	-0.3521	15.9320	0.08328	12.5	13.6	14.7	15.9	17.3	18.9	20.7
102.5	-0.3521	16.0801	0.08354	12.6	13.7	14.8	16.1	17.5	19.1	20.9
103.0	-0.3521	16.2298	0.08381	12.8	13.8	14.9	16.2	17.7	19.3	21.1
103.5	-0.3521	16.3812	0.08408	12.9	13.9	15.1	16.4	17.8	19.5	21.3
104.0	-0.3521	16.5342	0.08436	13.0	14.0	15.2	16.5	18.0	19.7	21.6
104.5	-0.3521	16.6889	0.08464	13.1	14.2	15.4	16.7	18.2	19.9	21.8
105.0	-0.3521	16.8454	0.08493	13.2	14.3	15.5	16.8	18.4	20.1	22.0
105.5	-0.3521	17.0036	0.08521	13.3	14.4	15.6	17.0	18.5	20.3	22.2
106.0	-0.3521	17.1637	0.08551	13.4	14.5	15.8	17.2	18.7	20.5	22.5
106.5	-0.3521	17.3256	0.08580	13.5	14.7	15.9	17.3	18.9	20.7	22.7
107.0	-0.3521	17.4894	0.08611	13.7	14.8	16.1	17.5	19.1	20.9	22.9
107.5	-0.3521	17.6550	0.08641	13.8	14.9	16.2	17.7	19.3	21.1	23.2
108.0	-0.3521	17.8226	0.08673	13.9	15.1	16.4	17.8	19.5	21.3	23.4
108.5	-0.3521	17.9924	0.08704	14.0	15.2	16.5	18.0	19.7	21.5	23.7
109.0	-0.3521	18.1645	0.08736	14.1	15.3	16.7	18.2	19.8	21.8	23.9
109.5	-0.3521	18.3390	0.08768	14.3	15.5	16.8	18.3	20.0	22.0	24.2
110.0	-0.3521	18.5158	0.08800	14.4	15.6	17.0	18.5	20.2	22.2	24.4
110.5	-0.3521	18.6948	0.08832	14.5	15.8	17.1	18.7	20.4	22.4	24.7
111.0	-0.3521	18.8759	0.08864	14.6	15.9	17.3	18.9	20.7	22.7	25.0
111.5	-0.3521	19.0590	0.08896	14.8	16.0	17.5	19.1	20.9	22.9	25.2
112.0	-0.3521	19.2439	0.08928	14.9	16.2	17.6	19.2	21.1	23.1	25.5
112.5	-0.3521	19.4304	0.08960	15.0	16.3	17.8	19.4	21.3	23.4	25.8

WHO Child Growth Standards

Weight-for-height BOYS

2 to 5 years (z-scores)

World Health Organization

Height (cm)	L	M	S	-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
				Z-scores (weight in kg)						
113.0	-0.3521	19.6185	0.08991	15.2	16.5	18.0	19.6	21.5	23.6	26.0
113.5	-0.3521	19.8081	0.09022	15.3	16.6	18.1	19.8	21.7	23.9	26.3
114.0	-0.3521	19.9990	0.09054	15.4	16.8	18.3	20.0	21.9	24.1	26.6
114.5	-0.3521	20.1912	0.09085	15.6	16.9	18.5	20.2	22.1	24.4	26.9
115.0	-0.3521	20.3846	0.09116	15.7	17.1	18.6	20.4	22.4	24.6	27.2
115.5	-0.3521	20.5789	0.09147	15.8	17.2	18.8	20.6	22.6	24.9	27.5
116.0	-0.3521	20.7741	0.09177	16.0	17.4	19.0	20.8	22.8	25.1	27.8
116.5	-0.3521	20.9700	0.09208	16.1	17.5	19.2	21.0	23.0	25.4	28.0
117.0	-0.3521	21.1666	0.09239	16.2	17.7	19.3	21.2	23.3	25.6	28.3
117.5	-0.3521	21.3636	0.09270	16.4	17.9	19.5	21.4	23.5	25.9	28.6
118.0	-0.3521	21.5611	0.09300	16.5	18.0	19.7	21.6	23.7	26.1	28.9
118.5	-0.3521	21.7588	0.09331	16.7	18.2	19.9	21.8	23.9	26.4	29.2
119.0	-0.3521	21.9568	0.09362	16.8	18.3	20.0	22.0	24.1	26.6	29.5
119.5	-0.3521	22.1549	0.09393	16.9	18.5	20.2	22.2	24.4	26.9	29.8
120.0	-0.3521	22.3530	0.09424	17.1	18.6	20.4	22.4	24.6	27.2	30.1

WHO Child Growth Standards

Appendix 2

Girls' weight-for-height z-scores

Weight-for-length GIRLS

Birth to 2 years (z-scores)

World Health Organization

				Z-scores (weight in kg)						
Length (cm)	**L**	**M**	**S**	**-3 SD**	**-2 SD**	**-1 SD**	**Median**	**1 SD**	**2 SD**	**3 SD**
45.0	-0.3833	2.4607	0.09029	1.9	2.1	2.3	2.5	2.7	3.0	3.3
45.5	-0.3833	2.5457	0.09033	2.0	2.1	2.3	2.5	2.8	3.1	3.4
46.0	-0.3833	2.6306	0.09037	2.0	2.2	2.4	2.6	2.9	3.2	3.5
46.5	-0.3833	2.7155	0.09040	2.1	2.3	2.5	2.7	3.0	3.3	3.6
47.0	-0.3833	2.8007	0.09044	2.2	2.4	2.6	2.8	3.1	3.4	3.7
47.5	-0.3833	2.8867	0.09048	2.2	2.4	2.6	2.9	3.2	3.5	3.8
48.0	-0.3833	2.9741	0.09052	2.3	2.5	2.7	3.0	3.3	3.6	4.0
48.5	-0.3833	3.0636	0.09056	2.4	2.6	2.8	3.1	3.4	3.7	4.1
49.0	-0.3833	3.1560	0.09060	2.4	2.6	2.9	3.2	3.5	3.8	4.2
49.5	-0.3833	3.2520	0.09064	2.5	2.7	3.0	3.3	3.6	3.9	4.3
50.0	-0.3833	3.3518	0.09068	2.6	2.8	3.1	3.4	3.7	4.0	4.5
50.5	-0.3833	3.4557	0.09072	2.7	2.9	3.2	3.5	3.8	4.2	4.6
51.0	-0.3833	3.5636	0.09076	2.8	3.0	3.3	3.6	3.9	4.3	4.8
51.5	-0.3833	3.6754	0.09080	2.8	3.1	3.4	3.7	4.0	4.4	4.9
52.0	-0.3833	3.7911	0.09085	2.9	3.2	3.5	3.8	4.2	4.6	5.1
52.5	-0.3833	3.9105	0.09089	3.0	3.3	3.6	3.9	4.3	4.7	5.2
53.0	-0.3833	4.0332	0.09093	3.1	3.4	3.7	4.0	4.4	4.9	5.4
53.5	-0.3833	4.1591	0.09098	3.2	3.5	3.8	4.2	4.6	5.0	5.5
54.0	-0.3833	4.2875	0.09102	3.3	3.6	3.9	4.3	4.7	5.2	5.7
54.5	-0.3833	4.4179	0.09106	3.4	3.7	4.0	4.4	4.8	5.3	5.9
55.0	-0.3833	4.5498	0.09110	3.5	3.8	4.2	4.5	5.0	5.5	6.1
55.5	-0.3833	4.6827	0.09114	3.6	3.9	4.3	4.7	5.1	5.7	6.3
56.0	-0.3833	4.8162	0.09118	3.7	4.0	4.4	4.8	5.3	5.8	6.4
56.5	-0.3833	4.9500	0.09121	3.8	4.1	4.5	5.0	5.4	6.0	6.6

WHO Child Growth Standards

Weight-for-length GIRLS

Birth to 2 years (z-scores)

World Health Organization

				Z-scores (weight in kg)						
Length (cm)	**L**	**M**	**S**	**-3 SD**	**-2 SD**	**-1 SD**	**Median**	**1 SD**	**2 SD**	**3 SD**
57.0	-0.3833	5.0837	0.09125	3.9	4.3	4.6	5.1	5.6	6.1	6.8
57.5	-0.3833	5.2173	0.09128	4.0	4.4	4.8	5.2	5.7	6.3	7.0
58.0	-0.3833	5.3507	0.09130	4.1	4.5	4.9	5.4	5.9	6.5	7.1
58.5	-0.3833	5.4834	0.09132	4.2	4.6	5.0	5.5	6.0	6.6	7.3
59.0	-0.3833	5.6151	0.09134	4.3	4.7	5.1	5.6	6.2	6.8	7.5
59.5	-0.3833	5.7454	0.09135	4.4	4.8	5.3	5.7	6.3	6.9	7.7
60.0	-0.3833	5.8742	0.09136	4.5	4.9	5.4	5.9	6.4	7.1	7.8
60.5	-0.3833	6.0014	0.09137	4.6	5.0	5.5	6.0	6.6	7.3	8.0
61.0	-0.3833	6.1270	0.09137	4.7	5.1	5.6	6.1	6.7	7.4	8.2
61.5	-0.3833	6.2511	0.09136	4.8	5.2	5.7	6.3	6.9	7.6	8.4
62.0	-0.3833	6.3738	0.09135	4.9	5.3	5.8	6.4	7.0	7.7	8.5
62.5	-0.3833	6.4948	0.09133	5.0	5.4	5.9	6.5	7.1	7.8	8.7
63.0	-0.3833	6.6144	0.09131	5.1	5.5	6.0	6.6	7.3	8.0	8.8
63.5	-0.3833	6.7328	0.09129	5.2	5.6	6.2	6.7	7.4	8.1	9.0
64.0	-0.3833	6.8501	0.09126	5.3	5.7	6.3	6.9	7.5	8.3	9.1
64.5	-0.3833	6.9662	0.09123	5.4	5.8	6.4	7.0	7.6	8.4	9.3
65.0	-0.3833	7.0812	0.09119	5.5	5.9	6.5	7.1	7.8	8.6	9.5
65.5	-0.3833	7.1950	0.09115	5.5	6.0	6.6	7.2	7.9	8.7	9.6
66.0	-0.3833	7.3076	0.09110	5.6	6.1	6.7	7.3	8.0	8.8	9.8
66.5	-0.3833	7.4189	0.09106	5.7	6.2	6.8	7.4	8.1	9.0	9.9
67.0	-0.3833	7.5288	0.09101	5.8	6.3	6.9	7.5	8.3	9.1	10.0
67.5	-0.3833	7.6375	0.09096	5.9	6.4	7.0	7.6	8.4	9.2	10.2
68.0	-0.3833	7.7448	0.09090	6.0	6.5	7.1	7.7	8.5	9.4	10.3
68.5	-0.3833	7.8509	0.09085	6.1	6.6	7.2	7.9	8.6	9.5	10.5

WHO Child Growth Standards

Weight-for-height GIRLS

2 to 5 years (z-scores)

World Health Organization

				Z-scores (weight in kg)						
Height (cm)	**L**	**M**	**S**	**-3 SD**	**-2 SD**	**-1 SD**	**Median**	**1 SD**	**2 SD**	**3 SD**
65.0	-0.3833	7.2402	0.09113	5.6	6.1	6.6	7.2	7.9	8.7	9.7
65.5	-0.3833	7.3523	0.09109	5.7	6.2	6.7	7.4	8.1	8.9	9.8
66.0	-0.3833	7.4630	0.09104	5.8	6.3	6.8	7.5	8.2	9.0	10.0
66.5	-0.3833	7.5724	0.09099	5.8	6.4	6.9	7.6	8.3	9.1	10.1
67.0	-0.3833	7.6806	0.09094	5.9	6.4	7.0	7.7	8.4	9.3	10.2
67.5	-0.3833	7.7874	0.09088	6.0	6.5	7.1	7.8	8.5	9.4	10.4
68.0	-0.3833	7.8930	0.09083	6.1	6.6	7.2	7.9	8.7	9.5	10.5
68.5	-0.3833	7.9976	0.09077	6.2	6.7	7.3	8.0	8.8	9.7	10.7
69.0	-0.3833	8.1012	0.09071	6.3	6.8	7.4	8.1	8.9	9.8	10.8
69.5	-0.3833	8.2039	0.09065	6.3	6.9	7.5	8.2	9.0	9.9	10.9
70.0	-0.3833	8.3058	0.09059	6.4	7.0	7.6	8.3	9.1	10.0	11.1
70.5	-0.3833	8.4071	0.09053	6.5	7.1	7.7	8.4	9.2	10.1	11.2
71.0	-0.3833	8.5078	0.09047	6.6	7.1	7.8	8.5	9.3	10.3	11.3
71.5	-0.3833	8.6078	0.09041	6.7	7.2	7.9	8.6	9.4	10.4	11.5
72.0	-0.3833	8.7070	0.09035	6.7	7.3	8.0	8.7	9.5	10.5	11.6
72.5	-0.3833	8.8053	0.09028	6.8	7.4	8.1	8.8	9.7	10.6	11.7
73.0	-0.3833	8.9025	0.09022	6.9	7.5	8.1	8.9	9.8	10.7	11.8
73.5	-0.3833	8.9983	0.09016	7.0	7.6	8.2	9.0	9.9	10.8	12.0
74.0	-0.3833	9.0928	0.09009	7.0	7.6	8.3	9.1	10.0	11.0	12.1
74.5	-0.3833	9.1862	0.09003	7.1	7.7	8.4	9.2	10.1	11.1	12.2
75.0	-0.3833	9.2786	0.08996	7.2	7.8	8.5	9.3	10.2	11.2	12.3
75.5	-0.3833	9.3703	0.08989	7.2	7.9	8.6	9.4	10.3	11.3	12.5
76.0	-0.3833	9.4617	0.08983	7.3	8.0	8.7	9.5	10.4	11.4	12.6
76.5	-0.3833	9.5533	0.08976	7.4	8.0	8.7	9.6	10.5	11.5	12.7

WHO Child Growth Standards

Weight-for-height GIRLS

2 to 5 years (z-scores)

World Health Organization

				Z-scores (weight in kg)						
Height (cm)	**L**	**M**	**S**	**-3 SD**	**-2 SD**	**-1 SD**	**Median**	**1 SD**	**2 SD**	**3 SD**
77.0	-0.3833	9.6456	0.08969	7.5	8.1	8.8	9.6	10.6	11.6	12.8
77.5	-0.3833	9.7390	0.08963	7.5	8.2	8.9	9.7	10.7	11.7	12.9
78.0	-0.3833	9.8338	0.08956	7.6	8.3	9.0	9.8	10.8	11.8	13.1
78.5	-0.3833	9.9303	0.08950	7.7	8.4	9.1	9.9	10.9	12.0	13.2
79.0	-0.3833	10.0289	0.08943	7.8	8.4	9.2	10.0	11.0	12.1	13.3
79.5	-0.3833	10.1298	0.08937	7.8	8.5	9.3	10.1	11.1	12.2	13.4
80.0	-0.3833	10.2332	0.08932	7.9	8.6	9.4	10.2	11.2	12.3	13.6
80.5	-0.3833	10.3393	0.08926	8.0	8.7	9.5	10.3	11.3	12.4	13.7
81.0	-0.3833	10.4477	0.08921	8.1	8.8	9.6	10.4	11.4	12.6	13.9
81.5	-0.3833	10.5586	0.08916	8.2	8.9	9.7	10.6	11.6	12.7	14.0
82.0	-0.3833	10.6719	0.08912	8.3	9.0	9.8	10.7	11.7	12.8	14.1
82.5	-0.3833	10.7874	0.08908	8.4	9.1	9.9	10.8	11.8	13.0	14.3
83.0	-0.3833	10.9051	0.08905	8.5	9.2	10.0	10.9	11.9	13.1	14.5
83.5	-0.3833	11.0248	0.08902	8.5	9.3	10.1	11.0	12.1	13.3	14.6
84.0	-0.3833	11.1462	0.08899	8.6	9.4	10.2	11.1	12.2	13.4	14.8
84.5	-0.3833	11.2691	0.08897	8.7	9.5	10.3	11.3	12.3	13.5	14.9
85.0	-0.3833	11.3934	0.08896	8.8	9.6	10.4	11.4	12.5	13.7	15.1
85.5	-0.3833	11.5186	0.08895	8.9	9.7	10.6	11.5	12.6	13.8	15.3
86.0	-0.3833	11.6444	0.08895	9.0	9.8	10.7	11.6	12.7	14.0	15.4
86.5	-0.3833	11.7705	0.08895	9.1	9.9	10.8	11.8	12.9	14.2	15.6
87.0	-0.3833	11.8965	0.08896	9.2	10.0	10.9	11.9	13.0	14.3	15.8
87.5	-0.3833	12.0223	0.08897	9.3	10.1	11.0	12.0	13.2	14.5	15.9
88.0	-0.3833	12.1478	0.08899	9.4	10.2	11.1	12.1	13.3	14.6	16.1
88.5	-0.3833	12.2729	0.08901	9.5	10.3	11.2	12.3	13.4	14.8	16.3

WHO Child Growth Standards

Weight-for-height GIRLS
2 to 5 years (z-scores)

World Health Organization

Height (cm)	L	M	S	Z-scores (weight in kg)						
				-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
89.0	-0.3833	12.3976	0.08904	9.6	10.4	11.4	12.4	13.6	14.9	16.4
89.5	-0.3833	12.5220	0.08907	9.7	10.5	11.5	12.5	13.7	15.1	16.6
90.0	-0.3833	12.6461	0.08911	9.8	10.6	11.6	12.6	13.8	15.2	16.8
90.5	-0.3833	12.7700	0.08915	9.9	10.7	11.7	12.8	14.0	15.4	16.9
91.0	-0.3833	12.8939	0.08920	10.0	10.9	11.8	12.9	14.1	15.5	17.1
91.5	-0.3833	13.0177	0.08925	10.1	11.0	11.9	13.0	14.3	15.7	17.3
92.0	-0.3833	13.1415	0.08931	10.2	11.1	12.0	13.1	14.4	15.8	17.4
92.5	-0.3833	13.2654	0.08937	10.3	11.2	12.1	13.3	14.5	16.0	17.6
93.0	-0.3833	13.3896	0.08944	10.4	11.3	12.3	13.4	14.7	16.1	17.8
93.5	-0.3833	13.5142	0.08951	10.5	11.4	12.4	13.5	14.8	16.3	17.9
94.0	-0.3833	13.6393	0.08959	10.6	11.5	12.5	13.6	14.9	16.4	18.1
94.5	-0.3833	13.7650	0.08967	10.7	11.6	12.6	13.8	15.1	16.6	18.3
95.0	-0.3833	13.8914	0.08975	10.8	11.7	12.7	13.9	15.2	16.7	18.5
95.5	-0.3833	14.0186	0.08984	10.8	11.8	12.8	14.0	15.4	16.9	18.6
96.0	-0.3833	14.1466	0.08994	10.9	11.9	12.9	14.1	15.5	17.0	18.8
96.5	-0.3833	14.2757	0.09004	11.0	12.0	13.1	14.3	15.6	17.2	19.0
97.0	-0.3833	14.4059	0.09015	11.1	12.1	13.2	14.4	15.8	17.4	19.2
97.5	-0.3833	14.5376	0.09026	11.2	12.2	13.3	14.5	15.9	17.5	19.3
98.0	-0.3833	14.6710	0.09037	11.3	12.3	13.4	14.7	16.1	17.7	19.5
98.5	-0.3833	14.8062	0.09049	11.4	12.4	13.5	14.8	16.2	17.9	19.7
99.0	-0.3833	14.9434	0.09062	11.5	12.5	13.7	14.9	16.4	18.0	19.9
99.5	-0.3833	15.0828	0.09075	11.6	12.7	13.8	15.1	16.5	18.2	20.1
100.0	-0.3833	15.2246	0.09088	11.7	12.8	13.9	15.2	16.7	18.4	20.3
100.5	-0.3833	15.3687	0.09102	11.9	12.9	14.1	15.4	16.9	18.6	20.5

WHO Child Growth Standards

Weight-for-height GIRLS
2 to 5 years (z-scores)

World Health Organization

Height (cm)	L	M	S	Z-scores (weight in kg)						
				-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
101.0	-0.3833	15.5154	0.09116	12.0	13.0	14.2	15.5	17.0	18.7	20.7
101.5	-0.3833	15.6646	0.09131	12.1	13.1	14.3	15.7	17.2	18.9	20.9
102.0	-0.3833	15.8164	0.09146	12.2	13.3	14.5	15.8	17.4	19.1	21.1
102.5	-0.3833	15.9707	0.09161	12.3	13.4	14.6	16.0	17.5	19.3	21.4
103.0	-0.3833	16.1276	0.09177	12.4	13.5	14.7	16.1	17.7	19.5	21.6
103.5	-0.3833	16.2870	0.09193	12.5	13.6	14.9	16.3	17.9	19.7	21.8
104.0	-0.3833	16.4488	0.09209	12.6	13.8	15.0	16.4	18.1	19.9	22.0
104.5	-0.3833	16.6131	0.09226	12.8	13.9	15.2	16.6	18.2	20.1	22.3
105.0	-0.3833	16.7800	0.09243	12.9	14.0	15.3	16.8	18.4	20.3	22.5
105.5	-0.3833	16.9496	0.09261	13.0	14.2	15.5	16.9	18.6	20.5	22.7
106.0	-0.3833	17.1220	0.09278	13.1	14.3	15.6	17.1	18.8	20.8	23.0
106.5	-0.3833	17.2973	0.09296	13.3	14.5	15.8	17.3	19.0	21.0	23.2
107.0	-0.3833	17.4755	0.09315	13.4	14.6	15.9	17.5	19.2	21.2	23.5
107.5	-0.3833	17.6567	0.09333	13.5	14.7	16.1	17.7	19.4	21.4	23.7
108.0	-0.3833	17.8407	0.09352	13.7	14.9	16.3	17.8	19.6	21.7	24.0
108.5	-0.3833	18.0277	0.09371	13.8	15.0	16.4	18.0	19.8	21.9	24.3
109.0	-0.3833	18.2174	0.09390	13.9	15.2	16.6	18.2	20.0	22.1	24.5
109.5	-0.3833	18.4096	0.09409	14.1	15.4	16.8	18.4	20.3	22.4	24.8
110.0	-0.3833	18.6043	0.09428	14.2	15.5	17.0	18.6	20.5	22.6	25.1
110.5	-0.3833	18.8015	0.09448	14.4	15.7	17.1	18.8	20.7	22.9	25.4
111.0	-0.3833	19.0009	0.09467	14.5	15.8	17.3	19.0	20.9	23.1	25.7
111.5	-0.3833	19.2024	0.09487	14.7	16.0	17.5	19.2	21.2	23.4	26.0
112.0	-0.3833	19.4060	0.09507	14.8	16.2	17.7	19.4	21.4	23.6	26.2
112.5	-0.3833	19.6116	0.09527	15.0	16.3	17.9	19.6	21.6	23.9	26.5

WHO Child Growth Standards

Weight-for-height GIRLS
2 to 5 years (z-scores)

World Health Organization

Height (cm)	L	M	S	Z-scores (weight in kg)						
				-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
113.0	-0.3833	19.8190	0.09546	15.1	16.5	18.0	19.8	21.8	24.2	26.8
113.5	-0.3833	20.0280	0.09566	15.3	16.7	18.2	20.0	22.1	24.4	27.1
114.0	-0.3833	20.2385	0.09586	15.4	16.8	18.4	20.2	22.3	24.7	27.4
114.5	-0.3833	20.4502	0.09606	15.6	17.0	18.6	20.5	22.6	25.0	27.8
115.0	-0.3833	20.6629	0.09626	15.7	17.2	18.8	20.7	22.8	25.2	28.1
115.5	-0.3833	20.8766	0.09646	15.9	17.3	19.0	20.9	23.0	25.5	28.4
116.0	-0.3833	21.0909	0.09666	16.0	17.5	19.2	21.1	23.3	25.8	28.7
116.5	-0.3833	21.3059	0.09686	16.2	17.7	19.4	21.3	23.5	26.1	29.0
117.0	-0.3833	21.5213	0.09707	16.3	17.8	19.6	21.5	23.8	26.3	29.3
117.5	-0.3833	21.7370	0.09727	16.5	18.0	19.8	21.7	24.0	26.6	29.6
118.0	-0.3833	21.9529	0.09747	16.6	18.2	19.9	22.0	24.2	26.9	29.9
118.5	-0.3833	22.1690	0.09767	16.8	18.4	20.1	22.2	24.5	27.2	30.3
119.0	-0.3833	22.3851	0.09788	16.9	18.5	20.3	22.4	24.7	27.4	30.6
119.5	-0.3833	22.6012	0.09808	17.1	18.7	20.5	22.6	25.0	27.7	30.9
120.0	-0.3833	22.8173	0.09828	17.3	18.9	20.7	22.8	25.2	28.0	31.2

WHO Child Growth Standards

Appendix 3

Boys' weight-for-age z-scores

Weight-for-age BOYS

Birth to 5 years (z-scores)

World Health Organization

					Z-scores (weight in kg)						
Year: Month	Month	L	M	S	-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
0: 0	0	0.3487	3.3464	0.14602	2.1	2.5	2.9	3.3	3.9	4.4	5.0
0: 1	1	0.2297	4.4709	0.13395	2.9	3.4	3.9	4.5	5.1	5.8	6.6
0: 2	2	0.1970	5.5675	0.12385	3.8	4.3	4.9	5.6	6.3	7.1	8.0
0: 3	3	0.1738	6.3762	0.11727	4.4	5.0	5.7	6.4	7.2	8.0	9.0
0: 4	4	0.1553	7.0023	0.11316	4.9	5.6	6.2	7.0	7.8	8.7	9.7
0: 5	5	0.1395	7.5105	0.11080	5.3	6.0	6.7	7.5	8.4	9.3	10.4
0: 6	6	0.1257	7.9340	0.10958	5.7	6.4	7.1	7.9	8.8	9.8	10.9
0: 7	7	0.1134	8.2970	0.10902	5.9	6.7	7.4	8.3	9.2	10.3	11.4
0: 8	8	0.1021	8.6151	0.10882	6.2	6.9	7.7	8.6	9.6	10.7	11.9
0: 9	9	0.0917	8.9014	0.10881	6.4	7.1	8.0	8.9	9.9	11.0	12.3
0:10	10	0.0820	9.1649	0.10891	6.6	7.4	8.2	9.2	10.2	11.4	12.7
0:11	11	0.0730	9.4122	0.10906	6.8	7.6	8.4	9.4	10.5	11.7	13.0
1: 0	12	0.0644	9.6479	0.10925	6.9	7.7	8.6	9.6	10.8	12.0	13.3
1: 1	13	0.0563	9.8749	0.10949	7.1	7.9	8.8	9.9	11.0	12.3	13.7
1: 2	14	0.0487	10.0953	0.10976	7.2	8.1	9.0	10.1	11.3	12.6	14.0
1: 3	15	0.0413	10.3108	0.11007	7.4	8.3	9.2	10.3	11.5	12.8	14.3
1: 4	16	0.0343	10.5228	0.11041	7.5	8.4	9.4	10.5	11.7	13.1	14.6
1: 5	17	0.0275	10.7319	0.11079	7.7	8.6	9.6	10.7	12.0	13.4	14.9
1: 6	18	0.0211	10.9385	0.11119	7.8	8.8	9.8	10.9	12.2	13.7	15.3
1: 7	19	0.0148	11.1430	0.11164	8.0	8.9	10.0	11.1	12.5	13.9	15.6
1: 8	20	0.0087	11.3462	0.11211	8.1	9.1	10.1	11.3	12.7	14.2	15.9
1: 9	21	0.0029	11.5486	0.11261	8.2	9.2	10.3	11.5	12.9	14.5	16.2
1:10	22	-0.0028	11.7504	0.11314	8.4	9.4	10.5	11.8	13.2	14.7	16.5
1:11	23	-0.0083	11.9514	0.11369	8.5	9.5	10.7	12.0	13.4	15.0	16.8
2: 0	24	-0.0137	12.1515	0.11426	8.6	9.7	10.8	12.2	13.6	15.3	17.1

WHO Child Growth Standards

Weight-for-age BOYS

Birth to 5 years (z-scores)

World Health Organization

					Z-scores (weight in kg)						
Year: Month	Month	L	M	S	-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
2: 1	25	-0.0189	12.3502	0.11485	8.8	9.8	11.0	12.4	13.9	15.5	17.5
2: 2	26	-0.0240	12.5466	0.11544	8.9	10.0	11.2	12.5	14.1	15.8	17.8
2: 3	27	-0.0289	12.7401	0.11604	9.0	10.1	11.3	12.7	14.3	16.1	18.1
2: 4	28	-0.0337	12.9303	0.11664	9.1	10.2	11.5	12.9	14.5	16.3	18.4
2: 5	29	-0.0385	13.1169	0.11723	9.2	10.4	11.7	13.1	14.8	16.6	18.7
2: 6	30	-0.0431	13.3000	0.11781	9.4	10.5	11.8	13.3	15.0	16.9	19.0
2: 7	31	-0.0476	13.4798	0.11839	9.5	10.7	12.0	13.5	15.2	17.1	19.3
2: 8	32	-0.0520	13.6567	0.11896	9.6	10.8	12.1	13.7	15.4	17.4	19.6
2: 9	33	-0.0564	13.8309	0.11953	9.7	10.9	12.3	13.8	15.6	17.6	19.9
2:10	34	-0.0606	14.0031	0.12008	9.8	11.0	12.4	14.0	15.8	17.8	20.2
2:11	35	-0.0648	14.1736	0.12062	9.9	11.2	12.6	14.2	16.0	18.1	20.4
3: 0	36	-0.0689	14.3429	0.12116	10.0	11.3	12.7	14.3	16.2	18.3	20.7
3: 1	37	-0.0729	14.5113	0.12168	10.1	11.4	12.9	14.5	16.4	18.6	21.0
3: 2	38	-0.0769	14.6791	0.12220	10.2	11.5	13.0	14.7	16.6	18.8	21.3
3: 3	39	-0.0808	14.8466	0.12271	10.3	11.6	13.1	14.8	16.8	19.0	21.6
3: 4	40	-0.0846	15.0140	0.12322	10.4	11.8	13.3	15.0	17.0	19.3	21.9
3: 5	41	-0.0883	15.1813	0.12373	10.5	11.9	13.4	15.2	17.2	19.5	22.1
3: 6	42	-0.0920	15.3486	0.12425	10.6	12.0	13.6	15.3	17.4	19.7	22.4
3: 7	43	-0.0957	15.5158	0.12478	10.7	12.1	13.7	15.5	17.6	20.0	22.7
3: 8	44	-0.0993	15.6828	0.12531	10.8	12.2	13.8	15.7	17.8	20.2	23.0
3: 9	45	-0.1028	15.8497	0.12586	10.9	12.4	14.0	15.8	18.0	20.5	23.3
3:10	46	-0.1063	16.0163	0.12643	11.0	12.5	14.1	16.0	18.2	20.7	23.6
3:11	47	-0.1097	16.1827	0.12700	11.1	12.6	14.3	16.2	18.4	20.9	23.9
4: 0	48	-0.1131	16.3489	0.12759	11.2	12.7	14.4	16.3	18.6	21.2	24.2

WHO Child Growth Standards

Weight-for-age BOYS

Birth to 5 years (z-scores)

World Health Organization

					Z-scores (weight in kg)						
Year: Month	Month	L	M	S	-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
4: 1	49	-0.1165	16.5150	0.12819	11.3	12.8	14.5	16.5	18.8	21.4	24.5
4: 2	50	-0.1198	16.6811	0.12880	11.4	12.9	14.7	16.7	19.0	21.7	24.8
4: 3	51	-0.1230	16.8471	0.12943	11.5	13.1	14.8	16.8	19.2	21.9	25.1
4: 4	52	-0.1262	17.0132	0.13005	11.6	13.2	15.0	17.0	19.4	22.2	25.4
4: 5	53	-0.1294	17.1792	0.13069	11.7	13.3	15.1	17.2	19.6	22.4	25.7
4: 6	54	-0.1325	17.3452	0.13133	11.8	13.4	15.2	17.3	19.8	22.7	26.0
4: 7	55	-0.1356	17.5111	0.13197	11.9	13.5	15.4	17.5	20.0	22.9	26.3
4: 8	56	-0.1387	17.6768	0.13261	12.0	13.6	15.5	17.7	20.2	23.2	26.6
4: 9	57	-0.1417	17.8422	0.13325	12.1	13.7	15.6	17.8	20.4	23.4	26.9
4:10	58	-0.1447	18.0073	0.13389	12.2	13.8	15.8	18.0	20.6	23.7	27.2
4:11	59	-0.1477	18.1722	0.13453	12.3	14.0	15.9	18.2	20.8	23.9	27.6
5: 0	60	-0.1506	18.3366	0.13517	12.4	14.1	16.0	18.3	21.0	24.2	27.9

WHO Child Growth Standards

Appendix 4

Girls' weight-for-age z-scores

Weight-for-age GIRLS

Birth to 5 years (z-scores)

World Health Organization

					Z-scores (weight in kg)						
Year: Month	Month	L	M	S	-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
0: 0	0	0.3809	3.2322	0.14171	2.0	2.4	2.8	3.2	3.7	4.2	4.8
0: 1	1	0.1714	4.1873	0.13724	2.7	3.2	3.6	4.2	4.8	5.5	6.2
0: 2	2	0.0962	5.1282	0.13000	3.4	3.9	4.5	5.1	5.8	6.6	7.5
0: 3	3	0.0402	5.8458	0.12619	4.0	4.5	5.2	5.8	6.6	7.5	8.5
0: 4	4	-0.0050	6.4237	0.12402	4.4	5.0	5.7	6.4	7.3	8.2	9.3
0: 5	5	-0.0430	6.8985	0.12274	4.8	5.4	6.1	6.9	7.8	8.8	10.0
0: 6	6	-0.0756	7.2970	0.12204	5.1	5.7	6.5	7.3	8.2	9.3	10.6
0: 7	7	-0.1039	7.6422	0.12178	5.3	6.0	6.8	7.6	8.6	9.8	11.1
0: 8	8	-0.1288	7.9487	0.12181	5.6	6.3	7.0	7.9	9.0	10.2	11.6
0: 9	9	-0.1507	8.2254	0.12199	5.8	6.5	7.3	8.2	9.3	10.5	12.0
0:10	10	-0.1700	8.4800	0.12223	5.9	6.7	7.5	8.5	9.6	10.9	12.4
0:11	11	-0.1872	8.7192	0.12247	6.1	6.9	7.7	8.7	9.9	11.2	12.8
1: 0	12	-0.2024	8.9481	0.12268	6.3	7.0	7.9	8.9	10.1	11.5	13.1
1: 1	13	-0.2158	9.1699	0.12283	6.4	7.2	8.1	9.2	10.4	11.8	13.5
1: 2	14	-0.2278	9.3870	0.12294	6.6	7.4	8.3	9.4	10.6	12.1	13.8
1: 3	15	-0.2384	9.6008	0.12299	6.7	7.6	8.5	9.6	10.9	12.4	14.1
1: 4	16	-0.2478	9.8124	0.12303	6.9	7.7	8.7	9.8	11.1	12.6	14.5
1: 5	17	-0.2562	10.0226	0.12306	7.0	7.9	8.9	10.0	11.4	12.9	14.8
1: 6	18	-0.2637	10.2315	0.12309	7.2	8.1	9.1	10.2	11.6	13.2	15.1
1: 7	19	-0.2703	10.4393	0.12315	7.3	8.2	9.2	10.4	11.8	13.5	15.4
1: 8	20	-0.2762	10.6464	0.12323	7.5	8.4	9.4	10.6	12.1	13.7	15.7
1: 9	21	-0.2815	10.8534	0.12335	7.6	8.6	9.6	10.9	12.3	14.0	16.0
1:10	22	-0.2862	11.0608	0.12350	7.8	8.7	9.8	11.1	12.5	14.3	16.4
1:11	23	-0.2903	11.2688	0.12369	7.9	8.9	10.0	11.3	12.8	14.6	16.7
2: 0	24	-0.2941	11.4775	0.12390	8.1	9.0	10.2	11.5	13.0	14.8	17.0

WHO Child Growth Standards

Weight-for-age GIRLS

Birth to 5 years (z-scores)

World Health Organization

					Z-scores (weight in kg)						
Year: Month	Month	L	M	S	-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
2: 1	25	-0.2975	11.6864	0.12414	8.2	9.2	10.3	11.7	13.3	15.1	17.3
2: 2	26	-0.3005	11.8947	0.12441	8.4	9.4	10.5	11.9	13.5	15.4	17.7
2: 3	27	-0.3032	12.1015	0.12472	8.5	9.5	10.7	12.1	13.7	15.7	18.0
2: 4	28	-0.3057	12.3059	0.12506	8.6	9.7	10.9	12.3	14.0	16.0	18.3
2: 5	29	-0.3080	12.5073	0.12545	8.8	9.8	11.1	12.5	14.2	16.2	18.7
2: 6	30	-0.3101	12.7055	0.12587	8.9	10.0	11.2	12.7	14.4	16.5	19.0
2: 7	31	-0.3120	12.9006	0.12633	9.0	10.1	11.4	12.9	14.7	16.8	19.3
2: 8	32	-0.3138	13.0930	0.12683	9.1	10.3	11.6	13.1	14.9	17.1	19.6
2: 9	33	-0.3155	13.2837	0.12737	9.3	10.4	11.7	13.3	15.1	17.3	20.0
2:10	34	-0.3171	13.4731	0.12794	9.4	10.5	11.9	13.5	15.4	17.6	20.3
2:11	35	-0.3186	13.6618	0.12855	9.5	10.7	12.0	13.7	15.6	17.9	20.6
3: 0	36	-0.3201	13.8503	0.12919	9.6	10.8	12.2	13.9	15.8	18.1	20.9
3: 1	37	-0.3216	14.0385	0.12988	9.7	10.9	12.4	14.0	16.0	18.4	21.3
3: 2	38	-0.3230	14.2265	0.13059	9.8	11.1	12.5	14.2	16.3	18.7	21.6
3: 3	39	-0.3243	14.4140	0.13135	9.9	11.2	12.7	14.4	16.5	19.0	22.0
3: 4	40	-0.3257	14.6010	0.13213	10.1	11.3	12.8	14.6	16.7	19.2	22.3
3: 5	41	-0.3270	14.7873	0.13293	10.2	11.5	13.0	14.8	16.9	19.5	22.7
3: 6	42	-0.3283	14.9727	0.13376	10.3	11.6	13.1	15.0	17.2	19.8	23.0
3: 7	43	-0.3296	15.1573	0.13460	10.4	11.7	13.3	15.2	17.4	20.1	23.4
3: 8	44	-0.3309	15.3410	0.13545	10.5	11.8	13.4	15.3	17.6	20.4	23.7
3: 9	45	-0.3322	15.5240	0.13630	10.6	12.0	13.6	15.5	17.8	20.7	24.1
3:10	46	-0.3335	15.7064	0.13716	10.7	12.1	13.7	15.7	18.1	20.9	24.5
3:11	47	-0.3348	15.8882	0.13800	10.8	12.2	13.9	15.9	18.3	21.2	24.8
4: 0	48	-0.3361	16.0697	0.13884	10.9	12.3	14.0	16.1	18.5	21.5	25.2

WHO Child Growth Standards

Weight-for-age GIRLS

Birth to 5 years (z-scores)

World Health Organization

					Z-scores (weight in kg)						
Year: Month	Month	L	M	S	-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
4: 1	49	-0.3374	16.2511	0.13968	11.0	12.4	14.2	16.3	18.8	21.8	25.5
4: 2	50	-0.3387	16.4322	0.14051	11.1	12.6	14.3	16.4	19.0	22.1	25.9
4: 3	51	-0.3400	16.6133	0.14132	11.2	12.7	14.5	16.6	19.2	22.4	26.3
4: 4	52	-0.3414	16.7942	0.14213	11.3	12.8	14.6	16.8	19.4	22.6	26.6
4: 5	53	-0.3427	16.9748	0.14293	11.4	12.9	14.8	17.0	19.7	22.9	27.0
4: 6	54	-0.3440	17.1551	0.14371	11.5	13.0	14.9	17.2	19.9	23.2	27.4
4: 7	55	-0.3453	17.3347	0.14448	11.6	13.2	15.1	17.3	20.1	23.5	27.7
4: 8	56	-0.3466	17.5136	0.14525	11.7	13.3	15.2	17.5	20.3	23.8	28.1
4: 9	57	-0.3479	17.6916	0.14600	11.8	13.4	15.3	17.7	20.6	24.1	28.5
4:10	58	-0.3492	17.8686	0.14675	11.9	13.5	15.5	17.9	20.8	24.4	28.8
4:11	59	-0.3505	18.0445	0.14748	12.0	13.6	15.6	18.0	21.0	24.6	29.2
5: 0	60	-0.3518	18.2193	0.14821	12.1	13.7	15.8	18.2	21.2	24.9	29.5

WHO Child Growth Standards

Appendix 5

Boys' height-for-age z-scores

Length-for-age BOYS

Birth to 2 years (z-scores)

World Health Organization

						Z-scores (length in cm)						
Year: Month	Month	L	M	S	SD	-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
0: 0	0	1	49.8842	0.03795	1.8931	44.2	46.1	48.0	49.9	51.8	53.7	55.6
0: 1	1	1	54.7244	0.03557	1.9465	48.9	50.8	52.8	54.7	56.7	58.6	60.6
0: 2	2	1	58.4249	0.03424	2.0005	52.4	54.4	56.4	58.4	60.4	62.4	64.4
0: 3	3	1	61.4292	0.03328	2.0444	55.3	57.3	59.4	61.4	63.5	65.5	67.6
0: 4	4	1	63.8860	0.03257	2.0808	57.6	59.7	61.8	63.9	66.0	68.0	70.1
0: 5	5	1	65.9026	0.03204	2.1115	59.6	61.7	63.8	65.9	68.0	70.1	72.2
0: 6	6	1	67.6236	0.03165	2.1403	61.2	63.3	65.5	67.6	69.8	71.9	74.0
0: 7	7	1	69.1645	0.03139	2.1711	62.7	64.8	67.0	69.2	71.3	73.5	75.7
0: 8	8	1	70.5994	0.03124	2.2055	64.0	66.2	68.4	70.6	72.8	75.0	77.2
0: 9	9	1	71.9687	0.03117	2.2433	65.2	67.5	69.7	72.0	74.2	76.5	78.7
0:10	10	1	73.2812	0.03118	2.2849	66.4	68.7	71.0	73.3	75.6	77.9	80.1
0:11	11	1	74.5388	0.03125	2.3293	67.6	69.9	72.2	74.5	76.9	79.2	81.5
1: 0	12	1	75.7488	0.03137	2.3762	68.6	71.0	73.4	75.7	78.1	80.5	82.9
1: 1	13	1	76.9186	0.03154	2.4260	69.6	72.1	74.5	76.9	79.3	81.8	84.2
1: 2	14	1	78.0497	0.03174	2.4773	70.6	73.1	75.6	78.0	80.5	83.0	85.5
1: 3	15	1	79.1458	0.03197	2.5303	71.6	74.1	76.6	79.1	81.7	84.2	86.7
1: 4	16	1	80.2113	0.03222	2.5844	72.5	75.0	77.6	80.2	82.8	85.4	88.0
1: 5	17	1	81.2487	0.03250	2.6406	73.3	76.0	78.6	81.2	83.9	86.5	89.2
1: 6	18	1	82.2587	0.03279	2.6973	74.2	76.9	79.6	82.3	85.0	87.7	90.4
1: 7	19	1	83.2418	0.03310	2.7553	75.0	77.7	80.5	83.2	86.0	88.8	91.5
1: 8	20	1	84.1996	0.03342	2.8140	75.8	78.6	81.4	84.2	87.0	89.8	92.6
1: 9	21	1	85.1348	0.03376	2.8742	76.5	79.4	82.3	85.1	88.0	90.9	93.8
1:10	22	1	86.0477	0.03410	2.9342	77.2	80.2	83.1	86.0	89.0	91.9	94.9
1:11	23	1	86.9410	0.03445	2.9951	78.0	81.0	83.9	86.9	89.9	92.9	95.9
2: 0	24	1	87.8161	0.03479	3.0551	78.7	81.7	84.8	87.8	90.9	93.9	97.0

WHO Child Growth Standards

Height-for-age BOYS

2 to 5 years (z-scores)

World Health Organization

						Z-scores (height in cm)						
Year: Month	Month	L	M	S	SD	-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
2: 0	24	1	87.1161	0.03507	3.0551	78.0	81.0	84.1	87.1	90.2	93.2	96.3
2: 1	25	1	87.9720	0.03542	3.1160	78.6	81.7	84.9	88.0	91.1	94.2	97.3
2: 2	26	1	88.8065	0.03576	3.1757	79.3	82.5	85.6	88.8	92.0	95.2	98.3
2: 3	27	1	89.6197	0.03610	3.2353	79.9	83.1	86.4	89.6	92.9	96.1	99.3
2: 4	28	1	90.4120	0.03642	3.2928	80.5	83.8	87.1	90.4	93.7	97.0	100.3
2: 5	29	1	91.1828	0.03674	3.3501	81.1	84.5	87.8	91.2	94.5	97.9	101.2
2: 6	30	1	91.9327	0.03704	3.4052	81.7	85.1	88.5	91.9	95.3	98.7	102.1
2: 7	31	1	92.6631	0.03733	3.4591	82.3	85.7	89.2	92.7	96.1	99.6	103.0
2: 8	32	1	93.3753	0.03761	3.5118	82.8	86.4	89.9	93.4	96.9	100.4	103.9
2: 9	33	1	94.0711	0.03787	3.5625	83.4	86.9	90.5	94.1	97.6	101.2	104.8
2:10	34	1	94.7532	0.03812	3.6120	83.9	87.5	91.1	94.8	98.4	102.0	105.6
2:11	35	1	95.4236	0.03836	3.6604	84.4	88.1	91.8	95.4	99.1	102.7	106.4
3: 0	36	1	96.0835	0.03858	3.7069	85.0	88.7	92.4	96.1	99.8	103.5	107.2
3: 1	37	1	96.7337	0.03879	3.7523	85.5	89.2	93.0	96.7	100.5	104.2	108.0
3: 2	38	1	97.3749	0.03900	3.7976	86.0	89.8	93.6	97.4	101.2	105.0	108.8
3: 3	39	1	98.0073	0.03919	3.8409	86.5	90.3	94.2	98.0	101.8	105.7	109.5
3: 4	40	1	98.6310	0.03937	3.8831	87.0	90.9	94.7	98.6	102.5	106.4	110.3
3: 5	41	1	99.2459	0.03954	3.9242	87.5	91.4	95.3	99.2	103.2	107.1	111.0
3: 6	42	1	99.8515	0.03971	3.9651	88.0	91.9	95.9	99.9	103.8	107.8	111.7
3: 7	43	1	100.4485	0.03986	4.0039	88.4	92.4	96.4	100.4	104.5	108.5	112.5
3: 8	44	1	101.0374	0.04002	4.0435	88.9	93.0	97.0	101.0	105.1	109.1	113.2
3: 9	45	1	101.6186	0.04016	4.0810	89.4	93.5	97.5	101.6	105.7	109.8	113.9
3:10	46	1	102.1933	0.04031	4.1194	89.8	94.0	98.1	102.2	106.3	110.4	114.6
3:11	47	1	102.7625	0.04045	4.1567	90.3	94.4	98.6	102.8	106.9	111.1	115.2
4: 0	48	1	103.3273	0.04059	4.1941	90.7	94.9	99.1	103.3	107.5	111.7	115.9

WHO Child Growth Standards

Height-for-age BOYS

2 to 5 years (z-scores)

World Health Organization

						Z-scores (height in cm)						
Year: Month	Month	L	M	S	SD	-3 SD	-2 SD	-1 SD	Median	1 SD	2 SD	3 SD
4: 1	49	1	103.8886	0.04073	4.2314	91.2	95.4	99.7	103.9	108.1	112.4	116.6
4: 2	50	1	104.4473	0.04086	4.2677	91.6	95.9	100.2	104.4	108.7	113.0	117.3
4: 3	51	1	105.0041	0.04100	4.3052	92.1	96.4	100.7	105.0	109.3	113.6	117.9
4: 4	52	1	105.5596	0.04113	4.3417	92.5	96.9	101.2	105.6	109.9	114.2	118.6
4: 5	53	1	106.1138	0.04126	4.3783	93.0	97.4	101.7	106.1	110.5	114.9	119.2
4: 6	54	1	106.6668	0.04139	4.4149	93.4	97.8	102.3	106.7	111.1	115.5	119.9
4: 7	55	1	107.2188	0.04152	4.4517	93.9	98.3	102.8	107.2	111.7	116.1	120.6
4: 8	56	1	107.7697	0.04165	4.4886	94.3	98.8	103.3	107.8	112.3	116.7	121.2
4: 9	57	1	108.3198	0.04177	4.5245	94.7	99.3	103.8	108.3	112.8	117.4	121.9
4:10	58	1	108.8689	0.04190	4.5616	95.2	99.7	104.3	108.9	113.4	118.0	122.6
4:11	59	1	109.4170	0.04202	4.5977	95.6	100.2	104.8	109.4	114.0	118.6	123.2
5: 0	60	1	109.9638	0.04214	4.6339	96.1	100.7	105.3	110.0	114.6	119.2	123.9

WHO Child Growth Standards

Appendix 6

Girls' height-for-age z-scores

Length-for-age GIRLS

World Health Organization

Birth to 2 years (z-scores)

						Z-scores (length in cm)						
Year: Month	**Month**	**L**	**M**	**S**	**SD**	**-3 SD**	**-2 SD**	**-1 SD**	**Median**	**1 SD**	**2 SD**	**3 SD**
0: 0	0	1	49.1477	0.03790	1.8627	43.6	45.4	47.3	49.1	51.0	52.9	54.7
0: 1	1	1	53.6872	0.03640	1.9542	47.8	49.8	51.7	53.7	55.6	57.6	59.5
0: 2	2	1	57.0673	0.03568	2.0362	51.0	53.0	55.0	57.1	59.1	61.1	63.2
0: 3	3	1	59.8029	0.03520	2.1051	53.5	55.6	57.7	59.8	61.9	64.0	66.1
0: 4	4	1	62.0899	0.03486	2.1645	55.6	57.8	59.9	62.1	64.3	66.4	68.6
0: 5	5	1	64.0301	0.03463	2.2174	57.4	59.6	61.8	64.0	66.2	68.5	70.7
0: 6	6	1	65.7311	0.03448	2.2664	58.9	61.2	63.5	65.7	68.0	70.3	72.5
0: 7	7	1	67.2873	0.03441	2.3154	60.3	62.7	65.0	67.3	69.6	71.9	74.2
0: 8	8	1	68.7498	0.03440	2.3650	61.7	64.0	66.4	68.7	71.1	73.5	75.8
0: 9	9	1	70.1435	0.03444	2.4157	62.9	65.3	67.7	70.1	72.6	75.0	77.4
0:10	10	1	71.4818	0.03452	2.4676	64.1	66.5	69.0	71.5	73.9	76.4	78.9
0:11	11	1	72.7710	0.03464	2.5208	65.2	67.7	70.3	72.8	75.3	77.8	80.3
1: 0	12	1	74.0150	0.03479	2.5750	66.3	68.9	71.4	74.0	76.6	79.2	81.7
1: 1	13	1	75.2176	0.03496	2.6296	67.3	70.0	72.6	75.2	77.8	80.5	83.1
1: 2	14	1	76.3817	0.03514	2.6841	68.3	71.0	73.7	76.4	79.1	81.7	84.4
1: 3	15	1	77.5099	0.03534	2.7392	69.3	72.0	74.8	77.5	80.2	83.0	85.7
1: 4	16	1	78.6055	0.03555	2.7944	70.2	73.0	75.8	78.6	81.4	84.2	87.0
1: 5	17	1	79.6710	0.03576	2.8490	71.1	74.0	76.8	79.7	82.5	85.4	88.2
1: 6	18	1	80.7079	0.03598	2.9039	72.0	74.9	77.8	80.7	83.6	86.5	89.4
1: 7	19	1	81.7182	0.03620	2.9582	72.8	75.8	78.8	81.7	84.7	87.6	90.6
1: 8	20	1	82.7036	0.03643	3.0129	73.7	76.7	79.7	82.7	85.7	88.7	91.7
1: 9	21	1	83.6654	0.03666	3.0672	74.5	77.5	80.6	83.7	86.7	89.8	92.9
1:10	22	1	84.6040	0.03688	3.1202	75.2	78.4	81.5	84.6	87.7	90.8	94.0
1:11	23	1	85.5202	0.03711	3.1737	76.0	79.2	82.3	85.5	88.7	91.9	95.0
2: 0	24	1	86.4153	0.03734	3.2267	76.7	80.0	83.2	86.4	89.6	92.9	96.1

WHO Child Growth Standards

Height-for-age GIRLS

World Health Organization

2 to 5 years (z-scores)

						Z-scores (height in cm)						
Year: Month	**Month**	**L**	**M**	**S**	**SD**	**-3 SD**	**-2 SD**	**-1 SD**	**Median**	**1 SD**	**2 SD**	**3 SD**
2: 0	24	1	85.7153	0.03764	3.2267	76.0	79.3	82.5	85.7	88.9	92.2	95.4
2: 1	25	1	86.5904	0.03786	3.2783	76.8	80.0	83.3	86.6	89.9	93.1	96.4
2: 2	26	1	87.4462	0.03808	3.3300	77.5	80.8	84.1	87.4	90.8	94.1	97.4
2: 3	27	1	88.2830	0.03830	3.3812	78.1	81.5	84.9	88.3	91.7	95.0	98.4
2: 4	28	1	89.1004	0.03851	3.4313	78.8	82.2	85.7	89.1	92.5	96.0	99.4
2: 5	29	1	89.8991	0.03872	3.4809	79.5	82.9	86.4	89.9	93.4	96.9	100.3
2: 6	30	1	90.6797	0.03893	3.5302	80.1	83.6	87.1	90.7	94.2	97.7	101.3
2: 7	31	1	91.4430	0.03913	3.5782	80.7	84.3	87.9	91.4	95.0	98.6	102.2
2: 8	32	1	92.1906	0.03933	3.6259	81.3	84.9	88.6	92.2	95.8	99.4	103.1
2: 9	33	1	92.9239	0.03952	3.6724	81.9	85.6	89.3	92.9	96.6	100.3	103.9
2:10	34	1	93.6444	0.03971	3.7186	82.5	86.2	89.9	93.6	97.4	101.1	104.8
2:11	35	1	94.3533	0.03989	3.7638	83.1	86.8	90.6	94.4	98.1	101.9	105.6
3: 0	36	1	95.0515	0.04006	3.8078	83.6	87.4	91.2	95.1	98.9	102.7	106.5
3: 1	37	1	95.7399	0.04024	3.8526	84.2	88.0	91.9	95.7	99.6	103.4	107.3
3: 2	38	1	96.4187	0.04041	3.8963	84.7	88.6	92.5	96.4	100.3	104.2	108.1
3: 3	39	1	97.0885	0.04057	3.9389	85.3	89.2	93.1	97.1	101.0	105.0	108.9
3: 4	40	1	97.7493	0.04073	3.9813	85.8	89.8	93.8	97.7	101.7	105.7	109.7
3: 5	41	1	98.4015	0.04089	4.0236	86.3	90.4	94.4	98.4	102.4	106.4	110.5
3: 6	42	1	99.0448	0.04105	4.0658	86.8	90.9	95.0	99.0	103.1	107.2	111.2
3: 7	43	1	99.6795	0.04120	4.1068	87.4	91.5	95.6	99.7	103.8	107.9	112.0
3: 8	44	1	100.3058	0.04135	4.1476	87.9	92.0	96.2	100.3	104.5	108.6	112.7
3: 9	45	1	100.9238	0.04150	4.1883	88.4	92.5	96.7	100.9	105.1	109.3	113.5
3:10	46	1	101.5337	0.04164	4.2279	88.9	93.1	97.3	101.5	105.8	110.0	114.2
3:11	47	1	102.1360	0.04179	4.2683	89.3	93.6	97.9	102.1	106.4	110.7	114.9
4: 0	48	1	102.7312	0.04193	4.3075	89.8	94.1	98.4	102.7	107.0	111.3	115.7

WHO Child Growth Standards

Height-for-age GIRLS

World Health Organization

2 to 5 years (z-scores)

						Z-scores (height in cm)						
Year: Month	**Month**	**L**	**M**	**S**	**SD**	**-3 SD**	**-2 SD**	**-1 SD**	**Median**	**1 SD**	**2 SD**	**3 SD**
4: 1	49	1	103.3197	0.04206	4.3456	90.3	94.6	99.0	103.3	107.7	112.0	116.4
4: 2	50	1	103.9021	0.04220	4.3847	90.7	95.1	99.5	103.9	108.3	112.7	117.1
4: 3	51	1	104.4786	0.04233	4.4226	91.2	95.6	100.1	104.5	108.9	113.3	117.7
4: 4	52	1	105.0494	0.04246	4.4604	91.7	96.1	100.6	105.0	109.5	114.0	118.4
4: 5	53	1	105.6148	0.04259	4.4981	92.1	96.6	101.1	105.6	110.1	114.6	119.1
4: 6	54	1	106.1748	0.04272	4.5358	92.6	97.1	101.6	106.2	110.7	115.2	119.8
4: 7	55	1	106.7295	0.04285	4.5734	93.0	97.6	102.2	106.7	111.3	115.9	120.4
4: 8	56	1	107.2788	0.04298	4.6108	93.4	98.1	102.7	107.3	111.9	116.5	121.1
4: 9	57	1	107.8227	0.04310	4.6472	93.9	98.5	103.2	107.8	112.5	117.1	121.8
4:10	58	1	108.3613	0.04322	4.6834	94.3	99.0	103.7	108.4	113.0	117.7	122.4
4:11	59	1	108.8948	0.04334	4.7195	94.7	99.5	104.2	108.9	113.6	118.3	123.1
5: 0	60	1	109.4233	0.04347	4.7566	95.2	99.9	104.7	109.4	114.2	118.9	123.7

WHO Child Growth Standards