Statistical Journal of the IAOS 40 (2024) 279–288
DOI 10.3233/SJI-230086
IOS Press

Computing levels of nutrient inadequacy from household consumption and expenditure surveys: A case study[1]

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Abstract. This paper presents an approach to estimate the between-subject variability in nutrient intake (through the coefficient of variation [CV]) and a method to estimate the prevalence of nutrient inadequacy (PoNI) (for eight micronutrients) using household consumption and expenditure survey (HCES) data. Prevalence values are compared to individual-level estimates derived using the National-Cancer-Institute method. Data come from the 2015 Bangladesh Integrated-Household-Survey, which conducted a household-level 7-day recall (7DR) and two rounds of individual-level 24-hour recall (24HR), filled by one respondent on behalf of all members, for the same rural households. The PoNI values based on 7DR are lower than those calculated from 24HR data, due to the larger average intake estimates from 7DR data. After controlling for differences in average intake estimates and adjusting household-level data for random measurement errors, the PoNI values from 7DR and 24HR data are remarkably close. This highlights the potential use of HCES data (conducted according to international agreed standards) for estimating the level of between-subject variability in usual nutrient intake in a population. The CVs from HCES could be used to compute the PoNI using average intake estimates from individual-level data; and the inadequacy of global nutrient supply using Supply and Utilization Accounts data.

Keywords: Nutrient inadequacy, household consumption and expenditure surveys, between-subject variability, national cancer institute method

1. Introduction

1.1. Background

Inadequate diets are one of the main contributors to the global burden of disease [1] and are threatening the sustainability of our planet [2]. Nevertheless, there is a big gap in the availability of large-scale nationally representative dietary data, particularly in low- and middle-income countries (LMICs) [3]. The gap in availability of dietary data hampers the design and implementation of robust food and nutrition policies, as highlighted in the 2022 report of the High-Level Panel of Experts on Food Security and Nutrition [4].

Individual quantitative dietary intake surveys are the best and preferred source of dietary data. However, although there has been an increase in the number of dietary surveys conducted across the world [5], the availability of datasets with multiple 24-hour recalls, representative of the entire population, is scarce [5,6]. Data from multiple 24-hour recalls are necessary to estimate the usual intake distributions of nutrients and the prevalence values of nutrient inadequacy (PoNI).

To attempt to partially fill this data gap, food consumption data from household consumption and expenditure surveys (HCES) have been used to inform food security and food consumption analyses [7,8].

[1]The Open Access publication of this paper was supported by funding from the WorldBank Development Data Group and the Food and Agricultural Organization of the United Nations.
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The term HCES is given to a family of surveys developed to inform economic policy, which usually represent the entire population in a country. By 2019, more than 845 surveys were conducted in at least 137 countries [9]. The HCES typically include a module that collects information on food acquired and/or consumed at household-level (i.e., apparent food consumption and nutrient intake; hereafter referred to as food consumption and nutrient intake), where one person (typically the one in charge of food preparation) reports the types and amounts of food. The reference period is typically seven or 14 days, and food that is wasted or given away is not accounted for. This contrasts with individual-level quantitative dietary intake surveys which are purposely designed to collect detailed information on individuals' food consumption. The assessment of food prepared and consumed away from home (FCAH) is also better performed through individual-level surveys that are designed to appropriately capture the type and quantity of FCAH, while HCES typically only capture the monetary value dimension of FCAH.

1.2. *Scope of this study*

Some researchers have used HCES data to estimate the PoNI [10,11,12]. They have applied the Estimated Average Requirement (EAR) cut-point method [13] and allocated food consumption to household members based on their energy requirements. In these studies, HCES food consumption data are not adjusted for random measurement errors that affect the distribution of food consumption and can bias PoNI estimates.

This paper aims to fill the global dietary data gap and to address previous methodological issues in estimating the PoNI from HCES data. Using household-level food consumption data, we develop (a) an approach to estimate the between-subject variability (measured through the coefficient of variation) in the distribution of usual nutrient intake, and (b) a method to estimate the PoNI. Both the approach and the method proposed in this study are based on those developed by the Food and Agriculture Organization of the United Nations (FAO) to estimate the prevalence of undernourishment (PoU) [14,15]. The PoNI values are compared to estimates from individual-level data derived using the National Cancer Institute (NCI) method.

2. Methods

2.1. *Data and data preparation*

We used data from the second round of the Bangladesh Integrated Household Survey (BIHS), conducted between January and June 2015. The BIHS is one of the very few surveys in the world including a household-level seven-day recall (7DR) module, and two rounds of a household-level 24-hour recall (24HR). Both modules are designed to capture at-home and away from home food consumption. The 7DR collects information on food consumption for the entire household in the previous seven days, with no information on the allocation of that food to individual members. The first 24HR round covers the entire sample, while the second round covers only ten percent of the households. The 24HR module is not a true individual-level 24-hour recall, but the data can be individualized because the female household member, in charge of food preparation, responded on behalf of children and adults in the household. The sample is statistically representative of rural Bangladesh based on sampling weights provided for each data type. The sample design consisted in two-stages stratified random sampling, the selection of primary sampling units (PSU) and households within each PSU, using the sampling frame developed from the 2001 population census of Bangladesh [16]. Data were downloaded from the Harvest Dataverse repository [17]. The final analytical samples consist of (a) 5427 households (representing 22319 household members) for the 7DR module, and (b) 5424 households (representing 21310 individuals after excluding those that were fasting, unwilling to consume food, breastfed children, etc.) for the 24HR module (considering both rounds).

For the analysis, we selected vitamins A, B1 (thiamine), B2 (riboflavin), B6, B12 and C, calcium, and zinc, for their public health relevance and their availability across food composition tables (FCT) and databases. Iron was excluded due to the skewness in the distribution of requirements among some groups of women. After careful consideration and analysis, folate was excluded because of the lack of folate data in FCTs that is needed to perform analyses of the prevalence of folate inadequacy. Recommended folate intakes are expressed in dietary folate equivalents (DFEs) [18,19], and, based on our own research of nutrient availability in FCTs [20], out of 66 FCTs assessed, only 10 of them published DFEs and only one published all the needed components to compute DFEs. In 2023, Bouckaert and colleagues [21] further performed a critical evaluation of folate data in European and international databases and suggested the adoption of DFEs in the future provided that both folic acid and total folate are available.

The source of the nutrient requirements was the same as those used in the validation of the Minimum Dietary

Diversity Score for Women of reproductive age [22], except for zinc. The sources were the US Health and Medicine Division [23] for vitamin A (in retinol activity equivalents, RAE) and calcium, and the FAO and the World Health Organization [24] for vitamins B1, B2, B6, C and B12. In the case of vitamins B1, B2, B6 and C, the requirements were calculated based on the recommended nutrient intakes assuming a normal distribution of requirements with a coefficient of variation of ten percent [25]. For zinc we used the requirements from the International Zinc Nutrition Consultative Group [26] defined for an unrefined diet, because the food supply in Bangladesh correspond to an unrefined diet (i.e., more than 50 percent of the dietary energy is coming from unrefined cereals or legumes and protein intake is very low) [27].

To convert quantities to nutrients we followed the FAO/International Network of Food Data Systems (INFOODS) food matching guidelines [28] and we adjusted food quantities to account for non-edible portions. Foods were matched to the raw or prepared (e.g., marmalade) form of the food unless otherwise specified from the survey food list. Based on the 24HR information on food cooking methods, nutrient content in raw foods were adjusted using retention factors, to account for alterations in nutrient content during cooking [29]. We used the United States Department of Agriculture (USDA) database [30] for vitamin B12, and the food composition table for Bangladesh [31] for the other nutrients.

In the 7DR module, only monetary values were reported for FCAH; therefore, we could not perform the food matching. Instead, the contribution of these items to households' nutrient intake was estimated using the amount spent on FCAH and the median nutrient unit cost from at-home intake at region-income quintile levels. The nutrient unit cost was estimated for each household and each nutrient as the ratio of at-home total food monetary value and at-home total quantity of nutrient consumed.

We applied the central interquartile range method to detect outliers (a) on the logarithm of the distribution of daily quantity, in grams, consumed per person for each food item for the 7DR data, and (b) on the logarithm of the distribution of daily nutrient intake per person for each nutrient for the 24HR data. Outliers at the left hand of the distribution were replaced by the 25th percentile value (corresponding respectively to less than 0.01 percent and less than 0.95 percent of the total observations for the 7DR and 24HR). Outliers at the distribution's right hand were replaced by the 75th percentile value (corresponding respectively to less than 0.01 percent and less than 0.22 percent of the total observations for the 7DR and 24HR). We adjusted the distribution of nutrient intake of both data types for a potential effect of seasonality using the ratio of the nutrient's weighted average intake, in the region, from January to June by the nutrient's weighted average intake in the household's month and region.

2.2. *FAO's probabilistic method to estimate the PoU and proposed extension to estimating the PoNI*

To estimate the PoU, the FAO Statistics Division has developed a method (hereafter referred to as the "FAO probabilistic cut-point method") [32,33]. This method is based on a single distribution for the entire population, which corresponds to the daily per capita (hereafter referred to "per person") usual dietary energy intake of an average person representative of the population. Under the assumption of lognormality, the distribution is characterized by the mean and the between-subject variability measured through the coefficient of variation (CV) (i.e., standard deviation divided by the mean) [34].

The EAR cut-point method assumes that the distribution of usual intake is statistically independent from the distribution of requirements and counts the individuals whose usual intake is below the mean of the distribution of requirements. For vitamins and minerals there is no conclusive evidence that this assumption is violated [35,36]. However, in the case of dietary energy, intake is highly correlated with energy requirements for people that are adequately nourished, while the correlation breaks down for the undernourished and the over nourished [37]. To overcome the issue of correlation between intake and requirements and to acknowledge the variability in energy requirements, when estimating the PoU the FAO (a) uses as cut-point the minimum of the range of energy requirements for the average individual (known as the Minimum Dietary Energy Requirement); and (b) estimates the CV in the distribution of usual dietary energy intake of the average individual using HCES data. The CV is estimated as the sum of two components [34] (a) the between-subject variability in dietary energy intake due to differences in socio-economic and geographic characteristics, and (b) the between-subject variability in dietary energy intake due to differences in energy requirements (because of differences in body weights and physical activity levels across individuals of the same sex and similar age).

When the FAO probabilistic cut-point method is used to estimate the PoNI assuming two independent distributions (i.e., intake and requirements), the CV of the distribution of usual nutrient intake corresponds only to differences in socio-economic and geographic characteristics, and the cut-point threshold corresponds to the average nutrient requirements.

2.3. *Prevalence of nutrient inadequacy computation*

We adjusted the random within-subject variation in the individuals' nutrient intake from the 24HR data using the NCI method. This method estimates usual intake with non-linear mixed regression models and assumes that the 24-hour intake is an unbiased estimator of individuals' usual intake [38]. Such method can be found in the MIXTRAN and DISTRIB macros, version 2.1, developed by the Center for Disease Control [39]. The MIXTRAN macro obtains parameter estimates, by fitting a model, and allows for the evaluation of covariate effects (e.g., sex and age). It has two variants, one that considers the probability of consumption and the amount consumed ("two-parts" model) and one that considers only the amount consumed ("one-part" model). The "two-parts" model (with both correlated and independent random effects) was adopted for vitamin B12 because its intake was sporadic, while the "one-part" model was adopted for the other nutrients. In this study we applied the MIXTRAN macro accounting for effects due to differences in sex, age, region, income decile group, sequence number of an individual's round records, and weekend or weekday record. The DISTRIB macro uses the parameters estimated by the MIXTRAN macro and a Monte Carlo method to compute the percentiles and mean of the usual nutrient intake distribution. It estimates the PoNI applying the EAR cut-point method [38].

Requirements are defined for sex-age groups and different age groups have different diet profiles; so, for the analysis of a population with a wide range of ages the full sample needs to be split into age groups [38]. Therefore, to estimate the PoNI, for the entire rural population, we adopted a stratified analysis based on sex and age groups. To do so, we first defined sex-age groups, independently for each nutrient, based on each nutrient's requirements source. Then, for each nutrient, we estimated the PoNI by sex-age group using the NCI macros and the EAR specific for each group. Finally, for each nutrient, the prevalence for the entire population was estimated as the weighted average of the respective sex-age groups' PoNI, using as weights the proportion of the population in each group.

For the 7DR data, we applied the probabilistic EAR cut-point method to compute the PoNI, under the assumption of lognormality as follows:

$$PoNI = \phi\left(\ln\left(EAR\right), \mu, s\right) \quad (1)$$

$$s = \sqrt{\ln\left(CV^2 + 1\right)} \quad (2)$$

$$\mu = \ln\left(mean\right) - 0.5 * s^2 \quad (3)$$

Where $\phi()$ is the normal probability density function of mean μ and standard deviation s. The *EAR* is the estimated daily per person average requirement of the average individual of the population. For each nutrient, we computed the EAR of the average individual of the population as the weighted average of the EAR of each sex-age group (as those defined for the 24HR) using as weights the proportion of the population in each group. The *mean* corresponds to the mean of the distribution of usual daily per person nutrient intake of the average individual of the population. We proxied the mean with the weighted average of daily per person households' nutrient intake (i.e., total household nutrient intake divided by household size), using population weights (i.e., household weight times household size). The *CV* is the coefficient of variation of the distribution of usual daily per person nutrient intake of the average individual of the population. Before computing the CV, the distribution of daily per person households' nutrient intake was adjusted to account for random measurement errors (hereafter referred to as "adjusted CV"). These errors cancel out when computing average estimates; however, they might have an impact on the CV estimate. The sources of these errors includes backward and forward telescoping, food consumption module reference period, interviewer and/or interviewee fatigue, interviewer misconception of questions, and the report of lower or higher quantities/values for appearing poorer or richer.

We compared the PoNI values from 7DR data before and after adjusting for random measurement errors. We also compared the PoNI using the average intake from the 24HR data and the CV from the 7DR data with the PoNI from the 24HR data. This adjustment for differences in average intake estimates is useful to assess the potential use of the CV as a proxy of the between-subject variability in usual nutrient intake.

2.4. *Adjustment of household-level data for measurement errors*

To account for random measurement errors in the 7DR data, the distribution of daily household nutrient intake per person was modelled against income and region using a simple Ordinary Least Squares regression:

$$NC_h = \ln(\mathit{Income}_h) + \ln(\mathit{Income}_h)^2 + \mathit{Region}_h + \mathit{Region}_h * \ln(\mathit{Income}_h) + \mathit{Region}_h * \ln(\mathit{Income}_h)^2 + \varepsilon_h \quad (4)$$

Where *NC* is the daily per person nutrient intake in household h, *Region* is a set of dummy variables indicating the region in which the household h is located, *Income* is the daily per person income in household h, e is the error term. The income distribution was proxied with aggregate levels of total consumption expenditure (i.e., the sum of food and non-food expenditures) received from the International Food Policy Research Institute. Seasonality influences household incomes (and consequently also expenditures), especially in rural areas [40]. To account for seasonality of income we further adjusted the households' daily per person income distribution using the ratio of the weighted average income, in the region, from January to June by the weighted average income in the household's month and region.

Numerous studies found that the quality and quantity of nutrients increase with income [41], and regional disparities in nutrient intake are also expected due to differences in the type of food available for consumption. Internal research conducted by the FAO Statistics Division, found that the inclusion of household heads' characteristics such as sex, age, education, occupation, economic activity, and marital status, did not have an impact on the CV estimates due to their high correlation with income. The random measurement error in the independent variables becomes part of the error term in the regression equation, under the assumption that the measurement error in the explanatory variable has mean zero, is uncorrelated with the true dependent, the independent variables and with the equation error [42].

The adjusted CV for each nutrient was computed as the ratio between the weighted standard deviation and the weighted average of the predicted values.

3. Results and discussion

Table 1 shows estimates of the average nutrient requirements and the average intake computed for rural Bangladesh using 24HR and 7DR data, as well as the CV before and after adjusting the 7DR data for random measurement errors.

The estimated average requirements for the average individual of the population computed from the 7DR and the 24HR are identical, the reason being that they have similar sex-age distributions.

3.1. Average nutrient intake estimates

For all nutrients tested, the average nutrient intake estimates from the 7DR module are higher than those from the 24HR module. The average intake (person/day) for 24HR and 7DR are, respectively: Calcium (mg) 336 and 471; Zinc (mg): 8.9 and 11.8; Vitamin A (μg of RAE): 196 and 277; Vitamin B1 (mg): 0.62 and 0.88; Vitamin B2 (mg): 0.60 and 0.84; Vitamin C (mg): 55 and 94; Vitamin B6 (mg): 1.11 and 1.50; Vitamin B12 (μg): 1.37 and 1.76. This is consistent with findings from Karageorgou et al. [43], based on data from the 2011-2012 BIHS round, confirming that HCES food modules, such as the 7DR, have limitations for food consumption analysis [44].

In the case of the BIHS, FCAH might be one of the factors for the higher consumption observed in the 7DR. Indeed, in both the 24HR and 7DR modules, one person reports food consumption for all household members, which is a challenge especially to capture FCAH. The percentage of total households reporting at least one FCAH was 92 percent in the 7DR data (last seven-days) and 69 percent in the 24HR data (last 24-hours). We expect an overestimation of nutrient intake from FCAH in 7DR data because nutrient intake from these foods was computed combining monetary values (that might have included service costs) and median at-home nutrient costs (that are not expected to include service costs) instead of using a food matching approach based on food quantities. However, excluding FCAH from the analysis might bias even more the mean and the between-subject variability estimates given the high number of households reporting outside consumption.

3.2. Data adjustment for random measurement errors

As expected, for all nutrients, adjusting the 7DR data for random measurement errors using the FAO approach, produces lower CV estimates than those obtained from the unadjusted 7DR data. Using the 7DR data, the CVs (in percentage) derived from unadjusted and adjusted data are, respectively, for Calcium: 62.2 and 42.3; Zinc: 34.5 and 23.5; Vitamin A: 81.9 and 36.6; Vitamin B1: 45.7 and 31.8; Vitamin B2: 46.5 and 33.1; Vitamin C: 59.8 and 34.4; Vitamin B6: 38.7 and 26.1; and Vitamin B12: 83.1 and 53.0.

Lower CV estimates, keeping the mean and the EAR constant, have an impact on PoNI estimates computed with the FAO probability cut-point method except for vitamin B2. For non-episodically consumed nutrients, when the average intake is equal to or higher than the

Table 1
Average intake, average requirement, and coefficient of variation, by nutrient and type of data

	Average intake (person/day)		Estimated average requirement (person/day)		Coefficient of variation (CV) (%)	
	24HR	7DR	24HR	7DR	7DR unadjusted[a]	7DR adjusted FAO[b]
Calcium	336 (mg)	471 (mg)	1084 (mg)	1077 (mg)	62.2	42.3
Zinc, unrefined diet	8.9 (mg)	11.8 (mg)	9.0 (mg)	8.9 (mg)	34.5	23.5
Vitamin A, in RAE	196 (μg)	277 (μg)	495 (μg)	491 (μg)	81.9	36.6
Vitamin B1	0.62 (mg)	0.88 (mg)	0.89 (mg)	0.88 (mg)	45.7	31.8
Vitamin B2	0.60 (mg)	0.84 (mg)	0.91 (mg)	0.91 (mg)	46.5	33.1
Vitamin C	55 (mg)	94 (mg)	35 (mg)	35 (mg)	59.8	34.4
Vitamin B6	1.11 (mg)	1.50 (mg)	1.03 (mg)	1.03 (mg)	38.7	26.1
Vitamin B12[c]	1.37 (μg)	1.76 (μg)	1.84 (μg)	1.84 (μg)	83.1	53.0

RAE: Retinol activity equivalents. 24HR: individualized data from two household-level 24-hour recall rounds. 7DR: household-level seven-day recall data. [a]CV computed from the 7DR without adjusting for random measurement error. [b]CV computed from the 7DR after adjusting for random measurement error. [c]The NCI two-part model with correlated and with independent random effects produced the same average intake for vitamin B12.

Table 2
Prevalence of nutrient inadequacy (PoNI) by nutrient and type of data

	PoNI, 24HR[a] (%)	PoNI, 7DR[b] (unadjusted) (%)	PoNI, 7DR[c] (adjusted) (%)
Calcium	99.8	95.8	98.8
Zinc	55.4	25.3	13.8
Vitamin A	98.0	87.7	96.4
Vitamin B1	91.2	59.4	57.2
Vitamin B2	92.0	64.9	64.8
Vitamin C	17.1	6.4	0.3
Vitamin B6	40.5	20.6	9.0
Vitamin B12	77.8	66.2	62.9

CV: Coefficient of variation. 24HR: individualized data from two household-level 24-hour recall rounds. 7DR: household-level seven-day recall data. [a]PoNI based on within-subject adjusted 24HR. [b]PoNI based on 7DR with non-adjusted CV. [c]PoNI based on 7DR with adjusted CV.

EAR the PoNI estimate decreases with a lower CV (zinc and vitamins B1, B6 and C); however, when the average intake is lower than the EAR a lower CV implies a similar or higher PoNI (calcium and vitamins A and B2) (Table 2). In the case of vitamin B12, episodically consumed in rural Bangladesh, despite its average intake is lower than the EAR the PoNI estimate decreases when data are adjusted for random measurement errors.

3.3. *Comparison of PoNI estimates from the 7DR and the 24HR*

For all nutrients, the PoNI values using the 7DR data are lower compared to those obtained from the 24HR data. The PoNI estimates (in percentage) derived from 24HR and adjusted 7DR data are, respectively, for Calcium: 99.8 and 98.8; Zinc: 55.4 and 13.8; Vitamin A: 98.0 and 96.4; Vitamin B1: 91.2 and 57.2; Vitamin B2: 92.0 and 64.8; Vitamin C: 17.1 and 0.3; Vitamin B6: 40.5 and 9.0; and Vitamin B12: 77.8 and 62.9. These differences might be explained by the higher levels of average intake estimates from 7DR data compared to the correspondent estimate based on 24HR data.

3.4. *Comparing PoNI estimates while controlling average intake estimates*

To test the effect of differences in average intake estimates on the PoNI values, we computed the PoNI, based on the probabilistic EAR cut-point method, using the average intake from the 24HR data and the CV from the 7DR data. Table 3 presents three PoNI estimates based on: (a) the NCI method using the individualized 24HR data adjusted for random within-subject variation, (b) the FAO probabilistic EAR cut-point method using the average intake from the 24HR data and the non-adjusted CV from the 7DR data, and (c) the FAO probabilistic EAR cut-point method using the average intake from the 24HR data and the adjusted CV from the 7DR data.

Despite measurement errors in both data types, and differences in data collection, analytical tools and methods used, after removing differences in average intake estimates, the PoNI values based on the FAO probabilistic cut-point method are remarkably close to those obtained by applying the NCI method on the individualized 24HR data. For all nutrients, except vitamin

Table 3
Prevalence of nutrient inadequacy (PoNI) by nutrient and type of data controlling for differences in average intake

	(A) PoNI, 24HR[a] (%)	(B) PoNI, 24HR and 7DR[b] (non-adjusted) (%)	(C) PoNI, 24HR and 7DR[c] (adjusted) (%)	Difference (percentage points)	
				absolute (C-A)	relative to the mean value (C-A) / mean (C, A) (%)
Calcium	99.8	99.0	99.9	0.1	0.1
Zinc	55.4	56.7	54.6	−0.8	−1.5
Vitamin A	98.0	95.0	99.7	1.7	1.7
Vitamin B1	91.2	84.9	90.0	−1.2	−1.3
Vitamin B2	92.0	87.6	92.7	0.7	0.8
Vitamin C	17.1	28.7	11.8	−5.3	−36.7
Vitamin B6	40.5	49.3	43.5	3.0	7.1
Vitamin B12	77.8	77.8	80.0	2.2	2.8

CV: Coefficient of variation. 24HR: individualized data from two household-level 24-hour recall rounds. 7DR: household-level seven-day recall data. [a]PoNI based on within-subject adjusted 24HR. [b]PoNI based on the average nutrient intake from 24HR and the non-adjusted CV from the 7DR. [c]PoNI based on the average nutrient intake from 24HR and the adjusted CV from the 7DR.

B12 (that was episodically consumed), the use of the adjusted CV produces a closer PoNI value to the one obtained with the 24HR data. The PoNI estimates (in percentage) derived from 24HR and the FAO method using the average intake from the 24HR and the adjusted CV from the 7DR are, respectively, for Calcium: 99.8 and 99.9; Zinc: 55.4 and 54.6; Vitamin A: 98.0 and 99.7; Vitamin B1: 91.2 and 90.0; Vitamin B2: 92.0 and 92.7; Vitamin C: 17.1 and 11.8; Vitamin B6: 40.5 and 43.5; and Vitamin B12: 77.8 and 80.0. Although there is no formal way to compute standard errors around the PoNI estimates, we note that the difference, in absolute value, exceeds 2.5 percent of the mean only for vitamins C, B6 and B12. For all other nutrients, the difference is negligible.

3.5. *Potential application of the coefficient of variation as a proxy for the between-subject variability and to estimate the PoNI using various data sources*

The use of CV estimates as a proxy of the between-subject variability in usual intake is quite promising for future assessments of levels of inadequate nutrient intake, in the absence of appropriate dietary data on individual food consumption [45].

Individual quantitative dietary intake surveys, representative of the entire population, are scarce and when they exist, they are usually based on one round of data collection preventing the computation of PoNI estimates. At the same time, most countries conduct HCES frequently (every one to ten years). We demonstrated that combining the FAO probabilistic cut-point method with the average intake estimate from the 24HR and the adjusted CV from the 7DR provides PoNI estimates close to those from the individualized 24HR. Thus, the average intake from a single 24-hour recall could be combined with the CV from a HCES, conducted close in time, to estimate the PoNI (for the nutrients under analysis) using the FAO probabilistic cut point method, assuming that the between-subject variability in usual nutrient intake at the national level remains stable across nearby years. Nevertheless, this method should not substitute the use of multiple 24-hour recalls for the estimation of the PoNI, which is the recommended approach.

Furthermore, estimates of the between-subject variability in usual nutrient intake from HCES data could be used to improve the estimation of the adequacy of the global nutrient supply using Food Balance Sheets (FBS) or Supply and Utilization Accounts (SUA) data. Researchers have been estimating the inadequacy of the global nutrient supply, based on FBS data and CVs from small dietary intake studies conducted in children in LMICs in the 1980s [46,47]. Those CVs are likely not representative of the distribution of usual nutrient intake across countries and decades, and likely bias prevalence values. FAO has recently released country-level supply of nutrients for human consumption, based on SUA data for 186 countries from 2010 [48]. The use of these values, together with up-to-date CVs derived from adjusted HCES data, and the FAO probabilistic cut-point method would greatly improve the monitoring of the adequacy of the global nutrient supply.

4. Conclusion

This paper presents an approach to estimate the between-subject variability in nutrient intake (through the CV) and the FAO probabilistic cut-point method to estimate the PoNI, for vitamins A, B1, B2, B6, B12 and C, calcium, and zinc, using food consumption data from HCES. PoNI values from a typical seven-day recall (7DR) household food consumption module, before and after adjusting for random measurement errors, are compared to estimates from individual-level 24-hour recall (24HR) data reported by one respondent on behalf of all members.

Results show that adjusting the 7DR household-level data for random measurement errors produces lower CVs compared to the unadjusted data and affects the PoNI estimates. For non-episodically consumed nutrients with average intake lower than requirements (calcium and vitamins A and B2), the PoNI remains the same or increases when data are adjusted for random measurement errors; on the contrary, for non-episodically consumed nutrients with average intake higher than requirements (zinc and vitamins B1, B6 and C), the PoNI decreases. In the case of vitamin B12, episodically consumed in rural Bangladesh, despite its average intake is lower than the requirements the PoNI estimate decreases when data are adjusted for random measurement errors.

The PoNI values based on 7DR are lower than those calculated from 24HR data, due to the larger average intake estimates from 7DR data. After controlling for differences in average intake estimates, the PoNI values based on the NCI method using the 24HR data only and those based on the FAO probabilistic cut-point method using the average from the 24HR data and the adjusted CV from the 7DR data are remarkably close (differences are less than or equal to 3.0 percentage points, except for vitamin C with a difference of 5.3 percentage points). This highlights the potential use of HCES data (conducted according to international agreed standards) for estimating the level of between-subject variability in usual nutrient intake in a population.

The CVs derived from HCES data could be used to: (a) estimate the PoNI using the average nutrient intake from individual-level data (useful when a 24-hour recall has only administered one round and it is not possible to estimate the usual intake distribution); and (b) estimate the inadequacy of the global nutrient supply using Food Balance Sheets or Supply and Utilization Accounts data.

However, more research is needed to determine the validity of PoNI estimates from HCES data only. These additional validation studies would ideally rely on data from an individual quantitative dietary intake survey (instead of individualized data from a household 24-hour recall) with multiple rounds and detailed information on quantities and composition of foods consumed away from home reported in the food consumption module from the HCES.

It is important to remember, that the use of food data collected in household surveys should be considered as an alternative for producing food and nutrient statistics only in the absence of individual quantitative dietary intake surveys representative of the entire population.

Acknowledgments

The authors gratefully acknowledge the financial support from the International Dietary Data Expansion (INDDEX) Project, which was implemented by the Tufts University's Gerald J. and Dorothy R. Friedman School of Nutrition Science and Policy with funding from the Bill & Melinda Gates Foundation; the financial support from the project "Produce reliable information on food security and nutrition to guide policies and interventions to end hunger and malnutrition" funded by the European Union, for making this study publicly available; the contributions received from Winnie Bell, Jennifer Coates and Beatrice Rogers (Tufts University's Gerald J. and Dorothy R. Friedman School of Nutrition Science and Policy), Bridget Holmes, Agnieszka Balcerzak, Giles HanleyCook, Jairo Castano, Piero Conforti, Filippo Gheri and Abdul Sattar (Food and Agriculture Organization from the United Nations); Klaus Grunberger and Catherine Leclercq (former FAO staff), Estefania Custodio (National Centre of Tropical Medicine, Instituto de Salud Carlos III); and Akhter Ahmed and Carlo Azzarri (International Food Policy Research Institute).

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