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Zimbabwe Economic Policy Analysis and Research Unit

Assessing the Multi-Dimensional Risk of Stunting Amongst Children Under Five Years in Zimbabwe

An Application of Machine Learning and Advanced Econometrics Techniques on Population Survey Datasets in Zimbabwe

Advanced policy-focused poverty analysis in Zimbabwe

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ABSTRACT

Background: Despite the commendable decline from a peak of 35% in 2005 (ZDHS 2005), child stunting in Zimbabwe remains high at 23.5% (MIC2019). The stunting prevalence nevertheless remains considerably lower than the sub-Saharan average of 34.1% in 2017 (WDI 2018). Despite the increasing knowledge on the patterns of stunting, a lot more is still to be established regarding the determinants of stunting in the Zimbabwe context. Global evidence and literature has provided a framework for understanding the determinants and pathways for child malnutrition.

The major causes of malnutrition include immediate causes that are anchored on the inadequate intake and utilisation of food with the right nutrient content and safe for human consumption; and the poor health status of individuals. Food insecurity, limited knowledge on diets, and sub-optimal child feeding, and care practices contribute to the inadequacy of quality food intake and utilisation. Poor health status is largely driven by limited access to health care services that have an impact on nutrition and a range of environmental factors. Although this understanding provides a sound basis for policy formulation, the extent to which these policies are translated to sound strategic actions depends to a large extent on a robust understanding of the role of the sub-components of these domains of influence and their interactions within the Zimbabwe context. This study sought to identify the key predictors of child stunting, quantify the multi-dimensional risk exposure amongst children in Zimbabwe as well as explore the interplay of stunting predictors and poverty.

Methods: In order to achieve the above, the study used Machine Learning and Artificial Intelligence techniques as the core tools of analysis. Specifically, the analysis focused on three interrelated steps: i) feature selection using Random Forest (RF) Model, ii) development of the Multi-dimensional Malnutrition Risk Index (MMRI) using selected features and iii) decomposition of the MMRI and exploratory analysis (including spatial mapping). This entailed initially selecting the most important predictor variables (feature selection) using the RF and Boruta Models, followed by using the selected features to compute a risk index, MMRI, based on a child's concurrent deprivations against these features and subsequently using the computed index scores in exploratory analysis with poverty measures.

Findings: The study reveals that child stunting in Zimbabwe is influenced by an interplay of a complex web of factors that align to the domains of health (status, behaviour, family planning and utilisation), biological, socio-economic, demographic and environmental factors as well as direct factors such as Feeding/Caregiving Practices. The extent to which children were exposed to the desired state for each of the selected predictor variables varies and the top most common areas of deprivations are related to breastfeeding practices, child care and maternal health care utilisation. In general, the analysis shows that the drivers of child malnutrition in Zimbabwe go beyond deficiencies in food consumption to include child care and feeding practices, health related behavioral practices, access to and utilisation of quality health care, socio-economic determinants as well as poverty induced inequities. The multiple concurrent exposure to deprivations with respect to the identified determinants (key predictors) is heterogenous in Zimbabwe.

INTRODUCTION

Key Messages

- Child malnutrition in Zimbabwe is driven by a range of factors that go beyond deficiencies in food consumption to include health related behavioral practices, access to and utilisation of quality health care, socio-economic determinants as well as poverty induced inequities. Multiple concurrent exposures to deprivations across these determinants heighten the risk of stunting amongst children.

- The programmatic response to the malnutrition burden should prioritize the continued provision of high impact nutrition interventions that aim to improve access and uptake of services noted to reduce stunting in children. Specific interventions have been noted for Zimbabwe, but these broadly align to the domains of the UNICEF Malnutrition Framework.

- The evidence supports adopting a sequenced geographical targeting approach for nutrition focused financing/investments and program implementation; that recognizes the current stunting burden with potential for scale-up in line with the varying intensity of stunting risk across the country. In that regard there is scope to strengthen the capacity of sub-regional structures.

- The multi-dimensional nature of the risks of stunting including the association with poverty underpins the need for a multi-sectoral response.

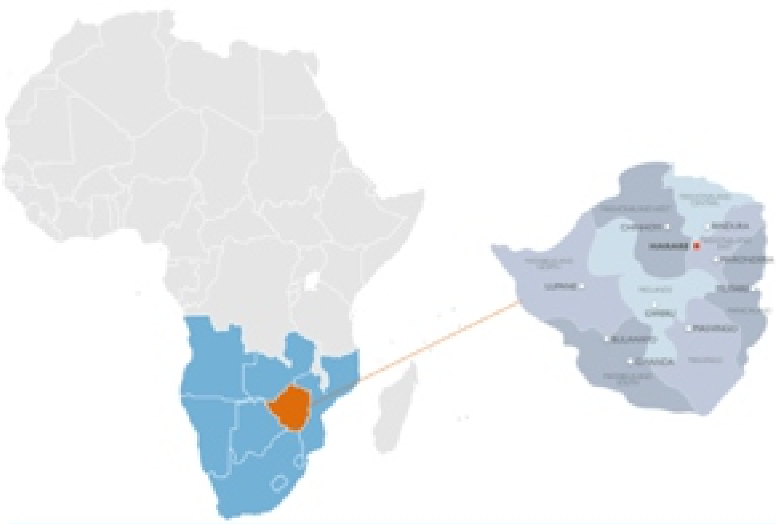
- Improving investments in nutrition specific interventions and efficiently allocating these in line with local needs provides a huge opportunity to accelerate the reduction in stunting prevalence. Strategically managing the allocation and use of resources across the programmatic component and the national multi-sectoral coordination is key.

- Advancements in technology, including use of Artificial Intelligence and Big Data Analytics, presents a low-hanging strategic opportunity that may be leveraged for strengthening data-driven decision making, including for targeting and adaptive learning from implementation.

COUNTRY CONTEXT

Zimbabwe is land-locked country in Southern Africa bordering with Botswana, Mozambique, South Africa and Zambia. It covers 390,757 square kilometres and had a total population of 13,061,239 according to the 2012 National Census. This translates to a population density of 33 persons per square kilometre. Women and girls account for 52 percent of the population whilst slightly over two thirds (67%) reside in the rural areas. The total fertility rate is estimated at 4 children per woman, and the age-specific fertility rate for women aged 15-19 years is 110 births per 1,000 women (ZDHS 2015). The population growth rate is estimated at 2.0% per year[1]. Youths represent over 50% of the population. While progress has been made in reducing malnutrition compared to other countries in the region, child stunting in Zimbabwe remains high at 23.5% (MICS 2019).

Figure 1: Geographical Location and Map of Zimbabwe



Nearly two decades of economic difficulties that started from the early 2000s and peaked in 2007/2008 left the country in a low-income food-deficit status and led to a decline in key human development indicators. Zimbabwe ranked 156th of 189 countries in the 2018 Human Development Index (HDI) and 107th of 119 countries in the 2018 Global Hunger Index. Life expectancy at birth estimated at 61.7 years, the expected and average years of schooling at 10.3 and 8.1 years respectively as well as the estimate of

[1]Zimbabwe Population Projections Thematic Report, ZIMSTAT/UNFPA 2015

the Gross National Income (GNI) per capita of $1,683 contributed to the HDI ranking. The 2019 Mini-PICES showed that in 2019 an estimated 57 percent of Zimbabweans were living below the poverty line, with 38 percent in extreme poverty. The latter marks an 8-percentage increase from the 2017 estimate of households living in extreme poverty. In rural areas, 51 percent of the population is extremely poor, and 72 percent is poor, compared with 28 percent poor in urban areas.[2] Although gender inequalities have decreased, they remain significant in some sectors; the 2018 Human Development Report gives a Gender Inequality Index of 0.534, placing Zimbabwe 128th of 189. Most sectors of the Government were severely weakened and have remained constraint as a result of the protracted economic crisis. The health sector, in particular, suffered from out-migration of skilled personnel and inadequate investments in pharmaceuticals and infrastructure, which led to a sharp decline in key health outcomes in the early years of this last decade.

Despite improvements in most health outcomes following collective efforts and investments in select high impact interventions in the last five years, the progress has been slow and respective indicators continue to fare poorly with respect to progress against milestone targets. For example, the Multiple Indicator Cluster Survey (MICS) of 2019 estimated the maternal mortality ratio at 462 maternal deaths per 100,000 live births; which remains high relative to the 2015 target of 300 maternal deaths per 100,000 live births. Under-5 mortality is currently at 69 deaths per 1,000 births and neonatal mortality has increased from 29 deaths per 1,000 live births in 2015 to 32 deaths per 1,000 live births in 2019 (MICS 2019). The table below provides a summary of key health outcomes in the past decade.

[2] 2019 Mini-PICES Report, ZIMSTAT

Table 1: Key Health Outcomes

Indicator	Measure and Source	ZDHS 2010-11	ZDHS 2015-16	MICS 2019 / Other
Maternal Mortality Ratio	Maternal Deaths per 100,000 Live Births	960	651	462
U5 Mortality	Deaths per 1,000 Live Births	84	69	65
Neonatal Mortality	Deaths per 1,000 Live Births	31	29	32
Stunting for Children U5	Prevalence (%)	32%	27%	23.5%
Adolescent Fertility Rate[3]	Live Births per 1,000 Adolescent Women	115	110	108
Teenage Pregnancy Rate[4]	Prevalence (%)	24%	22%	
Family Planning (FP) Coverage	Population Coverage (%)	59%	67%	68%
Unmet FP Needs	Prevalence (%)	13%	10%	8%
Adult HIV Prevalence	Prevalence (%)	15.2%	13.8%	12.7%
Malaria Incidence	Incidence Per 1,000 Population		29	19

REGIONAL AND COUNTRY SITUATION ON CHRONIC CHILD MALNUTRITION (STUNTING)

Malnutrition, in all its forms, includes undernutrition (wasting, stunting, and underweight), inadequate vitamins or minerals, overweight, obesity, and resulting diet-related non-communicable diseases (NCDs). Globally 1.9 billion adults are estimated to be overweight or obese, while 462 million are underweight. Forty-seven million children under 5 years of age are wasted, 14.3 million are severely wasted and 144 million are stunted, while 38.3 million are overweight or obese. Around 45% of under-five mortality is linked to undernutrition. These mostly occur in low- and middle-income countries. The developmental, economic, social, and medical impacts of the global burden of malnutrition are serious and lasting, for individuals and their families, for communities and for countries. (WHO, 2020)

Globally, in-spite the evidence of growing increase in knowledge on the patterns of stunting, the prevalence remains unacceptably high, with Low- and Middle-Income Countries (LMIC) continuing to be disproportionately affected with rates

[3]Number of live births to women aged 15 to 19 per 1,000 women aged 15 to 19.
[4]Proportion of pregnant women aged 15 to 19 per 1,000 women aged 15 to 19.

of 30 - 50%[5]. In Sub-Saharan Africa, stunting rates have stagnated even in countries where economic growth has been observed.[6] In 2019, nine of the SADC Member States had stunting prevalence rates of above 30%, which according to the WHO, are classified as very high (SADC-RVAA, 2019). The body of evidence around the causes of stunting and its pervasive persistence are multiple and variable and have been widely understood using the UNICEF conceptual framework [7] on undernutrition. The framework outlines that undernutrition is the impact of three levels: the basic, underlying, and immediate causes.

According to this framework, basic causes of malnutrition are linked to systemic-level challenges that reflect the structural and political processes in each society. These include social, economic, environmental, and political issues that lead to the lack of or imbalanced distribution of natural (e.g. productive land), and human, physical, social and financial resources. On underlying causes, the framework places emphasis on household food security, adequate care and feeding practices, access to health services, and residing in a healthy environment. The immediate causes emanate from the impact of the basic and underlying causes at the individual level through inadequate food quality intake and disease. This framework is also used to guide interventions from a multi-sectoral and multi-dimensional perspective, moving from macro to micro-levels of focus.

Box 1: Global Nutrition Targets

To address these global nutrition challenges and recognizing that accelerated global action is needed to reduce the persistent and vicious problem of malnutrition, in 2012 the World Health Assembly Resolution 65.6 recommended a comprehensive implementation plan on maternal, infant and young child nutrition, which specified a set of six global nutrition targets that by, 2025, aim to:

- Achieve a 40% reduction in the number of children under-5 who are stunted;
- Achieve a 50% reduction of anaemia in women of reproductive age;
- Achieve a 30% reduction in low birth weight;
- Ensure that there is no increase in childhood overweight;
- Increase the rate of exclusive breastfeeding in the first 6 months up to at least 50%;
- Reduce and maintain childhood wasting to less than 5%.

[5]Reinhardt, K. and Fanzo, J. (2015). Addressing chronic malnutrition through multi-sectoral, sustainable approaches: a review of the causes and consequences. Frontiers in nutrition. DOI: 10.3389/fnut.2014.00013 www.frontiersin.org

[6]

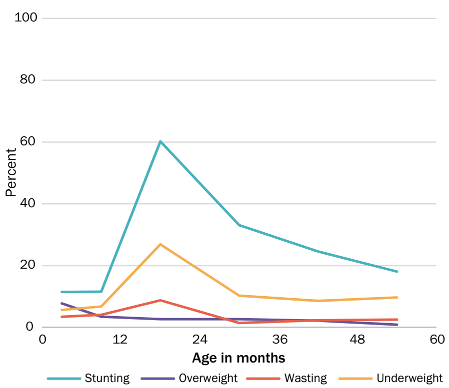
[7]UNICEF. Improving Child Nutrition: The achievable imperative for global progress. United Nations Children's Fund; 2013. p. 4.

To buttress the global efforts towards achieving Global Nutrition Targets by 2025 the United Nations (UN) General Assembly proclaimed 2016–2025 the United Nations Decade of Action on Nutrition. It sets a concrete timeline for implementation of the commitments to meet a set of global nutrition targets and diet-related NCD targets by 2025, as well as relevant targets in the Agenda for Sustainable Development by 2030 particularly, Sustainable Development Goal (SDG) 2 (end hunger, achieve food security and improved nutrition and promote sustainable agriculture) and SDG 3 (ensure healthy lives and promote wellbeing for all at all ages).

Stunting continues to be a major public health and socio-economic problem in Zimbabwe affecting mostly children under the age of five years and women of child bearing age. Stunting prevalence amongst children under five (5) years remains high despite a commendable decline from a peak of 35% in 2005 (ZDHS 2005) to 26% in 2018 (National Nutrition Survey - 2018) and now 24% (Multiple Indicator Cluster Survey 2019). The rate of decline has however not been fast enough to meet the target regional and international thresholds. Malnutrition, in all its forms, includes undernutrition (wasting, stunting, and underweight), inadequate vitamins or minerals, overweight, obesity, and resulting diet-related non-communicable diseases (NCDs).

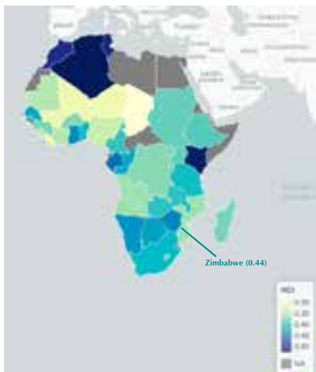
Child stunting is a key contributor to the Human Capital Index (HCI) - a measure of the amount of human capital that a child born today can expect to attain by age 18 given the risks of poor health and poor education that prevail in the country where s/he lives. Zimbabwe's Human Capital Index is 0.44, placing it at moderate position relative to other countries in the Africa region. Zimbabwe is a signatory to the international and regional agreements on the fight against malnutrition, therefore it is also tracking its performance towards the 2025 Global Nutrition Targets. The Zimbabwe Constitution recognizes the right to adequate food and nutrition coupled with access to basic health care and social services

Figure 1. Nutrition Trends - Zimbabwe



Source: MICS2019

Figure 2. HCI in Africa



Source: Author Using WB HCI Report Data

Previous analysis of survey data in Zimbabwe has shown some demographic and geographic variations in the country over years. Stunting is higher in rural areas (26.5%) than in urban areas (22.7%) and varies by Province with Manicaland having the highest (31.2%) whilst Matabeleland South had the lowest (24.2%) (NNS2018). Boys are more undernourished than girls, largely because boys are weaned at an earlier age; children in rural areas are significantly more malnourished than children in urban areas.

Evidence drawn from the malnutrition framework has often been mirrored to shape the narrative of the determinants and pathways for child malnutrition without sufficient adaptation to local settings. In that regard, interventions have been broadly fashioned to address the major causes of malnutrition as per the malnutrition framework (UNICEF, 2019, Black M, M et al, 2020). Unfortunately, interventions that have been loosely developed based on this framework fall short on the specifics of what needs to be done in the current context, and how to do it, due to a lack of robust understanding of the role of the sub-components of the frameworks' domains of influence and their local interactions. Current responses have had small and often poorly targeted (outside of the 1,000 days window) investments in nutrition programs, and this has consistently resulted in very slow and marginal improvements with stunting prevalence improving by 3% between 2015 and 2019[8] .

Additional knowledge on the determinants of stunting in the local context, therefore, remains a key priority for refining efforts to accelerate progress against the backdrop of constrained resources. A comprehensive understanding of the determinants of stunting, including the inter-relationships across these factors at the local level is essential in crafting the appropriate response package and delivery in a targeted manner. Although the understanding of the broader malnutrition framework provides a sound basis for policy formulation, the extent to which these policies are translated to sound strategic actions depends to a large extent on a robust local understanding of the role of the sub-components of these domains of influence and their interactions. Prior evidence has generally adopted a singular approach in validating associations or predictors of malnutrition based on the framework and other literature (Black, M.M, 2020; Chatwin, 2017). This is partly due to limitations in some standard analytic approaches that may not sufficiently address the architecture of big data and the likely correlations across multiple variables.

Zimbabwe has made good progress in establishing the appropriate policy environment to facilitate a national response to malnutrition in the country. Various legislation, policies and guidelines are in place to promote and safeguard access to services, safe products and sound practices that ensure good nutrition for the population.

[8]MICS 2019

These have been supported by relevant structures that include a Food and Nutrition Council (FNC) that is mandated to promote a cohesive national response to prevailing food and nutrition insecurity through a co-ordinated multi-sectoral action, and the Ministry of Health and Child Care (MOHCC) that leads the implementation of nutrition specific interventions, collaboratively with other line ministries and development partners in a multi-sectoral approach. A number of inhibitors to the response have been noted and these include the recent climatic and pandemic shocks that have compounded the already vulnerable health service delivery system owing to the protracted macro-economic challenges. This has further heightened the call to enhance the effectiveness and efficiency of the response to child malnutrition in order to accelerate the decline in prevalence against the backdrop of limited fiscal space in the country. Appendix I provides a synopsis of the Policy Environment and Profile of the Response to Child Malnutrition in Zimbabwe.

STUDY FOCUS AND POLICY QUESTIONS

The study aimed to identify the key predictors of child stunting and quantify the multi-dimensional risk exposure amongst children in Zimbabwe. The analysis sought to answer the following policy questions:

1. What is the nature and extent of interplay between demographic, environmental, social, economic and health related factors that predispose households to the increased risks of child stunting in Zimbabwe?

2. What are the priority target interventions to be considered in constituting a package of response to address inequities in child stunting in Zimbabwe?

3. What is the extent of alignment of the geographical distribution of current development investments focused on mitigating child stunting to the hotspots of the risk of child stunting in Zimbabwe?

In line with the above focus, this paper has been structured to provide an overview of findings and key policy considerations drawn from the analysis of determinants of stunting in Zimbabwe. The findings of the artificial intelligence (AI) enabled analysis of household survey data have provided additional insights into the key predictors of child stunting, the scope, scale and spread of multi-dimensional stunting risk exposure as well as the interplay between these determinants and poverty in driving stunting.

METHODOLOGY

Data Sources

This study is based on the 2018 National Nutrition Survey (2018 NNS) data and Poverty Income and Consumption Expenditure Survey (2017). The Zimbabwe National Statistics Agency (ZIMSTAT) in partnership with the Food and Nutrition Council of Zimbabwe and Ministry of Health and Child Care (MOHCC) conducted the survey with funding and technical support from development partners in health, food security and nutrition.

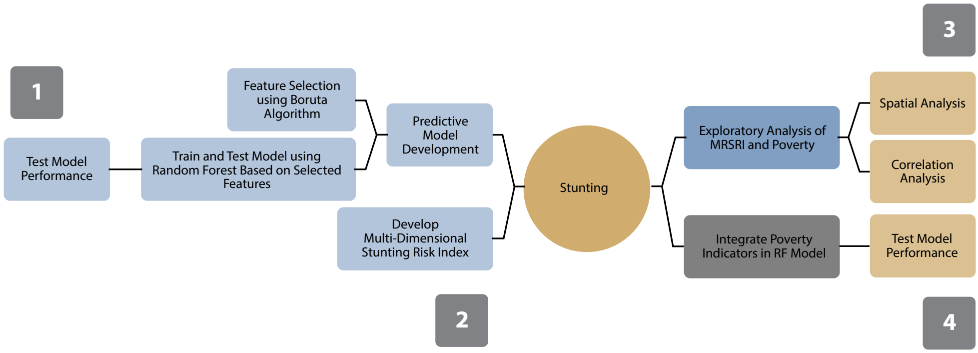
The NNS is a nationally representative survey that covers the entire population and is based on a two-stage stratified sampling framework. Stratification was based on the separation of urban and rural areas in each of the 10 provinces. The sample design was such that key food and nutrition indicators, particularly stunting prevalence, could be reported at domain level (60 rural and 4 urban) with at least 95% confidence. Stunting prevalence as the chosen key indicator for the survey informed the sample design as well as the sample size. The 2012 ZIMSTAT master sampling frame was used to draw 30 enumeration areas (EAs) for each domain using the Probability Proportional to Population Size (PPS) method. A total of 30 households to be enumerated were selected using systematic random sampling from a randomly selected village within the sampled EAs. Households with children under the age of 5 years were the sampling units. All children under 5 years in the households were considered for anthropometric measurements as well as key child nutrition and health indicators.

The NNS 2018 successfully held interviews for a total of 28,464 households and 34,714 children aged 6 to 59 months were measured. Of these children, the study used 31,704 for whom complete, credible anthropometric and age data were non-missing. The standard WHO definition for stunting based on the Height-for-Age, which is regarded as a measure of linear growth retardation and cumulative growth deficits was adopted and used for the study. All children whose height-for-age Z-score (HAZ) is below minus two standard deviations (-2 SD) from the median of the reference population are considered short for their age (Stunted), or chronically undernourished.

Analysis Approach

The analysis focused on three interrelated steps: i) feature selection using Random Forest Model, ii) development of the Multi-dimensional Malnutrition Risk Index (MMRI) using selected features and iii) decomposition of the MMRI and exploratory analysis (including spatial mapping). Figure 3 outlines the sequencing of the analysis, which entailed initially selecting the most important predictor variables (feature selection) using the RF and Boruta Models, followed by using the selected features to compute the MMRI and subsequently in exploratory analysis with Poverty measures. The section below provides a detailed description of each of the methods and how they were integrated in the analysis pipeline.

Figure 3. Steps in Analysis



a) Feature Selection Using the Boruta and Random Forest Algorithms

The identification of determinants was based on ML algorithms - Boruta and Random Forest Model (RF) applied on the NNS 2018 data. The RF algorithm was developed by Breiman (Breiman, L. 2001) to classify data using a set of decision trees. A multitude (k) of trees is built from an initial sample that corresponds to N records with F studied features, represented by a matrix of size (N, F). For each tree node f features are then randomly pulled among the F features (f is equal to rounded square root of F). A key property of the RF is that it enables the assessment of the importance of each feature through the computation of the OOB (Out Of Bag) error (%).

The analysis process entailed partitioning data into 70% training dataset and 30% test dataset. Modeling is done on the training dataset to construct the predictive classifier whilst the test dataset is applied to evaluate performance of the classifier. The importance of variables (features) is then evaluated by measuring the decrease in prediction performance, which is reported as either accuracy or the Gini index. In order to improve the performance of the RF, we used the Boruta Algorithm, which is a wrapper algorithm based on the Random Forest that has greater strength in feature selection as it creates a classification model based on shadow and original attributes to assess importance. The Boruta is able to confirm those attributes regarded as important and reject others. In this analysis, the RF was then used a second step as it was applied on only those features that Boruta had identified as important. The process was aimed at improving precision in the feature selection.

The use of the machine learning approach in this analysis was deemed appropriate and robust due to its ability to handle many features, capture nonlinear pattern relationships and provide more robust discriminant power compared to classical statistics when analyzing a huge number of variables. A total of 230 independent variables/features that ranged from demographics, socio-economic, environmental, geographic, health utilisation and other factors fitting in the framework for determinants of malnutrition were included in the modelling. The RF model has shown good performance in variable selection (Genuer, R., Poggi, J.M. etal, 2010) and demonstrates the ability to handle the problem of multi-collinearity that would arise when using other methods such as the classical Ordinary Least Squares (OLS) regression technique.

b) Computation of the Multidimensional Malnutrition Risk Index (MMRI)

The set of the selected variables were then transformed into binary variables coded as 1 representing a deprivation in a particular variable and 0 for non-deprivation. The classification of deprivation was based on evidence and policy. For example, the global recommendation for breastfeeding is to have exclusive breastfeeding for at least 6-months; and in that regard every child who was not exclusively breastfed for 6-months was considered as deprived and therefore awarded a code=1. Coding for every selected indicator and against every child allowed for the application of the Alkire-Foster (AF) Headcount approach in determining a Multidimensional Malnutrition Risk Index.

The AF method is typically used to measure the Multidimensional Poverty Index (MPI), an index designed to measure acute poverty. The MPI was used to measure children experiencing multiple deprivations, children who, for example, are not breastfed and do not have clean drinking water, adequate sanitation or electricity. The MPI combines two key pieces of information in its measure: the incidence of the negative outcome e.g. stunting, or the proportion of people (within a given population) who experience multiple deprivations in this case the incidence of multiple exposure to malnutrition risk, and the intensity of their deprivation - the average proportion of (weighted) deprivations they experience. The two measures, the incidence and intensity are relevant and valuable as they can easily be interpreted and comparisons across regions and other sub-populations can be determined. Using insights from the exploratory data analysis with a focus on the mean deprivations, a cut-off k=0.5 was applied implying the analysis provides information on the incidence of 18 or more concurrent exposures to malnutrition risks (Ho - Incidence) and the intensity (MMRI).

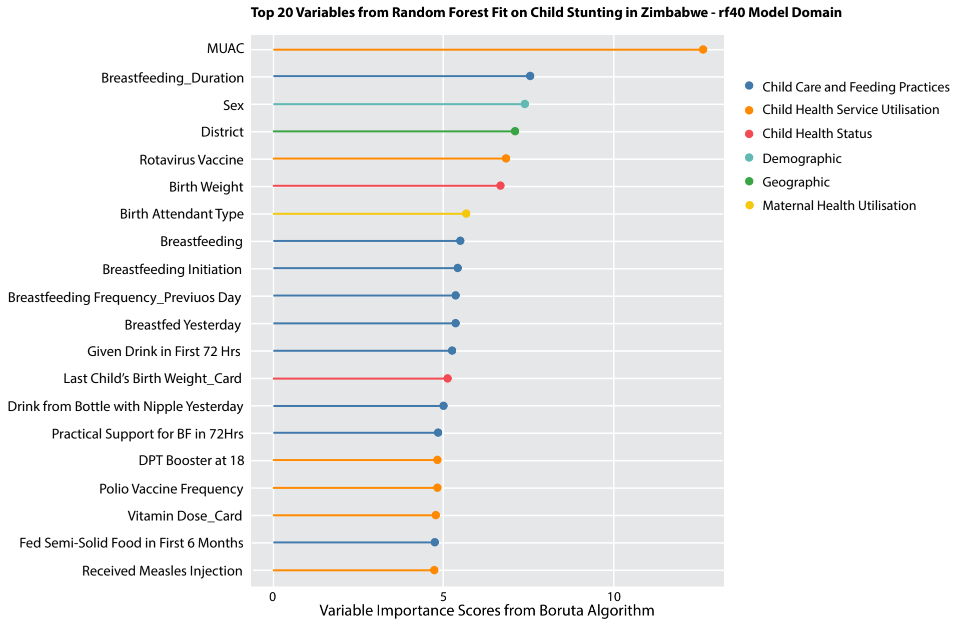
c) Exploratory Analysis of the Multidimensional Malnutrition Risk Index (MMRI)

Based on the computed MMRI and Incidence of multi-dimensional nutrition risk exposure, we conducted exploratory data visualizations to assess the decomposition of the index and determine contributions of the domains. Furthermore, spatial analysis was conducted using district level estimates of the stunting and MMRI derived from the NNS 2018 data as well as poverty estimates (proportion of poor and extremely poor households) drawn from the Poverty Income Consumption and Expenditure Survey (PICES).

FINDINGS - DETERMINANTS OF STUNTING

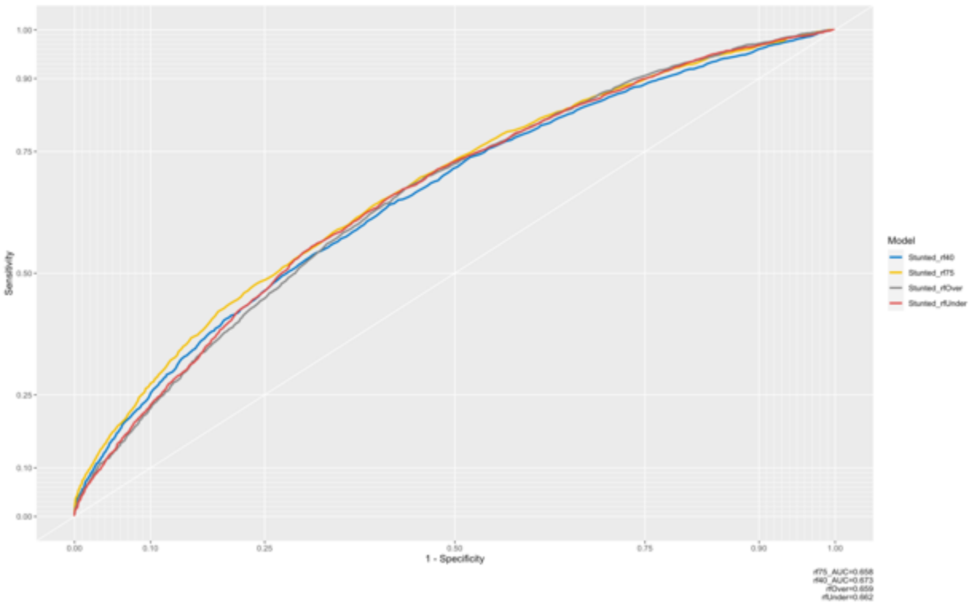
Child stunting in Zimbabwe is influenced by a complex web of factors that align to the domains of health (status, behaviour, family planning and utilisation), biological, socio-economic, demographic and environmental factors as well as direct factors such as Feeding/Caregiving Practices. The analysis showed that stunting could be accurately predicted by a modeled combination of children's and household characteristics. A total of ninety-five variables or features from the 320 variables in the NNS 2018 dataset were confirmed as important predictor variables for stunting. Two predictive models, the rf75 and rf40, with 75 and 40 variables respectively were successfully trained to predict stunting. These variables belong to several domains that confirm the multi-dimensional nature of stunting determinants and validate the strong alignment with the UNICEF Malnutrition Framework. Figure 4 provides a summary of the top predictors of stunting based on Boruta and Random Forest Model. A sample tree has been extracted and is attached in Appendix III. Both the chart below and the sample tree show Mid-Upper Arm Circumference as the top predictor, which is not surprising but remains critical given the role of growth monitoring in the nutrition response.

Figure 4: Variable Importance Plot Showing Top 20 Predictor Variables



The performance of the two models showed similar accuracy therefore justifying the use of the trimmed-up model with less variables. The rf75 and rf40 have accuracy of 72% and 71%; and Precision of 61% and 56% respectively. The precision estimates for the two models show that both models performed well in predicting the true negatives (Specificity) but poorly for the positives (Sensitivity). This was observed to have arisen from a "class imbalance problem" because the outcome of interest, stunting, is found in only a quarter of the children in the dataset. Some adjustments to the imbalance were made to the model through the use of an adjustment algorithm, the Random Over-Sampling Examples (ROSE) and this improved the Sensitivity from 15% to 62%. The Area Under Curve (AUC) estimates for the different models, including those obtained by adjusting through over-sampling (rfOver) and under-sampling (rfUnder) were similar at 66% implying that the adjustments that let to better Sensitivity did not negatively affect overall model performance (see Figure 6). Given that the focus of the Boruta and RF analysis in this study was predominantly for feature selection and not development of a stand-alone prediction model, focus was placed on identifying the list of priority predictors of Stunting for use in subsequent steps.

Figure 5: Receiver Operator Curve (ROC) Showing Model Area Under Curves

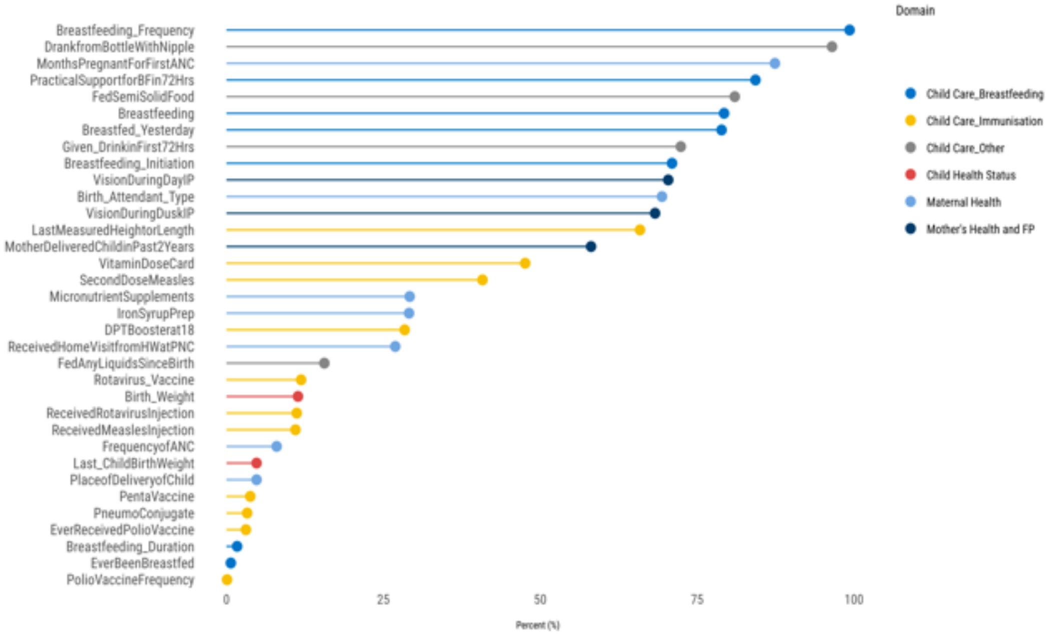


Dominant features in driving stunting in Zimbabwe reflect the need to prioritize child care feeding practices, utilisation of child care services including immunization and strengthening maternal health services including the health of the mother. The analysis shows that access to immunization is highly predictive of stunting status e.g: Receiving Vitamin A Supplementation is associated with children's growth and suggests that Vitamin A supplementation may be protective against stunting. Missing vaccination doses is observed as a less likely predictor of stunting in children contrary to other literature. Vitamin A deficiency in pregnancy is a predictor of stunting. The health status of children (including at birth) and that of mothers contributes to the nutrition status of children. Children who had early initiation of breastfeeding, mother received support with 72 hrs and were breastfed frequently are less likely to be stunted. Mothers who book early and receive skilled birth attendance at delivery are less likely to have stunted children. The occurrence of geographic features such as districts and provinces amongst the list of important predicters affirms the heterogeneity in stunting prevalence in the country, with the spatial patterns of severity reflecting some moderate consistency between the current status (NNS 2018) and previously in 2015.

The assessment of the extent to which children were exposed to the desired state for each of the selected determinants[9] shows that the top most common areas of deprivations are related to breastfeeding practices, child care and maternal health care utilisation. The ranked list shows inadequate breastfeeding frequency (99%), non-use of bottle with nipple (97%), delayed attendance of first antenatal care checkup for mother (87%), inadequate practical support for breastfeeding in the first 72 hours (84%) and non-exclusive breastfeeding (79%) as the top areas of deprivations. Although immunization related variables were identified amongst the key predictors of stunting, the frequency of deprivations amongst these was observed to relatively lower for most of the variables with the exception of Vitamin A Doses (less than 6 monthly) and Growth Monitoring (last measured more than three months), which had 66% and 48% deprivations respectively.

[9] Note that variables such as Sex and District are predictors but not necessarily regarded as drivers or determinants as they only foretell the state but do not determine

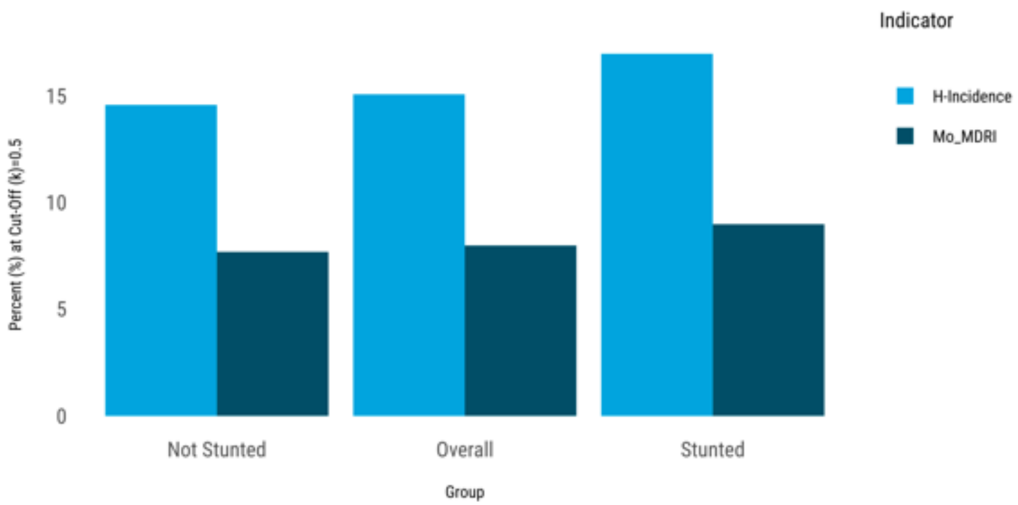
Figure 6: Frequency of Deprivations Amongst Children



The concurrent occurrence of deprivations (having multiple deprivations at the same time for each child) is higher amongst children that are stunted. The incidence of multi-dimensional deprivation (child with deprivations in 50%+ of the set of top 34[10] predictor variables) was observed to be higher amongst children who are stunted (17%) compared to those not-stunted (14.6%) and the overall group (15.1%) – Figure 8. Similarly, the Multi-Dimensional Stunting Risk Index is higher for stunted children (9%) though with only a percentage point difference relative to the other reference groups. Deprivations are more frequent for initiation and frequency of breastfeeding, utilisation of maternal health services (early ANC booking and frequency of ANC etc), mother's health during pregnancy (e.g vision challenges) and other child care practices

[10] Variable such as District and Province were removed from the rf40 list as they do not form a basis for classifying a child's deprivation

Figure 7: Incidence of Deprivations and Multidimensional Malnutrition Risk Index



Food consumption and dietary diversity are important considerations in understanding the prevalence of stunting in Zimbabwe. Though relatively lower in the ranking of predictor importance, food security and dietary intake related variables remained amongst the list of important predictor features in the rf75 predictor model. Zimbabwe's food and nutrition situation is classified as "serious" in the 2018 Global Hunger Index (Score - 32.9). The country failed to reach Goal One of the 2015 Millennium Development Goals (MDGs) – halving extreme poverty and hunger by 2015[11].

The interplay between poverty, food security and the multi-dimensional risk of deprivation to the stunting determinants also provides useful insights regarding its importance as a contributor to stunting. The heterogenous nature of poverty in Zimbabwe is well documented e.g through the Zimbabwe Poverty Atlas and PICES Reports. Specific districts and regions show much higher proportions of poor households. The pattern is however not distinctively correlated to the stunting risk or prevalence at the district level as illustrated by the spatial maps (Fig 9) and the scatter plot (Fig 10) below. However, though moderate, inequities in stunting are widened when stunting risk (as measured by the MDRI) is combined with poverty. Figure 11 shows that the Concentration Index for the weighted MDRI is 0.07, which is positive, and given the distribution scale it means that children that are exposed to more poverty and higher stunting risk scores are more likely to be stunted than their counterparts. Furthermore, a visual inspection of the spatial pattern of the combined Poverty Prevalence and Multi-Dimension Risk Index (MDRI) (Map 3) reflects some moderate alignment to the distribution of stunting in Zimbabwe.

[11] Zimbabwe Millennium Development Goals Final Progress Report, UNDP 2016

Figure 8: Spatial Patterns of Poverty, MDRI, Stunting and Poverty-Weighted MDRI

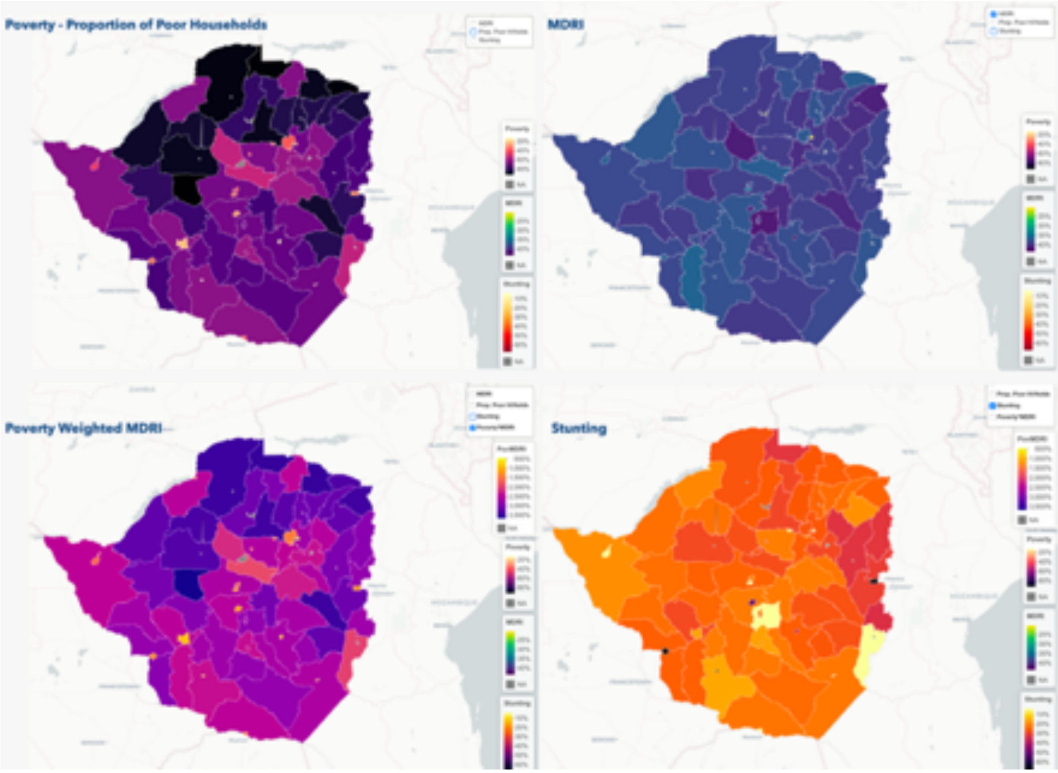


Figure 9: Scatter Plot of District Level Poverty and Stunting Prevalence

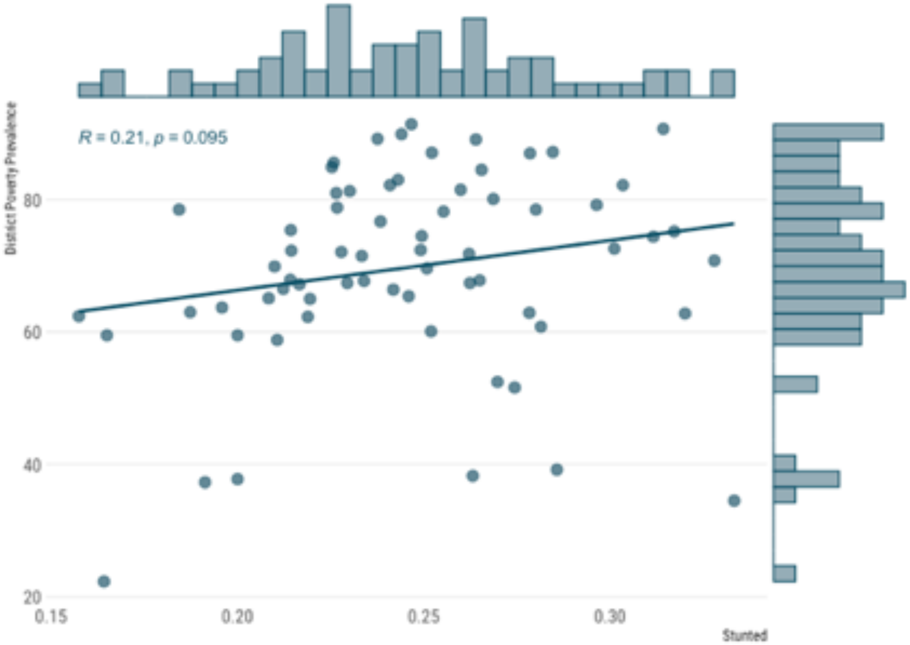
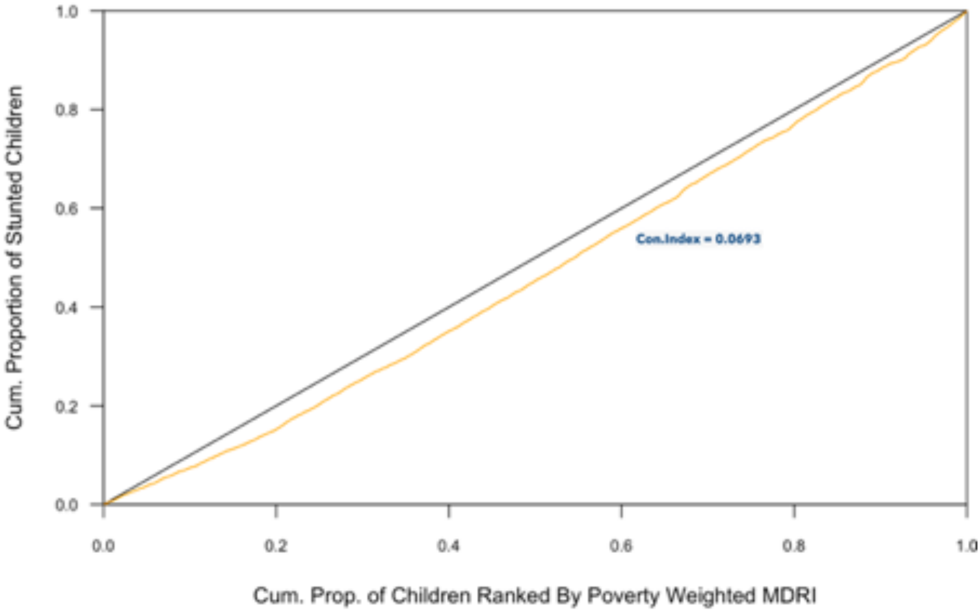


Figure 10: Concentration Curve Showing Poverty Weighted MDRI and Stunting Amongst Children



The findings show that child malnutrition in Zimbabwe is driven by a range of factors that go beyond deficiencies in food consumption to include health related behavioral practices, access to and utilisation of quality health care, socio-economic determinants as well as poverty induced inequities. Multiple exposures to these determinants further compound the risk of stunting in children. An effective national response to the stunting burden calls for a multi-sectoral approach and targeted interventions that aim to reduce exposure and break the complex linkages across these factors.

The outputs for this analysis are accessible on: https://devintel.shinyapps.io/Stunting_AI_RF/

POLICY AND STRATEGIC CONSIDERATIONS GOING FORWARD

The following key considerations are proffered in view of the evidence on the determinants of stunting and recognizing the operational and policy related bottlenecks in the response.

The programmatic response to the malnutrition burden should prioritize the continued provision of high impact nutrition interventions that aim to improve access and uptake of services noted to reduce stunting in children. There are opportunities to leverage on already existing programs such as the Results Based Financing (RBF) and Community Based Management of Acute Malnutrition (CBMAM) in terms of structure, systems and lessons learnt to accelerate:

- Improvements in access to Vitamin-A Supplementation (VAS) for U5s
- Introduction and adoption of adolescent micronutrient supplementation
- Uptake of early ANC booking and further reducing home deliveries
- Improve Infant and Young Child Feeding support structures from health facilities to the community

Given the potential disruptions in the provision of health services arising from the COVID-19 pandemic, it is important that Reproductive, Maternal, Newborn, Child and Adolescent Health (RMNCAH) services are prioritized as essential services requiring measures to safeguard their continuity in service provision.

The evidence supports adopting a sequenced geographical targeting approach for nutrition focused financing/investments and program implementation; that recognizes the current stunting burden with potential for scale-up in line with the varying intensity of stunting risk across the country. The heterogenous representation of stunting prevalence in the country justifies the need for a targeted approach in the national response. However, the composite multi-dimensional risk (as shown by the MDRI) is not distinctively varied across the country implying that districts with low stunting prevalence may still also have moderate to high risks and would still require some relative exposure to interventions that minimize stunting. The heterogeneity reflected at the level of the MDRI domains (decomposed index) gives credence to the need for localized adaptation of national response frameworks to meet the priority needs specific to sub-regional levels (wards, districts and provinces). There is therefore scope to strengthen the capacity of sub-regional structures in priority setting based on review of local level performance status against drivers of stunting and adaptation of national guidelines/frameworks to craft a customized response.

The multi-dimensional nature of the risks of stunting including the association with poverty underpins the need for a multi-sectoral response. The potential compounding effect of poverty on the risk of stunting provides additional pathways to addressing the underlying determinants of stunting by tackling the structural drivers of poverty. The involvement of all stakeholders in a collective response would therefore serve to address all potential bottlenecks across the pathways of change.

Improving investments in nutrition specific interventions and efficiently allocating these in line with local needs provides a huge opportunity to accelerate the decline in stunting prevalence. Increasing the allocation of resources to the nutrition response with strategic allocation to both programmatic needs and towards the country's national multi-sectorial response (including for the coordination, planning, monitoring and evaluation) would re-position the country to be on course to achieving the 2025 Global Nutrition Target on stunting.

It will be strategic for Government and stakeholders to consider leveraging on advancements in technology to strengthen data driven targeting and adaptive learning from implementation to enhance effectiveness and efficiencies in the response. Building on this study's use case of application of machine learning for nutrition, there are opportunities to use technology to scale the reach in health and nutrition promotion (e.g awareness on early breastfeeding initiation, duration and frequency), apply AI and Machine Learning Models to facilitate:

- Households' self-assessments/screening of child stunting risk and uptake of correction action. For example, using the models developed in this study Mobile Apps or Chatbots can be developed that allow for self-assessment and based on obtained scores guidance is provided for triaging and advice on course of action for immunization, care practices or ANC etc.

- Vulnerability assessments and household targeting for national programs

In order to facilitate the realisation of the optimal use of data for decision making in the national response, it will be important to invest appropriately in relevant Information Systems as well as policies for data access, privacy and utilisation.

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APPENDIX I: POLICY ENVIRONMENT AND PROFILE OF THE RESPONSE TO CHILD MALNUTRITION IN ZIMBABWE

The policy environment plays an important role in the implementation and effectiveness of nutrition interventions. Policies aim to influence diet quality by emphasising personal responsibility and choice through, but not limited to, dietary guidelines, food labels, menu labelling and clinical counselling.

The Zimbabwe Constitution recognizes the right to adequate food and nutrition coupled with access to basic health care and social services in terms of article 15 a, b and c; article 19 (2) (b), article 21 (2) (b) and article 77b. The Government of Zimbabwe recognises the importance of food and nutrition security as illustrated in its key policy frameworks, previously Zimbabwe Agenda for Sustainable Socio-Economic Transformation (ZimASSET) and the more recently the Transitional Stabilisation Programme (TSP). These policies express a shared vision and commitment for accelerated action by the Government and its development partners, to improve national and household level food security, improve the quality of diets, ensure food safety, improve nutrition for adolescents, pregnant women and young children and reduce stunting. Some of the policies include Zimbabwe Food and Nutrition Security Policy; Reproductive health and nutrition strategy; Zimbabwe National HIV and AIDS Strategic Plan; Zimbabwe Child Survival Strategy, Multi-Sectoral Community Based approach for Stunting Reduction, Zimbabwe School Health Policy (ZSHP), National Agricultural Policy Framework (NAPF) and the National Health Strategy. The mileage of these and other relevant policies and strategies shall be discussed in this documentation.

The Ministry of Health and Child Care is the government arm responsible for coordination, implementation and monitoring of the nutrition specific programs in Zimbabwe. The current interventions are particularly focused on Maternal Infant and Young Child Nutrition (MIYCN) programming. The operationalization of these interventions is through policies, guidelines and legal Acts such as (maternity protection policy, Public Health (Breast-milk Substitutes and Infant Nutrition) Regulations (SI 46 of 1998), at institutional level (health facility) and at community level. Programmes under maternal nutrition include Maternal Nutrition Education, Iron and Folate Supplementation as well as anthropometric screening during antenatal care visits. Programmes such as the national infant and young child feeding (IYCF) programme, Integrated Management of Acute Malnutrition (IMAM), Vitamin A supplementation, Growth Monitoring and Promotion are implemented both at health facility and community level.

The multifactorial nature of nutrition implies that no single interventions or agency may induce the intended effects of reducing or eradicating malnutrition. The Food and Nutrition Council (FNC) has the mandate to promote a cohesive national response to prevailing food and nutrition insecurity through co-ordinated multi-sectoral action. To facilitate this process the FNC facilitated establishment of multi-stakeholder Food and Nutrition Security Committees (FNSCs) all levels from as low as the ward to the national. This platform has allowed the MoHCC to integrate nutrition activities into mandates of other ministries and agencies including but not limited to, the Ministry of Primary and Secondary Education; Ministry of Agriculture as well as Ministry of Women Affairs. Programmes are implemented at national, sub-national and community levels and each stakeholder is mandated to monitor, evaluate, document and report on their line of responsibility to the committee.

The FNSCs has also been utilised to roll out the Multisectoral Community Based Model for Stunting Reduction across selected districts in the country. The multi-sectoral community-based approach is based on two of the Food and Nutrition Security Policy's Guiding Principles.

- **Principle 1:** strengthening collaboration across sectors, minimising duplication and fostering collective accountability towards a shared goal.

- **Principle 2:** reinforcing the central role and responsibility that communities and civil society have in ensuring food and nutrition security.

Enablers and Inhibitors in the Response

The country faces a dual burden of communicable and non-communicable diseases and this, against the backdrop of limited access to and utilisation of quality services has a notable effect on the health status of children and mothers, itself a confirmed predictor of stunting. HIV prevalence remains relatively high at 12.8% amongst adults and deaths due to TB remain high due to its twin relationship with HIV and AIDS. Malaria remains a major cause of morbidity and mortality in the country and more so in some geographic areas.

Recent climatic and pandemic shocks have compounded the already vulnerable health service delivery system that has been predisposed to the protracted macro-economic challenges. As noted in the findings, health service utilisation e.g the number of ANC visits attended and health behavioral practices such as for Family Planning (duration of preceding birth, number of children ever born) and the quality of services provided influence malnutrition outcomes in children. Although commendable strides have been made in the implementation and improved coverage of key maternal and child health high impact interventions, the quality of care has been sub-optimal and has constrained the achievement of anticipated targets. The number of pregnant women registering for antenatal care is 93% whilst those delivering in facilities with skilled birth attendants are 78%. Immunization coverage has improved in the past years with at least 82% of children being immunized against measles in 2015, up from 76% in 2009. However, despite the high coverage of services, the outcomes such as maternal and perinatal mortality rates have remained high and systematic reviews have pointed to gaps in the quality of care.

Inadequacies in the provision of Focused ANC (FANC) and PNC, where women are expected to obtain the full set of requisite clinical services during the visits (ANC, Delivery and PNC) have contributed to negative patient outcomes. Access to quality services has been limited due to health systems constraints related to shortages of critical health workforce, pharmaceutical supply chain challenges and aging infrastructure.

Despite the high-level commitment to improve nutrition and food security as evidenced by the existing structures, policies and guidelines; some gaps in the governance and policy environment have been noted as key inhibitors. Key amongst these and drawn from broad based consultations include i) the limited financial investments in the response, largely owing to a constrained fiscal space, ii) fragmented response at different levels of the response and hence weakening the coordination in-spite of existing structures, iii) inadequate and sub-optimal use of data for multisectoral collaboration as well as constraints in the numerical adequacy and capacity of human resources.

APPENDIX II: MATERIALS AND METHODS USED IN DETERMINANTS OF STUNTING IN ZIMBABWE STUDY

The outputs for this analysis are accessible on the platform: https://devintel.shinyapps.io/Stunting_AI_RF/

Data Source

This study is based on the 2018 National Nutrition Survey (2018 NNS) data. The Zimbabwe National Statistics Agency (ZIMSTAT) in partnership with the Food and Nutrition Council of Zimbabwe and Ministry of Health and Child Care (MOHCC) conducted the survey.

The NNS is a nationally representative survey that covers the entire population and is based on a two-stage stratified sampling framework. Stratification was based on the separation of urban and rural areas in each of the 10 provinces. The sample design was such that key food and nutrition indicators, particularly stunting prevalence, could be reported at domain level (60 rural and 4 urban) with at least 95% confidence. Stunting prevalence as the chosen key indicator for the survey informed the sample design as well as the sample size. The 2012 ZIMSTAT master sampling frame was used to draw 30 enumeration areas (EAs) for each domain using the Probability Proportional to Population Size (PPS) method. A total of 30 households to be enumerated were selected using systematic random sampling from a randomly selected village within the sampled EAs. Households with children under the age of 5 years were the sampling units. All children under 5 years in the households were considered for anthropometric measurements as well as key child nutrition and health indicators.

The NNS 2018 successfully held interviews for a total of 28,464 households and 34,714 children aged 6 to 59 months were measured. Of these children, we used 31,704 for whom complete, credible anthropometric and age data were non-missing. In this study we adopted the standard WHO definition for stunting based on the Height-for-Age, which is regarded as a measure of linear growth retardation and cumulative growth deficits. All children whose height-for-age Z-score (HAZ) is below minus two standard deviations (-2 SD) from the median of the reference population are considered short for their age (Stunted), or chronically undernourished.

Analysis Approach

The analysis focused on three interrelated steps: i) feature selection using Random Forest Model, ii) development of the Multi-dimensional Malnutrition Risk Index (MMRI) using selected features and iii) decomposition of the MMRI and exploratory analysis (including spatial mapping).

a) Feature Selection Using the Boruta and Random Forest Algorithms

The NNS 2018 data used for feature selection comprised of 31,704 records of children whose height for age measurements were recorded. Each child's stunting status was determined using standard code computation. A total of 230 independent variables/features that ranged from demographics, socio-economic, environmental, geographic, health utilisation and other factors fitting in the framework for determinants of malnutrition were included in the modelling.

The identification of determinants was based on ML algorithms - Boruta and Random Forest Model (RF) applied on the NNS 2018 data. The RF algorithm was developed by Breiman (Breiman, L. 2001) to classify data using a set of decision trees. A multitude (k) of trees is built from an initial sample that corresponds to N records with F studied features, represented by a matrix of size (N, F). For each tree node f features are then randomly pulled among the F features (f is equal to rounded square root of F). A key property of the RF is that it enables the assessment of the importance of each feature through the computation of the OOB (Out Of Bag) error (%).

The analysis process entailed partitioning data into 70% training dataset and 30% test dataset. Modeling is done on the training dataset to construct the predictive classifier whilst the test dataset is applied to evaluate performance of the classifier. The importance of variables (features) is then evaluated by measuring the decrease in prediction performance, which is reported as either accuracy or the Gini index. The Gini index evaluates the ability of the potential discriminative of each feature. In general, Mean Decrease in Gini Index (MDGI) is regarded to be more robust than the mean decrease in accuracy (Calle M. L. and Urrea V. Letter, 2011) and is used in this analysis to select the important predictors of stunting. Its interpretation is that the variable with the largest value of MDGI is the most important feature because it contributes the most to the prediction performance of the model. In order to further improve the performance of the RF, we used the Boruta Algorithm, which is a wrapper algorithm based on the Random Forest that has greater strength in feature selection as it creates a classification model based on shadow and original attributes to assess importance. The Boruta is able to confirm those attributes regarded as important and reject others. In this analysis, the RF was then used a second step as it was applied on only those features that Boruta had identified as important. The process was aimed at improving precision in the feature selection.

The use of the machine learning approach in this analysis was deemed appropriate and robust due to its ability to handle many features, capture nonlinear pattern relationships and provide more robust discriminant power compared to classical statistics when analyzing a huge number of variables. The RF model has shown good performance in variable selection (Genuer, R., Poggi, J.M. etal, 2010) and demonstrates the ability to handle the problem of multi-collinearity that would arise when using other methods such as the classical Ordinary

Least Squares (OLS) regression technique.

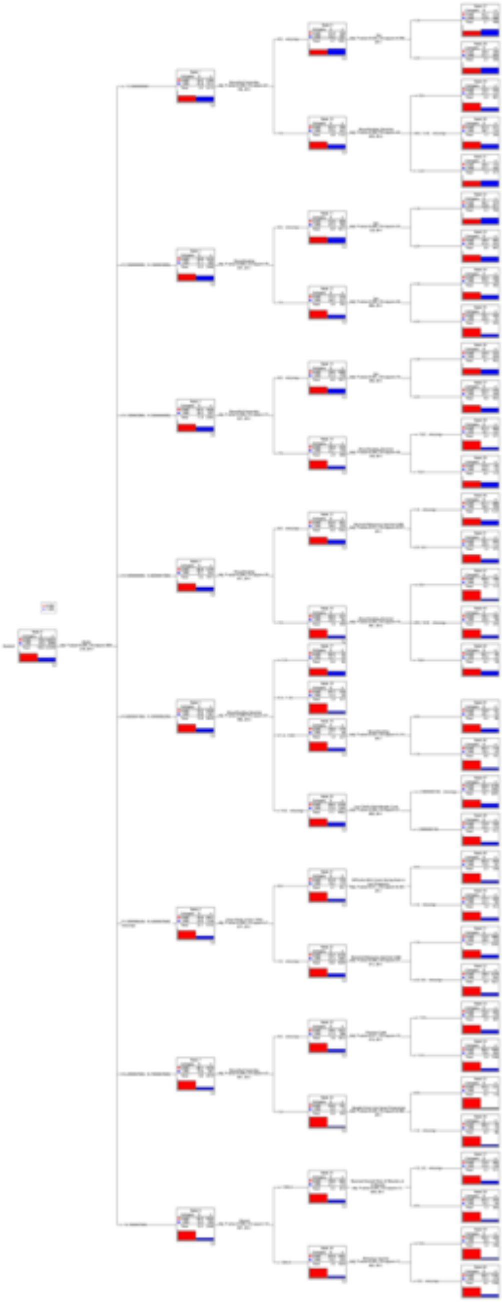
b) Computation of the Multidimensional Malnutrition Risk Index (MMRI)

The analysis applied the Alkire-Foster (AF) Headcount approach in determining the MMRI. The AF method is typically used to measure the Multidimensional Poverty Index (MPI), an index designed to measure acute poverty. The MPI was used to measure children experiencing multiple deprivations, children who, for example, are not breastfed and do not have clean drinking water, adequate sanitation or electricity. The MPI combines two key pieces of information in its measure: the incidence of the negative outcome e.g. stunting, or the proportion of people (within a given population) who experience multiple deprivations in this case the incidence of multiple exposure to malnutrition risk, and the intensity of their deprivation - the average proportion of (weighted) deprivations they experience. The two measures, the incidence and intensity are relevant and valuable as they can easily be interpreted and comparisons across regions and other sub-populations can be determined. Using insights from the exploratory data analysis with a focus on the mean deprivations, a cut-off k=0.5 was applied implying the analysis provides information on the incidence of 18 or more concurrent exposures to malnutrition risks (Ho - Incidence) and the intensity (MMRI).

c) Exploratory Analysis of the Multidimensional Malnutrition Risk Index (MMRI)

Based on the computed MMRI and Incidence of multi-dimensional nutrition risk exposure, we conducted exploratory data visualizations to assess the decomposition of the index and determine contributions of the domains. Furthermore, district-based estimation of the stunting, MMRI and poverty estimates drawn from the Poverty Income Consumption and Expenditure Survey (PICES) was applied in the spatial analysis.

APPENDIX III – EXTRACTED SINGLE TREE FROM RANDOM FOREST PLOT



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