ajfand SCHOLARLY, PEER REVIEWED
AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
Volume 20 No. 1
February 2020
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

Afr. J. Food Agric. Nutr. Dev. 2020; 20(1): 15344-15364 DOI: 10.18697/ajfand.89.18730

LINEAR MEASUREMENT OF CHILD NUTRITION IN LIBERIA: AN EXPLORATORY STUDY

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ajfand SCHOLARLY, PEER REVIEWED
AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
Volume 20 No. 1
February 2020
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

ABSTRACT

This research utilizes the Rasch model to generate linear measures of nutrition from data on foods fed to children, thus providing a gauge with which to measure levels of child nutrition across a population. Linear measures are standardized, interval units that allow comparisons of latent constructs over time and among differing socio-economic variables. In this research, the latent construct is child nutrition. The data were drawn from the 2007 and 2013 Liberian Demographic and Health Surveys (DHS). The DHS provides data on foods fed to children, grouped by differing nutritional values. The Rasch software constructs interval measures from the yes/no responses given to the questions regarding foods fed to children. The measures then rank the foods fed to children from most frequently fed to least frequently fed. An examination of the resulting patterns indicates the nutritional levels of the children's diets. In addition to these patterns, the overall measure of each child's nutrition is also inferred from the responses to the questions as to the foods given to each child. Those measures may then be aggregated by the various socio-economic variables in the DHS database, such as geographic location, family's wealth status, or mother's educational level. The resulting analysis shows patterns that health care workers and policy-makers may use to target needed interventions in specific locations or for specific sub-groups of the population. The Liberian data used for this study show a decline in nutrition levels between 2007 and 2013 across all Liberian counties, as well as across educational and wealth categories. Using a subset of the data controlled for appropriate statistical power, a statistically significant decline in the level of nutrition was shown between the two years, in spite of impressive (25%) per capita GDP growth during this period. The results of the analysis demonstrate the feasibility of using a linear measurement model to establish standardized units by which child nutrition levels across DHS surveys may be legitimately compared.

Key words: Liberia, Demographic and Health Surveys, child nutrition, unidimensional measurement model, Rasch model

DOI: 10.18697/ajfand.89.18730

INTRODUCTION

That nutrition is vital for the proper development of children is beyond question. It is also well understood that children in less-developed countries are at risk because the general poverty of those countries affects the nutritional status of both mothers and infants [1-3]. A lack of nutritional literacy [4, 5] and food security [6, 7] also affect children's nutrition. But how should nutrition be measured? Nutrition is currently measured in several ways. Anthropometric measures and biomarkers are used to measure nutritional levels [8-10]. Australian nutritionists, attempting to measure nutrition in hospital settings, have devised another way to measure nutrition [11]. Linear measurement, based on a mathematical model that infers interval measures from ordinal data, offers yet another way to measure nutritional levels.

Linear measurement has been used in various studies related to nutrition. Linear measurement was used to identify the food security status of households in two states in North-Central Nigeria [6]. Linear measurement was also used to determine the extent to which dietary guidelines were followed [5]. In contrast, the present article breaks new ground by using a linear measurement model to derive measures of child nutrition from child feeding data taken from Demographic and Health Surveys (DHS) funded by the United States Agency for International Development (USAID). A review of the relevant literature finds no published research using the linear measurement model to measure child nutrition using DHS data. The purpose of this article is to demonstrate the utility of linear measurement in the study of child nutrition, showing how measures derived from this model can be used to compare nutritional levels across a variety of variables.

Demographic and Health Surveys

Demographic and Health Surveys were instituted in 1984, and have since been conducted in over 70 countries [12]. In Liberia, surveys were conducted in 1986, 2007 and 2013 [13].

Liberian DHS reports presented summary statistics from the respective surveys. Anthropometric measures were reported, and comparisons with prior years presented. For example, the 2013 Liberian report compared the findings from that year with the findings from the 2007 survey. Stunting decreased from 39% in 2007 to 32% in 2013; wasting dropped from 8% to 6% and the percentage of underweight children fell from 19% to 15% [13]. These figures are encouraging.

The foods consumed by young children were also analyzed. The report presented data on foods consumed the day prior to the survey by children three years of age or younger living with their mother. Foods were categorized by type. The results were disaggregated by age group and breastfeeding status, and showed the percentage of children in each age group and status who consumed each type of food. The DHS data were also disaggregated by age group, urban/rural location, region, mother's education, and wealth group. The data reported were percentages of children in each category, in dense tables usually covering one page in fine print [13].

While these statistics may be informative, they are not actionable. The data presented are in actuality "indigestible masses of numbers." [14]. The data as presented cannot be easily used to show patterns across socio-economic groups or trends between the studies. Moreover, the data cannot be used by decision-makers or health practitioners to target specific interventions to solve specific problems in specific locations. If, however, the raw counts of foods consumed by children may be shown to have "the structure of quantity" and fit a linear unidimensional measurement model, an "interval-scaled measure of a latent variable can be inferred" from the original raw scores [15]. The latent variable in this study is child nutrition, and the resulting measures of that latent variable may be used "to guide action – for example, to identify starting points for treatments or interventions" [16]. The analysis that follows will demonstrate the greater utility of the measurement approach as compared with the statistical approach used in current reports. This is the objective of this analysis.

The Importance of Child Nutrition

The World Health Organization (WHO), in its *Global Strategy for Infant and Young Child Feeding,* stated the following: "Infant and young child feeding are a cornerstone of care for childhood development" [17]. Researchers have demonstrated the connection between early childhood nutrition and cognitive development [18, 19]. The World Health Organization has provided guidelines for infant and young child feeding. Those guidelines include the following recommendations for daily feeding: (1) meat, poultry, fish or eggs; (2) milk or milk products, such as yogurt, with increased amounts if the child is not given the meat, fish, or poultry; (3) grains and legumes, especially if meat and dairy products are not consumed; (4) orange or yellow vegetables; (5) dark green leafy vegetables; (6) fruits, including dark fruits rich in Vitamin A; and (7) potatoes and other tubers [7]. WHO also includes red palm oil in its list of recommended foods, but palm oil is not universally recommended for good nutrition [20, 21].

In short, WHO recommends a balanced diet that includes all major food groups, especially dairy products, fruits and vegetables, and foods high in protein. The analysis that follows will compare feeding patterns, and thus the nutritional levels of Liberian children, with this recommended diet.

Nutrition is also related to income; the theory is the higher the income, the greater the level of nutrition. This relationship has been established empirically, but as the authors of a World Bank report note, "There is much evidence that nutrition and economic development have a two-way relationship. Improved economic development contributes to improved nutrition (albeit at a very modest pace)." [22]. Liberia has seen gains in its per capita gross domestic product (GDP); between 2007 and 2013, the years for which DHS data for Liberia are available, per capita GDP in Liberia increased by nearly 25% [calculations by the author from World Bank World Development Indicators, 2018]. This analysis will show the extent to which child nutrition has changed in Liberia in light of the substantial increase in per capita GDP.

Benefits of Linear Measurement

The study of human behavior often involves latent traits. Physical attributes, such as height or weight, are measured by calibrated instruments having invariant units.

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Calibrated instruments having invariant units are found much less frequently in social science research. Linear measurement allows "estimation of values in a shared metric framework" [23].

In this research, the latent trait is child nutrition, and the task is to find a way to measure that latent trait with a standard, invariant unit. The DHS data provide counts of the number of children who were fed various types of foods. Those counts, however, are merely numerals. Counts of the number of children given particular foods are easy to generate; the data files used for this analysis show the number of children who were given various foods the night before the day of the survey. Those numerals, however, are not measures of the children's nutrition.

In order to move from a count of the number of times a given food was fed to a child to an actual measure of nutrition, measures must be inferred from raw scores, as Salzberger [15] explained. Bond and Fox (2015) argue, "invariant, interval-level measurement scales [are] the standard for scientific measurement. Currently, the Rasch [linear unidimensional measurement] model is the only model that is focused on providing for the construction of [such] measures." [24]. Therefore, in this study, a linear measurement model was used to construct usable interval measures of child nutrition from ordinal observations of the foods fed to children in order to allow "estimation of values in a shared metric framework" [23].

Research Questions

This research seeks to answer five questions with respect to child nutritional levels, as evidenced by feeding patterns, in Liberia in 2007 and 2013:

1) What is the nutritional level of foods given most frequently to infants and children?
2) What is the nutritional level of foods given least frequently to infants and children?
3) Is there an increase in the nutritional levels of foods given to infants and children between 2007 and 2013, *given the 24.6% increase in per capita GDP between those 2 years?*
4) Do patterns of nutritional levels differ geographically?
5) Do patterns of nutritional levels differ across socio-economic variables?

The types of foods fed to children have a direct bearing on the nutrition they receive. As noted above, certain foods are more nutritious than others, and the more nutritious foods are the ones children should receive most frequently. By converting the raw counts of the various foods to linear measures, levels of children's nutrition may be identified and compared over time and across socio-economic variables.

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MATERIALS AND METHODS

In order to answer these questions, results from the 2007 and 2013 DHS surveys for Liberia were analyzed. These two years were the only years the DHS was undertaken following Liberia's extended civil war. The specific data set chosen for analysis was the breastfeeding file from each of the two surveys. The breastfeeding file contains over 900 variables. In addition to basic demographic data on household members, the breastfeeding file contains food intake data for mother and child. The breastfeeding file also contains data on other health-related variables.

The breastfeeding file for 2007 contained over 22,000 observations; the corresponding 2013 file contained in excess of 30,000 records. While most of the data items were identical in both years, there were variations in the coding structure for some items. The coding of the food groups differed somewhat between the two surveys; they were harmonized for analysis, leaving seventeen matching food groups. In addition, records having codes for "don't know" and "other" in response to which foods were given to children were deleted so that cases having only "yes" and "no" responses remained. County codes were also harmonized between the two years. Finally, all variables not needed for the analysis were deleted from the dataset, leaving 25 variables. The resulting files for 2007 and 2013 had 9,322 and 10,400 records, respectively.

After cleaning, the questions regarding child food intake were in dichotomous yes/no format. Data were fit to a model of linear measurement model in the form

$$B_n - D_i = \ln (P_{ni} / 1\text{-}P_{ni}),$$

where B represents the ability of person n, D represents the difficulty of item i, ln is the natural logarithm, and P_{ni} is the probability of interviewee n responding "yes" to the question [25]. The model generates two measures: one measure is of the item difficulty; the other is the sum of each person's choices of the various items, or, in other words, a person's overall "ability," or measure, with respect to the questions answered. Item difficulties are estimated on the same scale and in the same unit as the person measures. As the person selects or endorses more difficult items, the person's measure increases. A high person measure in this analysis means the person responded "yes" more frequently to foods less often fed to children. Using the demographic and geographic variables in the breastfeeding file, it is possible to aggregate the person measures by those variables and analyze overall trends in nutritional levels by socio-economic characteristics or geographic location.

The data were analyzed using Winsteps.4.1.0 [26]. The files for the two years were stacked for analysis so both years would lie on the same measurement scale. All analyses were performed on this stacked file.

Summary statistics for the person and item measures are reported in Table 1.

The approach to unidimensional measurement adopted in this study requires data to fit the model. The model chosen specifies linear, interval units of comparison. Fit statistics show the degree to which the data fit model. Infit statistics are weighted to be sensitive to the overall pattern of the data and are thus less influenced by outliers [24, 27]. Item fit statistics for the 17 items (food groups) were generally within the acceptable range of 0.5 – 1.5, with the exception of formula, which value was 1.7. The mean of the person infit statistic was 0.86; a mean of 1.0 is ideal. The standard deviation was 0.95, indicating the degree of variation in the measures. Based on these statistics, it can be provisionally concluded the data fit the model.

RESULTS AND DISCUSSION

Analysis of Item Measures – The First Two Research Questions

The paragraph preceding Table 1 explains that items more easily endorsed have lower measures than items more difficult to endorse. In Table 2, the 17 food groups are ranked in order of their respective item measures, with the lowest (easiest to endorse) food groups at the lower end of the scale, and the highest (hardest to endorse) at the upper end of the scale.

Table 2 shows the foods given to children more frequently, in both survey years, include water, bread/grains and foods made from red palm oil.

While there was some variation in the order of the food groups, in both years the healthier foods, such as vegetables, fruits, dairy products, and foods higher in protein, appear to be given much less frequently. When compared with WHO guidelines for child feeding, these data suggest it is unlikely Liberian children receive more nutritious foods with the frequency they require. The data confirm one recent report on Liberian agricultural value chains, which noted, “children continue to eat mostly rice-laden meals with palm oil” [28]. The data presented in Table 2 thus answer the first two research questions because the item measures show the foods most often given to children are lower in nutritional value and the foods least often given to children have higher nutritional values.

Figure 1 presents a plot of the data from the two tables, with 2007 item measures on the abscissa and 2013 item measures on the ordinate. The measures from the two years are highly correlated: *r*= .99.

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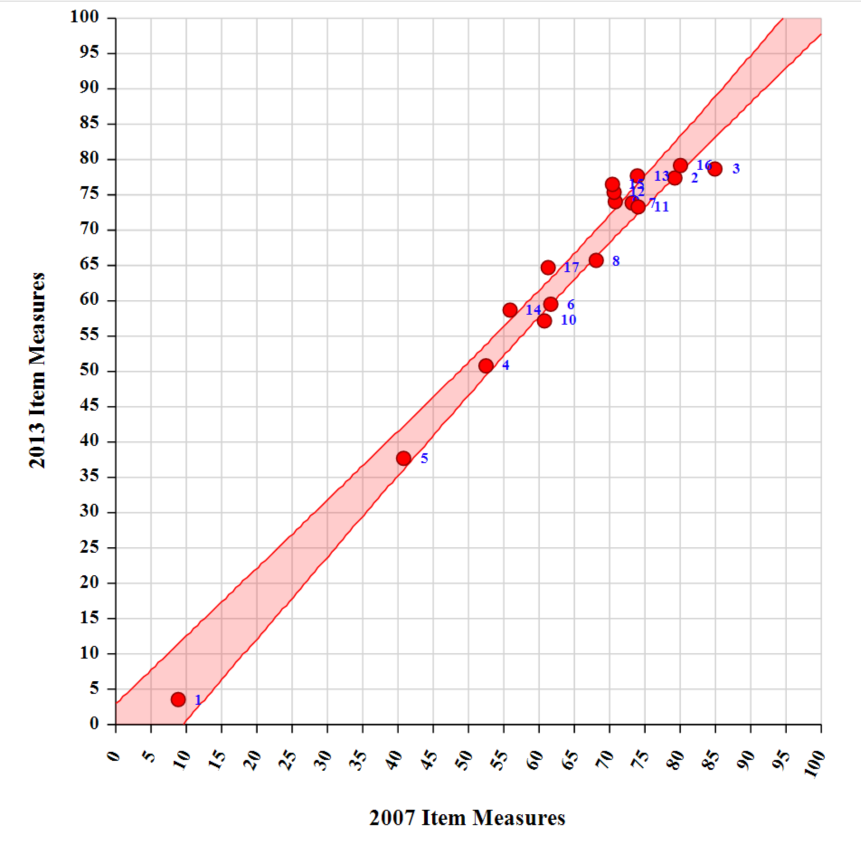
ISSN 1684 5374



Item Number	Name	Item Number	Name
1	Water	10	Greens
2	Milk	11	Vitamin A Fruits
3	Formula	12	Other Fruits
4	Red Palm Foods	13	Liver, etc.
5	Bread/Grains	14	Fish
6	Potato/Cassava	15	Legumes
7	Eggs	16	Other Dairy
8	Meat	17	Other Semi-Solid Food
9	Yellow Veg.		

Figure 1: Plot of the 2007 – 2013 Item Measures

Person Measure Analysis – Research Questions 3 - 5

DHS surveys capture data on educational level, household wealth, rural/urban residence, and county of residence. Person measures may be averaged and compared over these variables to show changes in the patterns of child feeding over time and among those variables. Analyzing the person measures in this manner permits responses to the final three research questions. Research question 3 asked whether there were any improvements in nutrition levels between the two years, given the nearly 25% increase in per capita GDP between the two years. The decline in the person measures between

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ISSN 1684 5374

the two years is depicted graphically in Figures 2 – 6. As can be seen in the figures, there was a noticeable decline in the person measures between the two years.

Research question 4 addressed geographic differences in nutritional levels. Aggregating the person measures by county code and by the urban versus rural indicator, the patterns may be observed in Figures 2 and 4.

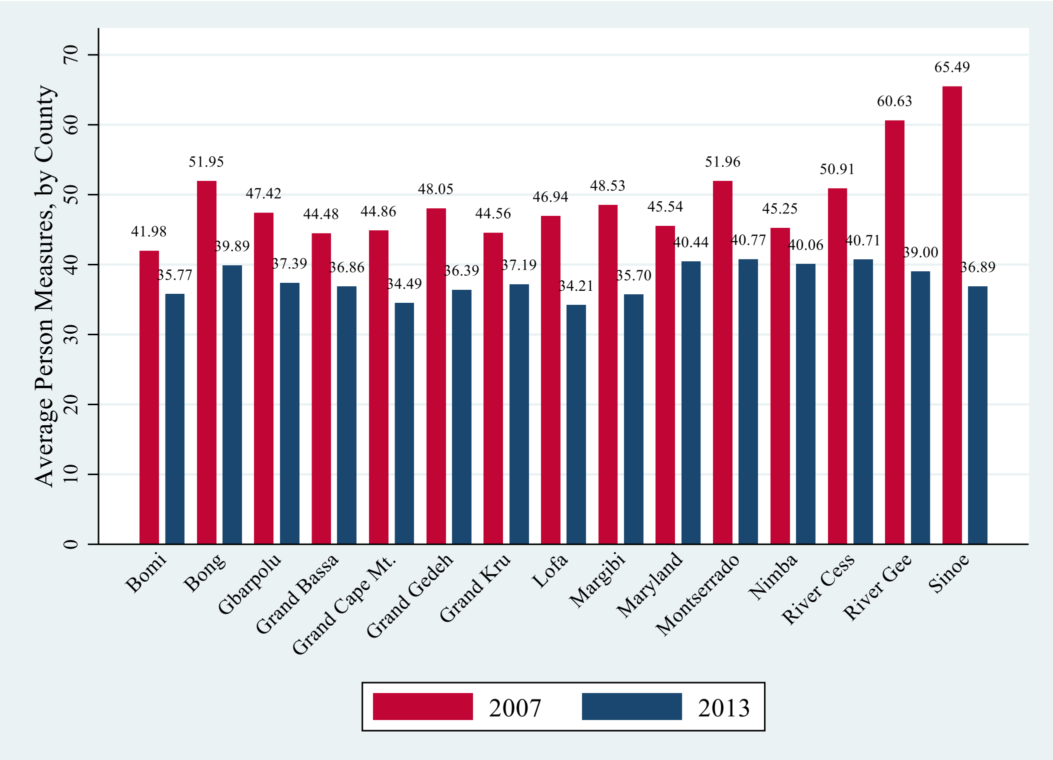

Figure 2: Comparison of Person Measures, Aggregated by County, 2007 – 2013

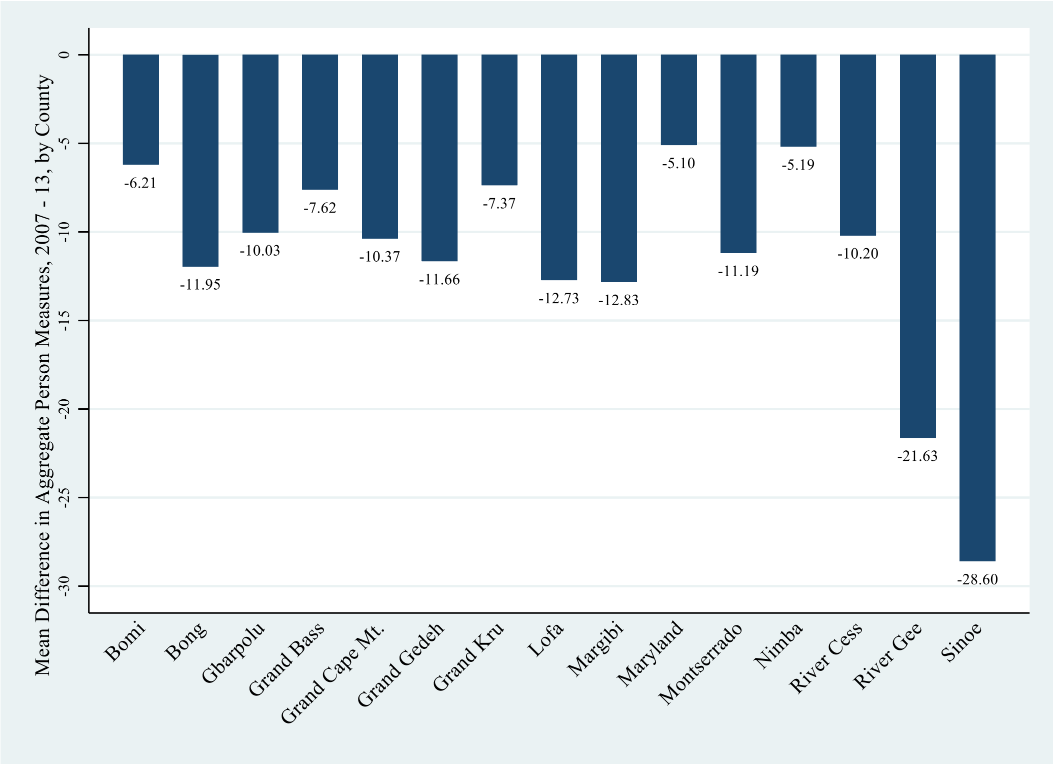

Figure 3: Mean Differences in Person Measures, Aggregated by County, 2007 – 2013

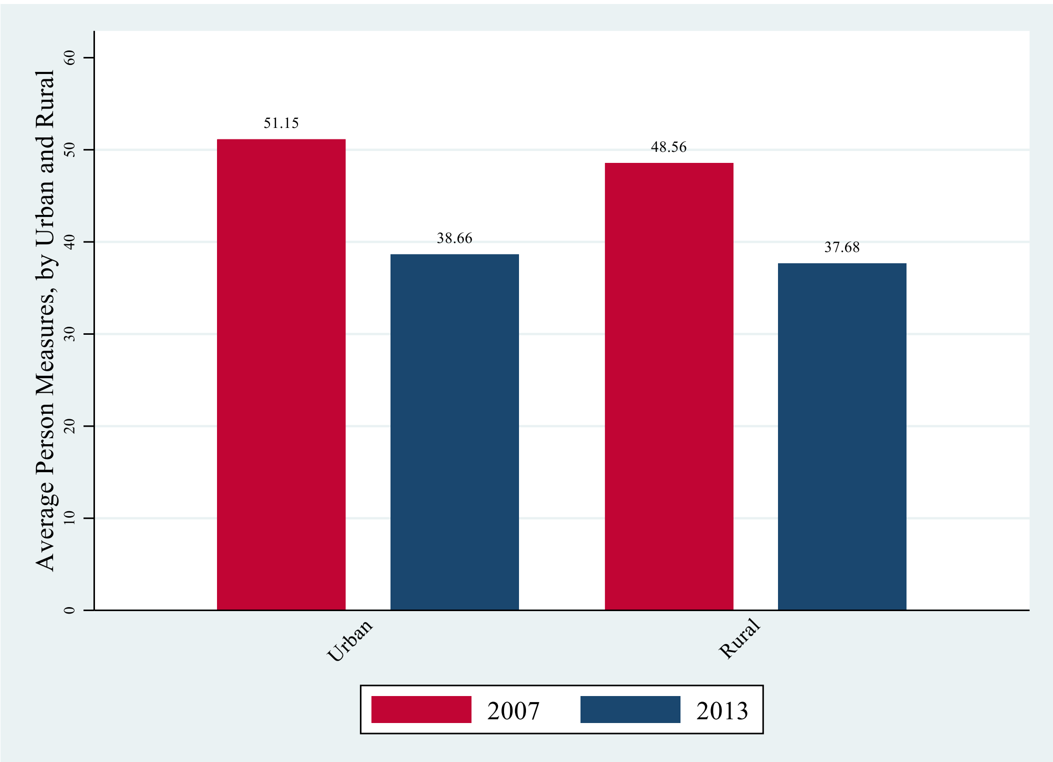

Figure 4: Comparison of Mean Person Measures, by Urban and Rural Status, 2007 - 2013

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The data as displayed on these charts answer research question 3 by showing a distinctive pattern – an overall decrease in the value of the person measures, and thus the nutritional levels, over geographic variables between the two survey years. This suggests the overall level of child nutrition in Liberia decreased, not increased, in spite of the 25% increase in per capita GDP between the two years. This decrease in nutrition levels is evident in every county; not one county showed an increase, thus answering research question 4. Of concern is the extreme decrease in two counties, Sinoe and River Gee. These two counties are located in the South-Eastern portion of Liberia. The data raise the question of what occurred in this part of Liberia that caused nutrition levels to drop so dramatically in a six-year period. Such geographic discrepancies have been noted by other researchers [29]. By displaying the person measures in this way, patterns can be seen so that, in Master's words, officials may begin "to guide action – [and] to identify starting points for treatments or interventions" [16].

Research question 5 asked if child nutritional levels differed over socio-economic variables. The two variables selected for this analysis were the level of the mother's education and the household wealth index. The education level coding is straightforward – no education, incomplete primary education, completed primary education, incomplete secondary education, completed secondary education, and higher education (incomplete or complete). The wealth index, however, is somewhat more complex. Survey designers determined that a better indicator of family economic status than household income was needed. Using a number of variables, including assets such as appliances, services such as water and electricity, means of transportation, type of flooring in the home, and home ownership, a wealth index was created. The index was then divided into quintiles, and each household included in the survey was assigned to one of the quintiles based on the household's responses to questions regarding the items in the index [30].

The person measures generated by the software were then aggregated by each of the subcategories of the wealth and education codes to yield the following patterns in the data.

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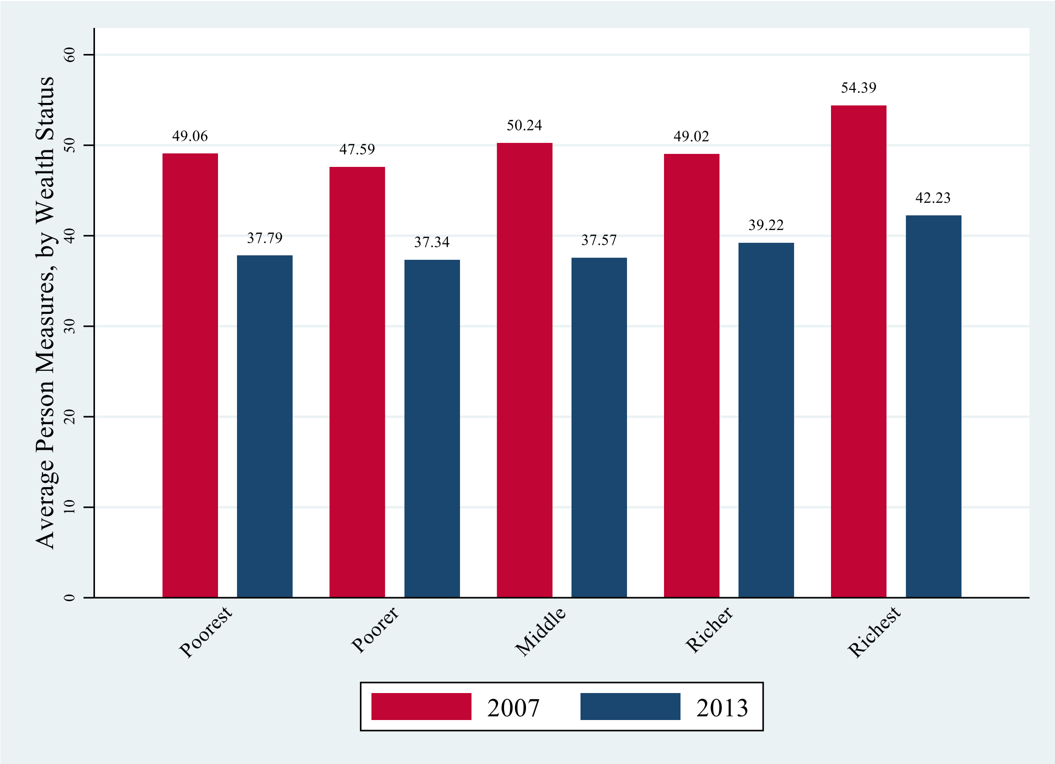

Figure 5: Comparison of Mean Person Measures, by Wealth Status, 2007 – 2013

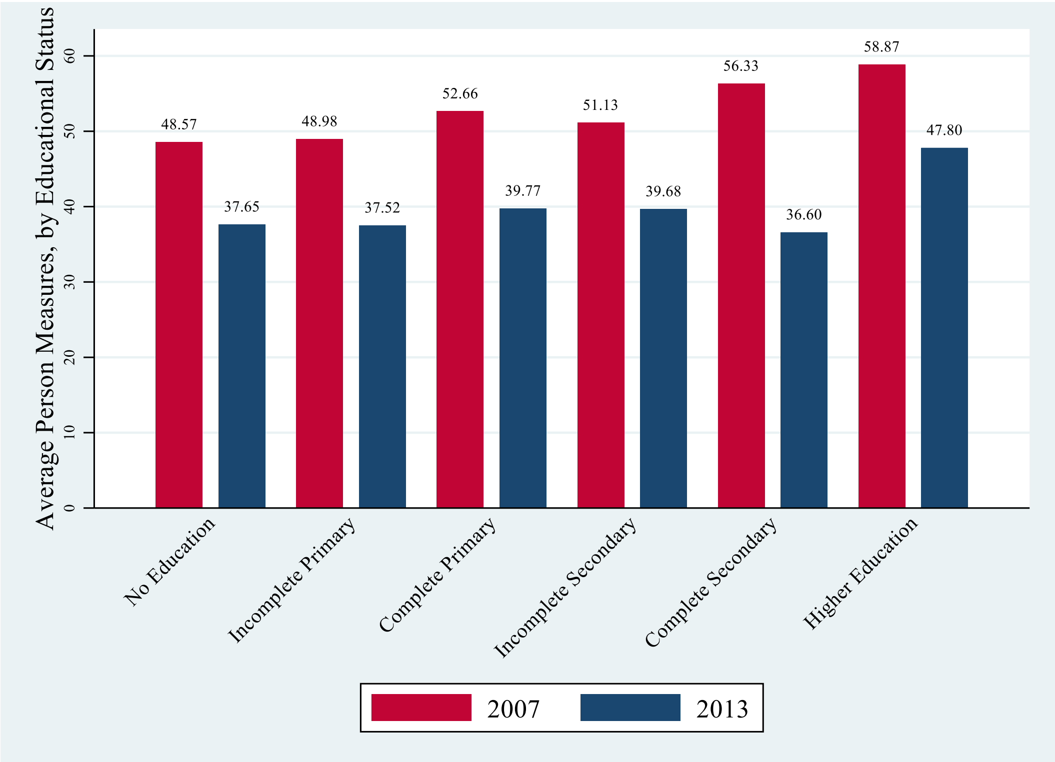

Figure 6: Comparison of Mean Person Measures, by Education Level, 2007 - 2013

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AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
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ISSN 1684 5374

Figures 5 and 6 show, as did Figures 2 – 4, a general decline in nutrition over the two surveys. Of note is the pattern for the year 2013 in Figure 5, showing relative stability in nutrition over the three lowest wealth groups; there does not appear to be an increase in nutritional levels as wealth rises until the highest wealth level. Other seeming anomalies are seen in Figure 6. In 2007, children of mothers with incomplete secondary education showed lower nutritional levels than children of mothers with complete primary education. In 2013, children with mothers with completed secondary education showed lower person measures than mothers in the four lower educational groups. These anomalies are discussed in the following paragraph.

Because of the large sample size, parametric statistics, such as *t*-tests, will show statistical significance. To determine if these changes were statistically significant, a random sample was drawn from the total of 19,722 observations. The sample size was selected to give an effect size of 0.5 and a statistical power of .95. The resulting sample of 176 cases was first analyzed with a *t*-test between the two years to determine if the observed drop in nutrition levels was statistically significant. The mean difference was 11.59, $t(174) = 3.52$, $p = .0006$, Cohen's $d = 0.53$. This test, on a sample drawn to give adequate statistical power, suggests the drop in nutrition levels was in fact statistically significant. But with respect to the mother's education and wealth variables, one-way ANOVA tests show no significant difference. These results are similar to those of a Bangladeshi study, which suggested low birth weight and child malnutrition were not affected by maternal education, household economic factors, or location (urban or rural) [31]. The same appears to be true in Liberia.

To further show the patterns seen in the entire data set hold true for the sample, Figures 3 – 6 were rerun against the smaller file. For the most part, the patterns remained the same; a general decline in aggregate mean person measures is observed. Because not all counties had data for all years in the sample, Figure 2 was not reproduced with data from the sample. Due to limitations on the number of figures, the educational level and wealth category figures for the smaller sample are not shown.

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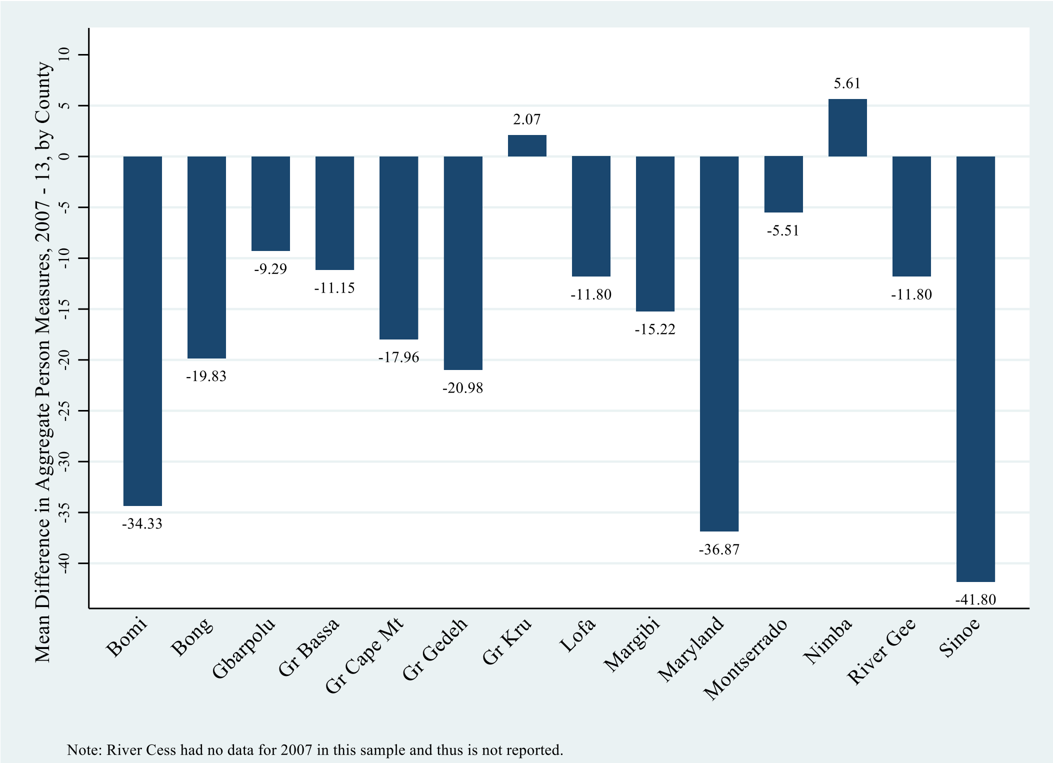

Figure 7: Mean Differences in Person Measures, Aggregated by County, 2007 - 2013 (176 observations)

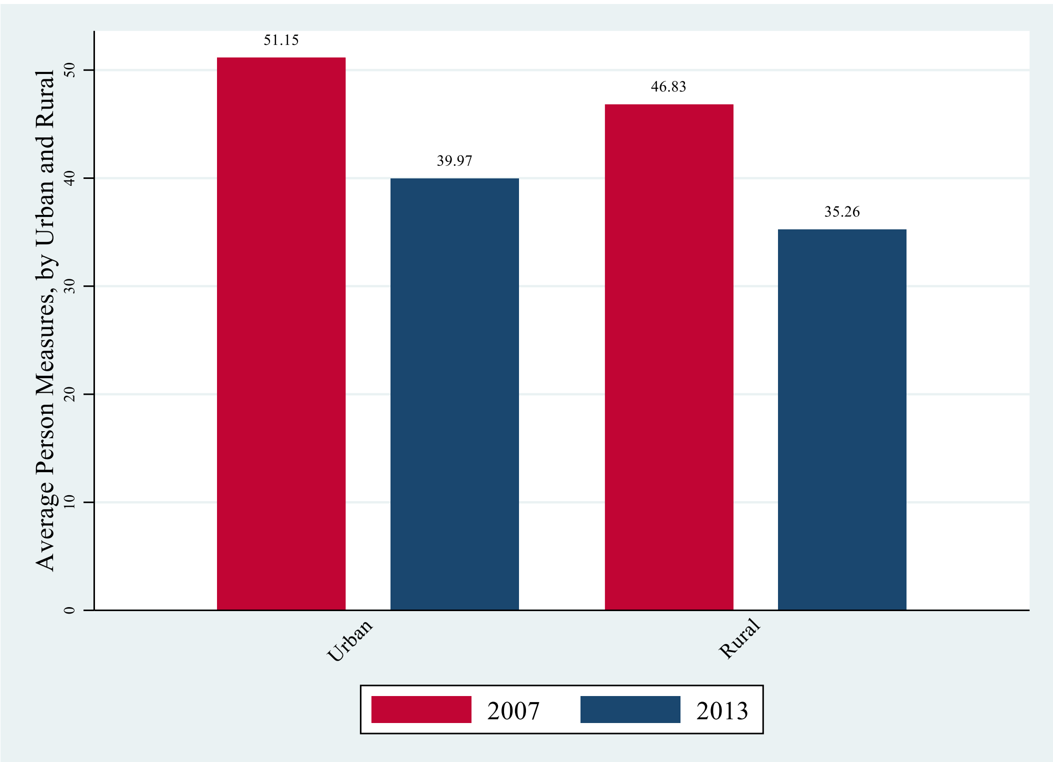

Figure 8: Comparison of Mean Person Measures, by Urban and Rural Status, 2007 – 2013 (176 observations)

The foregoing analysis suggests that despite Liberia's impressive gains in per capita GDP between 2007 and 2013, child nutrition, measured by a linear unidimensional model, may have declined. This is a disturbing finding and should concern Liberia's public health officials. The effects of impressive per capita GDP growth have not apparently enabled households to afford better food for their children.

This study has two limitations. The first is the infrequent nature of the DHS. While the analysis has shown the model can provide useful, even actionable, results, performing this analysis six years after the last survey provides little practical benefit. An analysis of this type must be done as soon as the data are released. Given available technology, the data may be gathered using self-scoring forms that could provide actionable information to nutrition counselors at the point of use. Such forms have been widely used in health care and education [32-34].

A second limitation appears to be the lack of familiarity with linear measurement of those who analyze DHS data. While a number of writers on nutrition, including African researchers, do utilize linear measurement [5 – 7], users of the DHS child nutrition data do not seem to be aware that the model can provide meaningful insights into child nutritional levels. This article is written to encourage the use of the unidimensional measurement model for this purpose.

Notwithstanding these limitations, use of linear measurement in nutrition studies should be expanded. Now that the utility of this approach has been demonstrated, the next step should be to take the results into the field and examine response patterns in specific locations to determine the reasons for the patterns the data show. This field work will be very labor-intensive. Yet getting the results into the field is crucial if the full value of measurement methodology is to be realized. This will require education of public health officials on the benefits of linear, unidimensional measurement. This will not be a quick or easy process. Over time, however, as the benefits of this type of analysis are proven, the utility of the results will hopefully convince officials to insist on linear measures over ordinal scores.

CONCLUSION

This article has demonstrated the utility of using measures to analyze child nutrition data from the Demographic and Health Surveys funded by USAID. The analysis demonstrates the beneficial use of measures in several ways. First, measures permit an ordering of foods given to children, from those more commonly given to those less commonly given. The ordering of foods in this way clearly shows which foods are most prevalent in children's diets, and which are least prevalent. This rank ordering permits health officials and others concerned with children's nutrition to see at a glance feeding patterns of Liberia's children. The results suggest children's diets in Liberia are relatively poor, and may have declined between the years for which data are available.

The second benefit of the use of measures, as opposed to statistics, is that the measures for each person in a given category, whether that is a geographic category such as a county, or a socio-economic category such as wealth or education, may be averaged for each category. This allows comparison and shows irregularities in the data that may indicate particular problems, such as the steep drop in nutritional levels in Sinoe County in 2013.

This paper appears to be the first attempt to use a linear unidimensional measurement model for analysis of DHS child nutrition data. Hopefully, other researchers will recognize linear measurement's value and use it in other contexts.

ACKNOWLEDGEMENTS

John Michael Linacre and William P. Fisher, Jr. assisted with technical matters regarding linear measurement. Thanks to participants in the 2017 International Outcome Measurement Conference and the 2018 International Objective Measurement Workshop, at which preliminary versions of this research were presented. The comments of three anonymous reviewers are acknowledged with appreciation. This study was self-sponsored with no outside funding.

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Table 1: Summary Statistics, Person and Item Measures

	Person Measures	Item Measures
Mean	43.37	63.72
Standard Deviation	20.67	18.09
Standard Error	8.49	0.20
Separation Index	2.12	86.92
Reliability Statistic	0.82	1.00
Cronbach's Alpha	0.84	Not computed

Table 2: Comparison of Item Measures for the 17 Food Groups, 2007 – 2013

2007			2013		
Item Measure	**S.E.**	**Food Group**	**Item Measure**	**S.E.**	**Food Group**
84.91	0.37	Formula	79.16	0.45	Other Dairy
80.03	0.31	Other Dairy	78.67	0.44	Formula
79.23	0.30	Milk	77.69	0.41	Liver, etc.
74.03	0.25	Vitamin A Fruits	77.40	0.40	Milk
73.93	0.25	Liver, etc.	76.49	0.38	Legumes
73.18	0.25	Eggs	75.37	0.36	Other Fruits
70.79	0.23	Yellow Vegetables	74.04	0.33	Yellow Vegetables
70.62	0.23	Other Fruits	73.86	0.33	Eggs
70.39	0.23	Legumes	73.30	0.32	Vitamin A Fruits
68.09	0.21	Meat	65.73	0.23	Meat
61.65	0.19	Potato/Cassava	64.70	0.22	Other Semi-Solid Food
61.28	0.19	Other Semi-Solid Food	59.52	0.20	Potato/Cassava
60.75	0.19	Greens	58.69	0.19	Fish
55.88	0.19	Fish	57.16	0.19	Greens
52.47	0.20	Red Palm Foods	50.79	0.19	Red Palm Foods
40.79	0.26	Bread/Grains	37.69	0.24	Bread/Grains
8.85	0.52	Water	3.54	0.55	Water

DOI: 10.18697/ajfand.89.18730

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Volume 20 No. 1
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ISSN 1684 5374

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ajfand SCHOLARLY, PEER REVIEWED
AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
Volume 20 No. 1
February 2020
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

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