CHILDHOOD UNDERNUTRITION WITHIN THE DRY ZONE OF MYANAMR: DOES GEOGRAPHIC LOCATION INFLUENCE HEALTH OUTCOMES?

by

Andrea Nicole Davis

A thesis submitted to the faculty of
The University of Utah
in partial fulfillment of the requirements for the degree of

Master of Science

Department of Geography

The University of Utah

December 2017

The University of Utah Graduate School

STATEMENT OF THESIS APPROVAL

The thesis of **Andrea Nicole Davis**

has been approved by the following supervisory committee members:

Neng Wan	, Chair	**08/08/2017** Date Approved
James VanDerslice	, Member	**08/08/2017** Date Approved
Mitchell James Power	, Member	**08/08/2017** Date Approved

and by **Andrea Brunelle** , Chair/Dean of

the Department/College/School of **Geography**

and by David B. Kieda, Dean of The Graduate School.

ABSTRACT

Food security is dependent on ecological conditions and alterations to local environments, including impacts from climate change. Myanmar is experiencing the second highest rate of extreme weather events in the world and a high level of food insecurity, which threatens the nutritional supply for its population, especially children. The primary purpose of this study is to understand environmental risk factors and develop a visualization tool that captures the spatial distribution of childhood undernutrition within the Dry Zone of Myanmar. Of particular interest is the first 1,000 days of development. This study uses geographic and spatial statistics methods to examine the association of child undernutrition and environmental risk factors in the study area. Results suggest a decrease in stunting and underweight with increased precipitation and increased cultivated land.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The last several decades have witnessed a marked improvement in child undernutrition worldwide (UNICEF and Bank 2014). However, despite the steadily decreasing undernutrition rate, undernourishment still accounts for 45 percent of deaths in children five years and under globally, resulting in 3 million deaths per year (Black, Victora, et al. 2013). Furthermore, climate change is predicted to reduce future global calorie availability—measured by the amount of consumable cereals—by 10 percent between 2000 and 2050 (Nelson et al. 2009). This decline will likely eliminate progresses made towards reducing child undernutrition.

The immediate causes of child undernutrition are diet and diseases, both of which are influenced by household food insecurity and environmental conditions, including impacts from climate change (Black et al. 2008; Morris, Cogill, and Uauy 2008). Food security exists when the entire population has consistent physical, social, and economic access to adequate amounts of safe, nutritious food required to meet dietary preferences and needs for a healthy life (Black et al. 2008; FAO 1996). Environmental change poses a threat to food security by altering crop production, which is dependent on ecological conditions and alterations to the local environment (Rosegrant et al. 2000). Changes in temperature and precipitation threaten the amount of arable land (Grace et al. 2012). Drought and floods are examples of extreme weather events that contribute to soil erosion and water stress. Such alterations impact traditional farming practices that can be a hindrance to attaining food security.

This study examines the association between child undernutrition and environmental risk factors in the Dry Zone of Myanmar. Results from this study will facilitate our understanding of the drivers of undernutrition and aid in the reduction of future infant and child mortality and physical and cognitive development problems among children by exposing areas with a higher risk of undernutrition.

Myanmar, formerly Burma, is among the countries with the lowest level of human development in the world, ranking 146 out of the 188 nations as described in the *Human Development Report* (United Nations Development Programme 2016). In this report, countries were compared using a Human Development Index which assessed the life expectance, level of education, and Gross National Income (GNI) per capita. Among Southeast Asian countries, Myanmar has the lowest life expectancy (i.e., 65 years of age compared to East Asia and the Pacific at 74.2), a low population education level (i.e., 4.7 expected years of schooling compared to East Asia and the Pacific at 7.7), and very low GNI per capita (i.e., $4,600 compared to East Asia and the Pacific at $12,215) (United Nations Development Programme 2016).

Land-centered activities dominate the agrarian economy of Myanmar, where two-thirds of the total population are involved in subsistence farming for their livelihoods (Tun, Shrestha, and Datta 2015). Myanmar was the sixth largest producer of rice in the world between 2006–2010 (GRiSP 2013). Milled rice production in 2010 was roughly 22.1 million tons harvested from over 8 million hectors, while exports during the same year were a mere 0.12 million tons (GRiSP 2013). This implies that the majority of the crops grown in Myanmar were consumed in the country. In terms of diet component, on average, over 80 percent of the calories consumed per capita comes from rice (48.3 percent) and other subsistence crops (34.3 percent) (GRiSP 2013). Small-scale farmers often rely on rainfed irrigation and subsistence crops, and are most vulnerable to climate change (FAO 2010). This raises an alarm on the diet of the Burmese because Myanmar is experiencing the second highest rate of extreme weather events in the world between 1995–2014 (Kreft et al. 2015). The alterations to traditional weather pattern can impact food security, ultimately increasing the prevalence of child undernutrition throughout the country.

Although the entire country is of concern for childhood undernutrition, one of the most vulnerable regions in Myanmar is the Dry Zone shown in Figure 1 (Tun, Shrestha, and Datta 2015; UNCCD 2000). The Dry Zone is a densely populated region that contains about 15.4 million people (one-third of Myanmar’s population) with 5 million being children 18 years of age and younger (UNICEF 2014). It is located in the central semiarid region of Myanmar positioned to the northeast of the Arakan mountain range. The Dry Zone is composed of 58 townships and encompasses 13 percent of the country’s total land (roughly the size of Portugal). The leeward location of the Dry Zone results in restricted moisture availability from the Bay of Bengal. Currently, the Dry Zone is prone to high temperatures, erratic rainfall, and extended dry spells, impacting growing conditions for crops (Tun, Shrestha, and Datta 2015). These seasonal changes impact agroecological conditions by altering growing season, planting and harvesting calendar, water availability, pests, weeds, and diseases (Rosegrant et al. 2000). These alterations to traditional agricultural patterns resulting from climate change can be life-threatening for developing communities, such as the Dry Zone, that rely heavily on local resource production to survive.

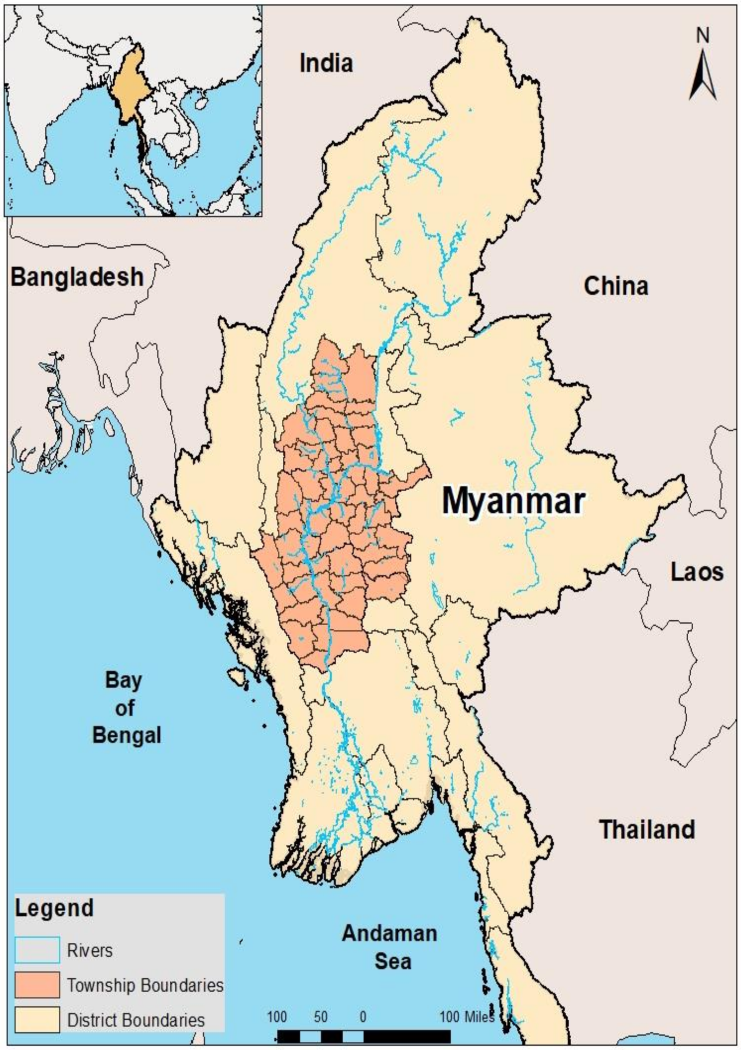

Figure 1. Location of Myanmar and the Dry Zone

The Dry Zone can be divided into three separate zones according to agroecological conditions: flood plains, dry land farming, and highland with sloping agriculture (Sibson 2014) (Figure 2). One of the hypotheses for this study is that children residing in dry land farming areas are more likely to experience undernutrition compared to those populations occupying the flood plains. Dry land farming consists of suitable soil for cultivation but has to fully rely on seasonal rains. The flood plains have the most fertile soils and is the areas with the highest access to irrigation within the Dry Zone, which makes multi-

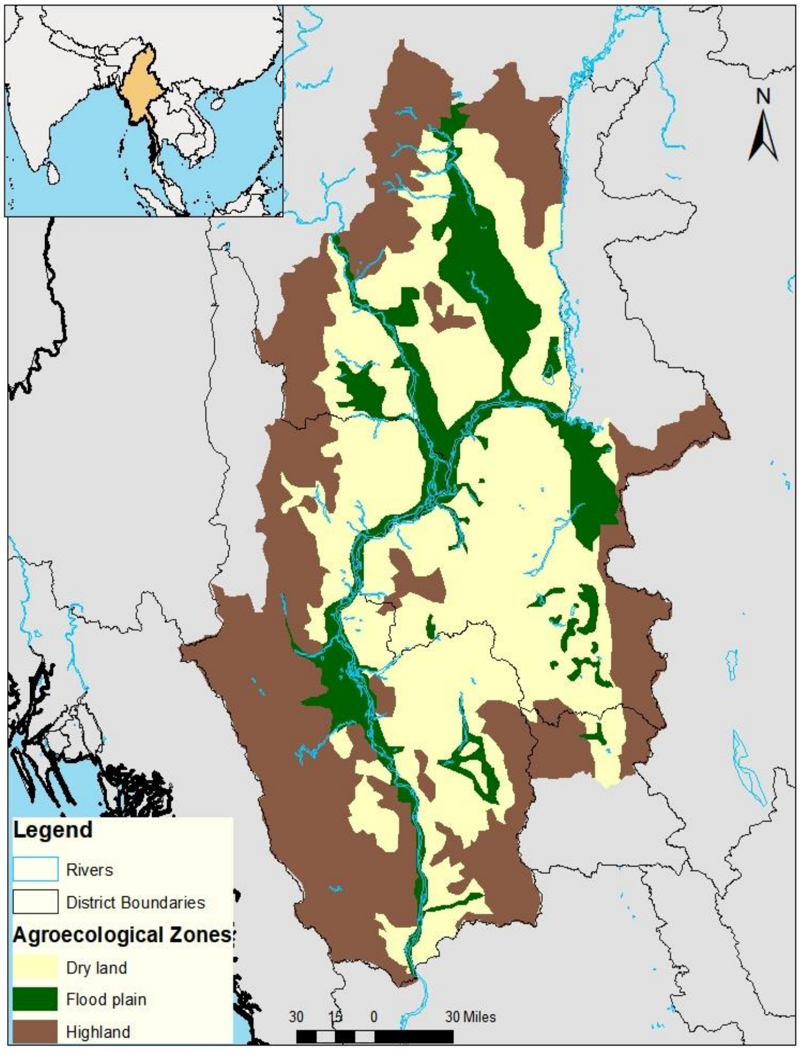

Figure 2. Agroecological zones in the Dry Zone of Myanmar

cropping possible year-round (Sibson 2014). Highland with sloping agriculture is classified by elevation (i.e., >=300 meters). Highlands are suitable for perineal crops, orchards, and plantations. These crops reduce the need for annual tilling in a region with sloping and shifting soils. Soils in the Dry Zone are mainly clay- and sand-rich soils susceptible to water and wind erosion, contributing to land degradation (Sibson 2014).

Geographic information has been used in recent decades to understand risk factors for undernutrition and food security in developing and under-developed countries (Brown et al. 2014; Qayum et al. 2015; Seid et al. 2014). Studies have been conducted to evaluate undernutrition in Myanmar (Davis et al. 2015), but are lacking a detailed evaluation of the spatial distribution of environmental risk factors and the association with child undernutrition throughout the region. De Sherbinin (2014) acknowledged a need for local vulnerability assessments that address context-specific situations based on detailed data and assumptions about mechanisms being assessed. Contributing to this need, this study aims to create a model to identify areas susceptible to undernutrition within the Dry Zone of Myanmar. Three research aims are proposed to complete this task: 1) identify the spatial pattern of undernutrition in the Dry Zone of Myanmar, 2) identify environmental risk factors associated with child undernutrition, and 3) visualize annual changes in undernutrition risk. Results derived from this study will provide innovative evidences towards addressing children undernutrition in Southeast Asia.

METHODS

Study Design and Period

This study utilized a cross-sectional health survey to examine the associations between environmental risk factors and measures of undernutrition among children in the Dry Zone of Myanmar born between July 2007 and June 2013. Specifically, it uses contingency tables to describe the linkages between the outcome of undernutrition and environmental risk factors. The environmental risk factors included in this study are growing season precipitation and temperature, area equipped for irrigation, and urban area. Spatial patterns of undernutrition in the study area was analyzed using Getis Ord Gi* (Turi, Christoph, and Grigsby-Toussaint 2013). Multiple regression was utilized to describe the relationship between undernutrition and environmental risk factors in the study area. Annual risk maps were created based on the results of the multiple regression models and are used to visualize changing risk of environmental factors assessed during the study time period.

Epidemiological Data

Epidemiological data for this study came from a health survey with a cross-sectional design collected in June and July 2013 by a joint effort between Save the Children, World Food Program (WFP), and the Ministry of Livestock, Fisheries and Rural Development (Sibson 2014). The goal of the survey was to assess nutrition and food security throughout the Dry Zone at individual, household, and village levels (Sibson 2014). The study surveyors collected data on 2,036 children, plus their mothers. These data provide information on nearly 1,800 households throughout 152 villages. The sampled villages are shown in Figure 3. The key variables of the dataset used in the analysis are gender, sex, age, and undernutrition status of the sampled children.

Undernutrition is defined as a lack of sufficient protein and micronutrients required to sustain body maintenance, growth, and development (Latham and Nations 1997). Stunting (height-for-age), underweight (weight-for-age), and wasting (weight-for-height)

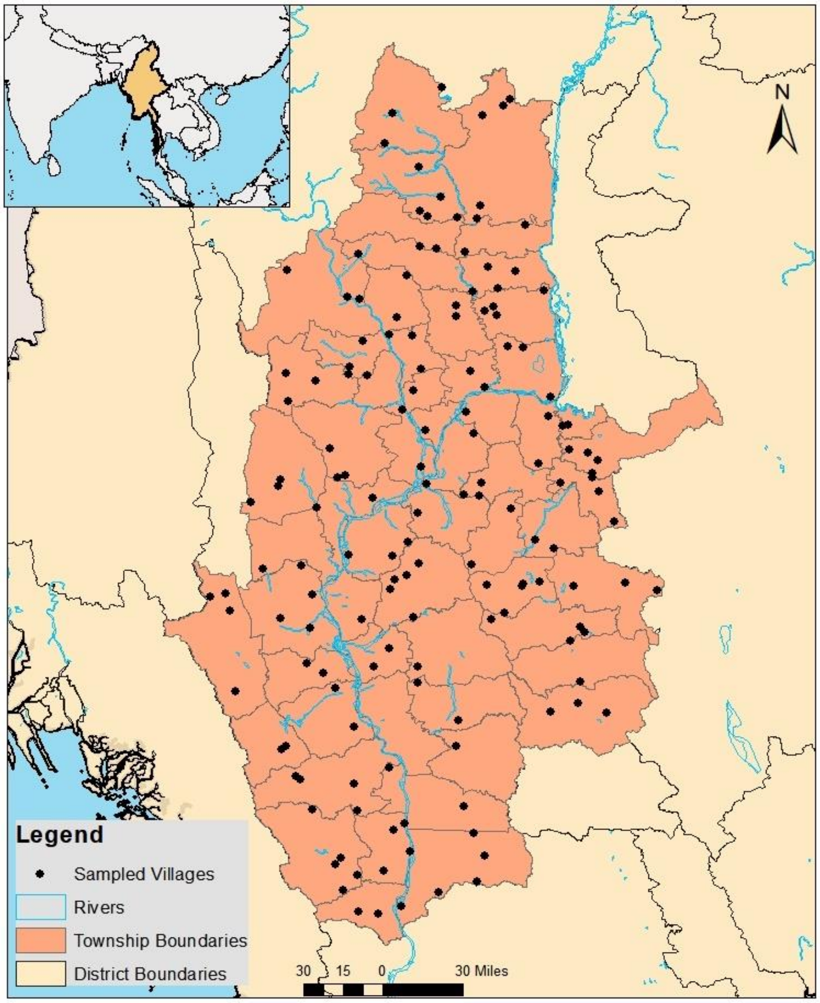

Figure 3. Sampled villages in the Dry Zone of Myanmar

are common measures of child undernutrition (Lloyd, Kovats, and Chalabi 2011). Stunting is a measure of long-term undernutrition restricting linear growth, whereas wasting is a result of short-term undernutrition restricting linear growth (Caulfield et al. 2006). Recommended standards for indicating undernutrition have been established by the World Health Organization. The cutoff for all parameters is set to a value equal to the median height-for-age, weight-for-age, and weight-for-height of the reference population minus two times the standard deviation from the mean. These standards are used to measure the full distribution of anthropogenic variables measuring undernutrition without restricting assumptions (Black, Victora, et al. 2013).

The first 1,000 days (i.e., from conception to age two) is the most critical period for child development (Black, Alderman, et al. 2013; WHO 2013). Maternal and child nutrition is reliant on accessibility, availability, stability and utilization of food during this time (Dawson, Perryman, and Osborne 2016). Particularly, when a child is 6 to 12 months of age, successful complementary feeding—extra nutrient required to meet dietary needs—is essential for preventing child undernutrition (Espo et al. 2002).

Climatic Data

Climate indicators used in this study include temperature and precipitation. Data of 2007–2012 were obtained from the Climate Research Unit (CRU) at the University of East Anglia (Harris et al. 2014). CRU Time Series (TS) version 4.0 from 1901–2015 data for temperature and precipitation was cropped to the geographic extent of the Dry Zone (Harris et al. 2014). Data were limited to 2007–2012 to account for growing season conditions for each child and optimize the weighted overlay used to visualize undernutrition. This gridded climate data are a product derived from a global weather station network and includes six weather stations in Myanmar. The interpolation method for the CRU TS 4.0 data used Angular Distance Weighting, which allows the selection of stations during the gridding process, and improves accuracy (Harris et al. 2014).

The growing season in the study area is June, July, and August. Growing season conditions were used to identify the association between the outcome of undernutrition and both precipitation and temperature maximums during the first 1,000 days. The growing season is a crucial time because optimal conditions are needed to provide a sufficient supply of food for the local population until the following year's harvest. For this study, the first 1,000 days of life were divided into four stages: pregnancy (0–9 months before birth), 0–6 months, 7–12 months, and 13–24 months. Climate data for the growing seasons were used to define climate factors. The growing season is a critical time period because it provides the majority of the food supply. For example, a mother who was pregnant between October 2007 and July 2008 was dependent on the 2007 growing season for the majority of her pregnancy. Her child would then be zero to six months of age between July and December of 2008 and reliant on the food supply from the 2008 growing season. This same growing season would supply the child with nutrients while the child was 7 to 12 months of age. Finally, the child now 13–24 months of age, between July and June of 2009, would receive the food supply from the growing season of 2009. It is impossible for one growing season to supply more than two stages of the 1,000-day growing period. For children born in January, February, or March, only two growing seasons supply nutrition for the majority of the 1,000-day period. However, children born during any other time during the year would rely on three specific growing seasons during the critical first 1,000 days.

Environmental Data

Environmental data were used to further understand the relationship with undernutrition outcomes. Urban area and cultivated land data came from the Harmonized Soil Database accessible online through the Food and Agriculture Organization of the United Nations (FAO) (Nachtergaele et al. 2010). Six geographic datasets (i.e., Global Map of Irrigated Area, LANDSCAN) were compiled by FAO to identify global land cover and land use. Median urban area was derived by measuring the presence of other land cover variables and regression equations relating population density to developed land (Nachtergaele et al. 2010). Total cultivated land was derived using the same process. The data are available in a 5-minute resolution, 10 km. These data are limited to one point in time, which restricts the ability to assess annual changes.

Irrigated area information was obtained from the FAO Global Map of Irrigated Areas, version 5, released in 2010 (Siebert et al. 2013). The data represent the percentage of area equipped for irrigation at a 5-minute or 10 km resolution. The percent of irrigated area was estimated using a compilation of sub-national irrigation statistics and geospatial information. Irrigation statistics data came from organizations such as FAO and WFP, and geospatial information came from digital and printed maps.

Spatial Analysis

To conceptualize the spatial distribution of undernutrition in the Dry Zone, the Getis-Ord Gi* statistics were used to measure spatial patterns of undernutrition outcomes (Getis and Ord 1992; Ord and Getis 1995). The test was run using ArcMap 10.5 (ESRI 2015). Getis-Ord Gi* is designed to consider each feature within the context of the neighboring features. Township was used in place of village-level spatial domain because of the relatively small sample sizes. Each township encompassed roughly three villages from the health survey. The prevalence of stunting and underweight within each township was used to determine if an unexpectedly high or low concentration of undernutrition occurs within the study area. A cluster is identified when the local sum of an outcome and its neighbors are compared proportionately to the sum of the entire sample. When the local sum of an outcome exceeds that of the total expected sum, and is too large to occur by random change, the cluster is identified as statistically significant. The distance band used for this study was a fixed 50,000 meters, roughly 30 miles.

Getis Ord Gi* statistic is given as

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j}x_j - \bar{X}\sum_{j=1}^{n} w_{i,j}}{S\sqrt{\frac{\left[n\sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2\right]}{n-1}}}$$

where x_j is the attribute value of feature j, w_{ij} is the spatial weight between feature i and j, and n is equal to the total number of features. Results are given in a z-score—a count of standard deviations above or below the mean—which can then be mapped based on each township to show the spatial pattern of undernutrition.

Statistical Analysis

The purpose of the statistical analysis was to assess the linkages between the outcome of undernutrition and the environmental risk factors. First, a variety of environmental variables were interrogated for their risk factors. Second, contingency tables were generated to describe the interrelations between dependent and independent variables.

Third, multiple regression analysis was conducted to further understand the potential linkages between the outcome of child undernutrition and environmental risk factors. Finally, the regression results were evaluated to determine the overall influence for each potential risk factor in a weighted overlay used to produce a visualization tool for assessing risks throughout the study area.

Categories for the environmental risk factors were established by considering a variety of optimum growing conditions for major crops in the study area. A few examples of crops commonly grown throughout the Dry Zone are groundnut (formally *arachis hypogaea)* and sorghum (formally *sorghum bicolor*). According to crop information provided by FAO, optimum growing conditions for groundnut requires 500 to 700 millimeters of rainfall during the growing season, and a reduction in yield occurs when temperatures exceed 33ºC. Sorghum has an optimum growing rainfall requirement of 450–650 mm. Crops such as corn, soybean, and cotton experience a sharp decline in production when temperatures exceed 32ºC (Hatfield and Prueger 2015).

Based on the average optimum growing conditions, categorical variables were created for both temperature and precipitation. Monthly averaged CRU data were used to explore the potential climate influence from zero-to-three months within a growing season, which exceeded the threshold of 32ºC for temperature maximums and 250 mm of rainfall. A second precipitation variable was created using the same process but was created to account for cultivated land equipped for irrigation. This was done by using a ratio of land equipped for irrigated over the total cultivated land. The threshold represents the top quarter of the sampled children with access to cultivated land equipped for irrigation (i.e., 35 percent). When the percent of cultivated land equipped for irrigation exceeded 35 percent, the total months above optimum became zero. This is because the variable is created to count the number of months exceeding growing season optimum. If we are assuming adequate access to cultivated land that is equipped for irrigation, then the number of inadequate months would be zero despite the level of precipitation. The final variables (temperature and two precipitation variables) were used to assess undernutrition outcomes when growing conditions exceed the growing season optimum.

For each child, additional temperature and precipitation variables were created to reflect his/her accumulated exposures over their 1,000-day development period. Children age 13–24 months between September 2012 and August 2013 were selected because food supply for this time period would come from the growing season of 2012. A total of 1,487 children out of the 2,036 sampled children fit this criterion.

Categorical variables were created for urban area, total cultivated land, and areas equipped for irrigated. The dataset could not be divided by individual growing seasons since the data are an assessment of area at one point in time. To create the variables, urban area was assessed based on the presence or absence. Limited access of urban area is defined by 5 percent (the mean) or less. The percent of area equipped for irrigation was divided based on natural breaks. The total cultivated lands were divided based on quantiles allowing an equal number of villages in each category to avoid small numbers.

Contingency tables were used to assess the associations between the aforementioned environmental risk factors and the measures of undernutrition (i.e., stunting, underweight, and wasting). The prevalence of undernutrition in each of the agroecological zones was compared to the overall average throughout the Dry Zone. In addition, chi-squared analysis, which identifies how likely an outcome occurs purely by chance (i.e. goodness of fit), was applied to determine the significance level of linkages in the contingency tables.

The categorical environmental risk factors were regressed against each of the outcome variables using a multivariate logistic regression. The regression results are used to determine the influence of each variable on the predicted probability of undernutrition. This is evaluated based on the odds ratio—a measure of association between the undernutrition outcome and environmental risk factors. These results are expected to further describe the relationship between child undernutrition and environmental risk facts. All analyses were implemented using R version 3.4.0 (R Core Team 2017).

Risk Mapping

A visualization of annual undernutrition risk was generated using a weighted overlay method (Qayum et al. 2015; Seid et al. 2014). This process was used because it allows for refinement of each input variable during the overlay analysis. A raster image for each significant environmental risk factor was used in the weighted overlay process. Each raster layer used in the analysis underwent reclassification based on the categories used in the statistical analysis. The categories in a raster were ranked based on the results from the contingency tables, the highest prevalence of undernutrition with a significant chi squared received the highest risk score. The overlay utilized each of the reclassified raster images and received a weighted score based on the odds ratios from the multiple regression, the highest odds received the highest percent of influence. Finally, all data were added to ArcMap 10.5 where the weighted overlay was carried out to visualize annual undernutrition risk

RESULTS

Health Survey Sample Characteristics

The study area consists of 152 villages in 58 townships in the three agroecological zones. As shown in Table 1, among the 2,036 children sampled in the health survey, 27.9 percent were stunted, 27.4 percent were underweight, and 11.7 percent were experiencing wasting. Children that were stunted during the health survey were 2.6 times more likely to experience underweight than those who were not stunted. Older age is associated with

Table 1. Health Survey Sample Characteristics 2013

Sample Characteristics	**Total Sample**	**Stunting**	**Underweight**	**Wasting**
	N (%)	**N (%)**	**N (%)**	**N (%)**
Full Sample	2036	567 (27.9)	557 (27.4)	238 (11.7)
Sex of Child				
Male	1038 (51.0)	297 (28.6)	288 (27.8)	133 (12.8)
Female	998 (49.0)	270 (27.1)	269 (27.0)	105 (10.5)
Age of Child				
< 1 year	446 (21.9)	50 (11.2)	52 (11.7)	36 (8.1)
1 year	403 (19.8)	107 (26.6)	90 (22.3)	38 (9.4)
2 years	430 (21.1)	148 (34.4)	135 (31.4)	54 (12.6)
3 years	404 (19.8)	141 (34.9)	142 (35.2)	60 (14.9)
4 years	353 (17.3)	121 (34.3)	138 (39.1)	50 (14.2)
Household Head Sex				
Male	1804 (88.6)	505 (28.0)	500 (27.7)	215 (11.9)
Female	215 (10.6)	54 (25.1)	52 (24.2)	22 (10.2)
No Response	17 (0.8)	8 (47.1)	5 (29.4)	1 (5.9)
Age of Mother				
17–24 years	265 (13.2)	42 (15.8)	49 (18.5)	21 (12.6)
25–34 years	1065 (53.2)	302 (28.4)	281 (26.4)	126 (8.5)
35–55 years	671 (33.5)	213 (31.7))	219 (33.5)	88 (7.6)
Agroecological Zone				
Dry Land Farming	687 (33.7)	215 (31.3)	217 (31.6)	687 (33.7)
Flood Plain	661 (32.5)	154 (23.3)	145 (21.9)	661 (32.5)
Highland	688 (33.8)	198 (28.8)	195 (28.3)	688 (33.8)

higher risks of being stunted. A similar pattern can be seen with the prevalence of underweight children; opposed to stunting, the prevalence continues to increase with age.

Spatial and Temporal Patterns of the Environmental Risk Factors

Within the Dry Zone, higher temperatures and erratic rainfall affect crop production, placing an increased child population at risk for undernutrition by impacting food availability and access (Battisti and Naylor 2009; Grace et al. 2012). Average annual temperature maximums and annual precipitation (1961–1990) for Myanmar provide the data for the annual average temperature maximum and annual precipitation for Myanmar, which can be seen in Figure 4. The average for both temperature maximum and

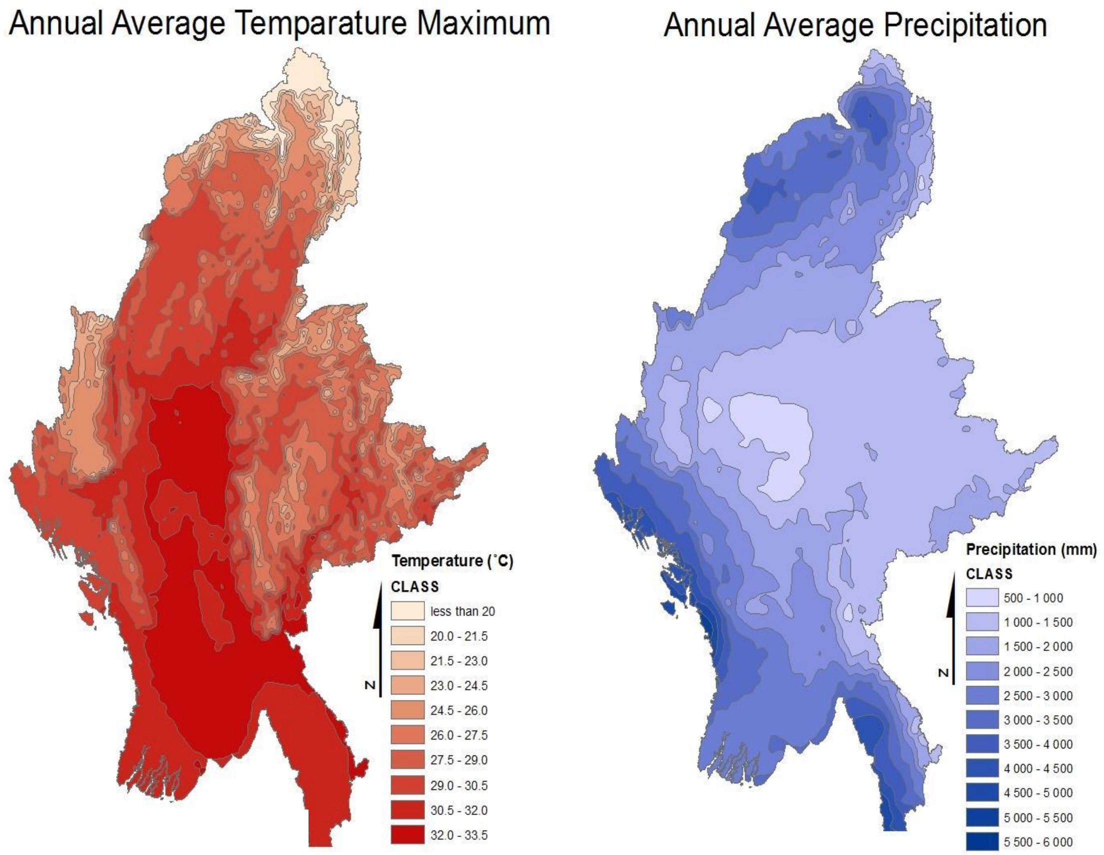

Figure 4. Annual temperature maximum and precipitation average for Myanmar.

precipitation where provided by FAO and used to show the typical climate conditions throughout the study area. On average, temperature maximums in the central portion of Myanmar are 32ºC or higher and mean annual rainfall in the region is ~1,000 mm, which is significantly lower than the national average of 2,300 mm (Matsuda 2013).

Growing season precipitation in the Dry Zone averaged 1,060 mm of rainfall between 2007–2012 among sampled villages in the health survey. During the same time period, the lowest levels of annual growing season rainfall occurred in villages located in flood plains (mean = 821 mm), followed by the dry land regions (mean = 972 mm). The highland villages had 39 percent greater growing season precipitation as compared to the villages in the flood zone (mean = 1,344 mm) with the highest amounts of precipitation. Figure 5 shows each of the environmental risk factors used in the analysis by agroecological zones. There was greater variability in growing season precipitation

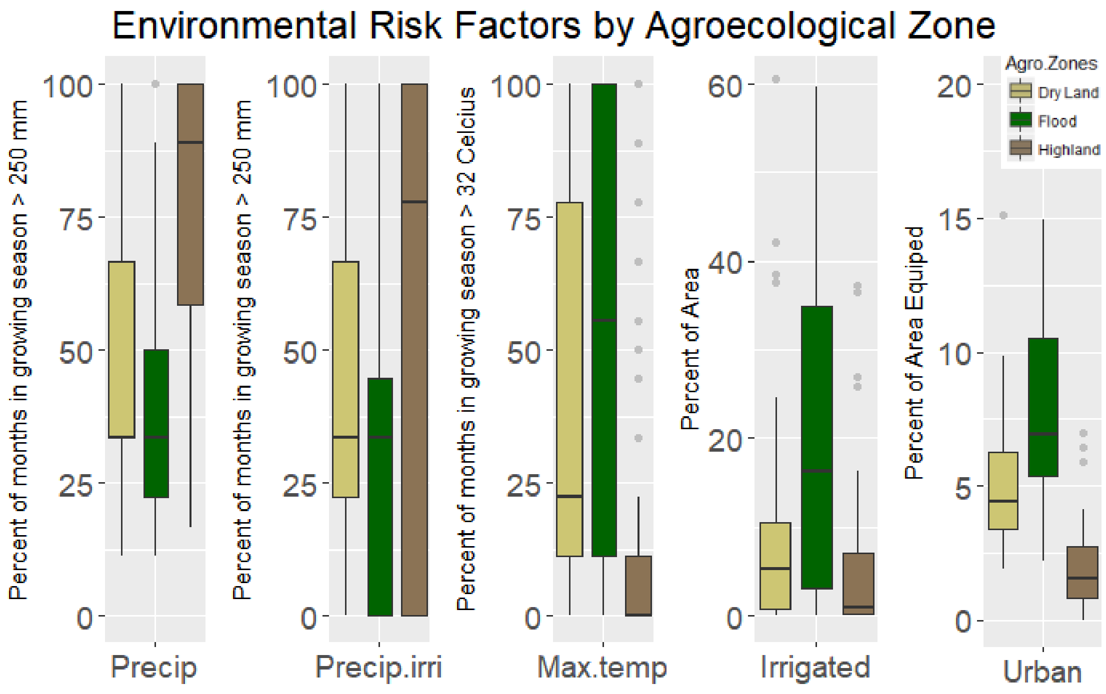

Figure 5. Environmental risk factors by agroecological zone

between the villages of the highland region compared to the other two agroecological zones. When assessing the variable created for precipitation accounting for cultivated land equipped for irrigation is used, a similar pattern occurs, but there is a difference within the agroecological zones. For example, highland areas experience the greatest number of months above optimum growing conditions. Although correction for irrigation brought a portion of children into the optimum conditions, the majority of children in the highlands experienced all three months in the growing season above optimum conditions when adjusting for irrigation. Irrigated area is concentrated in the flood zones with limited access present in dry land and highland areas. Urban areas are limited throughout the entire Dry Zone, which implies that the majority of the population resides in rural areas.

It is also important to consider the interannual variations in precipitation throughout the study area, which is shown in Figure 6. Of the villages sampled during the health

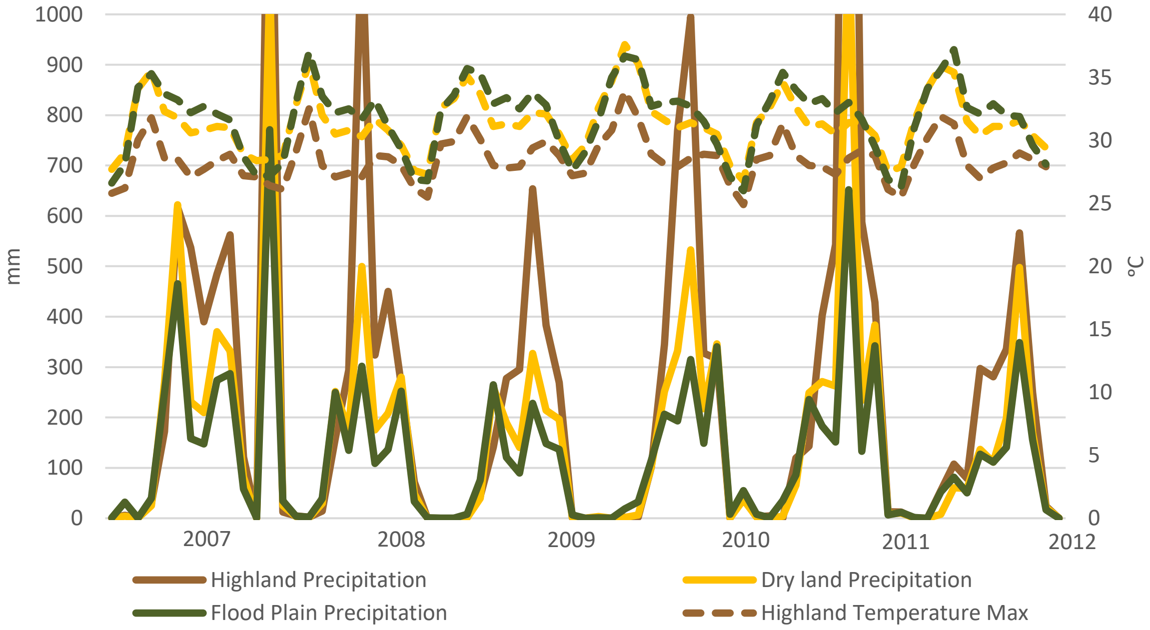

Figure 6. Interannual variability for temperature and precipitation in the Dry Zone of Myanmar, 2007–2012.

survey, the total annual rainfall during the growing season for 2011 was 1,837 mm, and in 2012, the measurement was 520 mm. During the same time period, average annual temperatures ranged between 30–31ºC, with variations spanning between 25– 33ºC for the sampled villages. On average, temperatures vary little throughout the Dry Zone with the cooler temperatures located in the highlands and the hottest temperatures being in the flood zones. Furthermore, for the trend in CRU data, annual temperature averages in the last decade have exceeded records throughout the last century. This interannual variation places stress on crop production, ultimately threatening food security within the study area. Annual food security is critically linked to growing season conditions, which support children during developmental phases.

Cluster Analysis of Undernutrition

The ultimate goal of the use of the Getis-Ord Gi* statistic is to identify the spatial pattern of undernutrition in the Dry Zone of Myanmar. Figure 7 shows the results of Getis-Ord Gi* undernutrition outcomes, including two areas with statistically significant clusters for stunting and underweight. To the northeast of the Dry Zone, there is an area of low prevalence of stunting and a larger, overlapping area of low underweight. To the southwest, there is an area of high prevalence of stunting and a much larger, overlapping area of high prevalence of underweight, both statistically significant. Wasting in the Dry Zone has an altogether different pattern than stunting and underweight, with significant areas of above average prevalence in the northwestern mountain range.

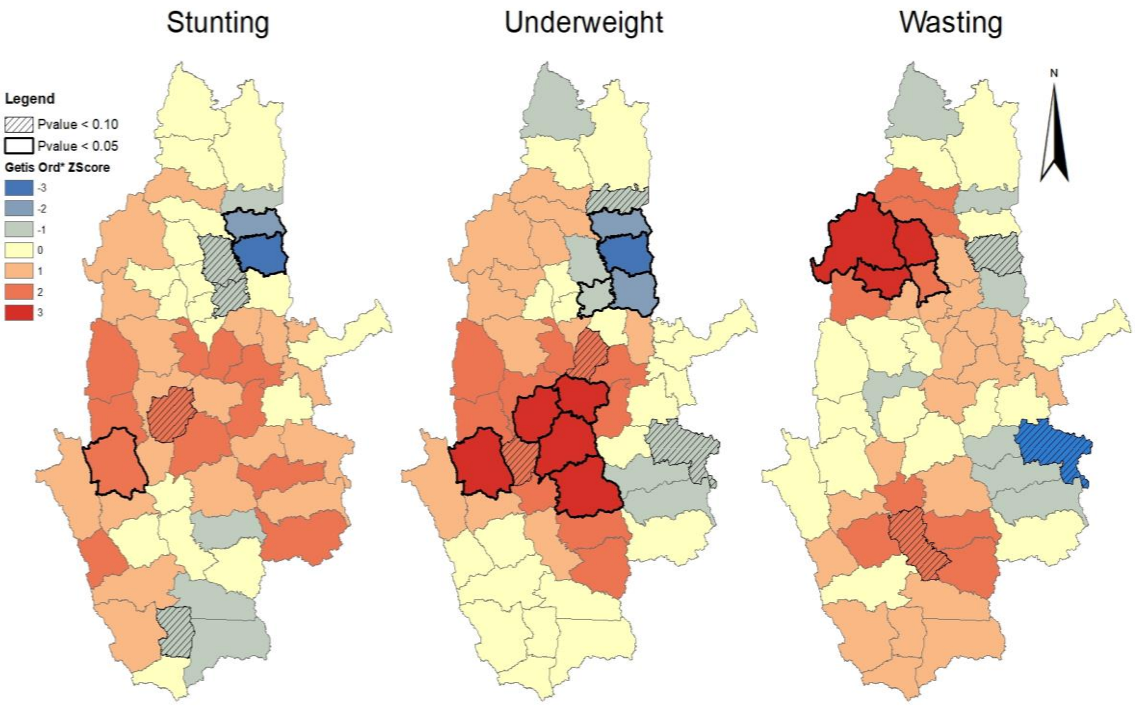

Figure 7. Getis-Ord Gi* results describing the spatial pattern of undernutrition outcomes

Determinants of Childhood Undernutrition

The major purpose of this section is to describe what exposure period is the most critical, and what environmental risk factors are the most critical during the first 1,000 days of development. First, the percent of months exceeding the growing optimum during the first 1,000 days of child development is assessed using three variables: temperature maximum, total monthly precipitation, and total monthly precipitation adjusted for access to irrigation. Second, to further understand the first 1,000-days of development, each of the phases in this time period were assessed for each of the undernutrition outcomes. Finally, area equipped for irrigation, total cultivated land, and urban area were described using the contingency tables for each of the undernutrition outcomes. Due to collinearity between each of the development phases, each variable is analyzed individually to further understand the environmental risk factors and the outcome of undernutrition.

Stunting

Stunting prevalence was assessed using contingency tables with growing season temperature and the precipitation variables during the first 1,000 days of development. Table 2 describes the prevalence of stunting for the study area, and for each of the three agroecological zones. The categorical environmental risk factors are used to describe the prevalence of stunting with an increase in the number of months exceeding the growing optimum. Children included in this analysis are those who experienced the entire 1,000-day development period. For these children, an increase in months above the growing optimum temperature maximum indicates a significant decrease in the outcome of stunting, as opposed to precipitation. Furthermore, there were no significant results in the overall study area for precipitation when adjusting for irrigation. When considering agroecological

Table 2. Linkages between precipitation and temperature during the first 1,000 days of development and the outcome of stunting with significant results bolded.

Environmental Risk Factor	**% of Months**	**Overall**	**Dryland**	**Flood**	**Highland**
		0.33 (489)	0.37 (183)	0.27 (134)	0.34 (165)
Temperature in growing season > 32 ºC	0	0.36 (210)	0.39 (45)	0.28 (34)	0.38 (131)
	<33	0.34 (114)	0.40 (66)	0.26 (23)	0.32 (25)
	33—66	0.36 (61)	0.43 (25)	0.31 (25)	0.34 (11)
	>67	0.28 (44)	0.35 (25)	0.22 (17)	0.25 (2)
	1	0.25 (60) *	0.25 (22	0.26 (35)	0.19 (3)
Precipitation in growing season > 250 mm	<33	0.29 (80)	0.33 (31)	0.28 (46)	0.14 (3)
	33—66	0.32 (225)	0.39 (109)	0.25 (66)	0.32 (50)
	>67	0.32 (67)	0.33 (25)	0.19 (7)	0.34 (35)
	1	0.40 (117) *	0.37 (18)	0.34 (15)	0.41 (84) *
Precipitation (adjusted for irrigation) in growing season > 250 mm	0	**0.32 (119)**	0.30 (24)	0.30 (49)	0.35 (46)
	<33	**0.25 (39)**	0.32 (20)	0.24 (19)	0.00 (0)
	33—66	**0.34 (172)**	0.42 (101)	0.24 (44)	0.31 (27)
	>67	**0.32 (58)**	0.34 (24)	0.22 (7)	0.34 (27)
	1	**0.39 (101)**	0.32 (14)	0.36 (15)	0.41 (72) *
Sample Total		1487	500	505	481

* p > 0.05**, p > 0.10**, data format of each cell: prevalence (sample total)

zones, both precipitation variables are significantly associated with an increase in the prevalence of stunting in the highland areas.

Table 3 describes the prevalence of stunted children by agroecological zone and the number of months during the growing season when temperature maximums exceed 32ºC during each phase of the first 1,000 days of development. There were no significant models for the temperature maximums when considering each of the different exposure periods during the first 1,000 days, unlike the overall temperature maximum variable described in the previous table.

An increase in the number of months receiving greater than 250 mm of precipitation

Table 3. Linkages between the prevalence of stunted children by agroecological zone and growing season temperature maximums during the first 1,000 days of development.

	Development Phase	Number of Months	Overall	Dryland	Flood	Highland
Growing Season Temperature Maximum	Pregnancy	0	**0.29 (338)**	0.32 (102)	0.26 (68)	0.29 (168)
		1	**0.32 (96)**	0.38 (53)	0.23 (22)	0.30 (21)
		2	**0.23 (41)**	0.26 (19)	0.20 (18)	0.24 (4)
		3	**0.24 (92)**	0.27 (41)	0.22 (46)	0.25 (5)
		Overall	**0.28 (567)**	0.31 (215)	0.23 (154)	0.29 (198)
	0–6 months	0	0.28 (332)	0.31 (107)	0.23 (59)	0.29 (166)
		1	0.33 (91)	0.38 (46)	0.26 (23)	0.33 (22)
		2	0.27 (50)	0.26 (21)	0.25 (22)	0.37 (7)
		3	0.24 (94)	0.29 (41)	0.22 (50)	0.15 (3)
		Overall	0.28 (567)	0.31 (215)	0.23 (154)	0.29 (198)
	7–12 months	0	**0.31 (327)**	0.36 (111)	0.26 (59)	**0.31 (157)**
		1	**0.35 (75)**	0.35 (30)	0.28 (19)	**0.42 (26)**
		2	**0.29 (55)**	0.33 (28)	0.25 (22)	**0.29 (5)**
		3	**0.25 (96)**	0.30 (42)	0.24 (51)	**0.13 (3)**
		Overall	**0.30 (553)**	0.34 (211)	0.25 (151)	**0.31 (191)**
	13–24 months	0	0.35 (298)	0.40 (77)	0.26 (45)	0.37 (146)
		1	0.34 (72)	0.36 (35)	0.29 (19)	0.36 (18)
		2	0.30 (37)	0.40 (26)	0.19 (8)	0.20 (3)
		3	0.28 (112)	0.32 (45)	0.27 (62)	0.20 (5)
		Overall	0.33 (489)	0.37 (183)	0.27 (134)	0.36 (172)

* $p > 0.05$, **$p > 0.10$**, data format of each cell: prevalence (sample total)

during the growing season is associated with an increase in the prevalence of stunting, as shown in Table 4. It was found that an increase in growing season precipitation during the child's first 1,000 days of development is significantly associated with an increase in stunting. In other words, areas that receive high levels of precipitation during the growing season have a higher prevalence of stunted children, except during the pregnancy phase. For zero to six months, the study area and the agroecological zone models yield significant results. This is the only development phase with an increase in the prevalence of stunting with an increase in the months above optimum growing conditions. Children through the study area experienced a 36 percent prevalence of stunting compared to the expected 28 percent during the zero to six-month development phase. When considering the specific

Table 4. Linkages between precipitation and the prevalence of stunted children by agroecological zone during the first 1,000 days of development.

	Development Phase	**Number of Months**	**Overall**	**Dryland**	**Flood**	**Highland**
Growing Season Precipitation	Pregnancy	1	0.27 (296)	0.33 (151)	0.23 (122)	0.22 (23)
		2	0.27 (54)	0.39 (20)	0.23 (7)	0.23 (27)
		3	0.29 (217)	0.25 (44)	0.25 (25)	0.32 (148)
		Overall	0.28 (567)	0.31 (215)	0.23 (154)	0.29 (198)*
	0–6 months	0	0.16 (63)	0.20 (27)	0.17 (31)	0.08 (5)
		1	0.29 (250)	0.35 (106)	0.23 (78)	0.32 (66)
		2	0.22 (48)	0.27 (17)	0.23 (8)	0.20 (23)
		3	0.36 (206)	0.36 (65)	0.37 (37)	0.34 (104)
		Overall	0.28 (567)*	0.31 (215)*	0.23 (154)*	0.29 (198)*
	7–12 months	0	0.25 (94)	0.31 (46)	0.24 (41)	0.13 (7)
		1	0.29 (211)	0.34 (92)	0.24 (72)	0.29 (47)
		2	0.26 (53)	0.29 (16)	0.28 (11)	0.24 (26)
		3	0.37 (195)	0.39 (57)	0.30 (27)	0.39 (111)
		Overall	0.30 (553)*	0.34 (211)	0.25 (151)	0.31 (191)*
	13–24 months	0	**0.32 (103)**	0.38 (53)	0.27 (38)	0.28 (12)
		1	**0.30 (155)**	0.34 (63)	0.26 (61)	0.32 (31)
		2	**0.31 (45)**	0.28 (9)	0.35 (12)	0.31 (24)
		3	**0.37 (186)**	0.40 (58)	0.26 (23)	0.40 (105)
		Overall	**0.33 (489)**	0.37 (183)	0.27 (134)	0.36 (172)

* p > 0.05**, p > 0.10**, data format of each cell: prevalence (sample total)

agroecological zones, this gap can be even more drastic. The difference between the pregnancy variable and other development phases for growing season precipitation is that there were no exposures during pregnancy where all months where within optimum growing conditions. Because of this, the variable will not be used in the multiple regression for stunting.

As expected, the patterns between the development phases for precipitation adjusted for irrigation are similar to those in the previous table. Table 5 shows the similarities occur for zero to six months with a significant increase in the odds of stunting with an increase in the months above growing optimum. This precipitation variable allows for a comparison between children with all months within and those with all months outside

Table 5. Linkages between precipitation adjusting for irrigation and the prevalence of stunted children by agroecological zone during the first 1,000 days of development.

	Development Phase	**Number of Months**	**Overall**	**Dryland**	**Flood**	**Highland**
Growing Season Precipitation Adjusted for Irrigation	Pregnancy	0	0.27 (136)	0.26 (27)	0.25 (54)	0.29 (55)
		1	0.28 (214)	0.35 (129)	0.21 (70)	0.20 (15)
		2	0.30 (37)	0.39 (20)	0.23 (7)	0.24 (10)
		3	0.29 (180)	0.24 (39)	0.26 (23)	0.31 (118)
		Overall	0.28 (567)	0.31 (215)*	0.23 (154)	0.29 (198)
	0–6 months	0	0.24 (178)	0.22 (49)	0.22 (69)	0.27 (60)
		1	0.29 (173)	0.37 (91)	0.18 (41)	0.33 (41)
		2	0.19 (33)	0.28 (17)	0.21 (7)	0.12 (9)
		3	0.36 (183)	0.36 (58)	0.40 (37)	0.34 (88)
		Overall	0.29 (567)*	0.31 (215)*	0.23 (154)*	0.29 (198)*
	7–12 months	0	**0.28 (196)**	0.28 (63)	0.26 (76)	0.29 (57)
		1	**0.29 (149)**	0.37 (80)	0.20 (38)	0.30 (31)
		2	**0.23 (37)**	0.32 (16)	0.28 (10)	0.15 (11)
		3	**0.37 (171)**	0.39 (52)	0.32 (27)	0.39 (92)
		Overall	**0.30 (553)**	0.34 (211)	0.25 (151)	0.31 (191)*
	13–24 months	0	0.32 (188)	0.38 (68)	0.28 (70)	0.33 (50)
		1	0.30 (102)	0.37 (54)	0.22 (29)	0.32 (19)
		2	0.30 (33)	0.27 (8)	0.38 (12)	0.27 (13)
		3	0.38 (166)	0.39 (53)	0.26 (23)	0.41 (90)
		Overall	0.33 (489)	0.37 (183)	0.27 (134)	0.36 (172)

* $p > 0.05$, **$p > 0.10$**, data format of each cell: prevalence (sample total)

of the optimum growing conditions. For children throughout the Dry Zone, the highest prevalence of stunted children residing in dryland areas. There are differing patterns in the development phases between the different agroecological zones. One particular difference between the precipitation variable and the variable adjusted for irrigations is the changes in the categories. The correction for irrigation allows for a comparison between the development phases with categories ranging low risk (0) to very high risk (4).

The results for urban area, area equipped for irrigation, total cultivated land, and the cultivated land equipped with irrigation are described in Table 6. No significant results were observed when comparing these variables to the outcome of stunting. Although the results are not significant, the areas equipped for irrigation are characteristic of the agroecological zones with the highest access residing in the flood plains and the lowest in the highlands.

Table 6. Linkages between the prevalence of stunted children and land cover classifications

Environmental Risk Factor	**Percent of Area**	**Overall**	**Dryland**	**Flood**	**Highland**
		0.28 (567)	0.31 (215)	0.23 (154)	0.29 (198)
Urban area	<5	0.29 (347)	0.31 (135)	0.21 (30)	0.29 (182)
	5-60	0.27 (220)	0.32 (80)	0.24 (124)	0.29 (16)
Area equipped for irrigation	0	0.29 (21)	0.00 (0)	0.23 (3)	0.31 (18)
	<20	0.28 (410)	0.32 (178)	0.23 (76)	0.28 (156)
	20–60	0.27 (136)	0.29 (37)	0.24 (75)	0.33 (24)
Total cultivated land	<25	0.27 (131)	0.39 (5)	0.29 (4)	0.27 (122)
	25–49	0.30 (125)	0.31 (65)	0.20 (10)	0.33 (50)
	50–74	0.28 (225)	0.32 (99)	0.25 (108)	0.32 (18)
	>75	0.25 (86)	0.31 (46)	0.20 (32)	0.29 (8)
Cultivated land equipped for irrigation	<25	0.29 (382)	0.32 (173)	0.23 (77)	0.30 (132)
	25–49	0.26 (76)	0.40 (24)	0.21 (28)	0.26 (24)
	50–74	0.26 (73)	0.26 (14)	0.24 (42)	0.31 (17)
	>75	0.27 (36)	0.16 (4)	0.47 (7)	0.27 (25)
Sample Total		2036	687	661	688

* $p > 0.05$**, p > 0.10**, data format of each cell: prevalence (sample total)

Underweight

The prevalence of underweight shows a pattern similar to stunting within the Dry Zone and between the agroecological zones. However, the underweight prevalence is higher than the prevalence of stunting. Table 7 describes the temperature and precipitation variables for the 1,000-day development period. Opposed to the stunting, all models containing underweight produced significant results with all three variables within the study area. However, similar to the stunting models, the agroecological zones indicate little differences between the agroecological zones.

Table 8 focuses on the outcome of underweight with an increase in the number of months above the optimum growing temperature maximum for each of the development phases during the first 1,000 days. Each phase of development was significant for the entire Dry Zone. This significant outcome for all models is different from the results found for the outcome of stunting. Agroecological zones have a significant impact on the earlier

Table 7. Linkages between precipitation and temperature during the first 1,000 days of development and the outcome of underweight

Environmental Risk Factor	**Percent of Months**	**Overall**	**Dryland**	**Flood**	**Highland**
		0.33 (485)	0.38 (191)	0.26 (129)	0.34 (165)
Temperature in Growing Season > 32 ºC	0	0.33 (195)	0.39 (45)	0.21 (26)	0.36 (124)
	<33	0.38 (126)	0.43 (71)	0.32 (29)	0.33 (26)
	33–66	0.37 (63)	0.45 (26)	0.32 (26)	0.34 (11)
	>67	0.30 (47)	0.40 (29)	0.21 (16)	0.25 (2)
	1	0.23 (54)*	0.23 (20)*	0.24 (32)	0.13 (2)
Precipitation in Growing Season > 250 mm	<33	0.24 (66)	0.28 (27)	0.23 (37)	**0.09 (2)**
	33–66	0.34 (235)	0.40 (113)	0.26 (67)	**0.36 (55)**
	>67	0.36 (77)	0.41 (31)	0.36 (13)	**0.32 (33)**
	1	0.36 (107)*	0.41 (20)	0.27 (12)	**0.37 (75)**
Precipitation (Adjusted for Irrigation) in Growing Season > 250 mm	0	0.31 (115)	0.33 (26)	0.27 (44)	0.35 (45)
	<33	0.21 (32)	0.25 (16)	0.19 (15)	0.09 (1)
	33–66	0.35 (180)	0.42 (101)	0.26 (47)	0.37 (32)
	>67	0.37 (66)	0.43 (30)	0.38 (12)	0.30 (24)
	1	0.35 (92)*	0.41 (18)	0.26 (11)	0.36 (63)
Sample Total		1487	500	505	482

*p > 0.05**, p > 0.10**, data format of each cell: prevalence (sample total)

Table 8. Linkages between the prevalence of underweight children by agroecological zone and temperature maximums during the first 1,000 days of development.

	Development Phase	**Number Of Months**	**Overall**	**Dryland**	**Flood**	**Highland**
Growing Season Temperature Maximum	Pregnancy	0	0.27 (319)	0.30 (98)	0.20 (54)	0.29 (167)
		1	0.36 (110)	0.42 (59)	0.33 (31)	0.29 (20)
		2	0.24 (43)	0.27 (20)	0.21 (19)	0.24 (4)
		3	0.22 (85)	0.27 (40)	0.19 (41)	0.20 (4)
		Overall	0.27 (557)*	0.32 (217)*	0.22 (145)*	0.28 (195)
	0–6 months	0	0.27 (324	0.31 (106)	0.20 (52)	0.29 (166)
		1	0.35 (98)	0.39 (47)	0.35 (31)	0.30 (20)
		2	0.25 (46)	0.26 (21)	0.21 (18)	0.37 (7)
		3	0.23 (89)	0.30 (43)	0.20 (44)	0.10 (2)
		Overall	0.27 (557)*	0.32 (217)	0.22 (145)*	0.28 (195)
	7–12 months	0	0.30 (317)	0.36 (112)	0.24 (53)	0.30 (152)
		1	0.35 (76)	0.35 (30)	0.35 (24)	0.36 (22)
		2	0.28 (53)	0.34 (29)	0.21 (18)	0.35 (6)
		3	0.24 (91)	0.30 (42)	0.22 (47)	0.09 (2)
		Overall	0.29 (537)*	0.34 (213)	0.24 (142)	0.30 (182)
	13–24 months	0	0.34 (258)	0.41 (79)	0.24 (41)	0.35 (138)
		1	0.37 (79)	0.40 (39)	0.34 (22)	0.36 (18)
		2	0.34 (42)	0.42 (27)	0.21 (9)	0.40 (6)
		3	0.27 (106)	0.32 (46)	0.25 (57)	0.12 (3)
		Overall	0.33 (485)*	0.38 (191)	0.26 (129)	0.34 (165)

* $p > 0.05$**, $p > 0.10$**, data format of each cell: prevalence (sample total)

phases of development, particularly pregnancy. On average, the highest prevalence of underweight occurs when one month during the growing season exceeds the growing optimum temperature maximums. However, as the month above the optimum continues to increase, there is a significant decrease in the outcome of underweight.

The precipitation variable and the precipitation adjusted for irrigation have the same significant models for the overall study area and between the agroecological models. Because of this, only the results of precipitation adjusted for irrigation were displayed in Table 9. Results of the association between precipitation variables and the outcome of undernutrition are not shown here but are available upon request. This pattern is also true for the outcome of stunting when compared to both precipitation variables.

Table 9. Linkages between precipitation adjusting for irrigation and the prevalence of underweight children during the first 1,000 days of development.

	Development Phase	**Number Of Months**	**Overall**	**Dryland**	**Flood**	**Highland**
Growing Season Precipitation Adjusted for Irrigation	Pregnancy	0	0.26 (133)	0.26 (28)	0.23 (50)	0.29 (55)
		1	0.27 (205)	0.32 (117)	0.20 (65)	0.30 (23)
		2	0.32 (39)	0.35 (18)	0.23 (7)	0.33 (14)
		3	0.29 (180)	0.34 (54)	0.26 (23)	0.27 (103)
		Overall	0.27 (557)	0.32 (217)	0.22 (145)	0.28 (195)
	1–6 months	0	0.22 (169)	0.20 (43)	0.20 (62)	0.28 (64)
		1	0.31 (186)	0.39 (95)	0.20 (44)	0.38 (47)
		2	0.22 (38)	0.33 (20)	0.18 (6)	0.16 (12)
		3	0.32 (164)	0.36 (59)	0.40 (33)	0.28 (72)
		Overall	0.27 (557)*	0.32 (217)*	0.22 (145)*	0.28 (195)*
	7–12 months	0	0.26 (182)	0.25 (56)	0.24 (68)	0.30 (58)
		1	0.31 (157)	0.40 (87)	0.20 (37)	0.32 (33)
		2	0.20 (31)	0.32 (16)	0.25 (9)	0.08 (6)
		3	0.37 (167)	0.40 (54)	0.33 (28)	0.36 (85)
		Overall	0.29 (537)*	0.34 (213)*	0.24 (142)	0.30 (182)*
	13–24 months	0	0.29 (171)	0.32 (61)	0.24 (59)	0.33 (51)
		1	0.33 (113)	0.40 (58)	0.25 (34)	0.36 (21)
		2	0.30 (33)	0.33 (10)	0.44 (14)	0.18 (9)
		3	0.38 (168)	0.46 (62)	0.25 (22)	0.38 (84)
		Overall	0.33 (485)*	0.38 (191)	0.26 (129)	0.34 (165)

* $p > 0.05$**, $p > 0.10$**, data format of each cell: prevalence (sample total)

The remaining land cover variables are addressed in Table 10, with only one model, total cultivated land, producing significant results. The overall study area is associated with a decrease in the outcome of underweight as total cultivated land increases, whereas the highland model suggests a significant increase in underweight as total cultivated land increases.

We did not implement similar analyzes on wasting. Wasting is a result of short-term restrictions in food security, which are difficult to assess with the types of data available to this study. In addition, the sample size obtained in the health survey results in small numbers in several areas.

Table 10. Linkages between the prevalence of underweight children by land cover classifications

Environmental Risk Factor	**Percent**	**Overall**	**Dryland**	**Flood**	**Highland**
		0.27 (557)	0.32 (217)	0.22 (145)	0.28 (195)
Urban area	<5	0.29 (346)	0.32 (139)	0.21 (30)	0.28 (177)
	5–60	0.26 (211)	0.31 (78)	0.22 (115)	0.33 (18)
Area equipped for irrigation	0	0.31 (205)	0.37 (68)	0.32 (33)	0.28 (104)
	<20	0.26 (227)	0.30 (113)	0.20 (48)	0.27 (66)
	20–60	0.25 (125)	0.29 (36)	0.21 (64)	0.35 (25)
Total cultivated land	<25	0.24 (116)	0.23 (3)	0.14 (2)	0.25 (111)
	25–49	0.33 (136)	0.35 (75)	0.25 (12)	0.31 (49)
	50–74	0.27 (219)	0.28 (88)	0.24 (105)	0.46 (26)
	>75	0.25 (86)*	0.34 (51)	0.16 (26)	0.32 (9)*
Cultivated land equipped for irrigation	<25	0.27 (381)	0.33 (178)	0.23 (79)	0.28 (124)
	25–49	0.26 (76)	0.35 (21)	0.17 (23)	0.34 (32)
	50–74	0.24 (67)	0.24 (13)	0.22 (38)	0.29 (16)
	>75	0.25 (33)	0.20 (5)	0.33 (5)	0.25 (23)
Sample Total		2036	687	661	688

* $p > 0.05$**, $p > 0.10$**, data format of each cell: prevalence (sample total)

Multiple Regression

Stunting and underweight are different nutrition measures, and separate models were created to describe the linkages between the outcome of undernutrition and the environmental risk factors. Variables used in the multiple regression were those that were significant in the contingency tables. However, not all environmental risk factors were included in the multiple regression models. Temperature maximums were omitted from the multiple regressions because of limited variability throughout the Dry Zone. Irrigated area was not used in the model, but rather accounted for in the precipitation variable. Insignificant results warranted the exclusion of urban area for both models. Individual multiple regression models for each agroecological zone were not created due to a concern for small sample sizes.

Precipitation adjusted for irrigation was placed in a multiple regression with age and gender shown in Table 11. The results from the multiple regression model developed

Table 11. Odds ratios from the multiple regression models used to analyze precipitation and the outcome of stunting, adjusting for age and gender, in the Dry Zone

Environmental Risk Factors	**Overall Dry Zone**			
	Preg.	**0–6**	**7–12**	**13–24**
Constant	1.11*	1.13*	1.18*	1.31*
Months 12–24	1.17*	1.14*	1.11*	-
Months 24–35	1.26*	1.23*	1.19*	1.08*
Months 36–48	1.27*	1.26*	1.21*	1.08
Months 48–60	1.26*	1.25*	1.21*	1.09*
Gender: Female	0.99	0.99	0.99	1.00
Precipitation: 1 month	1.01	0.98	0.97	0.96
Precipitation: 2 months	1.04	0.98	0.97	0.98
Precipitation: 3 months	1.03	1.05	1.05	1.03
Observations	2,036	2,036	1,828	1,487

* $p > 0.05$, **$p > 0.10$**, data format of each cell: prevalence (sample total)

for stunting suggest further research is needed to understand the potential environmental risk factors driving the outcome of stunting. Although the results are insignificant, an increase in stunting occurs with an increase in the number of months during the growing season when rainfall exceeded optimum growing conditions. The highest odds of stunting occurred when the child was between zero to six months and seven to twelve months. The time period is the most critical for successful complimentary feeding. This model did not meet the criteria need to create a weighted overlay.

Underweight was analyzed for linkages using precipitation adjusted for irrigation and total cultivated land in the multiple regression model. Both of the environmental risk factors included in this model yield significant results shown in Table 12. As the number of months exceed the optimum growing rainfall the odds of underweight increased by 7 percent in the final two stages of development. Total cultivated area is associated with an increase in the odds of underweight as the percent of cultivated decreases. In addition, as the age of the child increases, the odds of underweight increases with each development

Table 12. Odds ratios from the multiple regression models used to analyze precipitation and the outcome of underweight, adjusting for age and gender, in the Dry Zone.

Environmental Risk Factors	**Overall Dry Zone**			
	Preg.	**0-6**	**7-12**	**13-24**
Constant	1.07*	1.08*	1.10*	1.18*
Months 12-24	1.12*	1.10*	1.08*	-
Months 24-35	1.22*	1.20*	1.16*	**1.07**
Months 36-48	1.27*	1.26*	1.22*	1.09*
Months 48-60	1.32*	1.31*	1.28*	1.16*
Gender: Female	0.99	1.00	1.01	1.02
Precipitation: 1 month	1.00	1.00	0.98	0.99
Precipitation: 2 months	1.07	1.05	0.97	1.02
Precipitation: 3 months	1.04	1.05	1.07*	1.07*
Total cultivated 25-49%	1.10	1.10*	1.12*	1.15*
Total cultivated 50-74%	1.04*	1.04*	**1.05**	**1.06**
Total cultivated 75-100%	1.01	1.01	1.03	1.02
Observations	2,036	2,036	1,828	1,487

* p > 0.05**, p > 0.10**, data format of each cell: prevalence (sample total)

phase the child experiences low access to cultivated land. In the final development phase, children residing in areas with 25 to 50 percent total cultivated land experienced a 15 percent increase in the odds of underweight. Both significant environmental risk factors met the criteria for a weighted overlay. Results are described further in the following section.

Weighted Overlay

The weighted overlay created to visualize the annual risk in underweight is shown in Figure 8. The multiple regression for underweight suggests that both precipitation adjusted for irrigation and cultivated area were significantly associated with an increase in underweight. Therefore, growing season precipitation adjusted for irrigation and total cultivated areas were overlaid to produce an annual visualization of undernutrition risk. Influence for each variable was set at 60 percent and 40 percent influence for total

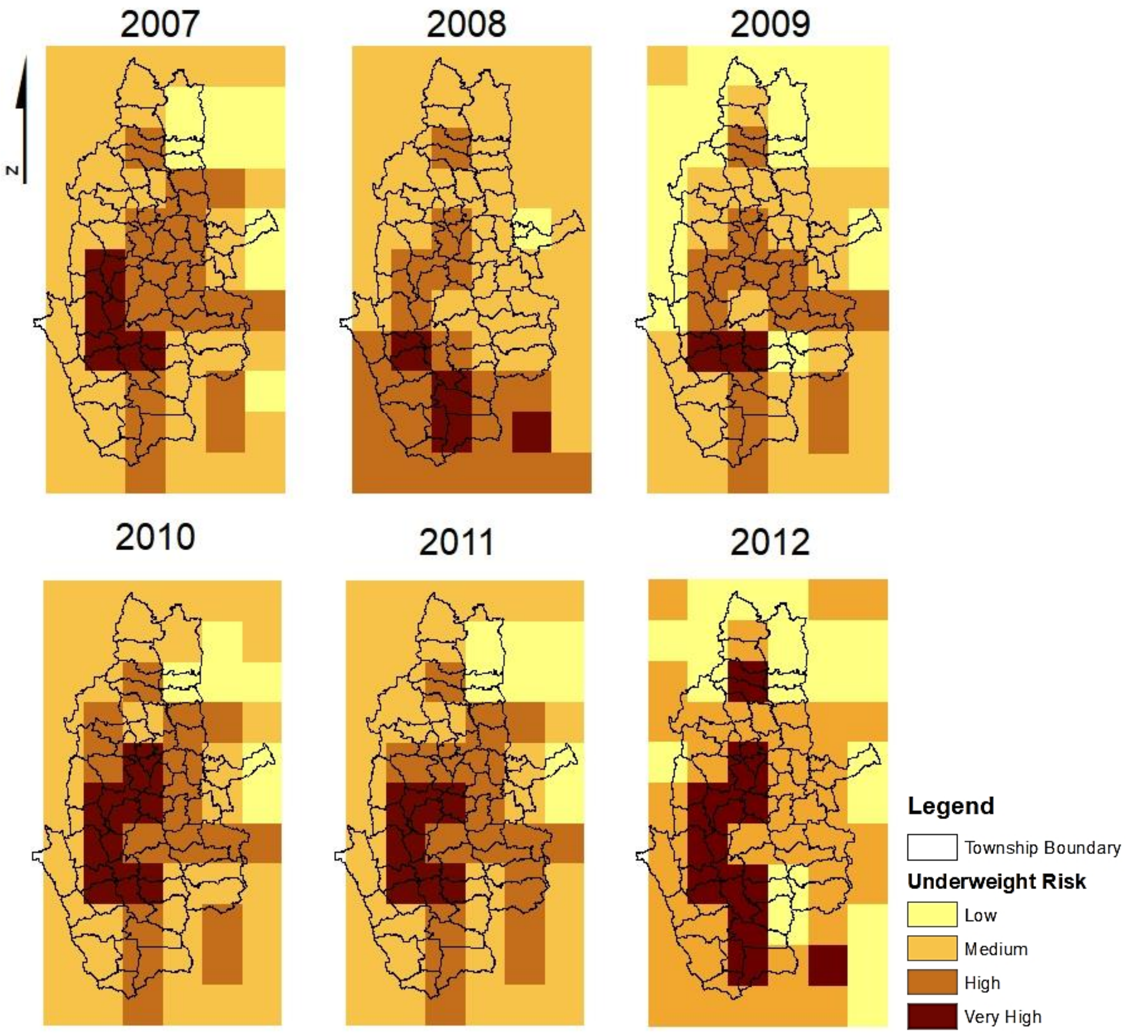

Figure 8. Visualization underweight risk in the Dry Zone of Myanmar, 2007-2012.

cultivated area and precipitation adjusted for irrigation. Cultivated received a higher overall influence in the weighted overlay because of the higher odds ratios in the multiple regression.

Results from the visualization of risk have similar characteristics to the results from the cluster analysis. There is a distinct pattern of annual high-risk to the southwest and a low-risk area in the northwest. This would suggest that the geographic location does influence the outcome of undernutrition during the first 1,000 days of development.

DISCUSSION

Inadequate short-term nutrition resulting from food insecurity will restrict linear growth in developing children, particularly in children experiencing multiple events of inadequate nutrients during the earliest stages of development. Although undernutrition is a public health issue that impacts children globally, there is a lack of understanding on the spatial distribution and environmental risk factors of undernutrition.

In this study, the amount of growing season precipitation and the access to total cultivated land during a child's first 1,000 days were found to be significant drivers of underweight. In other words, children residing in areas that receive high amounts of precipitation during the growing season have a higher risk of experiencing underweight before the age of two. In the Dry Zone, areas receiving rainfall exceeding optimum growing conditions for all three months in the growing season are more likely to experience underweight.

Climate change will likely increase the prevalence of undernutrition globally by 2050 (Nelson et al. 2009). Understanding the variability environmental risk factors have on agroecological conditions is important because farming practices are likely to alter with future climate conditions (Rosegrant et al. 2000). Shrestha, Thin, and Deb (2014) project an increase in rainfed paddy yield under multiple climate scenarios in 2020, 2050, and 2080. This increase in production suggests food security in Myanmar should improve; however, high amounts of precipitation can cause environmental degradation. An example of impacts from high precipitation would be soil erosion and flooding, which threatens food security in areas with inadequate adaption strategies (Shrestha, Thin, and Deb 2014). Although increases in precipitation may increase food security in some areas, it may negatively impact the outcome of undernutrition in other areas.

An increase in the prevalence of underweight occurs in the highland regions with an increase in the prevalence of cultivated land. This is different from the overall pattern in the Dry Zone. Potential causes for this could be soil degradation or conservation methods practices by the locals. High cultivated land maintained with limited conservation practices could contribute to a reduction in yield and ultimately an increase in the outcome of undernutrition. To account for this problem, a weighted overlay for each of the agroecological zones could account for improved accuracy in the visualization tool.

The rate of stunting and underweight within the Dry Zone increases with age. This same trend has been identified in a study in Malawi, Africa where undernutrition was examined in three-month intervals during the first year of birth. The trend in the prevalence of undernutrition increased from 27 percent at three months to 63 percent of the sampled children at nine months (Espo et al. 2002).

The use of improved data sources for the annual changes in land use and land cover could allow for an assessment within the development phases for each nutrition outcome, specifically, improved data sources with a longer temporal resolution. To improve the accuracy of temperature within the analysis and visualization tool, the number of days above optimum growing conditions could allow for comparisons between individual exposures. Monthly average is a limiting temporal scale reducing the ability to accurately compare individual exposures. Larger sample sizes would allow for an evaluation of risk within the different agroecological zone. This would improve the accuracy of the visualization tool by focusing on specific risks for areas with similar geographic characteristics. Further analysis is needed to understand the linkages between environmental risk factors and wasting in children.

This research exposes areas that are most likely to experience underweight. Using this technique, a visualization tool could be replicated to assess different time periods and health assessments globally. Education and infrastructure improvements are recommended to mitigated the losses that result from land degradation (Tun, Shrestha, and Datta 2015) This model provides a need-based assessment to assist in the distribution of resources, such as food aid and healthcare. Furthermore, the findings suggest that there is a need for a more in-depth evaluation of the drivers of undernutrition, particularly wasting, to aid in the reduction of at-risk child population.

BIBLIOGRAPHY

Battisti, David. S., and Rosamond L. Naylor. 2009. "Historical Warnings of Future Food Insecurity with Unprecedented Seasonal Heat." *Science* 323 (January): 240–44.

Black, Robert E., Harold Alderman, Zulfiqar A. Bhutta, Stuart Gillespie, Lawrence Haddad, Susan Horton, Anna Lartey, et al. 2013. "Maternal and Child Nutrition: Building Momentum for Impact." *The Lancet*. doi:10.1016/S0140-6736(13)60988-5.

Black, Robert E., Lindsay H. Allen, Zulfiqar A. Bhutta, Laura E. Caulfield, Mercedes de Onis, Majid Ezzati, Colin Mathers, and Juan Rivera. 2008. "Maternal and Child Undernutrition: Global and Regional Exposures and Health Consequences." *The Lancet* 371 (9608): 243–60. doi:10.1016/S0140-6736(07)61690-0.

Black, Robert E., Cesar G. Victora, Susan P. Walker, Zulfiqar A. Bhutta, Parul Christian, Mercedes De Onis, Majid Ezzati, et al. 2013. "Maternal and Child Undernutrition and Overweight in Low-Income and Middle-Income Countries." *The Lancet* 382 (9890): 427–51. doi:10.1016/S0140-6736(13)60937-X.

Brown, Molly E., Kathryn Grace, Gerald Shively, Kiersten B. Johnson, and Mark Carroll. 2014. "Using Satellite Remote Sensing and Household Survey Data to Assess Human Health and Nutrition Response to Environmental Change." *Population and Environment* 36 (1): 48–72. doi:10.1007/s11111-013-0201-0.

Caulfield, Laura E, Stephanie a Richard, Juan a Rivera, Philip Musgrove, and Robert E Black. 2006. "Stunting , Wasting , and Micronutrient Deficiency Disorders." *Disease Control Priorities in Developing Countries*, 551–67.

Davis, William W., Luke C. Mullany, Eh Kalu Shwe Oo, Adam K. Richards, Vincent Iacopino, and Chris Beyrer. 2015. "Health and Human Rights in Karen State, Eastern Myanmar." *PLoS ONE* 10 (8): 1–13. doi:10.1371/journal.pone.0133822.

Dawson, Terence P, Anita H Perryman, and Tom M Osborne. 2016. "Modelling Impacts of Climate Change on Global Food Security." *Climatic Change* 134 (3): 429–40. doi:10.1007/s10584-014-1277-y.

Espo, M, T Kulmala, K Maleta, T Cullinan, M L Salin, and P Ashorn. 2002. "Determinants of Linear Growth and Predictors of Severe Stunting during Infancy in Rural Malawi." *Acta Paediatrica* 91 (12): 1364–70. doi:10.1111/j.1651-2227.2002.tb02835.x.

ESRI (Environmental Systems Research Institute). ArcGIS. 2015; www.esri.com

FAO. 1996. “Rome Declaration on World Food Security and World Food Summit Plan of Action World Food Summit.”

Getis, Arthur, and J. K. Ord. 1992. “The Analysis of Spatial Association by Use of Distance Statistics.” *Geographical Analysis* 24 (3): 189–206. doi:10.1111/j.1538-4632.1992.tb00261.x.

Grace, Kathryn, Frank Davenport, Chris Funk, and Amy M. Lerner. 2012. “Child Malnutrition and Climate in Sub-Saharan Africa: An Analysis of Recent Trends in Kenya.” *Applied Geography* 35 (1–2): 405–13. doi:10.1016/j.apgeog.2012.06.017.

GRiSP (Global Rice Science Partnership). 2013. *Rice Almanac* doi:10.1093/aob/mcg189.

Harris, I., P. D. Jones, T. J. Osborn, and D. H. Lister. 2014. “Updated High-Resolution Grids of Monthly Climatic Observations - the CRU TS3.10 Dataset.” *International Journal of Climatology* 34 (3): 623–42. doi:10.1002/joc.3711.

Hatfield, Jerry L., and John H. Prueger. 2015. “Temperature Extremes: Effect on Plant Growth and Development.” *Weather and Climate Extremes* 10: 4–10. doi:10.1016/j.wace.2015.08.001.

Kreft, Sven, David Eckstein, C Kerestan, and U Hagen. 2015. *Global Climate Risk Index 2015: Who Suffers Most from Extreme Weather Events? Weather-Related Loss Events in 2013 and 1994 to 2013*. doi:978-3-943704-04-4.

Latham, Michael C., and Food and Agriculture Organization of the United Nations. 1997. *Human Nutrition in the Developing World*. https://books.google.com/books?hl=en&lr=&id=diGLEXZEGh8C&oi=fnd&pg=PR3&dq=Latham+1997&ots=zmznkYB0v9&sig=MEriF7uD0BT_rWGgJTKW3CTRsHwg.

Lloyd, Simon J, Sari Kovats, and Zaid Chalabi. 2011. “Climate Change, Crop Yields, and Undernutrition: Development of a Model to Quantify the Impact of Climate Scenarios on Child Undernutrtion” *Environmental Health Perspectives* 119 (12): 1817–23.

Matsuda, Masahiko. 2013. “Upland Framing Systems Coping with Uncertain Rainfall in the Central Dry Zone of Myanmar: How Stable Is Indigenous Multiple Cropping under Semi-Arid Conditions?” *Human Ecology* 41 (6): 927–36.

Morris, Saul S., Bruce Cogill, and Ricardo Uauy. 2008. “Effective International Action against Undernutrition: Why Has It Proven so Difficult and What Can Be Done to Accelerate Progress?” *The Lancet* 371 (9612): 608–21. doi:10.1016/S0140-6736(07)61695-X.

Nachtergaele, F., H. van Velthuizen, L. Verelst, N.H. Batjes, K. Dijkshoorn, V.W.P. van Engelen, G. Fischer, A. Jones, and L. Montanarela. 2010. "The Harmonized World Soil Database." *Proceedings of the 19th World Congress of Soil Science, Soil Solutions for a Changing World, Brisbane, Australia, 1-6 August 2010*, 34–37. doi:3123.

Nelson, Gerald C, Mark W Rosegrant, Jawoo Koo, Richard Robertson, Timothy Sulser, Tingju Zhu, Claudia Ringler, et al. 2009. "REPORT Impact on Agriculture and Costs of Adaptation." *Food Policy* 6 (September): 30. doi:10.2499/089629535.

Ord, J. K., and Arthur Getis. 1995. "Local Spatial Autocorrelation Statistics: Distributional Issues and an Application." *Geographical Analysis* 27 (4): 286–306. doi:10.1111/j.1538-4632.1995.tb00912.x.

Qayum, Abdul, Rakesh Arya, Pawan Kumar, and Andrew M Lynn. 2015. "Socio-Economic, Epidemiological and Geographic Features Based on GIS-Integrated Mapping to Identify Malarial Hotspots." *Malaria Journal* 14 (1): 192. doi:10.1186/s12936-015-0685-4.

R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Rosegrant, Mark W, Mandy Ewing, Gary Yohe, Ian Burton, Saleemul Huq, and Rowena Valmonte-santos. 2000. "Threats and Opportunities." *Practice Nursing* 108 (30): 12337–42. doi:10.1073/pnas.1017352108.

Seid, Ahmed, Endalamaw Gadisa, Teshome Tsegaw, Adugna Abera, Aklilu Teshome, Abate Mulugeta, Merce Herrero, et al. 2014. "Risk Map for Cutaneous Leishmaniasis in Ethiopia Based on Environmental Factors as Revealed by Geographical Information Systems and Statistics." *Geospatial Health* 8 (2): 377–87. doi:10.4081/gh.2014.27.

Shrestha, S., N. M M Thin, and P. Deb. 2014. "Assessment of Climate Change Impacts on Irrigation Water Requirement and Rice Yield for Ngamoeyeik Irrigation Project in Myanmar." *Journal of Water and Climate Change* 5 (3): 427–42. doi:10.2166/wcc.2014.114.

Sibson, Victoria. 2014. "A Nutrition and Food Security Assessment of the Dry Zone of Myanmar in June and July 2013 Save the Children , WFP and the Ministry of Livestock , Fisheries and Rural Development February 10th 2014," no. July 2013.

Siebert, Stefan, Verena Henrich, Karen Frenken, and Jacob Burke. 2013. "Global Map of Irrigation Areas Version 5." *University of Frankfurt (Main), Germany, and FAO, Rome, Italy.*, no. March 2013: 1–2. doi:10.13140/2.1.2660.6728.

Tun, Kyawt K.K., Rajendra P. Shrestha, and Avishek Datta. 2015. “Assessment of Land Degradation and Its Impact on Crop Production in the Dry Zone of Myanmar.” *International Journal of Sustainable Development & World Ecology* 22 (6): 533–44. doi:10.1080/13504509.2015.1091046.

Turi, Kedir N., Mary J. Christoph, and Diana S. Grigsby-Toussaint. 2013. “Spatial Distribution of Underweight, Overweight and Obesity among Women and Children: Results from the 2011 Uganda Demographic and Health Survey.” *International Journal of Environmental Research and Public Health* 10 (10): 4967–81. doi:10.3390/ijerph10104967.

UNCCD. 2000. “National Report on Implementation of United Nations Convention to Combat Desertification,” no. August.

UNICEF, and WHO The World Bank. 2014. “Levels and Trends in Child Malnutrition.” *Midwifery*, 4. doi:10.1016/S0266-6138(96)90067-4.

United Nations Development Programme. 2016. *Human Development Report 2016. United Nations Development Programme*. doi:eISBN: 978-92-1-060036-1.

WHO. 2013. “Essential Nutrition Actions.” *Essential Nutirittion Actions*, 144.