Household Consumption and Expenditure Surveys and the prevalence of nutrient inadequacy

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1. Introduction

Micronutrient deficiencies contribute greatly to the global burden of disease, affecting children's physical and cognitive development, exacerbating disease, and resulting in decreased work capacity and earning potential (Bailey et al., 2015). Deficiencies most likely occur when people do not have access to micronutrient-rich foods, usually because they are too expensive to buy or are locally unavailable (Bailey et al., 2015).

The sufficiency status of individuals for micronutrients is best determined using biomarkers. Unfortunately, there are no biomarkers for all nutrients of interests, while other biomarkers may not be practical or feasible for widespread assessment or for use outside the clinical setting (Bailey et al., 2015; Carriquiry, 2017). Although, it is well recognized that dietary intake surveys underestimate energy and protein usual intake, it is not clear how minerals and vitamins estimates are affected and their methodological challenges reliance on individual quantitative intake surveys is inevitable (Carriquiry, 2017) and are being considered the best dietary data source for nutrient intake assessment (Gibson et al., 2017). However, individual quantitative dietary data are usually not representative at national level, especially in low and middle-income countries (Micha et al., 2018), or they are nationally representative but do not cover the whole diet as found for 19 European countries (Rippin et al., 2018). To supply this gap, national aggregate Food Balance Sheet (FBS) data have been used to assess the prevalence of nutrient inadequacy (Arsenault et al., 2015; Beal et al., 2017). However, FBS data refer to food available for human consumption; therefore, there is no information on how food is distributed within countries. Therefore, researchers have based nutrient inadequacy estimates on studies conducted in the 80's and 90's for assessing the level of inequality in nutrient consumption, and apply the same level of inequality, by nutrient, to all countries.

Another dietary data source that has also being used to infer food and nutrient consumption statistics are Household Consumption and Expenditure Surveys (HCES) (e.g., Alvarez-Sanchez, C. et al., 2021; Troubat and Sharp, 2021), which are usually representative at national, regional and/or urban-rural areas. These surveys are also used to estimate the variability in the distribution of usual dietary energy consumption (Borlizzi et al., 2017; Wanner et al., 2014); however, to the best of our knowledge, there has not been research on estimating the inequality in the distribution of usual nutrient consumption using HCES data.

1.1. Usual consumption and need for the full distribution of usual consumption

Dietary recommendations are intended to be met over a long-term period; therefore, using dietary intake data, the assessment of nutrient inadequacy requires the estimation of the distribution of individuals' usual consumption (e.g., individual's average level of daily consumption during a year). Usually, HCES collect households' food consumption and/or acquisition (i.e., apparent consumption, from now on refer to as food consumption) during a reference period of 7 or 14 days (i.e., short-term consumption), which are subject to different types of measurement error (FAO and The World Bank, 2018). Furthermore, seasonality (especially in countries where food dietary patterns are influenced by the time of the year and agricultural seasons) induce variation in nutrient short-term consumption. Therefore, to estimate the distribution of usual consumption, short-term consumption data should be adjusted for seasonality, and modeled statistically to separate and remove the variation that could be introduced by measurement error.

1.2. Assessment of risk for suffering micronutrient inadequacy

To assess the PoNI in a group, using dietary data, we need to define a threshold of intake under which individuals are at risk of suffering nutrient inadequacy. The appropriate threshold for assessing the level of nutrient intake is the Estimated Average Requirement (EAR) of the individuals in the group under study (Carriquiry, 1999). Having defined the threshold, the best method to estimate the PoNI is the probability approach; however, due to its complexity, the EAR cut-point method (a simpler version of the probability approach) could be used under a set of assumptions (Carriquiry, 1999). Even though, computing levels of inadequacy based on counting intakes below a referenced threshold has several limitations, as discussed by Smith et al. (2006), researchers have been applying it, using HCES data, without statistically treating the reported short-term food consumption data for variance inflation due to random measurement errors.

Finally, FAO has been applying a method like the EAR cut-point but based on a parametric approach, to estimate the probability that energy consumption of individuals in a group are below a referenced threshold (Cafiero, 2014).

1.3. The FAO method

The FAO-method extended to nutrients refers to the probability that a randomly selected individual from a population has a usual food consumption inadequate to satisfy his/her nutrient requirements consistent with long-term and good health. The methodology is based on a single log-normal distribution, of usual nutrient intake for the whole population, which corresponds to the daily per capita intake of an average person representative of the population. An average person is an artificial individual, who reflects all sexes, ages, and physiological status of the individuals in the population under study. This individual does not exist; it is not based on energy or nutrient requirements, and it is not a reference individual as it is the adult male for the Adult Male Equivalent (AME) factors (Weisell and Dop, 2012). We refer to this fabricated individual as an average individual. The concept of an average individual has been implicitly applied by researchers to assess the PoNI with Food Balance Sheets (FBS) data (e.g., Arsenault et al., 2015; Beal et al., 2017), and to assess the prevalence of dietary energy inadequacy with both FBS (FAO et al., 2021) and HCES data (Moltedo et al., 2014).

The main difference between the formula used for estimating the prevalence of undernourishment and the prevalence of nutrient inadequacy is the threshold. Given that, unlike dietary energy intake, nutrient intake is uncorrelated to nutrient requirements (IOM, 2000), the average of the distribution of nutrient requirements (EAR) is used as threshold. The PoNI is obtained as the cumulative probability that the usual nutrient intake (x) is below the EAR as shown in Equation 1.

$$PoNI = \int_{x<EAR} f(x|\mu; CV)dx \qquad \text{[Equation 1]}$$

where EAR is the average nutrient requirement for the population; μ and CV are, respectively, the mean and the coefficient of variation (which reflects inequality in access to food) that define the log-normal distribution of usual nutrient intake.

1.4. The FAO-CV-Approach

The FAO Statistics Division has developed a method (from now on referred to as the FAO-CV-Approach) to estimate a proxy of the variability in the distribution of usual per capita dietary energy consumption using HCES data. A research study was conducted on the same data used for this study, which revealed that (a) data should be statistically adjusted for random measurement error before estimating the proxy, and (b) the FAO-CV-Approach produced close estimates to the variability in usual dietary energy intake from individual quantitative dietary intake data applying the National Cancer Institute-Method (forthcoming).

Using household level data, it is not possible to isolate the intra-household variation in food consumption because there is no information about how total household food is distributed among household members. In the absence of this information, an assumption is needed; therefore, based on the correlation that exists between individuals' dietary energy intake and requirements, the FAO-CV-Approach assumes that intra-household food allocation is driven by energy requirements to meet household members' needs (i.e., without interfering factors such as gender inequities). In other words, individuals' energy requirements are the main driving force for intra-household food distribution (i.e., higher energy requirements imply higher amounts of food consumed)

The main determinant factors of energy requirements are sex, age, pregnancy/lactating status, body weight and physical activity level (PAL). The FAO-CV-Approach is based on the distribution of dietary energy consumption of an average individual in the group. This distribution does not have variation due to sex, age, and pregnant/lactating status, in much the same way as any sex, age, and physiological status distribution of usual consumption. Therefore, in the distribution of usual dietary energy consumption of an average individual the variation due to differences in energy requirement is assumed to be the result of differences in body weights and physical activity levels.

The FAO-CV-Approach (forthcoming) estimates the variability in the distribution of usual dietary energy consumption (DEC) through the coefficient of variation (CV), after having adjusted short-term food consumption data for seasonality and variance inflation due to measurement error. The CV is estimated as the sum of two components reflecting the between-individual variation in consumption: the CV due to factors affecting food accessibility CV|y, and the CV due to two relevant factors that affect individuals' energy requirements, i.e., body weight and physical activity level CV|r (See Equation 2).

$$CV_{usual} \cong \sqrt{CV|r^2 + CV|y^2} \quad \text{[Equation 2]}$$

Using HCES data, under the assumption of intra-household distribution based on energy requirements, the novelty of this studies are (a) extending the FAO-CV-Approach to estimate a proxy for the level on inequality in the distribution of usual nutrient intake (i.e., after having adjusted short-term food consumption data for seasonality and variance inflation due to measurement error) and (b) exploring the possibility of estimating the levels of nutrient inadequacy.

2. Methodology

2.1. Data

We used data from the 2015 Bangladesh Integrated Household Survey (BIHS), conducted from January to June of that year, which includes a typical household-level seven-day recall (7DR) module and two 24-hour recalls (24HR). We downloaded the 2015 BIHS database from the data repository Harvard Dataverse (IFPRI, 2016a). Detailed information on the sampling procedures, survey methodology, and questionnaires are provided elsewhere (IFPRI, 2016b). The 7DR collected information on household food consumption in the previous 7 days. The 24HR module, collected information on prepared foods consumed by the household in the previous 24 hours and the intra-household food allocation. A second round of the 24HR was conducted in 10% of the households. Information on household's socio-economic characteristics, sex, age, pregnant and lactating status, and height of household members were also used.

We used the sample with representativeness at national (rural) level. We excluded 124 households with incomplete surveys (refused, migrated or were not at home during survey) and children less than two years of age because a large number were breastfed. In the 24HR module, we also excluded individuals with missing data, who were away from home, or who did not consume any food. The final analytical samples consisted of 5,427 households with 22,319 household members for the 7DR module, and 5,424 households with 21,310 individuals for the 24HR module.

2.2. Selection of micronutrients

The criteria used in selecting the micronutrients included: public health relevance, wide availability of nutrient data in food composition tables/food composition databases (FCTs/FCDBs), and suitability of the information collected through HCES to analyze the nutrient under consideration. The nutrients analyzed were vitamin B1 (thiamine), vitamin B2 (riboflavin), vitamin C, vitamin A, vitamin B6, vitamin B12, zinc, and calcium.

Iron, folate, iodine, and sodium were considered but not selected. Iron was excluded because the distribution of requirements of some groups is skewed and, in this case, the methodology to adjust household level data for variance inflation would be very complex and would require a separate study. Folate was excluded because reliable data on folate content in foods are generally not available in FCTs/FCDBs (Olivares et al., 2006). In the case of iodine and sodium, the best method to assess intake is urinary collection and not dietary assessment, given that results are likely to be underestimated (Carriquiry et al., 2016; McLean, 2014).

2.3. Nutrient requirements

The dietary reference value used to estimate the PoNI was the EAR. Each sex-age group has its specific EAR, and the EAR of an average individual in the population is calculated as the weighted average of the EAR in each sex-age group, using the proportion of the population in each group as weight.

The source of zinc requirements was the International Zinc Nutrition Consultative Group (Brown et al., 2004); we used the requirements for both unrefined diets and mixed/refined vegetarian diets, to calculate the prevalence of inadequacy of zinc for the two diet types. The US Health and Medicine Division (HMD) values were used for calcium, and vitamin A expressed in Retinol Activity Equivalents (RAE) (Food and Nutrition Board. Institute of Medicine. National Academies, 2011). The EAR of vitamin B12 was taken from FAO and WHO (2004). The EARs of vitamins B1, B2, B6 and C were back calculated from the Recommended Nutrient Intake (EAR = RNI - 2 standard deviations) values published by FAO and WHO (2004), assuming a normal distribution of requirements with a CV of 10% (IOM, 2006).

2.4. Dietary energy requirements

Information on dietary energy requirements was needed to estimate the between-individual variation in usual dietary energy consumption due to body weight and physical activity level (i.e., the CV|r). In a sex-age group of individuals of the same sex and physiological status, and similar age exists a range of acceptable energy requirements, compatible with long-term good health, due to differences in individuals’ body weight and physical activity level. The FAO-CV-Approach uses the minimum (MDER) and maximum (XDER) levels of the range of requirements, for an average individual in the population, to derive the between-individual variation in consumption due to differences body weight and physical activity level. Assuming a normal distribution of energy requirements, the MDER and XDER were used as a proxy of the 1st and 99th percentiles of the distribution.

The MDER and XDER for the average individual at national (rural) level were calculated as the weighted average (using as weights the proportion of the population in each group) of the MDERs and XDERs, respectively, of 58 sex-age groups (out of 62 sex-age groups because children less than 2 years were excluded from the analysis). Each sex-age group's MDER and XDER was estimated using equations published by FAO (2004) to compute total energy expenditure. A detailed description of the equations and parameters used to estimate the MDER and the XDER are presented elsewhere (forthcoming).

2.5. Preparation of the food consumption data

24HR dataset

For the 24HR data, the food matching with food composition data was based on the way the foods were consumed (raw, boiled, fried, etc.). There were five potential pathways involving single-ingredient foods and multi-ingredient dishes: (1) *Single-ingredient food consumed raw* (e.g., apple) were matched with a raw item in the FCTs/FCDBs; raw weights were used; adjustment for non-edible portions was applied as necessary. (2) *Single-ingredient food items* consumed *cooked* (e.g., rice) were matched with a raw item in the FCTs/FCDBs; retention factors (Vásquez-Caicedo et al., 2007) were applied to account for alterations in nutrient content during cooking; raw weights were used; adjustment for non-edible portions was applied as necessary. (3) *Multi-ingredient dishes* consumed *cooked* with *no list of ingredients* (e.g., burger) were matched with cooked mixed dishes in the FCTs/FCDBs; reported cooked weights were used. (4) For *multi-ingredient dishes* consumed raw with a *list of ingredients* (e.g., salad), each item/ingredient was matched with a raw item in the FCTs/FCDBs; raw weights were used; adjustment for non-edible portions was applied as necessary. (5) For *multi-ingredient dishes consumed cooked with* a *list of ingredients* (e.g., bhuna curry), each item/ingredient was matched with a raw item in the FCTs/FCDBs; retention factors were applied to account for alterations in nutrient content during cooking; raw weights were used; adjustment for non-edible portions was applied as necessary. The sum of nutrient content in the raw ingredients' quantities adjusted for retention factor corresponds to the total content of the nutrient in the cooked weight of the multi-ingredient dish.

The content of vitamins A, B1, B2, B6 and C, calcium and zinc in foods were obtained from the Food Composition Table for Bangladesh (Shaheen et al., 2013). Where necessary, it was supplemented with values from, in this order: the Indian FCT (Longvah et al., 2017), the ASEAN Food Composition Database (Mahidol University Institute of Nutrition, 2014), and the U.S. Department of Agriculture (USDA) Food Data Central database (U.S. Department of Agriculture, 2019). The content of vitamin B12 in foods was obtained from the USDA database.

The amount of FAFH reported by households in the 24HR was very low (suggesting an underestimation); however, we decided against removing FAFH from the analyses to reflect the limitations of both survey tools in the analysis of food consumption data.

The two inter quartile range in the logarithm scale was applied, separately for each of the sex-age group, to detect outliers at the individual's daily nutrient consumption level. Outliers were then imputed with the corresponding value of the 25th or 75th percentile of the distribution, for low or high outliers respectively.

The potential effect of seasonality in nutrient consumption was removed by adjusting daily per capita nutrient consumption using a seasonal factor.

7DR dataset

For the 7DR data, the same nutrient conversion table prepared for the 24HR dataset was used. The nutrient content of single-ingredient foods was calculated as described for the 24HR. In the case of multi-ingredient dishes prepared and consumed away from home (FAFH), the 7DR module did not collect information on quantities consumed, only on the associated expenditures. Therefore, the nutrient content of these items was estimated based on their expenditures along with median (at region-income quintile level) at-home nutrient unit cost (Moltedo et al., 2018). This procedure may overestimate the nutrient content in foods prepared and consumed away from home.

Food quantities were adjusted for non-edible portions, which were compiled from the Food Composition Table for Bangladesh (Shaheen et al., 2013). In the absence of non-edible portion information for a given food (e.g., for some types of fish), we used the respective value of a similar item.

The two inter quartile range in the logarithm of household's food consumption (grams/capita/day) was applied to detect food quantity outliers in the 7DR data. Outliers were then imputed with the corresponding value of the 25th or 75th percentile of the food quantity distribution, for low or high outliers respectively.

The potential effect of seasonality in nutrient consumption and income was removed by adjusting daily per capita nutrient consumption using two seasonal factors, one for nutrient consumption and one for income.

Individuals' height collected in the 2015 BIHS were used to estimate energy requirements. Missing information on individual's height was imputed with Bangladesh's median height of the corresponding sex-age group.

Aggregate household's expenditures received from IFPRI colleagues were used as a proxy of household's income; this information was used with the 7DR data to adjust for variance inflation using the FAO-CV-Approach and to classify households in income quintile groups. Consumer and Food Price Indices (FAOSTAT, 2019) were used to deflate households' income and food expenditure respectively.

3. Estimating the PoNI

3.1. 7DR (household) data

We used one model (7DR-FAO-CV) to estimate the PoNI using 7DR data; the model is based on the probabilistic EAR cut-point method, assuming a log-normal distribution for usual nutrient consumption. To estimate the PoNI values at the national (rural) level we need a proxy for the mean and for the CV of the distribution of daily per capita usual nutrient intake. From the 7DR data we estimated a proxy for the mean, and after having adjusted for variance inflation a proxy for the CV. The latter was estimated following the FAO-CV-Approach used by FAO for dietary energy (i.e., computing two components of the CV, CV|y and CV|r), except that the dependent variable used in the regression to adjust for variation due to measurement error is the daily per capita nutrient consumption, not dietary energy.

The characteristics of the 7DR-FAO-CV is shown in Table 1.

Table 1 Model using the 7DR data to estimate the PoNI[a] at national (rural) level

Model name	Framework	Statistically adjusted for variance inflation	PoNI estimated applying	Mean source[b]	CV used in the model to estimate the PoNI
7DR-FAO-CV	Aggregate[c]	Yes, with FAO-CV-Approach	The probabilistic EAR cut-point method	7DR	CV estimated after applying the FAO-CV-Approach

Notes. CV, coefficient of variation; PoNI, prevalence of nutrient inadequacy; 7DR, seven-day recall.

[a] The PoNI values were estimated applying the probabilistic EAR cut-point method.

[b] The average nutrient consumption based on 7DR data was used as a proxy for the mean of the distribution of usual nutrient intake.

[c] One-single distribution of consumption for the whole population

We processed the 7DR data, following five main steps, to estimate both proxies.

Step 1. Transform households' total consumption into per capita consumption

Households with more household members are expected to report higher consumption. Therefore, a component of between-household differences in short-term consumption is due to the number of household members (or food partakers). This component of variation was removed by converting households' total nutrient consumption into households' per capita nutrient consumption.

Step 2. Estimate a proxy for between-individual variation in usual consumption due to socio-economic characteristics and geographic location (CV|y)

The national (rural) short-term distribution of nutrient consumption and households' income were adjusted for seasonality using seasonal factors. Then, the short-term distribution of nutrient consumption was adjusted for variance inflation due to measurement errors using a regression that models household nutrient consumption as a function of the per capita income and region of residence (Equation 3). The CV of the predicted distribution was used as a proxy for the component of variation in usual nutrient consumption corresponding to socio-economic characteristics and geographic location, CV|y.

$$\begin{aligned} NC_h = \ln(Income_h) + \ln(Income_h)^2 + Region_h + \ Region_h * \ln(Income_h) \\ + Region_h * \ln(Income_h)^2 + \varepsilon_h \end{aligned} \qquad \text{[Equation 3]}$$

where h refers to household; NC is the daily per capita nutrient apparent consumption in household h; Income is the daily per capita income in household h; $Region$ is a set of dummy variables indicating the region or province in which the household h is located; ε is the error term.

Step 3 Estimate a proxy for between-individual variation in usual consumption due to differences in individuals' body weights and physical activity levels CV|r

The procedure to estimate the CV|r is the same as explained elsewhere (forthcoming). In the 7DR-FAO-CV, the MDER and XDER, for the whole population, were computed, respectively, as a weighted average of the MDER and XDER of the 58 sex-age groups. The weights used were the proportion of the population in each group. The CV|r is based on dietary energy requirements; therefore, it is the same for all the nutrients.

Step 4. Estimate a proxy for the CV and the mean in the distribution of usual nutrient intake

In the 7DR-FAO-CV model, we estimated a proxy for the CV in the distribution of usual daily per capita intake at national (rural) level, using the CV due to socio-economic characteristics and geographic location (which value differs for each nutrient), and the CV due to differences in body weight and PAL (which value is the same for all the nutrients), both at national (rural) level, applying Equation 2.

The proxy of the mean in the distribution of usual nutrient intake was the weighted (using population weights defined as household weight times household members) average apparent nutrient consumption from the 7DR data. The average of short-term nutrient consumption is considered an unbiased estimate of the mean in the distribution of usual nutrient consumption.

Step 5. Estimate the PoNI at national (rural) level

The PoNI was estimated at national (rural) level, applying, only once, the probabilistic EAR cut-point method, under the assumption of a log-normal distribution.

The equations used to estimate the PoNI were Equations 4, 5 and 6.

$$PoNI = \emptyset(\ln(EAR), \mu, sd) \qquad \text{[Equation 4]}$$

$$\mu = \ln(mean) - 0.5 * sd^2 \qquad \text{[Equation 5]}$$

$$sd = \sqrt{ln(CV^2 + 1)} \qquad \text{[Equation 6]}$$

Where *EAR* is the Estimated Average Requirement; *mean* is the inferred average apparent consumption; CV is the coefficient of variation calculated as CV = sqrt ($CV|r^2 + CV|y^2$); and $\phi()$ is the normal probability density function.

3.2. 24HR (individual) data

To adjust for within-individual variability and estimate the PoNI, we applied the validated National Cancer Institute method (NCI) using the MIXTRAN and DISTRIB macros, version 2.1, developed by the Center for Disease Control (US National Cancer Institute, 2021). The NCI-Method produces estimates of usual consumption based on non-linear mixed regression models assuming that 24HR intake is an unbiased estimator of individuals' usual intake on the original scale. This means that biases such as underreporting implicit in self-reported dietary data or other systematic bias are not removed when estimates of usual consumption are obtained (Ahluwalia et al., 2016).

The one-part (or amount-only) approach was applied to the pooled sample to all the nutrients, except for vitamin B12, adjusting the estimates of usual intake for sex, age, region, and income decile group, and for sequence and weekend effects. The percentage of individuals with zero consumption of vitamin B12 was above 10%; therefore, we applied the correlated and the non-correlated two-part models, to the pooled sample, adjusting for sex, age, sequence and weekend effects (adjustment for region and income decile group was not conducted due to the large amount of time needed to process the data). The sex-age groups were defined according to each nutrient's requirement groups and sampling weights were used to infer the estimates at the population level. Using 24HR data, PoNI estimates were computed based on two models (24HR-NCI-Disag and 24HR-NCI-Agg). The characteristics of the 24HR models are in Table 2.

24HR-NCI-Disag (disaggregate framework)

In the 24HR-NCI-Disag model the PoNI was estimated by sex-age group using the NCI-method. For each sex-age group, we estimated the number of individuals with usual consumption below the group's EAR (i.e., with inadequate consumption). Finally, the prevalence at national (rural) level was obtained by dividing the total number of individuals with inadequate usual consumption by the total number of individuals. As this method estimates the PoNI at national (rural) level based on sex-age group's PoNI obtained from the NCI-method, we refer to it as a disaggregate framework. In this framework, a distribution of usual nutrient consumption is estimated for each sex-age group.

24HR-NCI-Agg (aggregate framework)

In the 24HR-NCI-Agg model the PoNI value at national (rural) level (i.e., for the whole population) is estimated using the NCI-method and the EAR of the whole population at national level. As this method is based on a single distribution of usual nutrient consumption at national (rural) level, we refer to it as an aggregate framework.

Based on this framework, it was possible to estimate the variability in usual nutrient consumption, as the CV equal to weighted standard deviation divided by the weighted average of the distribution, using the distribution produced by the NCI-method.

Table 2 Models using the 24HR data to estimate the PoNI[a] at national (rural) level

Model name	**Framework**	**Statistically adjusted for variance inflation**	**PoNI estimated applying**	**Mean source[b]**	**CV used in the model to estimate the PoNI**
24HR-NCI-Disag	Disaggregate	Yes, with NCI SAS macros	NCI-method	24HR	Not applicable
24HR-NCI-Agg	Aggregate	Yes, with NCI SAS macros	NCI-method	24HR	Not applicable

[a] The PoNI values were estimated applying the SAS macros of the NCI-method

[b] The average nutrient consumption based on 24HR data was used as a proxy for the mean of the distribution of usual nutrient intake.

4. Results and Discussion

We estimated the average and the level of inequality in usual consumption, the average requirements, and the prevalence of nutrient inadequacy from 24HR data and 7DR data. Table 3 shows the average consumption and requirements at national (rural) level. While the average requirements from both datasets are similar, for all nutrients the average consumption estimates from 7DR are higher than those from 24HR. This study confirmed that household-level surveys, with food modules typically found in HCES data, produce, for the whole population, higher estimates of average nutrient consumption than those obtained from individual-level data, as found by Karageorgou and colleagues (2018). It also confirms that both types of data estimate similar levels of EAR for the whole population.

Table 3 Average consumption and estimated average requirements at national (rural) level from 24HR and 7DR data.

	Average (person/day) from 24HR data	**Average (capita/day) from 7DR data**	**EAR (person/day) from 24HR data**	**EAR (capita/day) from 7DR data**
Calcium, mg	336	471	1084	1077
Zinc, mg, refined diet	8.9	11.8	6.6	6.6
Zinc, mg, unrefined diet	8.9	11.8	9.0	8.9
Vitamin A, mcg RAE	196	277	495	491
Vitamin B1 (Thiamine), mg	0.62	0.88	0.89	0.88
Vitamin B2 (Riboflavin), mg	0.60	0.84	0.91	0.91
Vitamin C, mg	55	94	35	35
Vitamin B6, mg	1.11	1.50	1.03	1.03
Vitamin B12[a], mcg	1.37	1.76	1.84	1.84

EAR, estimated average requirements; RAE, retinol activity equivalents.

[a] The correlated and the non-correlated two part models produced the same average consumption estimate.

The study presents, for the first time, levels of inequality in nutrient consumption for the whole population based on individual quantitative dietary data. The inequality in usual nutrient intake differs between sex-age groups within a country, and between countries at population group levels. However, some researchers have been assessing the national whole population prevalence of nutrient inadequacy, for several countries, using CVs from studies conducted in the 80’s and 90’s to specific population groups (e.g., Arsenault et al., 2015; Beal et al., 2017). This confirms the importance of producing national and up-to-date estimates of inequality levels in nutrient consumption for the whole population and the relevance of publishing the PoNI estimates with clear and detailed metadata including information on the data sources used in the analysis. The dataset analyzed in this study, also allows for the comparison of the CVs obtained from 24HR data with CVs obtained from 7DR data.

Table 4 presents three CVs estimated as a proxy for the distribution of usual nutrient intake. One of them was estimated with the 24HR data after having adjusted for variance inflation using the

NCI-method, another one corresponds to 7DR data without adjusting for variance inflation, and the third one was estimated with 7DR data adjusted for variance inflation.

As expected, the level of inequality in usual nutrient consumption from household level short-term food consumption data (i.e., without adjusting for variance inflation) is higher than the inequality obtained after having adjusted for variance inflation. The direction of the effect of a smaller CV on the prevalence of nutrient inadequacy depends on the position of the mean of the distribution with respect to the EAR. When the mean is higher than the EAR, a smaller CV results in a smaller prevalence, whereas when the mean is lower than the EAR, a smaller CV results in an enlarged prevalence.

Adjusting the 7DR data for variance inflation using the 7DR-FAO-CV model, produces closer CV estimates to those from the 24HR data, than the CV obtained from the 7DR short-term nutrient consumption distribution (i.e., without adjusting for variance inflation). Overall, the CVs at national (rural) level, from 7DR data, adjusted for variance inflation, are similar or higher than those estimated using 24HR data. While for vitamin A the CV estimates were similar (37.1% with 24HR data and 37.7% with 7DR data), for vitamin B12 the 7DR data produced a higher CV than the 24HR data (53.7% and 36.3%, respectively). Therefore, the level of gap varies with the nutrient (from 0.6 percentage points for vitamin A to 17.4 percentage points for vitamin B12).

Table 4 Inequality in usual nutrient consumption at national (rural) level, measured by the CV, from 24HR and 7DR data.

	CV Model 7DR-Emp[b] (%)	**CV|x[c] (%)**	**CV|y[d] (%)**	**CV Model 7DR-FAO-CV Model[e] (%)**	**CV 24HR[e] (%)**	**Difference between CV 7DR-FAO-CV and CV 24HR**	
						Percentage points	**Percentage change difference**
Calcium	62.2	9.0	42.3	43.2	34.0	9.2	27.1
Zinc	34.5	9.0	23.5	25.1	22.2	2.9	13.1
Vitamin A	81.9	9.0	36.6	37.7	37.1	0.6	1.6
Vitamin B1 (Thiamine), mg	45.7	9.0	31.7	33.0	24.4	8.6	35.2

Vitamin B2 (Riboflavin), mg	46.5	9.0	33.1	34.3	25.1	9.2	36.7
Vitamin C	59.8	9.0	34.5	35.6	30.4	5.2	17.1
Vitamin B6	38.6	9.0	26.0	27.5	22.5	5	22.2
Vitamin B12	83.1	9.0	53.0	53.7	36.3	17.4	47.9

CV, Coefficient of variation.

[a] The CVs correspond to the distribution of short-term nutrient consumption, using 7DR data.

[b] CV|x, Coefficient of variation due to differences in body weights and physical activity levels, using 7DR data.

[c] CV|y, Coefficient of variation due to differences in socio-economic characteristics and geographic location, using 7DR data.

[d] The CVs were estimated, using 7DR data, adjusting for variance inflation due to measurement errors by applying the FAO-method. CV=sqrt(CV|x * CV|x + CV|y * CV|y)

[e] The CVs were estimated, using 24HR data, as the weighted standard deviation divided by the weighted mean of the distribution of usual nutrient consumption, derived with the NCI macros after having adjusted for within-individual variation.

Table 5 shows the PoNI values derived at national (rural) level produced by the NCI-method using 24HR data. When comparing the PoNI estimates from the two 24HR models the higher differences, in percentage change, correspond to zinc (33.1%) within a refined diet and vitamin C (13.5%). For these nutrients, the national whole population PoNI value produced by the NCI-method, is higher than the correspondent estimate based on prevalence values generated by the NCI-method for each sex-age group. While for the other nutrients the average consumption was lower or like the EAR, for zinc within a refined diet and vitamin C the average consumption was higher than the respective EAR for the whole population and for the sex-age groups (results by sex-age groups are not presented).

Table 5 PoNI estimates using 24HR data, national (rural) level.

	PoNI 24HR-NCI-Disag (%)	**PoNI 24HR-NCI-Agg (%)**	**Difference in percentage points [percentage change]**
Calcium, mg	99.8	99.9	0.1 [0.1]
Zinc, mg, refined diet	15.4	20.5	5.1 [33.1]
Zinc, mg, unrefined diet	55.4	51.4	-4.0 [-7.2]
Vitamin A, mcg RAE	98.0	98.4	0.4 [0.4]
Vitamin B1 (Thiamine), mg	91.2	89.0	-2.2 [-2.4]

Vitamin B2 (Riboflavin), mg	92.0	91.8	-0.2 [-0.2]
Vitamin C, mg	17.1	19.4	2.3 [13.5]
Vitamin B6, mg	40.5	41.2	0.7 [1.7]
Vitamin B12[a], mcg	77.8	78.1	0.3 [0.4]

RAE, retinol activity equivalents.

PoNI model 24HR-NCI-Disag, using 24HR data, corresponds to disaggregate framework, adjusted for variance inflation, and applying the non-probabilistic EAR cut-point method with the NCI-macros.

PoNI model 24HR-NCI-Agg, using 24HR data, corresponds to aggregate framework, adjusted for variance inflation, and applying the non-probabilistic EAR cut-point method with the NCI-macros.

PoNI model 24HR-Probabilistic, using 24HR data, corresponds to aggregate framework, adjusted for variance inflation, the distribution of usual consumption obtained with the NCI-macros, and applying the probabilistic EAR cut-point method.

[a] The correlated and the non-correlated two part models produced the same PoNI estimates.

Given that nutrient requirements are defined by sex-age group, the PoNI at national level computed from sex-age groups' prevalence values produced by the NCI-method was selected as referenced values for comparison estimates from 7DR data. **Error! Reference source not found.** presents the PoNI values at national (rural) level for the referenced model, 24HR-NCI-Disag, and the 7DR-FAO-CV. For all the nutrients, the PoNI estimates from 7DR data are lower than those estimated using 24HR data. The minimum differences are for calcium and vitamin A (less than 2.1 percentage points and percentage change), which prevalence values are higher than 95%. The maximum difference in percentage change was for vitamin C (98.2%) and for zinc within an unrefined diet in percentage points (39.6). The main cause of these differences is the level of average consumption estimates, as shown in Table 3; the average nutrient consumption from 7DR data is higher (almost doubled in the case of vitamin C) than the correspondent estimate using 24HR data.

Table 6 PoNI values (%) at national (rural) level derived using models 24HR-NCI-Disag and 7DR-FAO-CV

Nutrient	PoNI Model 24HR-NCI-Disag[a]	PoNI Model 7DR-FAO-CV[b]	Difference in percentage points [percentage change]
Calcium	99.8	98.6	-1.2 [-1.2]
Zinc, refined diet	15.4	1.3	-14.1 [-91.6]
Zinc, unrefined diet	55.4	15.8	-39.6 [-71.5]

Vitamin A	98.0	96.0	-2.0 [-2.0]
Vitamin B1 (Thiamine), mg	91.2	57.4	-33.8 [-37.1]
Vitamin B2 (Riboflavin), mg	92.0	64.9	-27.1 [-29.5]
Vitamin C	17.1	0.3	-16.8 [-98.2]
Vitamin B6	40.5	10.4	-30.1 [-74.3]
Vitamin B12	77.8	63.0	-14.8 [-19.0]

[a] PoNI model 24HR-NCI-Disag, using 24HR data, corresponds to disaggregate framework, adjusted for variance inflation, and sex-age groups's PoNI values estimated with the NCI-macros.

[b] PoNI model 7DR-FAO-CV, using 7DR data, for both the average consumption and the CV.

Vitamin A. By 2011, the rural prevalence of subclinical vitamin A deficiency in the preschool age children, school age children, and non-pregnant non-lactating women in reproductive age were 19.4%, 20.2% and 5.4%, respectively, measured as the prevalence of serum retinol <0.7mmol/l (ICDDR et al., 2013). In Bangladesh rural children received vitamin A supplementation between 2011 (ICDDR et al., 2013) and 2014 (National Institute of Population Research and Training (NIPORT) et al., 2016) and in 2013 vitamin A fortification of soybean and palm oil was decreed (Raghavan et al., 2019). Instead, in this study, according to the 24HR and 7DR data, more than 95% of the rural population do not have an adequate level of dietary vitamin A consumption; the levels of requirements double the level of usual consumption. This analysis confirms that vitamin A estimates obtained from serum retinol analysis and dietary analysis are not comparable. The causes include the fact that most HCES, like the BIHS, do not collect information on food fortification or supplements, and the different criteria to assess the level of vitamin A inadequacy (biomarker analysis evaluates the risk of suffering xerophthalmia, while the dietary analysis performed in this study is related to the adequate levels of vitamin A stored in liver).

Vitamin B12. Using the 24HR data, Vitamin B12 was classified as an episodically consumed nutrient with more than 10.7% of individuals having zero consumption and 37.8% with a daily consumption higher than 0 mcg and lower than 1 mcg. Instead, using the 7DR data, which has a larger reference period for food consumption data collection, the number of households with daily per capita zero consumption is 0.5%, and 28.1% of households had a daily per capita consumption higher than 0 mcg and lower than 1 mcg. In both datasets, vitamin B12 usual consumption is lower than its requirements. Using the 24HR and 7DR data, 77.8% and 63.0%, respectively, of the rural population did not have an adequate level of dietary vitamin B12 consumption. This level of inadequacy is much higher than the level found for rural non-pregnant non-lactating women in reproductive age in 2011 (21.5%), considering a cut-off point of 200.0-300.0 pg/ml (ICDDR et al., 2013).

Zinc. In the case of zinc there is one distribution of usual consumption but two EAR values (one for a refined diet and a higher value for an unrefined diet). Within a refined diet, the average consumption estimates (11.8 mg/capita/day and 8.9 mg/capita/day for household and individual level data respectively) are higher than requirements (6.6 mg/capita/day), being. In this case the PoNI values are 15.4% and 1.3%, for 24HR and 7DR data respectively. For an unrefined diet, which implies higher requirements, while the average consumption from 7DR data is still higher than the EAR, the average consumption from 24HR data is like the EAR. As expected, an increase in the level of requirements determined higher levels of nutrient inadequacy (55.4% from 24HR data and 56.1% from 7DR data). A previous study based on the 2011-12 Bangladesh National Micronutrient Status Survey in 2011-12 estimated that 48.6% of preschool-age children and 57.5% of non-pregnant non-lactating women in reproductive age had inadequate levels of zinc consumption (ICDDR et al., 2013). However, those estimates are wrongly based on a comparison of zinc consumption adjusted for bioavailability with recommended dietary allowance (RDA). The appropriate comparison would have been between dietary (i.e., not adjusted for bioavailability) zinc consumption with dietary average requirements (i.e., not RDA) defined for the level of bioavailability, or dietary zinc consumption adjusted for bioavailability with physiological (i.e., not dietary) average requirements.

Calcium. According to all the models, indistinctive of the dataset used, the level of calcium inadequacy in the population is extremely high (more than 98%). The high level found in this study is in concordance with the research made by Bromage and colleagues (2016), who identified online databases and several survey reports related to calcium levels of intake in Bangladesh, which analysis suggested an extensive dietary calcium inadequacy.

Vitamin C. Discrepancies appear in the case of vitamin C, where the PoNI from household level data is almost 0%, while using individual level data is 17%. In this case, usual consumption estimated with both types of data are higher than requirements; however, usual consumption using 7DR data (93.6 mg/capita/day) almost doubled usual consumption estimates with individual level data (54.9 mg/capita/day). This relative low level of dietary vitamin C inadequacy might be expected in rural areas as low vitamin C intake, is usually found in populations consuming monotonous diets, such as refugees and prisoners (WHO, 1999).

Vitamin B1 (Thiamine) and Vitamin B2 (Riboflavin). For both nutrients, using both datasets, usual nutrient consumption is lower than requirements; however, mean consumption estimates from 7DR are closer to requirements than those from 24HR data. Therefore, for these vitamins, the different levels of usual consumption estimates are the cause of estimating different PoNI values (57.4% for vitamin B1 and 64.9% for vitamin B2 from 7DR data, and more than 90% for both vitamins with 24HR data).

Vitamin B6. Discrepancies also appear for vitamin B6, average vitamin B6 consumption from household level data is higher than requirements, while from individual level data is similar, though higher, to requirements. Using 24HR data the level of vitamin B6 inadequacy at national (rural) Bangladesh is 40.5%, while the prevalence level using 7DR data is 10.4%.

Overall, most differences in PoNI estimates between 24HR and 7DR data are due to differences in average consumption estimates between both data types. Therefore, to eliminate the effect of average consumption estimates on the PoNI values we replaced the average consumption from the 7DR data with the corresponding value estimated from the 24HR data. Table 7 presents the new PoNI estimates, where the minimum differences are for calcium and vitamin B2 (less than 0.3 percentage points and percentage change), which prevalence values are higher than 92%. The maximum difference in percentage points and percentage change was for vitamin C (4.9 and 28.7% respectively). This implies a decreased of about 12 percentage points in the PoNI gap between both types of data for vitamin C.

Therefore, based on the overall decrease in PoNI gaps between both types of data, we could consider that the CV estimated from adjusted 7DR data could be used as a proxy for the level of inequality in the distribution of usual consumption, even for episodically consumed nutrients such as vitamin B12 in Bangladesh.

Table 7 PoNI values (%) at national (rural) level derived using models 24HR-NCI-Disag and 7DR-FAO-CV using 24HR average consumption.

Nutrient	PoNI Model 24HR-NCI-Disag[a]	PoNI Model 7DR-FAO-CV using 24HR average consumption[b]	Difference in percentage points [percentage change]
Calcium	99.8	99.9	0.1 [0.1]
Zinc, refined diet	15.4	13.9	-1.5 [-9.7]
Zinc, unrefined diet	55.4	56.7	1.3 [2.3]
Vitamin A	98.0	99.7	1.7 [1.7]
Vitamin B1 (Thiamine), mg	91.2	90.1	-1.1 [-1.2]
Vitamin B2 (Riboflavin), mg	92.0	92.2	0.2 [0.2]
Vitamin C	17.1	12.2	-4.9 [-28.7]
Vitamin B6	40.5	44.4	3.9 [9.6]
Vitamin B12	77.8	79.9	2.1 [2.7]

[a] PoNI model 24HR-NCI-Disag, using 24HR data, corresponds to disaggregate framework, adjusted for variance inflation, and sex-age groups's PoNI values estimated with the NCI-macros.

[b] PoNI model 7DR-FAO-CV, using 24HR data for the average consumption and 7DR for the CV.

5. Strengths and Limitations

The main strength of this analysis is the fact that the 7DR and the 24HR modules were conducted to the same households, and the 24HR module had a second round for 10% of the households. The latter is of outmost importance to estimate the distribution of usual consumption by treating short-term individual dietary intake data for variance inflation. On the other hand, one of the limitations of the analysis was the intra-household food distribution. In the 24HR module one person was responsible for reporting how at-home food was distributed among household members and what everyone consumed away from home. Therefore, one could expect that in the 24HR module individuals' consumption away from home were underreported. While underreporting is expected from 24HR data, nutrient consumption away from home obtained from 7DR data is expected to be overestimated because it is based on food expenditures and not food quantities. Another limitation that applies to both modules, is that we excluded from the analysis children under 2 years because a large number were breastfed. Finally, the 7DR data lacked information on intra-household food distribution, forcing the assumption of intra-household nutrient consumption driven by energy requirements.

6. Conclusions

This study confirms previous findings that survey data, based on food modules typically found in HCES, produce higher estimates of average nutrient consumption than those obtained from individual-level data. Consequently, estimated levels of nutrient inadequacy based on household level data are lower than respective levels from individual level data.

The study also highlights that the level of inequality in the distribution of usual nutrient consumption could be proxied based on adjusted 7DR data for variance inflation using the FAO-method. However, further analysis is needed to confirm the latter based on surveys including 2-rounds of a 24-hour recall performed to individuals and a household food module to the same sampled households.

Overall, producing and informing estimates of nutrient inadequacy based on household level data, as collected in HCES, is complex and should be interpreted with caution.

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