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# **Global estimation of dietary micronutrient inadequacies: a modelling analysis [H1]**

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**Summary**

**Background**

Inadequate micronutrient intakes and related deficiencies are a major challenge to global public health. Analyses over the past 10 years have assessed global micronutrient deficiencies and inadequate nutrient supplies, but there have been no global estimates of inadequate micronutrient intakes. We aimed to estimate the global prevalence of inadequate micronutrient intakes for 15 essential micronutrients and to identify dietary nutrient gaps in specific demographic groups and countries. **[A: OK, to state the aims of the study here?]**

**Methods**

In this modelling analysis, we adopted a novel approach to estimating micronutrient intake, which accounts for the shape of a population’s nutrient intake distribution and is based on dietary intake data from 31 countries. Using a globally harmonised set of age-specific and sex-specific nutrient requirements, we then applied these distributions to publicly available data from the Global Dietary Database on modelled median intakes of 15 micronutrients for 34 age–sex groups from 185 countries, to estimate the prevalence of inadequate nutrient intakes for 99·3% of the global population **[A: edits to this section OK?]**.

**Findings**

On the basis of estimates of nutrient intake from food (excluding fortification and supplementation), more than 5 billion people do not consume enough iodine (68% of the global population), vitamin E (67%), and calcium (66%). More than 4 billion people do not consume enough iron (65%), riboflavin (55%), folate (54%), and vitamin C (53%). Within the same country and age groups, estimated inadequate intakes were higher for women than for men for iodine, vitamin B₁₂, iron, and selenium and higher for men than for women for magnesium, vitamin B₆, zinc, vitamin C, vitamin A, thiamin, and niacin.

**Interpretation**

To our knowledge, this analysis provides the first global estimates of inadequate micronutrient intakes using dietary intake data, highlighting highly prevalent gaps across nutrients and variability by sex. These results can be used by public health practitioners to target populations in need of dietary interventions.

**Funding**

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## **Research in context [Prod: please set as unlinked panel]**

**Evidence before this study**

Analyses over the past 10 years have assessed global micronutrient deficiencies and global inadequate nutrient supply, but large gaps remain for many micronutrients and population groups. Owing to limited availability of dietary intake data and a scarcity of accurate nutrient distribution data, there have been no global estimates of inadequate micronutrient intakes. **[A: did you do a literature search before this analysis? If so, please provide details (databases searched, start and end dates of search, search terms used, number of results retrieved) and we will add this information to this section]**

**Added value of the study**

This analysis provides, to our knowledge, the first global estimates to date of inadequate global micronutrient intakes using dietary intake estimates, including for specific age and sex groups and incorporating population-specific distribution data. **[A: please expand this section a little to include how these findings add value to the existing evidence on this topic]**

**Implications of all the available evidence**

In combination with existing data on micronutrient deficiencies and supplies, estimates of inadequate global micronutrient intakes can help public health researchers and practitioners to identify populations in need of dietary intervention for a wide range of micronutrients. **[A: please expand to give any implications for practice or policy or any potential recommendations arising specifically from your findings]**

## **Introduction [H2]**

Micronutrient deficiencies are one of the most common forms of malnutrition globally.[1,2](https://www.zotero.org/google-docs/?2wl3Bi) A key pathway to micronutrient deficiencies is through inadequate intake of essential nutrients such as iron, zinc, vitamin A, iodine, and folate, among others, with deficiency in each nutrient having its own public health consequences. Iron deficiency is the most common cause of anaemia, leading to impaired cognition and adverse pregnancy outcomes.[3](https://www.zotero.org/google-docs/?fH3Tiq) Vitamin A deficiency is the leading cause of preventable blindness globally **[A: is this the case for people of all ages groups, or just for children <5 years? Could you cite a reference for this statement?]**. Both vitamin A and zinc have a crucial role in immunity, especially for populations facing a high burden of infectious diseases.[4,5](https://www.zotero.org/google-docs/?thLVTB) Folate is needed early in pregnancy to reduce the risk of stillbirths and neural tube defects, and iodine is essential for pregnant and breastfeeding women because of its role in fetal and child cognitive development.[6](https://www.zotero.org/google-docs/?QR1C5z)

Deficiencies in these and other micronutrients collectively contribute to a large burden of morbidity and mortality, but the scale and demographic specificities of the problem are unknown because of insufficient data **[A: OK? Please note that we use ‘limited’ only to mean ‘restricted’]**.[1,7](https://www.zotero.org/google-docs/?svCAmA) Clinical nutritional biomarkers have been used to estimate the global prevalence of micronutrient deficiencies **[A: please note that we do not use formatting for emphasis]** for selected populations and micronutrients;[1,8](https://www.zotero.org/google-docs/?9B9EkT) however, substantial data gaps persist for various micronutrients, specific population groups (especially males), and many geographies. Existing data are also often outdated. The global prevalence of inadequate micronutrient supplies has also been estimated using food availability data **[A: edits OK?]**, highlighting inadequacies in food supply.[9,10](https://www.zotero.org/google-docs/?iV5k1U) Owing to scarce quantitative dietary intake data and no suitable approach with which to accurately model nutrient intake distributions, to our knowledge there have been no global estimates of inadequate micronutrient intakes. Estimates of micronutrient deficiencies, inadequate micronutrient intakes, and inadequate micronutrient supplies are all required for a comprehensive understanding of the burden of micronutrient malnutrition.

To tackle such a large-scale public health crisis, we require estimates to identify which nutrients pose the greatest risk, where, and to whom.[11](https://www.zotero.org/google-docs/?h0Aszy) Although micronutrient deficiencies are presumably widespread, data for women and children are scarce. A pooled global analysis of biomarker data found that more than one in two children younger than 5 years are deficient in either iron, zinc, or vitamin A and two in three women aged 15–49 years are deficient in either iron, zinc, or folate **[A: which reference can be cited for this analysis; is this reference 1?]**.[1](https://www.zotero.org/google-docs/?ZzeChn) However, we know of no global, population-wide estimates of nutrient deficiencies for a wider range of micronutrients.

The Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) examines the burden of micronutrient malnutrition in 195 countries using a modelling approach that combines clinical outcomes (eg, goitre), biomarkers of micronutrient status (eg, serum retinol) and anaemia (eg, haemoglobin concentration), and inadequacy in the food supply (eg, zinc inadequacy).[12](https://www.zotero.org/google-docs/?T68mp0) These studies include **[A: OK to clarify ‘they’?]** estimates of disease for only four micronutrients (iodine, iron, zinc, and vitamin A) owing to scarce data;[12](https://www.zotero.org/google-docs/?aZ4hyg) however, 29 micronutrients are known to be essential.[13](https://www.zotero.org/google-docs/?dqHMES) Although the GBD modelling approach might be generated using **[A: could we rephrase as “Although GBD models might be generated using…” (or “Although the GBD modelling approach might use…”)?]** the best available methods and data, the gaps in micronutrient status biomarkers and dietary intake data hinder the ability to comprehensively model micronutrient malnutrition. Furthermore, the GBD approach to modelling micronutrient malnutrition is not replicable because their data, methods, code, and assumed nutrient distribution shapes are not publicly available.[14](https://www.zotero.org/google-docs/?RZSbEa)

Although nutritional biomarkers provide the best indication of nutritional deficiencies, these deficiencies can be caused by many factors including inadequate dietary nutrient intake, infectious diseases, or absorption issues. Therefore, the best way to identify populations at risk of diet-related malnutrition is to estimate inadequate nutrient intakes. Previous studies have estimated micronutrient adequacy of the food supply.[9,10,15–17](https://www.zotero.org/google-docs/?AGnQ87) Some of these studies have used terminology to imply that these estimates reflect nutrient intakes, including “estimated prevalence of inadequate intakes”,[10](https://www.zotero.org/google-docs/?AUzgre) “risk of inadequate intake”,[10](https://www.zotero.org/google-docs/?8DmQrK) and “apparent consumption”.[18](https://www.zotero.org/google-docs/?LxOxmH) Such terminology **[A: OK to clarify ‘this’?]** could have inadvertently led to confusion that global estimates of inadequate nutrient intakes already exist. However, nutrient adequacy estimates relying on food supplies do not account for household food waste, food service waste, small-scale food production, or wild harvest, and they have no information on how food is allocated across each country’s population (ie, there is no information for specific demographic groups, such as sex or age groups). Owing to these limitations, supply-based estimates are inaccurate, tending to underestimate inadequacy in high-income countries and overestimate inadequacy in many low-income and middle-income countries.[19](https://www.zotero.org/google-docs/?AM9a85)

In contrast to studies that rely primarily on food supplies, the Global Dietary Database (GDD) **[Prod: please add margin link with the text “For the Global Dietary Database see https://globaldietarydatabase.org/”] [A: please note that we have converted this to a margin link as per our style for whole websites]** provides the only estimates of micronutrient intakes, using data from individual dietary-intake surveys, household surveys, and national food supplies.20,21 For 10 years **[A: could we say “Since 2014”?]**, the GDD has standardised and compiled individual-level dietary datasets from 185 countries for more than 50 foods, beverages, and nutrients,21 providing the best available data to understand the amount of nutrients actually consumed by individuals rather than available for consumption. However, the GDD does not estimate micronutrient intake distributions or micronutrient requirements, which are needed to accurately estimate the prevalence of inadequate micronutrient intakes.

This Article provides a novel and reproducible approach to estimating the global prevalence of inadequate micronutrient intakes by accounting for the shapes of nutrient intake distributions and using globally harmonised nutrient reference values. We aimed to identify dietary nutrient gaps in specific demographic groups and countries, as well as estimate the total global burden of dietary micronutrient inadequacies for 15 essential micronutrients. **[A: please note that we have removed the sentence on implications here, as we conclude the Introduction section with the aims of the study]**

## **Methods [H2]**

### **Overview [H3]**

We estimated intake inadequacies for 15 micronutrients (appendix p 2 **[A: please state the relevant page of the appendix here]**) across 34 subnational age–sex groups in 185 countries. This approach required understanding nutrient intake and requirement distributions for every subnational population globally (figure 1). We developed these subnational nutrient intake distributions using estimates of distribution scale (ie, intake median) from the GDD and distribution shape (ie, intake variability) from the nutriR database (figure 1A).24 We then developed subnational nutrient requirement distributions using the harmonised average requirements defined by Allen and colleagues22 and common assumptions about variability in requirement amounts **[A: OK? (please note that we use level to mean position or rank, rather than concentration, amount etc)]** (figure 1B). We used the probability method[25](https://www.zotero.org/google-docs/?nIH4u4) to calculate intake inadequacies by comparing the derived intakes with the requirement distributions (figure 1C) and calculated the number of people with intake adequacies using subnational human population size estimates from the World Bank.[26](https://www.zotero.org/google-docs/?bQ0PfV) All analyses were done using R **[A: please note that we have removed the citation to R as per style]** and all data and code are available on GitHub **[Prod: please add margin link with text “For all data and code see https://github.com/cfree14/global\_intake\_inadequacies”]**. We used an interactive R Shiny web application **[Prod: please add margin link with the text “For the R Shiny web application see https://emlab-ucsb.shinyapps.io/global\_intake\_inadequacies/”]** to explore the results in detail.

### **Defining subnational populations [H3]**

Using World Bank definitions, we estimated human population size within 34 age–sex groups (males and females in 17 age groups: 0–80 years in 5-year groups and an ≥80 years group) for 218 countries or territories.[26](https://www.zotero.org/google-docs/?1gn0kU) We refer to these country–age–sex groups as subnational populations throughout the Article. Race and ethnicity are not reported in the World Bank population estimates or the GDD intake estimates, so results were not disaggregated by these dimensions **[A: sentence edits OK? (please note that we do not use ‘and/or’)]**. We used estimates for 2018, when the global population was approximately 7·57 billion people (appendix p 6 **[A: please state the relevant page of the appendix here]**), as this is the most recent year with GDD data. The 185 countries with GDD data encompass 7·52 billion people (99·3% of the global population).

### **Defining subnational intake medians [H3]**

We developed subnational nutrient intake distributions with median intakes equivalent to the estimates provided in the GDD.20 The GDD uses datasets from household surveys and food balance sheets to estimate the median intake of 17 micronutrients from 19 food and beverage categories (appendix p 3 **[A: please state the relevant page of the appendix here]**) by subpopulation in 185 countries from 1990 to 2018 (5-year intervals from 1990 to 2015). Subpopulations are defined by 44 age–sex groups, three levels of education (ie, low, medium, and high **[A: could you provide further details here; what is classed as low, medium, and high?]**), and two areas of residence (ie, rural and urban). We excluded two nutrients from the analysis: potassium, which does not have accepted average requirement amounts; and vitamin D, which **[A: “the distribution of which”?]** is highly geographically variable in risk because the average requirement amounts can be met through sun exposure rather than dietary intake.27 This exclusion leaves 15 micronutrients (nine vitamins and six minerals) available for analysis (appendix p 2 **[A: please state the relevant page of the appendix here]**). We defined median intakes for each age–sex group using the average provided by the GDD across areas of residence and levels of education. We then averaged these intake estimates to match the 34 age groups used in the Word Bank human population data (appendix p 4 **[A: please state the relevant page of the appendix here]**). Finally, to account for the supply of calcium and magnesium in drinking water, we assumed that all people consume their daily adequate intake of drinking water and that this water has an average concentration of 46 mg of calcium and 16 mg of magnesium per litre. Age-specific and sex-specific adequate intakes are from the US Institute of Medicine28 and calcium and magnesium concentrations are the average of those in global water sources from WHO.29

### **Defining subnational intake shapes [H3]**

We defined the shape of each subnational nutrient intake distribution using estimates of subnational nutrient intake shapes provided in the nutriR database **[Prod: please add margin link with text “For the nutriR database see https://github.com/cfree14/nutriR”]**.24 Passarelli and colleagues24 assembled a database of dietary recall surveys from 31 countries and used this database to construct statistical distributions—either log-normal or gamma distributions—that describe usual intakes for 51 nutrients. The 31 countries were selected for inclusion on the basis of whether **[A: “if”? Or did not all of these requirements need to be fulfilled?]** there was an available dataset with individual-level dietary data, calculated nutrient-level data, at least 2 days of dietary intake (for at least some participants), data based on a 24-h recall or a diet record or food diary **[A: OK to avoid the solidus?]**, and a sample size of more than 200 people.24 Owing to limitations in the coverage of dietary recall surveys, distribution shapes are not available for all subnational groups, even within the 31 countries with data. We therefore matched every subnational group evaluated in this study with the shape parameters of the most similar subnational group with data. We conducted this matching with preference for shape parameters from the actual subpopulation (known), the nearest age group within the country and sex (nearest age group), the corresponding age group from the opposite sex within a country (opposite sex), and the corresponding age–sex group from the country with the most similar nutrient intakes to the country of interest (most similar country). We identified the country with the most similar nutrient intakes to the country of interest as the country with the smallest Euclidean distance in a dissimilarity matrix computed using the 2018 national nutrient intakes estimated in the GDD (appendix p 7 **[A: please state the relevant page of the appendix here]**); ie, **[A: OK?]** the country with the most similar nutrient intakes in multivariate space. The extent and sources of borrowed shape information are shown in the appendix (p 8 **[A: please state the relevant page of the appendix here]**).

### **Defining subnational intake distributions [H3]**

We specified the final usual intake distribution for each subnational group using its median value and matched shape parameters (figure 1A). The matched shape parameters describe the variability of each distribution but produce different medians to those prescribed by the GDD estimates. Therefore, we shifted the shape parameters to match the GDD median while maintaining the variability described by the matched shape parameters. For intake distributions parameterised using a log-normal distribution, we maintained the variability parameter, σ, and shifted the centrality parameter, µ. For intake distributions parameterised using a gamma distribution, we maintained the variability parameter, α, and shifted the centrality parameter, β. The shifted parameters were derived analytically for the log-normal distribution and numerically for the gamma distribution using the *shift\_dist()* function in the *nutriR* package. For a conceptual illustration of these distribution shifts, see appendix p 9 **[A: please state the relevant page of the appendix here]**.

### **Estimating subnational intake inadequacy [H3]**

We estimated the prevalence of intake inadequacy, also known as summary exposure value (SEV), using the probability method[25](https://www.zotero.org/google-docs/?tPSsRz) as implemented in the *nutriR* package. The probability method compares intake distributions against a continuous relative risk curve with a value of 1 at low intakes, 0·5 at the average intake requirement, and 0 at large intakes (figure 1C). These risk curves are defined on the basis of the cumulative normal distribution described by the average requirement and its standard deviation (figure 1B). We used the harmonised age-specific and sex-specific average requirements provided by Allen and colleagues22 as the average requirements for this analysis (appendix p 10 **[A: please state the relevant page of the appendix here]**). We assumed a coefficient of variation of 0·25 for the requirement of vitamin B₁₂ and 0·10 for the requirement of all other distributions **[A: nutrients?]** according to the **[A: OK?]** recommendation of Renwick and colleagues.23 The coefficient of variation is used to derive the standard deviation of the requirement distribution.

We further specified country-specific average requirements for zinc and iron on the basis of dietary factors that inhibit or enhance their absorption (appendix p 11-12 **[A: please state the relevant page of the appendix here]**). First, phytate inhibits zinc and iron absorption,30 which means that average requirements for zinc and iron increase with higher phytate intakes.22 Second, the consumption of non-dairy animal-source foods enhances iron absorption,31 which means that average requirements for iron decrease with higher intakes of such foods.22 Although calcium absorption is also affected by dietary factors such as phytate, oxalate, and dairy intakes, we were unable to account for these effects given a lack **[A: scarcity or absence?]** of data on global oxalate intakes—the dominant factor affecting calcium absorption.32

We derived country-specific average requirements for zinc on the basis of average country-level estimates of phytate intake from Wessels and Brown33 (appendix p 13 **[A: please state the relevant page of the appendix here]**) by linearly interpolating between the lowest average requirement and lowest phytate intake and the highest average requirement and highest phytate intake within each age–sex group (appendix p 11 **[A: please state the relevant page of the appendix here]**). We derived country-specific average requirements for iron accounting for the joint effects of phytate and non-dairy animal-source foods on iron absorption using a procedure similar to that of Beal and colleagues.[10](https://www.zotero.org/google-docs/?mFAXzG) First, we scaled the country-level phytate intakes (appendix p 13 **[A: please state the relevant page of the appendix here]**) between 0 and 1, where 0 indicates low iron absorption (high phytate intake) and 1 indicates high iron absorption (low phytate intake). Then, we scaled country-level estimates of non-dairy animal-source food intakes (ie, the sum of seafood, processed meat, unprocessed red meat, and egg intakes; unprocessed poultry meat is excluded because it is not available in the GDD; appendix p 3, 14 **[A: please state the relevant page of the appendix here]**) from the GDD between 0 and 1, where 0 indicates low iron absorption (low non-dairy animal-source food intake) and 1 indicates high absorption (high non-dairy animal-source food intake). Next, we averaged these two indicators to create a single absorption index, in which lower values indicate lower absorption and higher values indicate higher absorption, and scaled these averages between 5% and 16% absorption, the range of real-world iron absorption values22 (appendix p 15 **[A: please state the relevant page of the appendix here]**). Finally, we derived the absorption-specific average requirements by linearly interpolating between the average requirements specified by Allen and colleagues22 (appendix p 12 **[A: please state the relevant page of the appendix here]**).

We calculated the number of people with inadequate intakes within each subnational group as the product of the number of people and the prevalence of inadequate intakes in the group.

**Role of the funding source [H3]**

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

## **Results [H2]**

Estimates of inadequate intake were generally high (figure 2) and were especially common for iodine (5·1 billion people; 68% of the population), vitamin E (5·0 billion people; 67% of the population), calcium (5·0 billion people; 66% of the population), and iron (4·9 billion people; 65% of the population). Niacin had the lowest estimate of inadequate intake (1·7 billion people; 22% of the population), followed by thiamin (2·2 billion people; 30% of the population) and magnesium (2·4 billion people; 31% of the population; figure 2). A few countries had estimated intake inadequacies that diverged from the general patterns. For example, in India, estimated inadequate intakes of riboflavin, folate, vitamin B₆, and vitamin B₁₂ were especially high; Madagascar and the Democratic Republic of the Congo had high inadequate niacin intakes; and Russia, Mongolia, and Kazakhstan had high inadequate selenium intakes (figure 2).

Calcium intake inadequacy was highest in countries in south Asia, sub-Saharan Africa, and east Asia and the Pacific (figure 3). Intake inadequacy was high across all age–sex groups in these countries, but especially among people aged 10–30 years. Only countries in North America, Europe, and central Asia had a consistently low prevalence of inadequate calcium intake (figure 3). Low prevalence of inadequate iodine intake was observed only in Europe and Canada **[A: please clarify; if naming New Zealand and Australia here, from figure 2 it looks as though Canada and a few countries in South America also have a similar prevalence of inadequate intake?]** (figures 2, 3) and, for vitamin E, only **[A: correct? (rather than also?) or “mainly”?]** in Pacific Island countries (figures 2, 3). For riboflavin and vitamin B₁₂, high prevalences of inadequate intakes were common only in countries in south Asia and Africa **[A: inadequacy seems highest of all in Kenya and also common in a few other countries in Africa, so saying high prevalences are common only in south Asia doesn’t seem accurate; could we change to “For riboflavin and vitamin B₁₂, inadequate intakes were most common in countries in south Asia” (or maybe “most prevalent”)?]** (figures 2, 3) **[A: please clarify the citation to figure 1 here, as it does not seem to contain these results. Should this citation be to figures 2 and 3 instead?]**.

Globally, the prevalence of inadequate intakes was consistently higher for females than for males in the same country and age group for iodine, vitamin B₁₂, iron, and selenium (figure 4). The prevalence was higher for females than for males in most regions for calcium, riboflavin, vitamin E, and folate. Conversely, the prevalence of inadequate intakes was consistently higher for males than for females in the same country and age group for magnesium, vitamin B₆, zinc, vitamin C, vitamin A, thiamin, and niacin (figure 4).

## **Discussion [H2]**

This analysis provides a new, replicable, and accessible method for estimating micronutrient intake inadequacy. Globally, we found that more than 5 billion people do not consume enough of each of three nutrients: iodine, vitamin E, and calcium. More than 4 billion people do not consume enough of each of another four nutrients: iron, riboflavin, folate, and vitamin C. Our analysis shows that the majority of the global population has inadequate micronutrient intake.

Globally, we found that women had a higher prevalence of inadequate intake than men for iodine, vitamin B₁₂, iron, selenium, calcium, riboflavin, and folate. Conversely, men have higher intake inadequacies than women for magnesium, vitamin B₆, zinc, vitamin C, vitamin A, thiamin, and niacin **[A: sentence edits OK? (we removed “including” as this was the complete list)]**. Many of the differences observed could relate to a combination of differing dietary patterns between sexes **[A: could we move this to the end of the sentence; would this retain your meaning?]**, dietary requirements, and consumption quantities.

This Article builds on work that estimates the global prevalence of micronutrient deficiencies and inadequate nutrient supplies. Stevens and colleagues[1](https://www.zotero.org/google-docs/?iH0Cjl) assessed micronutrient deficiency on the basis of biomarker data for all datasets available globally (24 nationally representative datasets) for non-pregnant women and preschool-aged (6-59 months) children **[A: could you provide an age range here, if available?]**, estimating that more than half of preschool-aged children and two-thirds of non-pregnant women have micronutrient deficiencies. Our estimates generally show a higher prevalence of intake inadequacy than their biomarker data. One reason for this difference might be that our estimates do not include supplements and fortified foods, so our estimates are reflective of nutrient adequacy from unfortified foods. Additionally, nutritional deficiencies (as measured by clinical biomarkers), although highly correlated with nutrient intake,34 can **[A: correct instead of may?]** be strongly influenced by disease status, inflammation, the microbiome, and other contextual factors. Although many analyses have modelled inadequate nutrient supplies, ours is the first to our knowledge to estimate global inadequate intakes by applying nutrient intake distributions to estimated intake data using age-specific and sex-specific intake distributions

**[A: please note that we do not have separate subheadings for limitations and conclusions]** Our analysis is subject to limitations—most notably, data availability (appendix p 9 **[A: please state the relevant page of the appendix here]**). There remains a lack **[A: “scarcity”, or “sparsity”?]** of individual dietary intake data worldwide, especially nationally representative datasets and datasets with 2 or more days of intake. Although GDD coverage has increased to include more than 99% of the global population and become more precise over time, recent **[A: please give a timeframe to clarify ‘recent’]** nationally representative quantitative dietary intake data within the last 10 years are scarce, which limits the ability to validate the modelled estimates across countries.35 This scarcity of data **[A: correct clarification of ‘this’?]** also limited the number of statistical distributions that could be estimated in the nutriR database. By basing the global intake distribution shapes on datasets from only 31 countries, some of the distribution shapes could have been incorrectly estimated, resulting in inaccurate estimates of inadequacy.

The estimates we present are of inadequate nutrient intake and do not include information on fortification or supplementation. In essence, this means that our inadequate intake estimates are likely to overestimate risk for some key nutrients (eg, iodine) in particular locations. Nonetheless, supplementation and fortification with many of these micronutrients is scarce **[A: OK instead of ‘limited’?]** globally.36 Among countries with available data from the Demographic and Health Surveys programme **[A: correct?]**, which operates in more than 90 low-income and middle-income countries **[A: OK? Please note that we do not use ‘developing countries’]**, supplementation for selected demographic groups is somewhat common for iron, with 32% of pregnant women consuming an iron supplement **[A: correct?]** for more than 90 days of their pregnancy and 14% of children **[A: could you provide an age range?]** consuming a supplement in the previous week.37 The proportion of supplementation is highest for vitamin A in children; an estimated 55% **[A: of children of what age?]** have received a high-dose vitamin A supplement in the previous 6 months.37 Data on fortification are inadequate for most nutrients except iodine; UNICEF estimates that 89% of people worldwide consume iodised salt.38 Therefore, iodine might be the only nutrient for which inadequate intake from food is largely overestimated.

A final limitation is that our nutrient intake estimates, with the exception of iron and zinc, do not include nutrient-to-nutrient interactions or recognition of nutrient absorption and bioavailability. Accounting for these factors **[A: OK to clarify ‘this’?]** would be impossible for some nutrients without knowledge of accompanying infection and inflammation status; unfortunately, nutritional science is not sufficiently advanced to accurately produce algorithms for these internal physiological mechanisms on the basis of dietary nutrient intake data alone. Such algorithms might not be available for **[A: OK to clarify ‘this’? Or is this statement broader than just the algorithms?]** the foreseeable future and, until the state of the science advances, we cannot provide more nuanced estimates to account for this complexity.

This Article highlights the vast scale of micronutrient intake inadequacy across the world—especially for iodine, vitamin E, calcium, iron, riboflavin, and folate. Clear patterns emerged for the differing levels of estimated inadequacy for specific nutrients on the basis of sex, greater than the patterns observed across age groups within a given sex. Understanding these patterns can help us to better understand where nutritional interventions are needed, such as dietary interventions, biofortification, fortification, and supplementation. Moreover, examining which nutrient intake inadequacies are correlated with each other could help to identify which nutritional responses need to be coordinated to improve the efficiency of intervention delivery. Particular geographies warrant further investigation into the causes and severity of deficiencies before adopting fortification, supplementation, and dietary intervention policies.

This analysis represents, to our knowledge, the first estimate of inadequate micronutrient intakes globally and across diverse subpopulations. We have made our code and underlying data publicly available so that others can use and build upon these results. We hope that this analysis improves our understanding of global micronutrient inadequacy so that public health interventions can be better equipped to address deficiencies. We envision this research providing invaluable information for researchers, policy makers, public health specialists, and other stakeholders involved in nutrition and food system interventions. These data can provide insight into the crucial micronutrient gaps that could afflict particular regions and subpopulations and can also act as a call to action for locations without necessary data to calculate these estimates, such as in many small island developing statesin the Pacific. Future research on the role of fortification, supplementation, and other broad-scope nutrition and food system interventions can be used to calculate the public health gains associated with such actions.

Editorial note: The Lancet Group takes a neutral position with respect to territorial claims in published maps and institutional affiliations.

## **Contributors [H6]**

SP, CMF, TB, and CDG conceived the analysis and contributed to the design of the methods. SP and CMF conducted the analysis and wrote the initial draft of the manuscript, which was reviewed and edited by all authors. CMF built the R Shiny web application. All authors accessed and verified the data and have final responsibility for the decision to submit for publication. **[A: please state the contributions of authors AS and CB here]**

## **Declaration of interests [H6]**

We declare no competing interests. **[A: please confirm that this statement matches the information given on the ICMJE forms of all authors]**

## **Data sharing [H6]**

All data and code are available on GitHub (https://github.com/cfree14/global\_intake\_inadequacies).

## **Acknowledgments [H6]**

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**[A: alongside your proof corrections, please resupply the appendix. Please ensure that the new appendix is paginated (beginning with the first supplemental item, table S1), includes a contents page, and is submitted as a PDF; thank you]**

**[A: please note that the references have been renumbered to account for the conversion of some to margin links and to ensure that all are cited in numerical order of first citation according to our style. Please check carefully throughout to ensure that each citation in the text corresponds to the correct reference in the list. Please note that references that are cited in the figures are taken to be cited where the figure itself is first cited in the text (ie, Allen et al and Renwick et al are taken to be first cited in the Methods section where figure 1 is first cited)]**

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***Figure 1:* Methods for estimating the prevalence of inadequate micronutrient intakes**

Iron intakes in Kazakhstan are used as an example. The top row illustrates the procedure for males aged 15–19 years and the bottom row illustrates the results for all age–sex groups. (A) First, we derived a skewed (gamma or log-normal) intake distribution, for which the median (blue line) of distribution was drawn from the GDD and the shape of the distribution was drawn from the nutriR database. (B) Second, we derived a normal requirement distribution, for which the mean of the distribution was drawn from the study by Allen and colleagues22 and the SD of the distribution was derived assuming a coefficient of variation of 0·25 for vitamin B₁₂ and 0·10 for all other nutrients based on the work of Renwick and colleagues.23 (C) Finally, we derived the percentage of inadequate intake by intersecting these two distributions using the probability approach. We calculated the number of people with inadequate intakes using population estimates from the World Bank.[26](https://www.zotero.org/google-docs/?uWzmgV) In (A)–(C), the vertical dotted line indicates the average requirement. (D) We repeated this process for every age–sex group. The points represent the median intake based on the GDD, the thick lines represent the inner 50% of the intake distribution, and the thin lines represent the inner 95% of the intake distribution. The black lines show the sex-specific and age-specific average requirements. GDD=Global Dietary Database.

***Figure 2:* Estimated prevalence of intake inadequacies by country and nutrient in 2018**

The estimated number and proportion of the global population with inadequacies is stated alongside each map. Countries with land areas of less than 25 000 km² are shown as points to increase visibility. **[A: should vitamin A be listed as “Vitamin A (RAE)” here?]**

***Figure 3:* Prevalence of intake inadequacies by World Bank region and nutrient in 2018**

Nutrients and regions are arranged in order of decreasing prevalence of inadequate intakes. For a map of the World Bank regions, see appendix (p 16). **[A: correct page of the appendix added?]** RAE=retinol activity equivalents **[A: correct?]**.

***Figure 4:* Distribution of subnational differences in the prevalence of intake inadequacies between females and males by World Bank region**

Values greater than 0 indicate a higher prevalence of intake inadequacies in females than in males in the same country and age group, whereas values less than 0 indicate a higher prevalence of intake inadequacies in males than in females in the same country and age group. In the boxplots, the solid line indicates the median, the box indicates the IQR, the whiskers indicate 1·5 times the IQR, and the points beyond the whiskers indicate outliers. For a map of the World Bank regions, see appendix p 16 **[A: please state the appropriate page of the appendix here]**. RAE=retinol activity equivalents.