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Calculation of the contribution of water to calcium intake in low- and middle-income countries

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Abstract

Dietary calcium intake is low in many countries, particularly in low- and middle-income countries (LMICs). Water is often overlooked as a source of dietary calcium despite it being universally consumed and providing good calcium bioavailability. Our objective was to assess water distribution systems in LMICs and to develop a formula to simulate the contribution of different water sources to calcium availability. We calculated the contribution of drinking water considering different calcium concentration levels to estimate total calcium availability. We consider a country's households' access to drinking water sources and the distribution of the country's population by age and gender. Calcium availability could be increased by an average of 49 mg of calcium per person per day in the 62 countries assessed if calcium in drinking water was considered. In 22 (31%) of the countries studied, 80% of households are supplied by water sources that could increase calcium availability. Improving calcium concentration in water could be considered as a strategy in LMICs to slightly improve calcium availability.

KEYWORDS
bottled water, calcium, sources of drinking water, tap water, water

INTRODUCTION

Calcium intake is well below recommendations in most low- and middle-income countries (LMICs).[1] Low calcium intake is also observed in some population groups of high-income countries.[1,2] Appropriate calcium intake has demonstrated many health benefits, including preventing osteoporosis, reducing hypertensive disorders during pregnancy, lowering blood pressure, lowering cholesterol values, lowering blood pressure in children whose mothers were supplemented with calcium during pregnancy, and preventing the recurrence of colorectal adenomas.[3–5]

The contribution of water to mineral intake is rarely considered when estimating dietary calcium intake or calcium availability.[6,7] Many dietary assessments and food chemical composition data do not include water intake or composition. From the nutritional and public health point of view, water could provide a good source of calcium depending on the calcium concentration of the water.[8,9] Water is universally consumed, provides good bioavailability of calcium—similar to that of milk—and has high rates of absorption due to its consumption throughout the day.[10,11] Water does not impose any change in calorie intake, a key consideration in populations with low calcium intake and high obesity rates.[7]

There are limited data on drinking water calcium content. Data from high-income countries, such as Spain and France, show that mineral and tap water containing between 50 and 100 mg/L of calcium could provide almost a quarter of the total calcium daily intake for adults.[12,13] One study found that the average calcium concentration in tap water in Canada, the United States, and Spain ranged between 6.8 and 200 mg/L.[14,15] A study from Argentina showed low calcium concentrations in water—less than 20 mg/L for tap water and less than 50 mg/L for bottled water.[16] Higher values with water concentrations between 64 and 523 mg/L were published in another study conducted in Algeria.[17] In the Epidémiologie de l'ostéoporose (EPIDOS) prospective cohort, calcium content of tap water supplies ranged between 43 and 118 mg/L. Studies have shown that regular consumption of calcium-rich water that provides an increase of 100 mg of calcium per day was associated with a 0.5% increase in bone mineral density in women.[18] Some observational studies have suggested a protective effect of high concentrations of calcium in drinking water against cardiovascular mortality.[19,20] Governmental regulations on the content of calcium in water could be used to improve calcium intake. Several countries in the European Union regulate a minimum of 30 mg/L of calcium and other minerals in drinking tap water to improve diet and decrease health risks.[21,22]

The objective of this review is to assess water distribution systems in LMIC countries and to develop a formula to simulate the contribution of different water sources to calcium intake assuming three scenarios of calcium concentration in water.

MATERIALS AND METHODS

In this study, we conducted a database review to assess sources of drinking water by household in each target country. Using country demographics and assuming water intake, we calculated how calcium availability in each country would increase if drinking water had different hypothetical calcium concentrations.

Sources of drinking water

For each available country in the Demographic Health Survey (DHS) data repository, we obtained information on household access to different sources of drinking water.[23] The DHS collects household data from countries across Africa, Asia, Latin America/Caribbean, and Eastern Europe. According to DHS data, we categorized households access to different sources of water into three groups:

- Group 1 was defined as "Centralized water distribution" and included types of water, such as piped tap water, either on or off premises.
- Group 2 was defined as "Water in distributed containers" and included bottled water, tanker trucks, and sachet water.
- Group 3 was defined as "Water from open sources" and included streams, rivers, and wells.

Model framework to estimate calcium availability

Calcium availability and calcium deficiency risk were taken from Kumssa et al., with the assumption that these values have not changed since 2011.[7,23–26] Kumssa et al. used national food balance sheets reported by the Food and Agriculture Organization of the United Nations (UN) as a proxy for food consumption.[24] These data overestimate calcium intake as the data are not adjusted for household waste or inter- or intrahousehold variation in access to food. The study also provides a population–demographic weighted calcium requirement threshold to assess calcium adequacy, which we used to estimate calcium adequacy by calculating different calcium concentrations in water.

Given that calcium availability provided by Kumssa et al. does not contemplate calcium available in drinking water, and it is unlikely that water contains no calcium, we assumed three scenarios with different calcium concentrations in basal water, starting with a minimum calcium concentration of 20 mg/L of water for all types of drinking water:

- Scenario 1: calcium concentration of 20 mg/L of water for drinking water of Group 1 (i.e., tap water), Group 2 (i.e., bottled water), and Group 3 (i.e., open-source water).
- Scenario 2: calcium concentration of 50 mg/L for drinking water of Groups 1 and 3 and 100 mg/L of water for drinking water of Group 2.

- Scenario 3: calcium concentration of 100 mg/L for drinking water of Groups 1 and 3 and 400 mg/L of water for drinking water of Group 2. We considered these values to calculate the basal availability of calcium of each country.[24]

Formulas 1 and 2 were used to calculate hypothetical calcium availability in each country using the calcium content described in each scenario. To calculate the additional calcium provided by water, we considered daily water intake by gender and age using data from the US National Nutrition Survey and we assumed that water intake in all countries was the same as those of the United States.

We calculated each country's access to water sources considering all individuals in the household from the DHS data.[23] We obtained the distribution of the country's population by age and gender from the UN and then assumed that the households surveyed in the DHS data had the population distribution as provided by the UN. Considering this information, we obtained the distribution of different types of water sources in each country, which was then multiplied by the calcium levels in each scenario considering water intake and water type. All the analyses were done by age and gender (Formula 1).

$$\textit{Total } Ca_{jw} = \overbrace{\left(\sum_i \textit{Proportion of source of water}_{ijw} \cdot \textit{Assumed } Ca_{ijw}\right) \cdot N^\circ \textit{ of members}_{jw}}^{A} + \overbrace{\left(\textit{Ca avalability}_w \cdot N^\circ \textit{ of members}_{jw}\right)}^{B}$$

Formula 1: Formula used to calculate calcium availability using calcium level for each type of water source in each scenario.

By multiplying the calcium availability provided by Kumssa et al. with the UN data, we obtained the country distribution of calcium availability. The distribution was then multiplied by the number of members in each household (Formula 2). Calculations again were stratified by gender and age group. The total calcium available for each country was the result of the sum of A and B, divided by the total members in a household per country.

$$\textit{Total Calcium} = \frac{\sum_j \textit{Total } Ca_{jw}}{\textit{Total number members}_w}$$

Formula 2: Formula used to calculate the country total calcium availability.

- *Assumed* Ca_{ijw} is the calcium availability considering the three scenarios of calcium concentration of water (mg/day) for the *i*-th source of water, the *j*-th age and gender group in the *w*-th country. This value was calculated considering the daily water intake in each of the age groups.
- $\textit{Assumed } Ca_{ijw} = \textit{Water intake}_j \textit{ per day} \cdots \text{Assumed } Ca_i$
- $\textit{Ca avalability}_w$ mg/person per day Ca availability for the *w*-th country
- $N^\circ \textit{ of members}_{jw}$ is the number of members at the *j*-th age and gender group at the *w*-th country, the household's distribution in each country. This value was obtained considering the age and gender population distribution and the amount of household members in the DHS database for the *j*-th age and gender group at the *w*-th country [https://dhsprogram.com/Methodology/survey-search.cfm?pgtype=main&SrvyTp=country, September 2020].
- $\textit{Total number members}_w$ are the total household members for the *w*-th country, obtained from the DHS data.

RESULTS

We obtained information on water source access for 1,607,110 households from 71 LMICs from the DHS reports.[23] Table 1 shows the number and percentage of households with access to different types of water sources for each country. Most countries, 48 (67.6%), had 50% or more of households with access to centralized water distribution and 12 (16.9%) countries had 80% or more of households with access to centralized water distribution (Table 1). Only one country had more than 80% of households with access to open sources of water and 15 countries (21.4%) had more than 50% of households with access to open sources of water.

We assessed the calcium availability considering higher calcium in the water for 62 countries out of the 71 reported in Table 1 as nine countries did not have data on calcium availability reported in the Kumssa et al. study.

Figure 1 shows the average calcium availability per person per day for each of the 62 countries. Without considering calcium in the water, 13 out of the 62 countries (21%) had sufficient calcium availability levels to cover the needs of their population. Figure 1 also shows the results considering the three scenarios of calcium concentration of water. Considering scenario 1, one country would increase its calcium availability to levels sufficient for the needs of its population, giving 14 projected countries (22.6%) with sufficient calcium availability. Considering scenario 2, two countries would increase their calcium availability to levels sufficient for the needs of their population, resulting in 16 projected countries (25.8%) with sufficient calcium availability. Finally considering scenario 3, six countries would increase their calcium availability to levels sufficient for the needs of their population, resulting in 22 projected countries (35.5%) with sufficient calcium availability.

According to the analysis performed in these countries, water could provide an average of 49.0 mg of calcium per person per day (SD 11.0) considering the maximum level we assumed for each water group. More information about calcium availability before and after considering scenario 2 of calcium concentration of water, as well as the calcium availability gain in each country, is provided in Table S1.

Assuming that the calcium concentration of water distributed centralized or in containers (Groups 1 and 2) is feasible to be increased, Figure 2 shows the percentage of households with access to these types of water in the 62 countries analyzed. Eight countries (12.9%)

TABLE 1 Number and percentage of households with access to different water sources.

Country	Centralized water distribution *n* (%)	Water in distributed containers *n* (%)	Water from open sources *n* (%)	Other or missing *n* (%)
Egypt	7432 (98.9)	78 (1.0)	3 (0.0)	3 (0.0)
Armenia	7642 (96.8)	143 (1.8)	107 (1.4)	1 (0.0)
Bangladesh	16,712 (96.6)	71 (0.5)	494 (2.8)	23 (0.1)
Jordan	10,630 (56.5)	7589 (40.4)	583 (3.1)	0 (0.0)
Dominican Republic	1988 (17.4)	8779 (76.6)	641 (5.6)	56 (0.5)
South Africa	9909 (89.4)	469 (4.2)	677 (6.1)	28 (0.3)
Nepal	9858 (89.3)	272 (2.5)	909 (8.2)	1 (0.0)
Albania	11,392 (72.1)	3022 (19.1)	1397 (8.9)	12 (0.1)
Turkey	7102 (60.2)	3189 (27)	1472 (12.5)	31 (0.2)
Namibia	8414 (85.4)	119 (1.2)	1057 (10.7)	259 (2.6)
Ghana	3185 (54.9)	1802 (31)	812 (14.0)	0 (0.0)
Tajikistan	6331 (80.7)	369 (4.7)	1143 (14.6)	0 (0.0)
Guatemala	12,420 (58.1)	5791 (27.1)	3126 (14.6)	46 (0.2)
Malawi	3161 (84.8)	2 (0.1)	564 (15.1)	2 (0.1)
Bolivia	16,158 (82.6)	248 (1.3)	2855 (14.6)	303 (1.6)
Sao Tome and Principe	2940 (83.1)	3 (0.1)	593 (16.8)	0 (0.0)
Honduras	10,802 (50.6)	6972 (32.6)	3320 (15.6)	268 (1.2)
Kyrgyzstan	6615 (82.2)	72 (0.9)	1333 (16.6)	20 (0.3)
Gambia	5119 (82.3)	28 (0.5)	1028 (16.5)	42 (0.7)
Uzbekistan	3319 (79.6)	120 (2.9)	702 (16.8)	27 (0.6)
Peru	20,360 (74.8)	2039 (7.4)	3414 (12.5)	1405 (5.2)
Colombia	30,556 (68.5)	6143 (13.8)	7499 (16.8)	416 (0.9)
Philippines	12,336 (44.9)	9829 (35.7)	5325 (19.4)	6 (0.0)
Lesotho	7203 (76.7)	48 (0.5)	2151 (22.8)	0 (0.0)
Kazakhstan	4347 (74.3)	148 (2.6)	1327 (22.7)	22 (0.4)
Azerbaijan	4674 (65.2)	711 (9.9)	1749 (24.3)	46 (0.6)
Senegal	3052 (67.3)	341 (7.5)	1135 (25.0)	10 (0.2)
Ecuador	3297 (72.0)	75 (1.6)	1206 (26.3)	0 (0.0)
Brazil	9145 (68.8)	498 (3.7)	3175 (23.9)	465 (3.5)
Burkina Faso	4542 (71.9)	26 (0.4)	1727 (27.3)	27 (0.4)
Liberia	2548 (60.4)	467 (11.1)	1199 (28.5)	4 (0.1)
Ukraine	9107 (68.1)	451 (3.4)	3803 (28.4)	18 (0.2)
Timor-Leste	7468 (64.9)	500 (4.3)	3534 (30.7)	0 (0.0)
Cameroon	7624 (65.1)	421 (3.6)	3659 (31.3)	6 (0.1)
Morocco	7695 (66.8)	196 (1.7)	3599 (31.3)	23 (0.2)
Uganda	5939 (66.3)	159 (1.8)	2855 (31.9)	4 (0.0)
Comoros	2905 (64.9)	141 (3.1)	1304 (29.1)	132 (2.9)
Benin	9450 (66.7)	106 (0.7)	4541 (32.0)	59 (0.4)
Eswatini	3166 (65.4)	74 (1.5)	1591 (32.8)	12 (0.2)
Guinea	5021 (63.5)	97 (1.2)	2794 (35.4)	0 (0.0)
Nicaragua	7251 (64.0)	0 (0.0)	4063 (35.8)	14 (0.1)
Togo	2855 (58.1)	182 (3.7)	1872 (38.2)	0 (0.0)
Côte d'Ivoire	5939 (61.3)	34 (0.4)	3627 (37.5)	86 (0.9)

(Continues)

TABLE 1 (Continued)

Country	Centralized water distribution *n* (%)	Water in distributed containers *n* (%)	Water from open sources *n* (%)	Other or missing *n* (%)
Indonesia	11,566 (24.1)	17,992 (37.5)	18,396 (38.4)	9 (0.0)
Gabon	5712 (58.5)	84 (0.9)	3883 (39.8)	76 (0.8)
Mozambique	3622 (58.5)	45 (0.8)	2512 (40.5)	17 (0.3)
Mali	5261 (55.3)	288 (3.0)	3949 (41.5)	12 (0.1)
Nigeria	19,085 (47.2)	4335 (10.8)	16,953 (41.9)	54 (0.1)
Ethiopia	9069 (54.5)	304 (1.8)	7258 (43.6)	19 (0.1)
Guyana	1836 (32.6)	1310 (23.3)	2449 (43.5)	37 (0.7)
Haiti	3513 (26.3)	3685 (27.5)	6206 (46.3)	1 (0.0)
Myanmar	4600 (36.8)	2039 (16.3)	5832 (46.6)	29 (0.2)
Kenya	3057 (47.2)	316 (4.8)	3083 (47.6)	25 (0.4)
Niger	5554 (51.7)	36 (0.3)	5134 (47.7)	26 (0.2)
Moldova	5172 (46.6)	409 (3.7)	5508 (49.7)	6 (0.0)
India	270,969 (45.0)	19,074 (3.2)	310,310 (51.6)	1156 (0.2)
United Republic of Tanzania	4265 (45.7)	214 (2.3)	4850 (52)	1 (0.0)
Chad	8088 (47.0)	124 (0.7)	8991 (52.2)	30 (0.1)
Angola	5569 (34.5)	1850 (11.4)	8446 (52.4)	244 (1.5)
Rwanda	2078 (41.2)	102 (2.0)	2856 (56.7)	5 (0.1)
Congo	4517 (38.8)	130 (1.1)	6670 (57.3)	315 (2.7)
Afghanistan	8126 (33.3)	1544 (6.4)	14,407 (59.1)	318 (1.3)
Sierra Leone	4599 (34.3)	685 (5.1)	8115 (60.5)	0 (0.0)
Burundi	5789 (36.2)	29 (0.2)	10,139 (63.5)	20 (0.1)
Maldives	827 (13.6)	1178 (19.5)	4026 (66.6)	19 (0.3)
Vietnam	1922 (30.3)	51 (0.8)	4354 (68.7)	10 (0.2)
Madagascar	3216 (28.5)	86 (0.8)	7974 (70.6)	8 (0.1)
Papua New Guinea	3158 (19.7)	388 (2.5)	12,406 (77.4)	69 (0.4)
Congo Democratic Republic	3680 (20.2)	71 (0.4)	14,381 (79.1)	39 (0.2)
Central African Republic	902 (16.3)	0 (0.0)	4616 (83.1)	33 (0.6)
Pakistan	10,707 (7.4)	805 (0.6)	1554 (1.0)	132,366 (91.0)

Note: Data from 1,607,110 households of 71 low- and middle-income countries from the Demographic Health Survey.
Source: Demographic Health Survey.

had greater than 90% of households with access to water sources that could have higher calcium concentrations. Twenty-two (35.5%) countries had more than 80% of their households with access to water sources that could have higher calcium concentrations, and 54 countries (87.1%) had more than 50% of their households with access to water sources that could have higher calcium concentrations. Only 11 (17.7%) countries had more than 50% of households with access to open sources of water (e.g., streams, rivers, and wells)—a source that is less feasible to be modified (Figure 2).

DISCUSSION

In the current article, we analyzed water distribution systems in LMICs using DHS data to model the contribution of water to dietary calcium by considering different levels of calcium in water depending on water sources, such as centralized distributed water and water distributed in containers. We compiled available information on water sources and calcium availability, which can be used to calculate the contribution of calcium water to the diet.

Using information of 62 countries, we found that calcium availability could be increased by an average of 49.0 (SD 11.0) mg per person per day considering that tap and open-source drinking water could contain 50 mg/L and bottled water contains 100 mg/L. Additionally, our calculations showed that if tap and open-source drinking water had 100 mg/L and bottled water had 400 mg/L, nine countries could have calcium availability at a level that would provide enough calcium to satisfy the needs of their populations. We also found that only 17.7% of countries had more than 50% of households with access to water from streams, rivers, and wells as their main source of

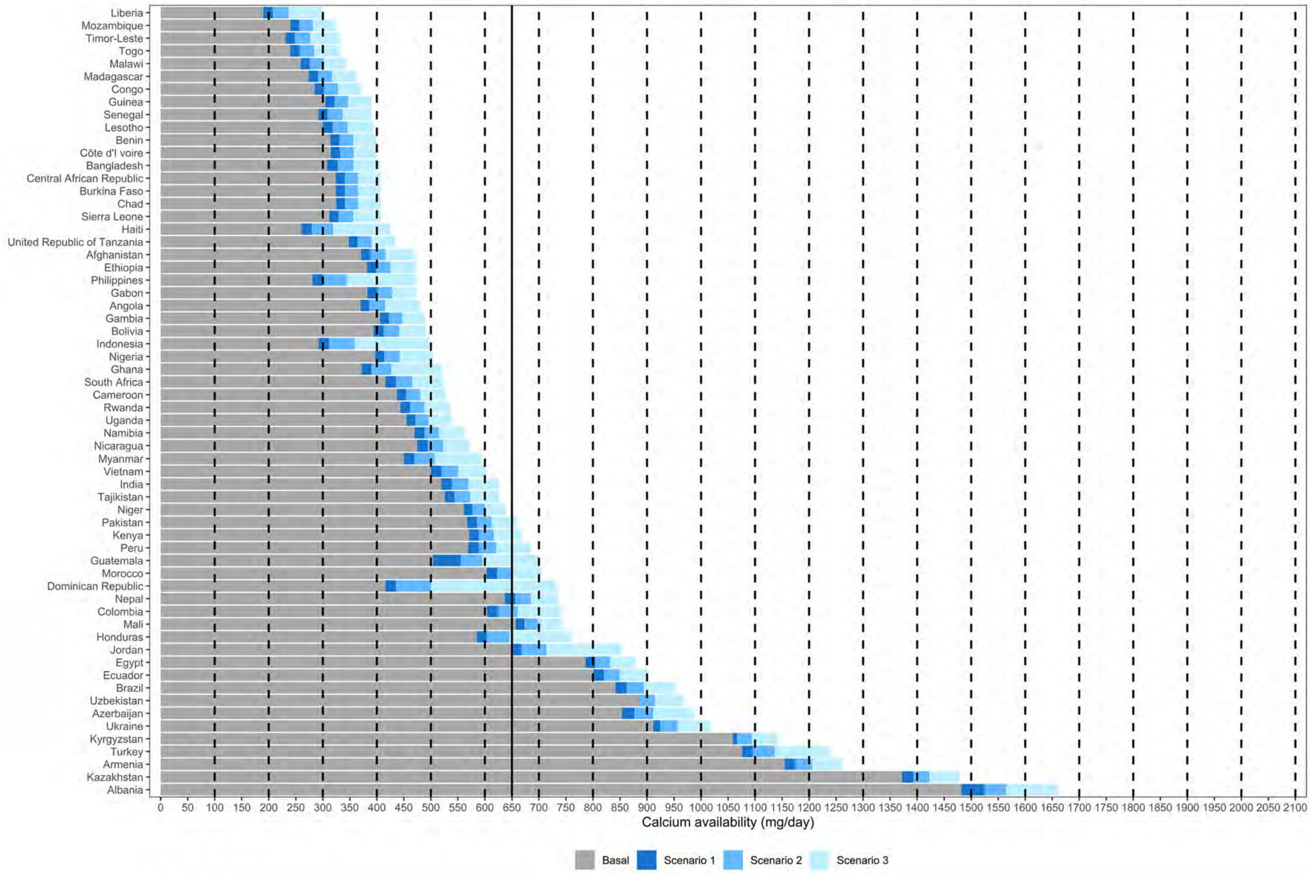

FIGURE 1 Average calcium availability per person per day for each of the 62 countries before and after considering three scenarios of calcium concentration in water.

water, and regulating the mineral content of these sources would be unfeasible.

This study has several limitations. We used the calcium food availability determined by Kumssa et al., which usually overestimates intake, so the calcium deficiency shown in this study could be even higher.[24] The limited number of LMICs provided by Balk et al. was the main reason not to use these data even though the calculated calcium intake provided is more reliable than calcium availability.[1] Additionally, we assumed that the age and gender population distribution described in the UN data was similar to the DHS distribution. Although the DHS did not provide data by age and gender, we were able to simulate calcium availability by age and gender via the United Nations Population Estimates and Projections, which are calculated based on information from over 200 censuses.[23,25]

We developed the analyses by extrapolating daily water intake statistics from the US National Survey to other countries as there are limited data on water intake by age and gender for most of the countries included in our analysis.[23,25] Accurate knowledge of water intake is not well studied, especially in LMICs. Water intake by age and gender is not well documented in many countries, and most dietary assessments do not report water intake or the calcium concentration of water. Daily water intake can vary in different parts of the world, especially when considering seasonally and rural areas in hot climates. Therefore, we were unable to consider these changes as this information is not available in the DHS repository.[27] Water intake is also affected by socioeconomic factors, individual and interpersonal factors, education levels, water quality issues, and environmental factors.[28] Local adjustments to the daily water intake value may be needed in setting local standards. Unfortunately, there is no solid evidence on how to proceed to adjust this information. We used data from the US National Survey—a country with a variety of climates.

To investigate the impact of water on calcium availability, we assumed different scenarios of calcium concentrations in water. WHO recommends a minimum of 20–30 mg of calcium per liter of water, and to prevent the risk of cardiovascular disease.[27] Thus, we calculated the concentration of 20 mg/L of calcium in water as a minimum value and then calculated higher levels depending on the water source. Our findings show potential for areas with low calcium concentration in their drinking water to improve calcium availability or intake by regulating the calcium concentration in water.

There is a body of literature showing the feasibility of improving calcium concentration in water from reverse osmosis systems as it is recommended to remineralize low mineral water to avoid health problems.[29,30] Reverse osmosis uses a semipermeable membrane that removes 94–98% of the calcium. One study showed that water freshness is improved with calcium chloride with calcium concentrations ranging between 46 and 117 mg/L.[29,30] Other possible strategies could include a domestic enriching calcium device at the point-of-entry of tap

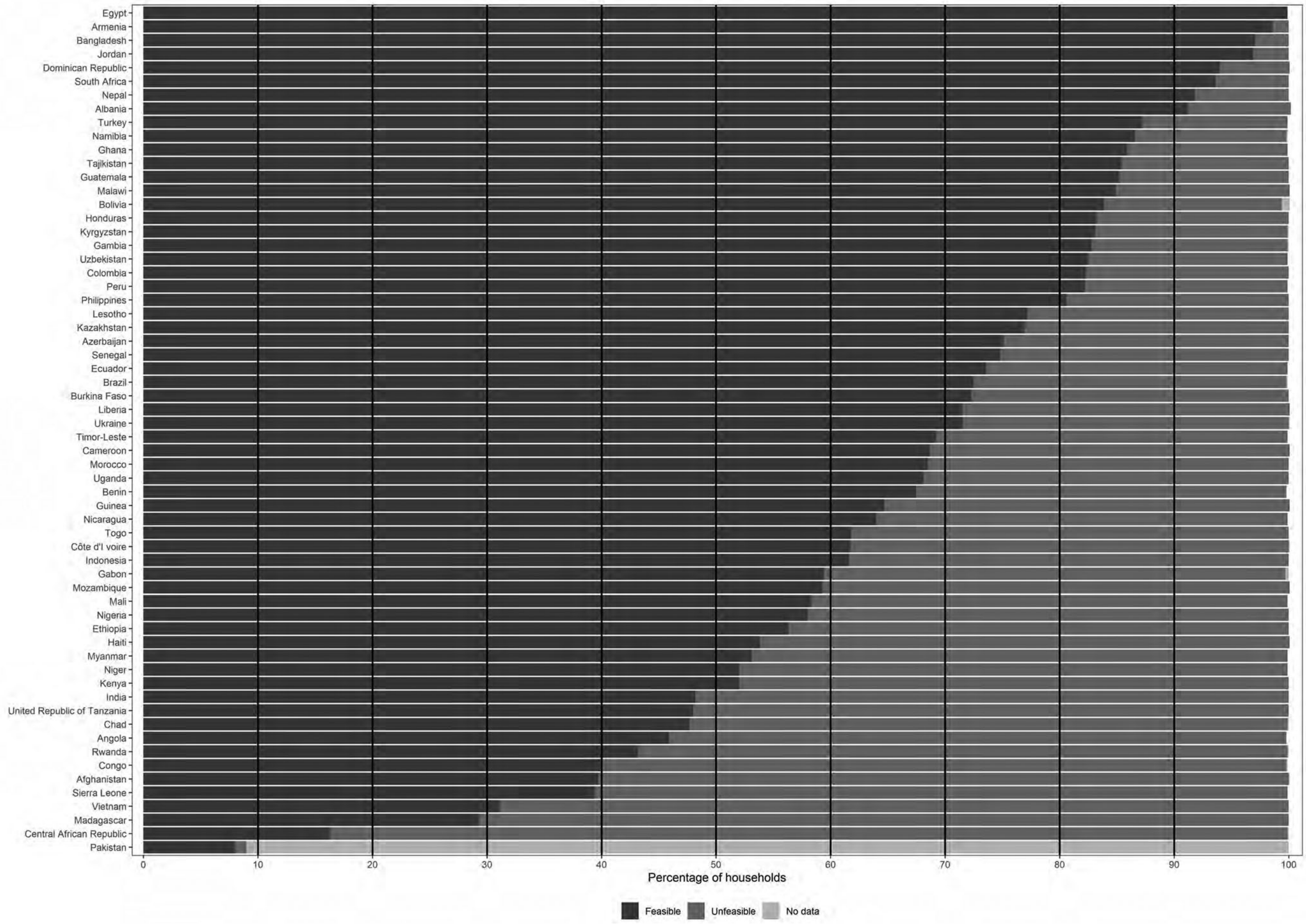

FIGURE 2 Percentage of households in the 62 countries analyzed with access to water distributed centralized, in containers or to open sources of water.

water, or a point-of-use mineralization unit under the kitchen sink with a tap separate from where the water is used mainly for cooking.

Simulations in population groups of LMICs have shown that water with up to 500 mg of calcium per liter of water increases the percentage of people reaching adequate intake without exceeding the recommended upper limit for calcium intake.[7] In laboratory tests, we found that table water containing 20 mg of calcium per liter could reach up to 100 mg of calcium per liter by adding calcium chloride.[31] This water complied with WHO standards for tap water.[31] Higher levels could be reached using organic salts; however, when using organic salts, the final water could only be distributed in containers or bottles or prepared at the point of use by adding the calcium salts. Using a triangle test, a water consumer panel perceived no difference in organoleptic properties between table water containing 20 mg of calcium per liter and the same water with added calcium. The taste threshold for calcium chloride was 291 $\pm$ 73 mg of calcium per liter. The threshold for calcium gluconate is 587 $\pm$ 131 mg of calcium per liter.[31]

Further research will be necessary for this possible intervention, including investigating the technical feasibility of incorporating calcium salts, the economic impact of using public water sources, the organoleptic acceptability in different populations, and local regulatory aspects. Much of the added calcium to tap water could be wasted, as most domestic water is not used for human drinking. Point-of-use mineralization devices could overcome this problem. Additionally, the design of the implementation should consider more reliable data on water intake, especially in young children. Although simulation studies have shown that a strategy of calcium-enriched water is safe, young children could be at risk of excess calcium intake depending on their daily water intake. The distribution of calcium salts may be an acceptable strategy that merits implementation research. Actions can be taken in conjunction with strategies to improve drinking water in populations without access to safe water sources. Given the benefits that adequate calcium intake has on health, quality of life, and survival as well as the large number of populations without access to adequate dietary calcium, actions to improve access to safe sources of water are seen as high-impact interventions.

CONCLUSION

Considering that calcium availability is low in many countries around the world, strategies to improve calcium concentration in water could be used to slightly improve calcium availability in LMICs. These strategies could have more impact in areas where the content of calcium is low, or in areas where the consumption of water in containers is high. Drinking water could be a good source of calcium and contribute to improve calcium intake recommendations and related health benefits.

AUTHOR CONTRIBUTIONS

G.C. and J.M.B. had the original idea. G.C. wrote the first protocol and draft of this manuscript. M.L.W., P.M.N., M.D., and A.D. gathered and compiled the information and did the first analysis. E.S., L.G., and G.C. developed the formula and performed the statistical analysis. N.M. and M.B.P. provided critical information in developing the idea. All authors reviewed and approved the last version of this manuscript.

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COMPETING INTERESTS

The authors declare no competing interests.

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PEER REVIEW

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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