Exploring the association of undernourishment indicators for under-five children in Sub-Saharan Africa: an application of log-linear model for three-way table

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Research Article

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Abstract

Background: Childhood undernutrition was a central public health difficulty. Several studies have considered determinants of childhood undernutrition and haven't focused on the connection of undernourishment indicators, the remains have focused on the link of indicators with their factors and have ignored the connection of the dimensions themselves, therefore this study tested pairwise relationships among the dimensions.

Methods: In the current study multiple correspondence analysis (MCA) was applied to look at the visual association of the indicators. Moreover, the log-linear model was wont to see the model of the best suitable examine the nutritional status of youngsters. The interaction terms within the model have represented deviations from independence.

Result: The result shows that out of 185,541 weighted sampled children 32.28%, 16.67%, and 6.82% were stunted, underweight, and wasted respectively. The overall prevalence of undernutrition was about 37.85%. The log-linear model showed that being underweight has an association with both stunting (P-value < 0.001), and wasting (P-value < 0.001). There was no association between stunting and wasting (P-value = 0.999). Also, there's no three-way relationship between stunting, wasting, and being underweight (P-value = 1.000).

Conclusion: The study shows that there is no three-way interaction between undernourishment indicators. This shows the three undernourishment indicators of under-five children have multi-dimensional characteristics. Accordingly, the alarmed body should assume the three indicators concurrently to assess the actual problem of childhood undernutrition as they are not terminated to each other.

Background

Childhood undernourishment was a central public health difficulty [1]. It touches children's mental and physical progress, raises the outlook of infections, and meaningfully contributes to the child's illness and death [2, 3]. A good diet sets children on the trail to persist and succeed. Well-nourished children raise, mature, acquire, play, contribute and participate while undernutrition mugs children of their complete potential, with concerns for teenagers, nations, and thus the world [4]. Measures of under-five children's undernourishment are familiarized to touch on development progress and socioeconomic inequalities in several low and middle-income countries. Scarce food within the primary thousand days of duration may a consequence of reduced physical development, which integrates a long-term influence on power thus resulting in reduced educational performance and economic productivity in maturity [5].

The three commonly known measures of under-five children's undernourishment indicators are stunting, wasting, and underweight [6]. Being stunting and wasting indicate chronic and acute malnutrition respectively, underweight may be a pooled indicator, and comprises both acute (wasting) and chronic (stunting) malnutrition [6]. So, different dimensions of undernourishment may take place concurrently in under-five children [6].

A baby who is simply very short for his or her age (low height for age) is known as stunting. Children tormented by stunting can suffer severely irreparable physical and cognitive injuries that go together with their stunted growth. The devastating consequences of stunting can last a lifespan and even touch the long run group [7]. A baby who is simply very thin for his or her height (low weight for height) is called wasting. It is the outcome of current fast weight loss or the failure to achieve weight. A wasted child has an increased risk of death, but management is feasible. Likewise, underweight states to a baby who is simply very small for his or her age (low weight for age) which is the weight for age less than negative 2 standard deviation(SD) of the WHO Child Growth Standards median [7, 8].

Height for age, weight for height, and weight for age standard scores were calculated based on the 2006 WHO childhood growth criteria endorsed for worldwide sets [4]. Children are considered stunted after they have a height for age standard score below minus two compared with the WHO Child Growth criteria median of same age and gender. Wasting is defined by weight for height standard score (WHZ) below negative two and suggests acute undernutrition or rapid weight loss. Underweight is defined by weight for age standard score (WAZ) below negative two [9].

Globally malnutrition in children is exceptionally prevalent and remains a giant challenge [10]. Keeping with the worldwide organization Children's Fund (UNICEF) report in 2020, 22% of youngsters under the age of 5 years are stunted, 12.6% are underweight and 6.7% are wasted [4]. Two districts in the world such as Asia and Africa bear the two in all the best burdens of undernutrition. Stunting affected around 149.2 million children age under-five in 2020. of those 53% of stunted under-five children lived in Asia and 30.7% lived in Africa [4]. During this year, wasting contributed to threatening the lives of an estimated 45.4 million under-five children. Of these, over two-thirds of all wasted under-five children are found in Asia and over one quarter was found in Africa [4]. However, a more detailed have a look at the distribution of undernutrition within the African region shows that Eastern Africa (32.6%) encompasses a better prevalence of stunting compared to Western Africa (30.9%), Central Africa (36.8%), Northern Africa (21.4%) and Southern Africa (23.3%) [4]. While Western Africa (6.9%) incorporates a better rate of wasting than the remainder of African regions, Southern Africa (3.2%), Central Africa (6.2%, Northern Africa (6.6%), and Eastern Africa (5.2%) [4]. These estimates reveal regional disparities within the distribution of undernutrition.

Numerous studies have assessed determinants of childhood undernutrition [11–13] and haven't focused on the association between undernourishment indicators. The rest studies have focused on the relationship of babyhood undernourishment indicators with their factors [1, 14], and have ignored the association of stunting, underweight, and wasting themselves while the other studies consider only single country [9], therefore the current study intended to investigate the association of under-five children stunting, underweight, and wasting using a log-linear model for the three-way table to evaluate the pairwise and three-dimensional association of indicators for Sub-Saharan region. The significance of showing the three-dimensional relationship is that it helps to judge whether childhood undernourishment indicators are distinct (main effects) or even taken integrated effect. The concurrent (interaction) effect would be reflected to represent possible relationship of the magnitude [1].

Methods

Data source

This study was supported the foremost current Demographic and Health Surveys (DHS) conducted within the 33 Sub-Saharan African countries. These datasets were merged to work out the association between three anthropometric measures among under-five children within the region. The DHS may be a nationally representative survey that collects data on basic health indicators like mortality, morbidity, planning service utilization, fertility, maternal and child health. the data for this study were taken from

https://www.dhsprogram.com/data/dataset_admin/login_main.cfm . Demographic health (DHS) survey has different datasets (men, women, children, birth, and household datasets). For this study, we used the kid data set (KR file). within the KR file, all children who were born within the previous five years before the survey within the selected enumeration area were included.

Sampling procedures

The DHS used two stages of stratified sampling technique to select the study participants. We analyzed the DHS surveys conducted in the 33 Sub-Saharan African countries and a total weighted sample of 185,541 under-five children were included in the study.

Variables of the study

The three undernutrition indicators are measured through z-scores for height for age (stunting), weight for height (wasting), and weight for age (underweight) and are defined as

$$Z_i = \frac{A_{Ii} - \mu}{\sigma} \quad [1]$$

Where A_{Ii} is the single (child) anthropometric indicator, μ, and σ denote respectively to the median and standard deviation of the reference population [15, 16]. The variables of interest produced were: stunted (0 = No if HAZ ≥ -2 and 1 = Yes if HAZ < − 2), wasted (0 = No if WHZ ≥ − 2 and 1 = Yes if WHZ < − 2), and underweight (0 = No if HAZ ≥ -2 and 1 = Yes if HAZ < − 2). The procedure for calculating the indicators was founded on the 2006 WHO Child Growth Criteria [15, 16].

Statistical Analysis

Log-linear model for three-way table

The log-linear models are wont to see the many relations supported the cross-tabulation. A log-linear model may be a statistical model for the log of the predictable frequency and interpreted as generalized linear models which treat the cells counts as independent observations from the distribution with corresponding means up to the predictable cell counts. The Log-linear model is employed when all factors will be treated as dependent variables [17]. Consequently, during this study, the three factors (stunting, wasting, and underweight) were treated as responses, and also the focus is on their structure of relationship by modeling $2^3 + 1 = 9$ log-linear possible models [1]. Thus, nine log-linear models of the expected cell count from the three factors are presented below. Log-linear models are fitted to check the hypotheses about complex relations, but the parameter estimates are simply interpreted. Estimated parameters are log odds ratios of the associations.

Model	Expression	Description
	$\lambda + \lambda_i^{S} + \lambda_j^{U} + \lambda_k^{W}$	Complete independence among the three factors. Concurrent term is not included (pair-wise independent).
	$\lambda + \lambda_i^{S} + \lambda_j^{U} + \lambda_k^{W} + \lambda_{ik}^{SW}$	This model encompasses the interaction between stunting and wasting. Being underweight is independent of stunting and wasting.
	$\lambda + \lambda_i^{S} + \lambda_j^{U} + \lambda_k^{W} + \lambda_{ij}^{SU}$	This model holds the interaction between stunting and being underweight. Wasting is independent of stunting and being underweight.
	$\lambda + \lambda_i^{S} + \lambda_j^{U} + \lambda_k^{W} + \lambda_{jk}^{UW}$	This model encompasses the interaction between underweight and wasting. Stunting is independent of wasting and being underweight.
Log of the mean of cell counts = $\log\left(\mu_{ijk}\right)$	$\lambda + \lambda_i^{S} + \lambda_j^{U} + \lambda_k^{W} + \lambda_{ij}^{SU} + \lambda_{ik}^{SW}$	This model comprehends the interaction terms between underweight and stunting; stunting and wasting. Wasting & underweight are temporarily independent of stunting.
	$\lambda + \lambda_i^{S} + \lambda_j^{U} + \lambda_k^{W} + \lambda_{ik}^{SW} + \lambda_{jk}^{UW}$	The model encompasses the interaction terms between wasting and underweight; wasting and stunting. Stunting and being underweight are independent of wasting.
	$\lambda + \lambda_i^{S} + \lambda_j^{U} + \lambda_k^{W} + \lambda_{ij}^{SU} + \lambda_{jk}^{UW}$	The model encompasses the interaction terms between wasting and underweight; underweight and stunting. Stunting & wasting are conditionally independent of being underweight.

Model	Expression	Description
	$\lambda + \lambda_i^S + \lambda_j^U + \lambda_k^W + \lambda_{ij}^{SU} + \lambda_{jk}^{UW} + \lambda_{ik}^{SW}$	Homogenous relation (every factor have relation with each other, but all three factors have no interaction between them)
	$\lambda + \lambda_i^S + \lambda_j^U + \lambda_k^W + \lambda_{ij}^{SU} + \lambda_{jk}^{UW} + \lambda_{ik}^{SW} + \lambda_{ijk}^{SUW}$	All possible interactions between the factors are included in the model.

S, U, W represents stunting, underweight, and wasting respectively; $\lambda_i^S, \lambda_j^U and \lambda_k^W$ are represents stunting, underweight and wasting effects respectively.

Reminder that in the last model of the above table the interactions between stunting and underweight; underweight and wasting; stunting and wasting; stunting, underweight, and wasting are included. Unsaturated models can include in the interaction terms for tables with at least three variables. After, log-linear models are used to describe associations through two-factor terms than describing odds through single-factor terms [18]. Interaction terms resemble to associations among variables.

To test whether the saturated (full) model is significantly better than the reduced model, we applied the test called goodness-of-fit tests of a log-linear model, including Chi-squared statistic $\left(X^2\right)$ and likelihood ratio test $\left(G^2\right)$. The two tests can be used to choice the best-fitting model. Likewise, AIC is used to select the best model. The larger the values of $\left(X^2\right)$, $\left(G^2\right)$, and AIC, the more evidence exists against independence [18]. Saturated model includes all possible main effects and interactions effects. For analyzing the data, the authors were used R version 4.0.5 with a 0.05 significance level.

Results

Descriptive characteristics of the study participants

A weighted total sample size of 185,541 under-five children was included for this study (Table 1). Of these, 75,287 (40.6%) from East Africa, 70,346 (37.9%) from West Africa, 3,784 (3.8%) in Southern Africa and 36,122 (19.5%) in Central Africa. Regarding to the nutritional status of under-five children, 55.7% of under-five children in Burundi were stunted, 36.2% and 18.1% of under-five children in Niger were underweight and wasted. This is the highest prevalence of stunted, underweight, and wasted respectively among sampled children in Sub-Saharan African countries.

Table 1
Number of under-five children included in the study, and survey years of the countries

Region	Country	Sample size (weighted)	Prevalence of stunting	Prevalence of underweight	Prevalence of wasting	DHS year
Eastern region	Burundi	6213	55.7	29.2	5.1	2016/2017
	Comoros	2468	1.3	15.6	11.1	2012
	Ethiopia	9494	38.3	23.3	10.1	2016
	Kenya	17291	25.8	10.6	4.1	2014
	Malawi	5127	36.5	11.0	2.7	2015/2016
	Rwanda	3593	37.7	9.1	2.3	2014/2015
	Tanzania	8758	34.0	13.4	4.7	2015/2016
	Uganda	8630	28.2	9.9	3.7	2016
	Zambia	8545	34.4	11.6	4.2	2018
	Zimbabwe	5166	25.9	25.9	3.5	2015
Table 1. (continued)						
Region	Country	Sample size (weighted)	Prevalence of stunting	Prevalence of underweight	Prevalence of wasting	DHS year
Southern region	Lesotho	1298	32.4	10.8	3.1	2014
	Namibia	1438	22.0	10.0	7.6	2013
	South Africa	1049	25.4	5.2	2.5	2016
Western region	Burkina Faso	6660	34.5	25.7	15.8	2010
	Benin	11682	31.5	16.3	5.0	2017/2018
	Côte d’Ivoire	3041	29.8	14.7	7.8	2011/2012
	Ghana	2636	17.9	10.8	4.7	2014
	The Gambia	3503	16.9	11.3	5.3	2019/2020
	Guinea	3278	30.7	15.3	8.9	2018
	Liberia	2161	28.8	10.0	3.7	2019/2020
	Mali	8764	26.6	18.2	8.9	2018

Region	Country	Sample size (weighted)	Prevalence of stunting	Prevalence of underweight	Prevalence of wasting	DHS year
	Nigeria	11361	36.4	21.2	6.8	2018
	Niger	5113	43.3	36.2	18.10	2012
	Sierra leone	4006	28.8	13.1	5.6	2019
	Senegal	5082	17.5	14.0	8.0	2019
	Togo	3058	26.7	15.7	6.8	2013/2014
Central region	Angola	5837	36.8	18.3	5.0	2015/2016
	Chad	9805	39.6	28.8	13.2	2014/2015
	Congo	3859	23.1	11.1	5.6	2011/2012
	Dr. Congo	7900	42.3	22.4	7.9	2013/2014
	Cameroon	4646	28.8	10.8	4.4	2018
	Gabon	2792	16.0	5.9	3.5	2012
	Sao Tome Principe	1285	29.4	13.2	10.4	2008/2009

Table 2
Cross classification of stunting, wasting, and underweight

Wasting			Underweight		Total
			No	Yes	
No	Stunting	No	115306	2038	117344
		Yes	35115	20425	55540
Yes	Stunting	No	4215	4219	8434
		Yes	0	4223	4223
Total			154636	30905	185541

Table 2 shows cross-tabulation of wasting, stunting, and underweight. There were 32.21% stunted children, 16.67% underweight children and 6.82% wasted children from all sampled children in the region.

Table 3
Categories of the Composite Indicator of Anthropometric Failure

CIAF category	Frequency (%)
No failure	115306 (62.15)
Stunted only	35115 (18.93)
Underweight only	2038 (1.10)
Wasted only	4215 (2.27)
Stunted and underweight	20425 (11.00)
Wasted and underweight	4219 (2.27)
Stunted, wasted, and underweight	4223 (2.28)

Figure 1 shows that the multiple correspondence analysis (MCA) of the three dimensions of childhood undernutrition. There is no relationship between chronic and acute malnutrition as wasting in the first and third quadrants and stunting in the second and fourth quadrants. Whereas, underweight is located on the boundary line and indicated that it had a relationship with both chronic and acute malnutrition.

The whole prevalence of undernourishment for under-five years children can be calculated based on composite index of anthropometric failure (CIAF) [19]. Rendering to CIAF arrangement, under-five years' children can be separated to No failure; Stunted only; Underweight only; Wasted only; both Stunted and underweight; both underweight and wasted, and the combination of three indicators (stunted, underweight and wasted. Therefore, the classifications of CIAF are presented in Table 3 and it shows Classifications of the Composite Indicator of Anthropometric Failure along with its frequency calculated from Table 2. Based on the result about 37.85% = {(18.93 + 1.10 + 2.27 + 11.0 + 2.27 + 2.28) %} of under-five children were suffered with undernourishment whereas 62.15% were not suffered with undernourishment from the sampled children in Sub-Saharan Africa. This suggests that 37.85% of under-five children were malnourished. This implies that the total prevalence of undernourishment in under-five years' children is about 37.85% in the region. The CIAF result does not indicate any information on the prevalence of undernourishment indicators relative to total undernourishment, but it shows total prevalence of undernourishment.

Table 4
The goodness of fits tests for log-linear models relating stunting (S), wasting (W), and underweight (U)

Model	Log-linear model	AIR	G^2 (Likelihood ratio)	X^2 (Pearson)	DF	P-value	
						G^2	X^2
1	(S, U, W)	61910	61828.08	63535.70	4	< 0.001	< 0.001
2	(W, SW)	61910	61819.84	62904.10	3	< 0.001	< 0.001
3	(W, US)	25540	25448.58	44893.43	3	< 0.001	< 0.001
4	(S, UW)	44440	44354.49	44112.59	3	< 0.001	< 0.001
5	(US, SW)	25530	25440.33	45284.19	2	< 0.001	< 0.001
6	(UW, SW)	44440	44346.24	44103.22	2	< 0.001	< 0.001
7	(US, UW)	8065	7974.99	7631.01	2	< 0.001	< 0.001
8	(US, UW, SW)	329.60	237.98	127.19	1	< 0.001	< 0.001
9	(USW)	93.50	0	0	0	1.0	1.0

The likelihood ratios chi-square (G^2), Pearson chi-square (x^2), and Akaike Information Criteria (AIC) are reported in Table 4. The observed and fitted cell counts are associated with the fit statistics. The null hypothesis is stated the observed and also fitted cell counts are identical (the data is well fitted by the model). The choice hypothesis states that the observed and the fitted cell counts are different. A P-value less than 0.05 level of significance for the fit statistics indicates stronger suggestion in contradiction of the model's goodness of fit and a P-value superior than 0.05 level of significance for the fit statistics displays strong suggestion that the model fits the data well. The p-value for models one to eight are less than the significance level, therefore model 1 to eight don't fit the data well, while the p-value for the fit statistics is greater than the 0.05 level of significance (P-value = 1.000) and has the tiniest AIC value for model 9. Accordingly, the results of the saturated model (model 9) are presented and interpreted further. Table 5 shows the results of the saturated model (model 9). The null hypothesis of the individual test of coefficient of the interaction term is stated as there is no interaction term between indicators of undernourishment. Therefore, there is a highly significant interaction between underweight and stunting since the P-value of the estimates of the interaction term Stunting*underweight is smaller than the 0.05 significance level (P-value < 0.001). there's also a highly significant interaction between underweight and wasting (P-value < 0.001), but no interaction between stunting and wasting because the P-value is way greater than 0.05 significance level (P-value = 0.999). Also, the complete log-linear model displays a scarcity of a three-factor relationship among undernourishment indicators (P-value = 1.000).

Table 5
Estimates for the saturated log-linear model for stunting, wasting and underweight

Coefficient	Estimate	Standard error	Z-value	P-value
Intercept	11.66	0.003	3957.78	< 0.001
Underweight	-4.04	0.022	-180.60	< 0.001
Stunting	-1.19	0.006	-195.07	< 0.001
Wasting	-3.31	0.016	-211.00	< 0.001
Underweight and stunting	3.49	0.024	145.47	< 0.001
Underweight and wasting	4.04	0.031	129.37	< 0.001
Stunting and wasting	-29.46	42250	-0.001	0.999
Underweight, stunting, and, wasting	27.16	42250	0.001	0.999

Discussion

In the current study, a log-linear model was fitted for the three-way table to investigate the relationship among undernutrition indicators. Within a log-linear model, the relationship of the undernutrition indicators was shown by the concurrent terms. The log-linear models have the benefit of determining the three-way concurrent terms besides exploring pairwise relationships, [9, 17, 19]. Hence the p-values for the saturated model (model 9) are bigger than the 0.05 significance level (P-value = 1.000) as compared to the rest unsaturated models; data were well fitted by the saturated log-linear model (model 9). The saturated model indicates that being underweight is a statistically significant association with stunting (P-value < 0.001). Saturated model also displays that being underweight and wasting are statistically significant relationships (P value < 0.001). These findings coincide with earlier studies conducted in Malawi, Ethiopia and India respectively [1, 9, 14] respectively. Besides, this result's agreed with fact that underweight can be a composite measure of stunting and wasting [16, 20]. The current study indicates stunting and wasting aren't interrelated (P-value = 0.999). This finding goes with studies done in Malawi, Ethiopia, and India [1, 9, 14] respectively. Furthermore, the saturated model shows the three-way interaction among undernourishment indicators was insignificant (P-value = 1.000). This finding also coincides with the findings in Malawi, Ethiopia, and India [1, 9, 14]. The dearth of three-way interaction indicates that undernourishment indicators have a statistically significant valid multidimensional nature.

Conclusion

The current study concludes that both stunting and wasting have significantly correlated with being underweight. The observed relationship of both stunting and wasting with underweight doesn't imply one undernutrition indicator causes the other indicator because the analysis was based on cross-sectional data. furthermore, the study suggested that stunting and wasting were not related. Keeping the above result, the present study concludes that there is no three-way association among undernourishment indicators. From the dearth of three-way association, the authors conclude that the undernourishment indicators of under-five children have multidimensional characteristics. Accordingly, the concerned body should consider the three dimensions simultaneously to estimate the particular load of under-five children undernourishment as they do not seem to be ended to every other. Lastly, the authors recommended that supplementary studies can undertake whether a causal relationship occurs between the indications or not through the data from prospective or retrospective cohort studies.

Abbreviations

AIC: Akaike's information criterion; CIAF: Composite Indicator of Anthropometric Failure; EDHS: Demographic and Health Survey; HAZ: Height-for-age z-score; UNICEF: United Nations International Children's Emergency Fund; WAZ: Weight for age z-score; WHO: World health organization; WHZ: Weight for height z-score

Declarations

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Authors' contributions

AA wrote the proposal, analyzed the data and manuscript writing. YA accredited the proposal with revisions, analysis the data and manuscript writing. Both YA and AA read and approved the very last manuscript.

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Availability of data and materials

The data used in this study are available from http://dhsprogram.com.

Ethics approval and consent to participate

This study was based on an analysis of secondary data with all identifier information removed. The Institutional Review Board (IRB) of Inner City Fund (ICF) International Macro at Fairfax, Virginia in the USA reviewed and approved the MEASURE Demographic and Health Surveys Project Phase III. The 2010–2018 DHS's were categorized under that approval. The Institutional Review Board (IRB) of Inner City Fund (ICF) International Macro complied with the United States Department of Health and Human Services guidelines and requirements for the "Protection of Human Subjects" (45 CFR 46). All protocols were carried out in accordance with relevant guidelines and regulations on confidentiality, benevolence, non-maleficence, and informed consent. All study participants gave written informed consent before participation and all information was collected confidentially. DHS Program has remained consistent with confidentiality and informed consent over the years. We obtained express approval to use the data from ICF Macro with Accession number 140625. No further approval was required for this study.

The data owners can be contacted at https://dhsprogram.com/Data/terms-of-use.cfm and data can be found at https://www.dhsprogram.com/data/dataset_admin/login_main.cfm. Further documentations on ethical issues relating to the surveys are available at http://dhsprogram.com.

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests.

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Figures

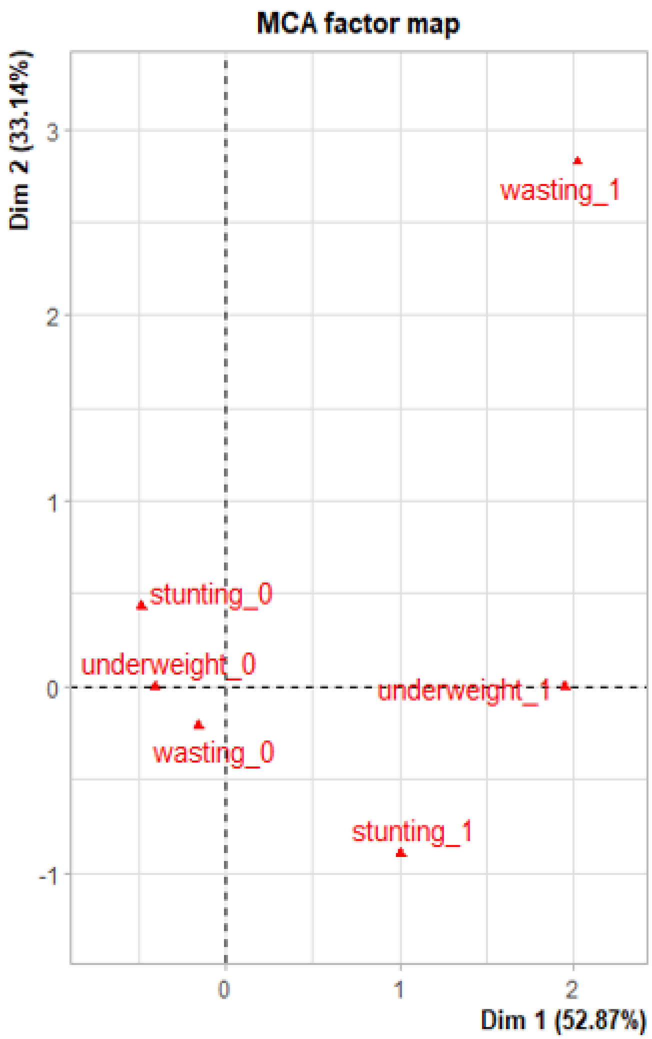

Figure 1

Multiple correspondence analyses of three indicators of child undernutrition