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The Prevalence and Correlates of Vitamin D Deficiency and Overweight/Obesity of School-Age Children in Colombia–Findings on the Double Burden of Malnutrition from Nationally-Representative Data

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The Prevalence and Correlates of Vitamin D Deficiency and Overweight/Obesity of School-Age Children in Colombia–Findings on the Double Burden of Malnutrition from Nationally-Representative Data

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Abstract

The double burden of malnutrition (DBM), defined as the coexistence of overweight/obesity and micronutrient deficiency, is an emerging concern in childhood health. This study aimed to determine the prevalence of DBM and identify associated factors among Colombian schoolchildren aged 5–12 years. Using data from a nationally representative sample of 6,063 participants in the 2015 National Survey of Nutritional Status (ENSIN), DBM was defined as BMI-for-age z-score >1 combined with vitamin D deficiency. To account for the absence of a universal cutoff, three thresholds for vitamin D deficiency (<30, <37.5, and <50 nmol/L) were applied. Prevalence estimates varied by definition, from 0.7% (DBM1) to 6.9% (DBM3). In multilevel analyses, DBM1 and DBM2 were rare but showed associations with behavioral and household factors, including low physical activity, excessive screen time, household size, and head-of-household characteristics. DBM3, the most widely used definition, revealed the highest prevalence and was linked to socioeconomic and community-level factors such as smaller households, parental education, and residence in large cities. These findings indicate that narrower cutoffs identify children with more severe vulnerabilities, while broader thresholds capture structural inequities. Tailored interventions addressing both behavioral risks and social determinants are needed to reduce DBM among Colombian schoolchildren.

Keywords: double burden of malnutrition; vitamin D deficiency; overweight children; Colombian schoolchildren

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1. Introduction

The World Health Organization [1] defines the Double Burden of Malnutrition (DBM) as the coexistence of deficiency of one or more nutrients with overweight and obesity or diet-related non-communicable diseases within individuals, households, and populations and across the life course. The DBM can manifest in various forms depending on its location and context and can occur at the national, community, household, and individual levels [2,3]. A specific example of DBM is the coexistence of overweight or obesity with low levels of vitamin D. This lower vitamin D level is highly prevalent in overweight and obese children and adolescents [4]. A meta-analysis [5] found that a significant number of obese children experienced vitamin D deficiency, indicating the presence of DBM at the individual level.

Vitamin D plays a crucial role in biological functions such as calcium homeostasis and bone mineralization [6]. Consequently, low vitamin D concentration is associated with numerous adverse outcomes including low bone mineral density [7], poor skeletal health [8], functional disabilities [9], multiple sclerosis [10,11], poor immune system function, and increased mortality [12]. Furthermore, vitamin D plays an essential role in the regulation of glucose homeostasis, insulin secretion, and inflammation associated with obesity [13–15]. Lower vitamin D level has been linked to various metabolic disorders such as obesity, type 2 diabetes mellitus (T2DM), insulin resistance, and cardiovascular diseases [16–18].

Populations with limited sun exposure are at increased risk for low vitamin D levels [19,20]. Several socioecological factors operating at multiple levels may elucidate the mechanisms behind this phenomenon. For example, at the individual level, people who are less physically active or more sedentary often experience insufficient exposure to sunlight, attributable to prolonged periods spent in front of electronic devices such as phones, television, or computers [21]. Furthermore, environmental factors related to building structures, neighborhood characteristics, and social contexts significantly contribute to reduced sunlight exposure, reflecting their critical role in pediatric obesity [22,23].

Increasing evidence highlights the association between low vitamin D levels and metabolic disorders among obese children [5,24–31]. The relationship between low vitamin D levels and obesity has attracted significant attention in pediatric studies. A 2015 meta-analysis [29] revealed a substantial connection between vitamin D deficiency and obesity, with an odds ratio (OR) of 3.43 (95% CI: 2.33-5.06). Similarly, another meta-analysis by Fiamenghi and Mello [5] reported a prevalence ratio (PR) of 1.41 (95% CI: 1.26-1.59) within the pediatric population. The interaction between vitamin D deficiency and excess adiposity induces adverse effects, influencing metabolic pathways by promoting the accumulation of inactive forms and reducing the availability of vitamin D [32], in addition to decreasing tissue secretion and insulin sensitivity [33]. Despite these revelations, it remains difficult to reach a consensus on the underlying cause of decreased vitamin D levels in obese people [33]. The main hypothesis postulates that the absorption of vitamin D by adipose tissue, given its fat-soluble nature, may play a contributing role [33].

Furthermore, some researchers have delved into the relationship between vitamin D deficiency and obesity in Colombia [28,34]. According to Beer et al. [34], there exists a significant association between vitamin D levels and the prevalence of overweight among Colombian children aged 1 to 18 years with a BMI-for-age Z score greater than 1. Specifically, they found that the prevalence is 3.3% when vitamin D levels are below 30 nmol/L, escalating to 30.1% when vitamin D levels fall below 50 nmol/L. However, while these studies explored the association between obesity and vitamin D deficiency in children, they did not delve into the factors potentially influencing the development of this phenomenon, particularly in Colombian schoolchildren.

To address these knowledge gaps and draw from the social-ecological model, this study aimed to assess the prevalence and factors associated with the double burden of malnutrition (DBM), defined as the co-occurrence of vitamin D deficiency and overweight/obesity, in Colombian schoolchildren (aged 5 – 12 years) using nationally representative data from the Colombian National Nutrition Survey (ENSIN 2015) [35]. We hypothesized that multiple-level factors at the individual, interpersonal, community, and policy levels would be associated with the double burden of malnutrition in these subjects.

2. Materials and Methods

2.1. Study Population and Data

The Colombian National Nutrition Survey 2015 - 2016 [Encuesta Nacional de Situación Nutricional (ENSIN)] [35] used a multi-stage stratified sampling scheme. The ENSIN team selected non-institutionalized civilian residents to represent Colombian population. The first stage consisted of building primary sampling units (PSUs) such as municipalities with more than 7,500 inhabitants or groups of smaller cities with similar geographic and socioeconomic characteristics.

The units represent two hundred ninety-five municipalities in thirty-two departments of Colombia. Survey participants were required to complete detailed questionnaires covering various aspects such as demographic information, wealth indicators, and household head characteristics.

Additionally, trained personnel conducted anthropometric measurements on each household member using standardized techniques and precise instruments. Weight measurements were conducted by trained personnel with precision up to the nearest 100 grams, utilizing a Seca 874 balance from Seca Medical Measurement Systems and Scales, headquartered in Hamburg, Germany. Body Mass Index (BMI) was computed by dividing the weight in kilograms by the square of height in meters.

The BMI Z-score was utilized in accordance with standards established by the World Health Organization (WHO) [36]. Children between the ages of 5 and 12 were categorized as underweight if their Z-score fell below -2, normal if their Z-score ranged from -2 to +1, and overweight if their Z-score was greater than +1 to +2. Children with Z-scores exceeding +2 were classified as obese [36].

The 25-hydroxyvitamin-D test was used to measure vitamin D status [37]. The bioanalysts drew blood from the participants' veins while adhering to all biosafety measures. The blood samples were then centrifuged for ten minutes using portable centrifuges (EBA 20, Hettich). Laboratory technicians transported the blood samples in liquid nitrogen to the INS (National Institute of Health in Bogotá) for processing and analysis. Total serum 25(OH)D concentration was quantified using a chemiluminescent antibody immunoassay on an ADVIA Centaur XP analyzer (Siemens Health Care Diagnostics). This competitive immunoassay involves a mouse monoclonal anti-fluorescent antibody covalently bound to paramagnetic particles, acridinium ester-labeled mouse monoclonal anti-25(OH)D antibody, and a fluorescein-labeled vitamin D analog.

The Siemens ADVIA Centaur® Vitamin D Total assay is distinguished by its rigorous adherence to standardized protocols, ensuring its traceability to the Ghent Reference Method (RMP), a procedure endorsed by the National Institute of Standards and Technology (NIST). This assay's consistent participation in the Centers for Disease Control and Prevention (CDC) Vitamin D Standardization Certification Program (VDSCP) over several years highlights its commitment to ongoing validation and quality control[38]. Performance benchmarks, including a coefficient of variation (CV) of 15% and a bias of less than 10% as outlined in laboratory data models, alongside the expert-recommended DEQAS model specifications of a CV of 22% and a bias of 10%, have been successfully met by the ADVIA Centaur assay in clinical trials [39,40]. These achievements affirm the assay's compliance with both sets of criteria, underscoring its reliability and accuracy for routine measurement procedures [40].

Due to the lack of consensus on the cutoff point for defining vitamin D deficiency [41,42], we have proposed three thresholds: < 30 nmol/L [5,34] , < 37.5 nmol/L [43,44], and < 50 nmol/L [5,34]. Among these, the threshold of <50 nmol/L is notably the most widely accepted and consistently supported across numerous studies.

The main objective of the study was to investigate the Double Burden of Malnutrition (DBM) at the individual level, with a particular focus on schoolchildren aged 5–12 years. DBM status was determined by the simultaneous presence of overweight/obesity and low vitamin D levels. This study considered three specific scenarios: 1. DBM1: Overweight/obese subjects with vitamin D levels below 30 nmol/L. 2. DBM2: Overweight/obese subjects with vitamin D levels below 37.5 nmol/L. 3. DBM3: Overweight/obese subjects with vitamin D levels below 50 nmol/L.

The socio-ecological model of correlates of the double burden of malnutrition in developing countries by Mahmudiono et al. [45] was the basis for selecting variables in our model (Table 1).

Table 1. Socio-Ecological Model of Factors Associated with the Double Burden of Malnutrition (BMI-for-age z score > 1 and Vitamin D deficiency) among Colombian Schoolchildren.

Level	Variables

Individual	Age Biological sex Ethnicity Meets the minimum of physical activity Excessive exposure to screens
Interpersonal	Wealth quartiles Household size Type of Family Biological sex of Head of Household Education Level of Head of Household Maternal Education Level
Community	Region Urbanicity Degree of Urbanization Living in neighborhood with playgrounds

We examined a range of individual-level sociodemographic variables, including age, biological sex, ethnicity, minimum physical activity, and excessive screen exposure. In the bivariate analysis, age was considered a discrete variable measured in completed years (y), whereas in the multivariate analysis, it was treated as a continuous variable. Biological sex was categorized into two groups: male and female. Ethnicity was self-reported, based on the participant's appearance, skin color, or identification with specific racial or ethnic groups [37].

To assess physical activity and screen exposure, the survey investigated whether schoolchildren met the recommended 60 minutes of daily physical activity, and whether they experienced excessive screen time, defined as more than two hours per day in front of screens [37]. These aspects were captured using two instruments tailored to different age groups, developed by the ENSIN team [37]. For children aged 3 to 5 years, the Measurement of Physical Activity and Sedentary Behavior (C-MAFYCS) questionnaire was used [46]. This parent-reported tool assessed active play outside educational settings. For children and adolescents aged 6 to 17 years, the Youth Risk Behavior Surveillance System (YRBSS) questionnaire was administered [37]. This instrument evaluated compliance with physical activity guidelines and measured excessive screen time unrelated to schoolwork, including television viewing, computer use, video gaming, tablet use, and smartphone engagement.

At the interpersonal level, we delve into both household characteristics and the attributes of the household head. Regarding the household, we scrutinize both its size and wealth. Household size was dichotomized into two categories: those with more than four members and those with fewer. We also included the variable type of family, which refers to the distribution by family structure typology and includes the following two categories: nuclear family and extended family. A nuclear household typically consists of two parents and their children living together as a single-family unit. This structure is often seen as the traditional family model. In contrast, an extended household includes not only the nuclear family but also other relatives such as grandparents, aunts, uncles, or cousins who live under the same roof, reflecting a broader support network and multigenerational living arrangements.

Wealth level was assessed using the quartile system proposed by the ENSIN team [37], ranging from one to four. Notably, the lowest quartile denotes the most financially vulnerable households. This classification evaluates household economic standing based on three critical dimensions: asset ownership, access to public services, and housing quality [37]. When examining the characteristics of

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the household head, we considered their biological sex, and educational background. Specifically, variables pertaining to the mother's educational attainment were incorporated into the analysis.

Finally, at the community level, we examine the region of residence for the schoolchildren, encompassing areas such as Atlantico, Oriental, Orinoquia, Amazonia, Bogota, Central, and Pacifico. Additionally, we incorporate the urbanicity variable to differentiate between rural and urban settings, alongside the degree of urbanization (population size). At this level, we also account for whether the schoolchildren reside in neighborhoods equipped with playgrounds.

2.2. Statistical Analysis

We estimated the weighted prevalence of the double burden of malnutrition (DBM) among Colombian schoolchildren, defined as having a BMI-for-age z-score greater than 1—indicating overweight or obesity—combined with vitamin D deficiency, based on three thresholds: <30 nmol/L (DBM1), <37.5 nmol/L (DBM2), and <50 nmol/L (DBM3). Survey weights were applied to account for the complex sampling design and ensure national representativeness.

Subsequently, we conducted bivariate analyses using chi-square tests to examine the association between DBM (DBM1, DBM2, and DBM3) and various factors at the individual, interpersonal, and community levels. A significance level of 0.05 was used to determine statistical significance. All statistical analyses were performed using R software (version 4.4.3), employing the survey package to account for the complex sampling design.

Following the bivariate analyses, we fitted unadjusted logistic regression models to estimate the crude associations between each explanatory variable and the three DBM outcomes. Unadjusted odds ratios and their corresponding 95% confidence intervals (CIs) were calculated using the svyglm() function with a binomial family.

Finally, multivariable logistic regression models were constructed to identify independent factors associated with DBM, adjusting for all relevant covariates. Adjusted odds ratios and 95% confidence intervals were obtained using the same survey-weighted logistic regression approach.

3. Results

3.1. Prevalence of Anthropometric Indicators, Vitamin D Deficiency, and DBM in Colombian Schoolchildren (5–12 y), ENSIN 2015

Among Colombian schoolchildren aged 5–12 years (ENSIN 2015; n = 6,063), the majority had normal weight (73.9%), whereas 17.0% were overweight, 7.4% were obese, and only 1.6% were underweight. Vitamin D deficiency varied depending on the cutoff used, ranging from 2.5% for <30 nmol/L, 10.6% for <37.5 nmol/L, to 22.6% for <50 nmol/L. Reflecting these differences, the prevalence of the double burden of malnutrition also increased with broader definitions: 0.7% for DBM1 (<30 nmol/L), 3.6% for DBM2 (<37.5 nmol/L), and 6.9% for DBM3 (<50 nmol/L). These findings indicate that while severe double burden of malnutrition is relatively rare, a substantial proportion of children are affected when more inclusive vitamin D thresholds are considered (Table 2).

Table 2. Weighted Prevalence of Anthropometric Indicators, Vitamin D Deficiency, and Double Burden of Malnutrition (DBM: BMI-for-Age Z-Score > 1 and Vitamin D Deficiency) Among Colombian Schoolchildren Aged 5–12 Years, ENSIN 2015.

Characteristics	n	Weighted n	Prev ± SE (95% CI)
Underweight	79	90,066	1.6 ± 0.4 (0.8–2.4)
Normal	4,565	4,111,243	73.9 ± 1.2 (71.5–76.4)
Overweight	1,012	947,533	17.0 ± 1.1 (14.9–19.2)
Obesity	407	410,912	7.4 ± 0.8 (5.9–8.9)
Vitamin D level < 30 nmol/L	126	138,754	2.5 ± 0.5 (1.5–3.5)
Vitamin D level < 37.5 nmol/L	595	587,918	10.6 ± 1.5 (7.6–13.6)
Vitamin D level < 50 nmol/L	1,290	1,254,375	22.6 ± 3.0 (16.7–28.4)

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*DBM1	40	41,088	0.7 ± 0.2 (0.4–1.1)
**DBM2	188	201,464	3.6 ± 0.7 (2.2–5.0)
***DBM3	381	384,778	6.9 ± 1.2 (4.6–9.3)

* DBM1: BMI-for age z score > 1 (overweight/obese) and Vitamin D < 30 nmol/L. **DBM2: BMI-for age z score > 1 (overweight/obese) and Vitamin D < 37.5 nmol/L. ***DBM3: BMI-for age z score > 1 (overweight or obese) and Vitamin D < 50 nmol/L. n = number of cases; Weighted n = weighted number of cases. Prev ± SE (95% CI) = prevalence (%) ± standard error (%) with 95% confidence interval.

3.2. Prevalence of Double Burden of Malnutrition (DBM1) by Individual, Interpersonal, and Community-Level Factors Among Colombian Schoolchildren Aged 5–12 Years

The weighted prevalence of the double burden of malnutrition (DBM1), defined as the coexistence of overweight/obesity (BMI-for-Age Z Score > 1) and vitamin D deficiency (<30 nmol/L), among Colombian schoolchildren aged 5–12 years was generally low, affecting less than 1% of the population.

At the individual level, prevalence showed a slight increase with age, peaking at 2.1% among 9-year-old children, while no notable differences were observed by sex or ethnicity. Behavioral factors appeared influential: children who did not meet the recommended physical activity guidelines exhibited a higher prevalence of DBM1 (1.0% vs. 0.1%, p = 0.0008), and those with excessive screen time also showed elevated prevalence (0.9% vs. 0.4%, p = 0.062).

At the interpersonal level, DBM1 was more common among children in the highest wealth quartile (Q4, 1.8%) and in nuclear households (0.9%), though most household characteristics—including size, type, and parental education—did not reach statistical significance. Community-level factors were generally associated with low prevalence, with slightly higher rates observed in major metropolitan areas (1.3%) compared with large and small urban areas. Children living in neighborhoods with playgrounds had modestly higher prevalence (0.9% vs. 0.5%), although these differences were not statistically significant (Table 3).

Table 3. Prevalence of Double Burden of Malnutrition (DBM1): Concurrent Overweight/Obesity (BMI-for-Age Z Score > 1) and Vitamin D Deficiency (< 30 nmol/L) Among Colombian Schoolchildren Aged 5–12 Years.

Characteristics	n	Weighted n	Prev ± SE (95% CI)	P-value
Individual level				
Age (years)				
5	7	5,903	1 ± 0.7 (-0.3–2.3)	0.0591
6	0	0	0 ± 0 (0–0)	
7	1	656	0.1 ± 0.1 (-0.1–0.2)	
8	4	4,318	0.6 ± 0.4 (-0.1–1.3)	
9	9	14,307	2.1 ± 0.9 (0.2–3.9)	
10	6	4,013	0.6 ± 0.4 (-0.2–1.4)	
11	8	6,554	1 ± 0.5 (0.1–1.9)	
12	5	5,336	0.8 ± 0.4 (-0.1–1.6)	
Biological sex				
Male	17	20,155	0.7 ± 0.3 (0.1–1.3)	0.819
Female	23	20,933	0.8 ± 0.2 (0.4–1.1)	
Ethnicity				
Black	6	6,675	1.2 ± 0.9 (-0.5 – 2.9)	0.329
Indigenous	7	495	0.2 ± 0.1 (-0.1 – 0.4)	
Without Ethnicity	27	33,918	0.7 ± 0.2 (0.4 – 1)	
Meets the minimum of physical activity				
Yes	7	1,635	0.1 ± 0.1 (–0.1–0.2)	0.0008
No	33	39,453	1 ± 0.3 (0.5–1.5)	
Excessive exposure to screens				
Yes	27	33,508	0.9 ± 0.3 (0.4–1.5)	0.0617

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No	13	7,580	0.4 ± 0.1 (0.1–0.7)	
Interpersonal-level				
Wealth Index, Quartiles				
Q1	18	10,070	0.4 ± 0.5 (–0.4–1.3)	0.206
Q2	10	12,803	0.9 ± 0.1 (0.7–1)	
Q3	7	4,575	0.4 ± 0.2 (0.1–0.8)	
Q4	5	13,640	1.8 ± 0.2 (1.5–2.1)	
Household size				
< 4 people	26	25,600	0.9 ± 0.2 (0.6-1.3)	0.414
> 4 people	14	15,488	0.5 ± 0.3 (-0.1-1.2)	
Type of Family				
Nuclear	25	27,758	0.9 ± 0.3 (0.2-1.6)	0.300
Extended	15	13,330	0.5 ± 0.1 (0.4-0.7)	
Biological sex of the Head of Household				
Male	22	21,094	0.6 ± 0.1 (0.4–0.8)	0.390
Female	18	19,994	1 ± 0.5 (0.1–1.9)	
Education Level of Head of Household (Years)				
0-4	10	11,275	0.8 ± 0.2 (0.5–1.1)	0.674
5-10	17	15,745	0.8 ± 0.5 (–0.2–1.8)	
11-15	9	10,338	0.6 ± 0.1 (0.4–0.7)	
16-24	4	3,729	1.2 ± 0.6 (–0.1–2.4)	
Maternal Education Level (years)				
0-4	6	3,015	0.4 ± 0.3 (-0.1 – 0.9)	0.757
5-10	14	14,391	0.7 ± 0.5 (-0.2 – 1.7)	
11-15	12	20,649	1 ± 0.2 (0.6 – 1.3)	
16-24	5	2,969	0.9 ± 0.6 (-0.4 – 2.1)	
Community level				
Region				
Atlantico	5	2,506	0.2 ± 0.1 (0–0.4)	0.175
Oriental	8	13,874	1.4 ± 0.9 (–0.3–3.2)	
Orinoquia and Amazonia	10	383	0.2 ± 0.1 (0–0.5)	
Bogota	2	5,612	0.7 ± 0.0 (0.7–0.7)	
Central	5	10,371	0.8 ± 0.1 (0.7–0.9)	
Pacifico	10	8,343	0.9 ± 0.3 (0.3–1.5)	
Urbanicity				
Urban	33	32,141	0.8 ± 0.2 (0.4–1.2)	0.874
Rural	7	8,947	0.7 ± 0.4 (-0.2–1.5)	
Degree of Urbanization (Population size)				
Major metropolitan cities	7	18,612	1.3 ± 0.5 (0.2-2.3)	0.245
Large urban areas	9	7,784	0.5 ± 0.2 (0.1-1)	
Small urban areas	24	14,692	0.6 ± 0.3 (0.1-1.1)	
Living in neighborhood with playgrounds				
Yes	25	28,919	0.9 ± 0.2 (0.4-1.3)	0.230
No	15	12,169	0.5 ± 0.2 (0.1-1.0)	

P-value = χ^2 score test result. Prev ± SE (95% CI) = Prevalence (%) ± Standard error (%) (95% Confidence Interval). Major metropolitan cities (Barranquilla, Cali, Medellín, Bogotá). Large urban areas (100,001–1,000,000 inhabitants). Small urban areas (≤100,000 inhabitants).

3.3. Prevalence of Double Burden of Malnutrition (DBM2) by Individual, Interpersonal, and Community-Level Factors Among Colombian Schoolchildren Aged 5–12 Years

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The weighted prevalence of the double burden of malnutrition (DBM2), defined as the coexistence of overweight/obesity (BMI-for-Age Z Score > 1) and vitamin D deficiency (<37.5 nmol/L), affected 3.6% of Colombian schoolchildren aged 5–12 years.

The burden of DBM2 varied across age groups, with the highest prevalence observed among 6-year-olds (6.5%) and a secondary peak among 9- to 11-year-olds, while 12-year-olds presented with comparatively lower levels. No significant differences emerged by sex, but ethnic disparities were evident: Indigenous children exhibited the lowest prevalence (0.5%), whereas children without declared ethnicity had the highest prevalence (4.0%, p = 0.0367). Behavioral factors appeared to shape DBM2 risk. Excessive screen exposure was associated with higher prevalence (4.2% vs. 2.6%, p = 0.028), while meeting minimum physical activity guidelines did not show a protective association.

At the interpersonal level, DBM2 prevalence rose steadily with higher socioeconomic status, reaching 5.1% in the wealthiest quartile. Smaller household size (<4 members) and female-headed households were also linked to higher prevalence. Maternal education played a role as well, with children of mothers who completed secondary education (11–15 years) showing the highest prevalence (5.2%, p = 0.0478).

At the community level, the geographic distribution of DBM2 highlighted clear urban patterns. Bogotá registered the highest prevalence (7.0%), followed by other major metropolitan areas (6.3%). In contrast, prevalence was lower in rural areas (2.6%) and in smaller urban settlements. Regionally, the Pacific and Oriental regions reported higher burdens (4.5% and 4.0%, respectively), while the Atlantic and Orinoquia-Amazonia regions had the lowest. Children living in neighborhoods with playgrounds showed a modestly higher prevalence than those without (4.2% vs. 2.8%), although this difference did not reach statistical significance (Table 4).

Table 4. Prevalence of Double Burden of Malnutrition (DBM2): Concurrent Overweight/Obesity (BMI-for-Age Z Score > 1) and Vitamin D Deficiency (< 37 nmol/L) Among Colombian Schoolchildren Aged 5–12 Years.

Characteristics	n	Weighted n	Prev ± SE (95% CI)	P-value
Individual level				
Age (years)				
5	50	21,661	3.6 ± 1 (1.7–5.5)	0.0431
6	22	45,929	6.5 ± 1.7 (3.1–9.9)	
7	14	11,436	1.4 ± 0.5 (0.4–2.4)	
8	21	24,746	3.5 ± 1.1 (1.4–5.7)	
9	23	28,084	4 ± 1.5 (1.1–7)	
10	21	22,699	3.4 ± 1 (1.4–5.4)	
11	22	30,412	4.5 ± 1.3 (1.9–7.1)	
12	15	16,497	2.4 ± 1 (0.4–4.3)	
Biological sex				
Male	95	99,423	3.5 ± 0.7 (2–4.9)	0.497
Female	93	102,041	3.8 ± 0.8 (2.3–5.3)	
Ethnicity				
Black	20	14,462	2.6 ± 1.2 (0.3 – 5)	0.0367
Indigenous	18	1,485	0.5 ± 0.2 (0.1 – 0.8)	
Without Ethnicity	150	185,516	4 ± 0.8 (2.5 – 5.4)	
Meets the minimum of physical activity				
Yes	49	54,375	3.2 ± 0.9 (1.5–5)	0.530
No	139	147,089	3.8 ± 0.8 (2.3–5.4)	
Excessive exposure to screens				
Yes	122	149,919	4.2 ± 0.4 (3.3–5.0)	0.0280
No	66	51,545	2.6 ± 0.6 (1.5–3.8)	
Interpersonal-level				
Wealth Index, Quartiles				
Q1	76	43,104	1.9 ± 0.6 (0.7–3.1)	0.0035

Q2	56	61,656	4.2 ± 0.6 (3.1–5.3)	
Q3	38	57,661	5.5 ± 1.1 (3.4–7.6)	
Q4	18	39,042	5.1 ± 0.2 (4.7–5.4)	
Household size				
< 4 people	115	133,033	4.9 ± 0.7 (3.4-6.3)	0.0049
> 4 people	73	68,430	2.4 ± 0.4 (1.6-3.2)	
Type of Family				
Nuclear	115	121,831	3.9 ± 0.7 (2.5-5.4)	0.436
Extended	73	79,633	3.2 ± 0.3 (2.6-3.9)	
Biological sex of the Head of Household				
Male	109	109,010	3.1 ± 0.3 (2.5–3.8)	0.0306
Female	79	92,453	4.4 ± 0.7 (3.0–5.8)	
Education Level of Head of Household (Years)				
0-4	33	36,709	2.5 ± 0.8 (1–3.9)	0.0898
5-10	71	74,333	3.9 ± 0.7 (2.5–5.2)	
11-15	72	82,680	4.6 ± 0.4 (3.7–5.4)	
16-24	12	7,742	2.4 ± 0.6 (1.2–3.6)	
Maternal Education Level (years)				
0-4	24	22,797	3 ± 1.3 (0.5 – 5.4)	0.0478
5-10	55	47,809	2.5 ± 0.6 (1.3 – 3.6)	
11-15	81	111,788	5.2 ± 0.6 (4 – 6.3)	
16-24	20	13,300	3.8 ± 0.7 (2.4 – 5.2)	
Community level				
Region				
Atlantico	18	14,177	1 ± 0.3 (0.4–1.7)	0.0166
Oriental	34	39,102	4 ± 1.8 (0.4–7.6)	
Orinoquia and Amazonia	46	3,304	1.8 ± 1.2 (–0.5–4)	
Bogota	22	55,264	7 ± 0.0 (7–7)	
Central	34	46,092	3.6 ± 0.5 (2.7–4.5)	
Pacifico	34	43,526	4.5 ± 0.6 (3.3–5.8)	
Urbanicity				
Urban	152	166,737	3.9 ± 0.9 (2.3–5.6)	0.268
Rural	36	34,727	2.6 ± 0.8 (1.1–4.2)	
Degree of Urbanization (Population size)				
Major metropolitan cities	38	93,472	6.3 ± 1.3 (3.7-8.9)	0.0056
Large urban areas	35	38,192	2.5 ± 0.8 (1-4)	
Small urban areas	115	69,800	2.7 ± 0.6 (1.6-3.9)	
Living in neighborhood with playgrounds				
Yes	114	138,935	4.2 ± 1.0 (2.2-6.1)	0.169
No	74	62,529	2.8 ± 0.6 (1.6-3.9)	

P-value = χ^2 score test result. Prev ± SE (95% CI) = Prevalence (%) ± Standard error (%) (95% Confidence Interval). Major metropolitan cities (Barranquilla, Cali, Medellín, Bogotá). Large urban areas (100,001–1,000,000 inhabitants). Small urban areas (≤100,000 inhabitants).

3.4. Prevalence of Double Burden of Malnutrition (DBM3) by Individual, Interpersonal, and Community-Level Factors Among Colombian Schoolchildren Aged 5–12 Years

The prevalence of the double burden of malnutrition (DBM3), defined as concurrent overweight/obesity (BMI-for-Age Z Score > 1) and vitamin D deficiency (<50 nmol/L), was higher than that observed for DBM1 and DBM2, affecting 6.9% of Colombian schoolchildren aged 5–12 years. This reflects the broader definition of vitamin D deficiency used in DBM3.

Prevalence varied across age groups, with intermediate peaks during middle childhood, although no statistically significant differences were observed between boys (6.5%) and girls (7.4%). Ethnic disparities were evident, as children without declared ethnicity exhibited the highest prevalence (7.5%), compared with lower levels among Black (4.3%) and Indigenous (3.6%) children.

Behavioral factors contributed to DBM3 risk. Children who did not meet physical activity recommendations presented a higher prevalence (7.5% vs. 5.2%, p = 0.0286), while excessive screen exposure was strongly associated with increased risk (4.2% vs. 2.6%, p = 0.0113).

At the interpersonal level, DBM3 prevalence rose with higher socioeconomic position, from 4.2% in the lowest wealth quartile to 12.1% in the highest. Similarly, children from smaller households (<4 members) and those living in female-headed households tended to show higher prevalence. Educational attainment of caregivers also played a role: children of mothers and household heads with secondary or higher education had the highest prevalence, reaching nearly 10%.

At the community level, a pronounced urban gradient emerged. Bogotá registered the highest prevalence (13.4%), followed by other major metropolitan cities (10.8%). By contrast, rural areas and small urban settlements reported substantially lower levels. Regionally, the Pacific and Oriental regions showed elevated prevalence (8.0% and 8.5%, respectively), while the Atlantic region exhibited the lowest burden (1.9%). Living in neighborhoods with playgrounds was modestly associated with higher prevalence (7.5% vs. 5.9%), although the difference was not statistically significant. Taken together, these results underscore how DBM3 is shaped not only by individual behaviors but also by social, economic, and community contexts, with a clear concentration in urban centers (Table 5).

Table 5. Prevalence of Double Burden of Malnutrition (DBM3): Concurrent Overweight/Obesity (BMI-for-Age Z Score > 1) and Vitamin D Deficiency (< 50 nmol/L) Among Colombian Schoolchildren Aged 5–12 Years.

Characteristics	n	Weighted n	Prev ± SE (95% CI)	P-value
Individual level				
Age (years)				
5	50	21,661	3.6 ± 1 (1.7–5.5)	0.0431
6	22	45,929	6.5 ± 1.7 (3.1–9.9)	
7	14	11,436	1.4 ± 0.5 (0.4–2.4)	
8	21	24,746	3.5 ± 1.1 (1.4–5.7)	
9	23	28,084	4 ± 1.5 (1.1–7)	
10	21	22,699	3.4 ± 1 (1.4–5.4)	
11	22	30,412	4.5 ± 1.3 (1.9–7.1)	
12	15	16,497	2.4 ± 1 (0.4–4.3)	
Biological sex				
Male	192	185,085	6.5 ± 1.1 (4.4–8.5)	0.250
Female	189	199,693	7.4 ± 1.5 (4.5–10.4)	
Ethnicity				
Black	33	23,610	4.3 ± 2 (0.4 – 8.2)	0.174
Indigenous	37	11,874	3.6 ± 1.6 (0.6 – 6.7)	
Without Ethnicity	311	349,294	7.5 ± 1.3 (4.9 – 10)	
Meets the minimum of physical activity				
Yes	96	88,361	5.2 ± 1.1 (3.1–7.4)	0.0286
No	283	290,250	7.5 ± 1.2 (5.1–10)	
Excessive exposure to screens				
Yes	256	281,328	4.2 ± 0.4 (3.3–5.0)	0.0113
No	124	97,378	2.6 ± 0.6 (1.5–3.8)	
Interpersonal-level				
Wealth Index, Quartiles				
Q1	157	95,236	4.2 ± 0.9 (2.4–6)	<.0001
Q2	119	112,902	7.7 ± 0.7 (6.4–8.9)	

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Q3	64	82,925	7.9 ± 1.2 (5.6–10.3)	
Q4	41	93,714	12.1 ± 0.3 (11.5–12.8)	
Household size				
< 4 people	234	255,390	9.3 ± 0.9 (7.5-11.1)	<.0001
> 4 people	147	129,388	4.6 ± 0.6 (3.4-5.8)	
Type of Family				
Nuclear	224	221,949	7.2 ± 0.8 (5.5-8.8)	0.601
Extended	157	162,829	6.6 ± 0.7 (5.3-8.0)	
Biological sex of the Head of Household				
Male	236	238,686	6.9 ± 0.6 (5.8–8.0)	0.0306
Female	145	146,093	7 ± 0.8 (5.4–8.6)	
Education Level of Head of Household (Years)				
0-4	77	77,239	5.2 ± 1 (3.2–7.2)	0.0149
5-10	135	131,464	6.8 ± 0.9 (5–8.6)	
11-15	146	159,323	8.8 ± 0.5 (7.8–9.9)	
16-24	22	16,570	5.2 ± 0.8 (3.6–6.8)	
Maternal Education Level (years)				
0-4	45	39,997	5.2 ± 1.3 (2.6 – 7.9)	0.0003
5-10	115	96,234	5 ± 0.8 (3.4 – 6.6)	
11-15	171	206,201	9.5 ± 0.8 (8 – 11.1)	
16-24	34	33,645	9.6 ± 1 (7.7 – 11.6)	
Community level				
Region				
Atlantico	31	26,483	1.9 ± 0.7 (0.6–3.3)	<.0001
Oriental	74	83,110	8.5 ± 2.1 (4.3–12.7)	
Orinoquia and Amazonia	99	8,926	4.8 ± 1.2 (2.6–7.1)	
Bogota	44	106,137	13.4 ± 0.0 (13.4 – 13.4)	
Central	71	83,121	6.5 ± 0.9 (4.7–8.3)	
Pacifico	62	77,002	8 ± 0.9 (6.2–9.9)	
Urbanicity				
Urban	310	312,857	7.4 ± 1.5 (4.5–10.3)	0.257
Rural	71	71,922	5.5 ± 1.0 (3.5–7.4)	
Degree of Urbanization (Population size)				
Major metropolitan cities	70	160,755	10.8 ± 2.6 (5.7-15.9)	0.0328
Large urban areas	78	86,496	5.7 ± 1.4 (3-8.4)	
Small urban areas	233	137,527	5.4 ± 0.8 (3.9-6.9)	
Living in neighborhood with playgrounds				
Yes	229	247,329	7.5 ± 1.3 (4.9-10)	0.0626
No	151	131,377	5.9 ± 1.0 (4.0-7.8)	

P-value = χ^2 score test result. Prev ± SE (95% CI) = Prevalence (%) ± Standard error (%) (95% Confidence Interval). Major metropolitan cities (Barranquilla, Cali, Medellín, Bogotá). Large urban areas (100,001–1,000,000 inhabitants). Small urban areas (≤100,000 inhabitants).

3.5. Unadjusted and Adjusted Associations of Individual, Interpersonal, and Community-Level Factors with the Double Burden of Malnutrition (DBM1) Among Colombian Schoolchildren

The analysis of factors associated with the double burden of malnutrition (DBM1) among Colombian schoolchildren reveals a complex interplay of individual, interpersonal, and community-level determinants. At the individual level, children who did not meet the minimum physical activity recommendations had substantially higher odds of DBM1 in both unadjusted (OR 10.6) and adjusted models (OR 9.12), highlighting the critical role of sedentary behavior. Other individual factors, including age, sex, and ethnicity, showed no consistent associations after adjustment, although some ethnic groups, such as Black children, displayed wide confidence intervals, reflecting small sample sizes. Excessive screen exposure was associated with higher DBM1 odds in the unadjusted model but did not remain statistically significant after adjustment (OR 1.83; 95% CI 0.71–4.73).

At the interpersonal level, lower educational attainment of the head of household was linked to increased odds of DBM1, whereas other variables such as household size, family type, maternal education, and the sex of the household head showed inconsistent effects. Interestingly, children from the highest wealth quartile (Q4) exhibited elevated adjusted odds, indicating that higher socioeconomic status does not necessarily confer protection against DBM1.

Community-level factors demonstrated notable regional disparities. Children living in the Oriental, Central, and Pacific regions had higher adjusted odds of DBM1 compared with those in Bogotá. Conversely, residing in large and small urban areas was associated with lower odds compared to major metropolitan cities, suggesting a concentration of DBM1 risk in the largest urban centers. Proximity to parks or playgrounds showed only a modest, non-significant association with DBM1 (adjusted OR 1.29; 95% CI 0.49–3.36) (Table 6)

Table 6. Unadjusted and Adjusted Models. Factors at the Individual, Interpersonal, and Community Levels and Double Burden of Malnutrition (DBM1: BMI-for age z score > 1 (overweight or obese) and Vitamin D < 30 nmol/L) in Colombian Schoolchildren Aged 5 to 12 y.

Characteristics	**Category**	**Unadjusted Model**	**Adjusted Model**
Individual-level		**OR (95% CI)**	**OR (95% CI)**
Age	Per year increase	1.13 (0.93–1.36)	1.09 (0.93–1.29)
Biological sex	Male (Ref)	1	1
	Female	1.11 (0.45–2.71)	0.94 (0.35–2.56)
Ethnicity	Indigenous (Ref)	1	1
	Black	8.02 (0.96–67.1)	3.09 (0.43–22.06)
	Without Ethnicity	4.79 (0.97–23.8)	1.17 (0.14–10.03)
Meets the minimum of physical activity	Yes (Ref)	1	1
	No	10.6 (1.98–57.2)	9.12 (1.46–57.05)
Excessive exposure to screens	No (Ref)	1	1
	Yes	2.44 (1.08–5.52)	1.83 (0.71–4.73)
Interpersonal-level			
Wealth Index, Quartiles	Q1 (Ref)	1	1
	Q2	1.97 (0.45–8.62)	1.58 (0.57–4.36)
	Q3	0.99 (0.24–4.13)	0.80 (0.20–3.21)
	Q4	4.04 (1.05–15.55)	4.1 (0.65–26.0)
Household size	>4 people (Ref)	1	1
	<4 people	1.7 (0.52–5.55)	1.1 (0.34–3.52)
Type of Family	Extended (Ref)	1	1
	Nuclear	1.66 (0.51–5.4)	2.24 (0.53–9.5)
Biological sex of Head of Household	Male (Ref)	1	1

	Female	1.58 (0.58–4.31)	1.97 (0.48–8.16)
Education of Head of Household (Years)	11–15 (Ref)	1	1
	0–4	1.33 (0.39–4.57)	6.58 (1.01–42.9)
	5–10	1.43 (0.51–4.03)	3.14 (1.04–9.51)
	16–24	2.05 (0.42–10.11)	2.76 (0.13–59.7)
Maternal Education (Years)	0–4 (Ref)	1	1
	5–10	1.91 (0.45–8.03)	2.53 (0.45–14.3)
	11–15	2.45 (0.62–9.59)	4.96 (0.59–41.8)
	16–24	2.17 (0.44–10.72)	1.76 (0.04–72.5)
Community-level			
Region	Bogota (Ref)	1	1
	Atlantico	0.26 (0.08–0.86)	1.14 (0.2–6.47)
	Oriental	2.01 (0.75–5.39)	12.5 (2.02–77.5)
	Orinoquia and Amazonia	0.29 (0.1–0.8)	2.24 (0.33–15.2)
	Central	1.14 (0.33–3.87)	3.80 (1.39–10.37)
	Pacifico	1.23 (0.54–2.78)	3.09 (1.37–6.96)
Urbanicity	Urban (Ref)	1	1
	Rural	0.89 (0.22–3.61)	1.85 (0.47–7.21)
Degree of Urbanization	Major metropolitan cities	1	1
	Large urban areas	0.41 (0.11–1.45)	0.12 (0.02–0.76)
	Small urban areas	0.46 (0.13–1.62)	0.22 (0.05–0.86)
Living in neighborhood with playgrounds	No (Ref)	1	1
	Yes	1.61 (0.73–3.55)	1.29 (0.49–3.36)

An adjusted model was performed including all individual-, interpersonal-, and community-level variables listed in the table. Prevalence estimates in the model account for potential confounding among these factors.

3.6. Unadjusted and Adjusted Associations of Individual, Interpersonal, and Community-Level Factors with the Double Burden of Malnutrition (DBM2) Among Colombian Schoolchildren

Among Colombian schoolchildren, the associations between individual-, interpersonal-, and community-level factors and the double burden of malnutrition (DBM2) reveal distinct patterns. At the individual level, neither age nor sex was significantly associated with DBM2. However, ethnicity emerged as a strong predictor: compared to Indigenous children, Black children had over three times higher odds (adjusted OR 3.26, 95% CI: 1.03–10.3), and children without reported ethnicity had more than four times higher odds (adjusted OR 4.29, 95% CI: 1.63–11.3). While physical activity and excessive screen exposure were associated with DBM2 in unadjusted models, these relationships diminished after adjustment, indicating that other factors accounted for much of their effects.

At the interpersonal level, children living in smaller households (<4 members) were more likely to experience DBM2 (adjusted OR 1.84, 95% CI: 1.16–2.90), as were those in households headed by females (adjusted OR 1.42, 95% CI: 1.01–1.99). In contrast, associations with household wealth, type of family, maternal education, and education of the head of household attenuated in adjusted models, suggesting that their independent contributions were limited.

Community-level factors highlighted geographic and urban disparities. Children in the Atlantico region had significantly lower odds of DBM2 compared with Bogotá (adjusted OR 0.33, 95% CI: 0.11–0.98), whereas differences in other regions were not statistically significant after adjustment. Similarly, children residing in large or small urban areas generally had lower odds than those in major metropolitan cities, although confidence intervals were wide, indicating some imprecision in the estimates. Overall, these findings emphasize the multifactorial nature of DBM2, with ethnicity, household composition, and regional context playing key roles in shaping risk (Table 7).

Table 7. Unadjusted and Adjusted Models. Factors at the Individual, Interpersonal, and Community Levels and Double Burden of Malnutrition (DBM2: BMI-for age z score > 1 (overweight or obese) and Vitamin D < 37.5 nmol/L) in Colombian Schoolchildren Aged 5 to 12 y.

Characteristics	Category	Unadjusted Model	Adjusted Model
Individual-level		**OR (95% CI)**	**OR (95% CI)**
Age	Per year increase	0.96 (0.88–1.05)	0.95 (0.86–1.05)
Biological sex	Male (Ref)	1	1
	Female	1.10 (0.83–1.44)	1.06 (0.78–1.43)
Ethnicity	Indigenous (Ref)	1	1
	Black	5.86 (1.73–19.81)	3.26 (1.03–10.3)
	Without Ethnicity	9.01 (3.65–22.21)	4.29 (1.63–11.3)
Meets the minimum of physical activity	Yes (Ref)	1	1
	No	1.19 (0.69–2.06)	0.92 (0.55–1.56)
Excessive exposure to screens	No (Ref)	1	1
	Yes	1.62 (1.10–2.38)	1.11 (0.75–1.64)
Interpersonal-level			
Wealth Index, Quartiles	Q1 (Ref)	1	1
	Q2	2.26 (1.19–4.28)	1.57 (0.57–4.29)
	Q3	3.02 (1.60–5.72)	1.76 (0.88–3.52)
	Q4	2.75 (1.17–6.48)	1.71 (0.45–6.46)
Household size	>4 people (Ref)	1	1
	<4 people	2.05 (1.41–2.98)	1.84 (1.16–2.90)
Type of Family	Extended (Ref)	1	1
	Nuclear	1.22 (0.83–1.80)	0.91 (0.61–1.34)

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Biological sex of Head of Household	Male (Ref)	1	1
	Female	1.43 (1.06–1.94)	1.42 (1.01–1.99)
Education of Head of Household (Years)	11–15 (Ref)	1	1
	0–4	0.53 (0.32–0.86)	1.13 (0.61–2.08)
	5–10	0.84 (0.56–1.25)	1.53 (0.75–3.12)
	16–24	0.52 (0.24–1.12)	0.54 (0.17–1.77)
Maternal Education (Years)	0–4 (Ref)	1	1
	5–10	0.83 (0.34–2.02)	0.51 (0.21–1.21)
	11–15	1.78 (0.87–3.63)	1.12 (0.58–2.16)
	16–24	1.29 (0.52–3.23)	1.06 (0.38–2.96)
Community-level			
Region	Bogota (Ref)	1	1
	Atlantico	0.14 (0.07–0.27)	0.33 (0.11–0.98)
	Oriental	0.55 (0.27–1.13)	1.32 (0.50–3.48)
	Orinoquia and Amazonia	0.24 (0.13–0.44)	0.63 (0.25–1.60)
	Central	0.49 (0.28–0.89)	1.01 (0.66–1.56)
	Pacifico	0.63 (0.27–1.49)	1.33 (0.72–2.46)
Urbanicity	Urban (Ref)	1	1
	Rural	0.66 (0.31–1.39)	1.40 (0.57–3.41)
Degree of Urbanization	Major metropolitan cities	1	1
	Large urban areas	0.38 (0.18–0.83)	0.43 (0.16–1.14)
	Small urban areas	0.42 (0.22–0.79)	0.59 (0.31–1.15)
Living in neighborhood with playgrounds	No (Ref)	1	1
	Yes	1.52 (0.83–2.79)	1.10 (0.66–1.85)

An adjusted model was performed including all individual-, interpersonal-, and community-level variables listed in the table. Prevalence estimates in the model account for potential confounding among these factors.

3.7. Unadjusted and Adjusted Associations of Individual, Interpersonal, and Community-Level Factors with the Double Burden of Malnutrition (DBM3) Among Colombian Schoolchildren

The associations between individual-, interpersonal-, and community-level factors and the double burden of malnutrition (DBM3: overweight/obesity plus vitamin D <50 nmol/L) among Colombian schoolchildren are summarized in Table 8. At the individual level, neither age nor sex was significantly associated with DBM3 after adjustment. Physical activity and excessive screen exposure were significant predictors in unadjusted models but lost significance once other factors were accounted for. Ethnicity showed no statistically significant association in adjusted models.

At the interpersonal level, household size emerged as a strong predictor: children from smaller households (<4 members) had more than twice the odds of DBM3 compared with children from larger households (adjusted OR 2.31, 95% CI: 1.70–3.14). Children living in nuclear families exhibited slightly lower odds than those in extended families (adjusted OR 0.73, 95% CI: 0.53–0.99). Other interpersonal factors, including the sex of the head of household and parental education, showed no consistent effects after adjustment, although higher maternal education (11–15 years) was associated with increased odds in the unadjusted model but not after adjustment.

Community-level differences were also evident. Children residing in the Atlantico region were significantly less likely to experience DBM3 compared with those in Bogotá (adjusted OR 0.23, 95% CI: 0.07–0.72). Associations for other regions, degree of urbanization, rural versus urban settings, and living in neighborhoods with playgrounds were attenuated after adjustment and were not statistically significant. Overall, these findings highlight the particularly strong influence of household composition on DBM3, while community-level and individual behavioral factors appear less influential once confounders are considered (Table 8).

Table 8. Unadjusted and Adjusted Models. Factors at the Individual, Interpersonal, and Community Levels and Double Burden of Malnutrition (DBM3: BMI-for age z score > 1 (overweight or obese) and Vitamin D < 50 nmol/L) in Colombian Schoolchildren Aged 5 to 12 y.

Characteristics	Category	Unadjusted Model	Adjusted Model
Individual-level		**OR (95% CI)**	**OR (95% CI)**
Age	Per year increase	0.99 (0.91–1.09)	1.00 (0.91–1.09)
Biological sex	Male (Ref)	1	1
	Female	1.16 (0.90–1.51)	1.08 (0.84–1.38)
Ethnicity	Indigenous (Ref)	1	1
	Black	1.18 (0.32–4.33)	0.63 (0.19–1.98)
	Without Ethnicity	2.13 (0.79–5.70)	0.88 (0.36–2.15)
Meets the minimum of physical activity	Yes (Ref)	1	1
	No	1.47 (1.04–2.08)	1.12 (0.82–1.53)
Excessive exposure to screens	No (Ref)	1	1
	Yes	1.63 (1.22–2.18)	1.16 (0.87–1.57)
Interpersonal-level			
Wealth Index, Quartiles	Q1 (Ref)	1	1
	Q2	1.90 (1.20–2.99)	1.29 (0.66–2.52)
	Q3	1.97 (1.23–3.17)	1.11 (0.61–2.00)
	Q4	3.15 (1.85–5.39)	1.60 (0.86–2.97)
Household size	>4 people (Ref)	1	1
	<4 people	2.13 (1.59–2.86)	2.31 (1.70–3.14)
Type of Family	Extended (Ref)	1	1
	Nuclear	1.09 (0.80–1.47)	0.73 (0.53–0.99)

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Biological sex of Head of Household	Male (Ref)	1	1
	Female	1.02 (0.78–1.33)	0.91 (0.69–1.20)
Education of Head of Household (Years)	11–15 (Ref)	1	1
	0–4	0.57 (0.35–0.92)	1.27 (0.73–2.19)
	5–10	0.76 (0.51–1.14)	1.31 (0.74–2.30)
	16–24	0.56 (0.29–1.10)	0.45 (0.21–0.96)
Maternal Education (Years)	0–4 (Ref)	1	1
	5–10	0.96 (0.49–1.84)	0.68 (0.34–1.33)
	11–15	1.92 (1.08–3.41)	1.41 (0.78–2.56)
	16–24	1.94 (0.80–4.69)	1.70 (0.79–3.63)
Community-level			
Region	Bogota (Ref)	1	1
	Atlantico	0.13 (0.06–0.27)	0.23 (0.07–0.72)
	Oriental	0.59 (0.38–0.94)	1.08 (0.39–3.01)
	Orinoquia and Amazonia	0.33 (0.24–0.44)	0.61 (0.24–1.55)
	Central	0.45 (0.29–0.67)	0.69 (0.37–1.31)
	Pacifico	0.56 (0.26–1.21)	0.96 (0.40–2.30)
Urbanicity	Urban (Ref)	1	1
	Rural	0.72 (0.41–1.27)	1.17 (0.63–2.16)
Degree of Urbanization	Major metropolitan cities	1	1
	Large urban areas	0.49 (0.23–1.09)	0.65 (0.21–1.99)
	Small urban areas	0.47 (0.25–0.87)	0.71 (0.31–1.62)
Living in neighborhood with playgrounds	No (Ref)	1	1
	Yes	1.29 (0.99–1.69)	0.95 (0.68–1.32)

An adjusted model was performed including all individual-, interpersonal-, and community-level variables listed in the table. Prevalence estimates in the model account for potential confounding among these factors.

4. Discussion

Using nationally representative data, we examined the prevalence and determinants of the double burden of malnutrition (DBM) among Colombian schoolchildren aged 5–12 years, characterized by the co-occurrence of overweight/obesity (BMI-for-age z score > 1) and vitamin D deficiency (<30 nmol/L, <37.5 nmol/L, or <50 nmol/L). In our study population, the prevalence of overweight and obesity was 17.0% and 7.4%, respectively, while vitamin D deficiency affected 2.5%,

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10.6%, and 22.6% of children, depending on the cutoff used. Consequently, the simultaneous presence of overweight/obesity and vitamin D deficiency—the DBM—was relatively low, with prevalences of 0.7% (DBM1), 3.6% (DBM2), and 6.9% (DBM3). These prevalence estimates are notably lower than those reported in other countries [5]. For example, in Mexico, 18.2% of children exhibited vitamin D deficiency (<50 nmol/L) with overweight, rising to 24.7% when obesity was considered [46]. Similarly, in the United States, 17% of overweight and 31% of obese children had vitamin D levels <50 nmol/L [47]. Our findings highlight the relative rarity of DBM in Colombian schoolchildren, despite a substantial proportion of children being either overweight/obese or vitamin D deficient individually.

The recent trajectory of the double burden of malnutrition at the individual level, characterized by the simultaneous presence of overweight/obesity and vitamin D deficiency among Colombian schoolchildren, remains uncertain due to the absence of population-level data until now [48,49]. Moreover, making cross-population comparisons is challenging due to variations in the definitions of vitamin D deficiency and the lack of standardized data collection methods [41,50]. Nevertheless, notwithstanding the seemingly low prevalence of overweight/obesity coupled with low vitamin D levels among Colombian children, we argue that this issue persists as a significant public health concern, liable to worsen over time. This assertion gains prominence against the backdrop of Colombia's ongoing nutritional transition [51–53]. While current prevalence rates may appear moderate, it's imperative to acknowledge the likelihood of future escalation, underscoring the necessity for sustained surveillance and intervention initiatives.

In the context of Colombia's tropical climate and abundant sunlight, our focus turned to factors that hinder children's sunlight exposure, potentially impacting both body mass index and vitamin D levels. Employing a socio-ecological model, we discerned that children with reduced physical activity face an elevated risk of experiencing the double burden of malnutrition (DBM). Notably, this association was strongest for DBM1 and DBM2, which correspond to more severe vitamin D deficiencies (<30 nmol/L and <37.5 nmol/L), suggesting that insufficient physical activity may particularly exacerbate the risk when vitamin D status is critically low. While the effect of low physical activity on DBM3 (<50 nmol/L) was attenuated after adjusting for individual-, interpersonal-, and community-level factors, our findings highlight the central role of active behaviors in mitigating the coexistence of overweight/obesity and vitamin D deficiency. These results underscore that promoting regular physical activity—particularly outdoor activities—remains a critical strategy for improving both weight management and vitamin D status among Colombian schoolchildren.

The landscape of physical activity among Colombian schoolchildren is intricate, showcasing both encouraging trends and areas of concern [54]. For instance, data gleaned from the ENSIN 2015 survey[54] revealed that while a substantial proportion (71.7%) of Colombian children and adolescents rely on walking or cycling as their primary mode of school transportation, only approximately 35.5% of children aged 6 to 17 engage in at least 60 minutes of physical activity on four or more days a week. Notably, these statistics underscore pronounced disparities across age brackets, with prevalence rates spanning from 26% among adolescents aged 13 to 17 years to 42% among 6-12 years, signifying that merely 3 out of 10 Colombian children meet the recommended activity thresholds.

Numerous studies emphasize the pivotal role of physical activity in children's well-being [47,55–58]. For instance, Logan et al [56] underscored the pivotal role of physical activity in children's health, stimulating metabolism and fostering positive growth outcomes. Furthermore, physical activity facilitates weight management by enhancing lipolysis rates and mobilizing adipose tissue, potentially bolstering serum vitamin D levels. While outdoor physical activity during daylight hours serves as an indirect measure of sun exposure, exercise itself contributes to maintaining vitamin D status beyond mere sunlight exposure [59]. Indeed, physical activity is recognized for increasing local bone mass, diminishing calcium excretion, and enhancing absorption efficiency, consequently elevating serum calcium levels and conserving serum vitamin D. Moreover, physical activity's impact on weight reduction via lipolysis can further augment vitamin D serum levels by facilitating its release from adipose tissue [57].

In line with our socio-ecological framework [45], excessive screen exposure emerged as an important factor related to the double burden of malnutrition among Colombian schoolchildren. In the unadjusted models, children with high screen time exhibited higher odds of DBM1 and DBM2 (OR = 2.44, 95% CI 1.08–5.52 for DBM1; OR = 1.62, 95% CI 1.10–2.38 for DBM2; Tables 6 and 7), suggesting a strong link between sedentary behaviors and the co-occurrence of overweight/obesity and vitamin D deficiency. However, after adjusting for individual-, interpersonal-, and community-level factors, the associations attenuated and lost statistical significance (adjusted ORs = 1.83, 0.71–4.73 for DBM1; 1.11, 0.75–1.64 for DBM2; Table 7), particularly for DBM3 (adjusted OR = 1.16, 0.87–1.57; Table 8). These findings indicate that while screen exposure may not exert a direct causal effect on DBM, it likely operates indirectly by promoting sedentary lifestyles and reducing outdoor physical activity, which in turn may influence both BMI and vitamin D status [60]. This underscores the need to consider lifestyle behaviors such as screen time in public health strategies aimed at preventing concurrent nutritional deficiencies and overweight/obesity in children [61,62].

At the household level, our analysis indicates that children from smaller households (<4 members) had higher odds of experiencing DBM2 and DBM3 (adjusted OR = 1.84, 95% CI 1.16–2.90 for DBM2; OR = 2.31, 1.70–3.14 for DBM3; Tables 7 and 8), suggesting that limited household size may reduce opportunities for social support and shared childcare, which in turn could influence children's dietary habits and physical activity levels (64). Similarly, the sex of the head of household was associated with DBM2 and DBM3, with children in female-headed households showing slightly increased odds (adjusted OR = 1.42, 95% CI 1.01–1.99 for DBM2; OR = 0.91, 95% CI 0.69–1.20 for DBM3; Tables 7 and 8), potentially reflecting differences in time availability, caregiving patterns, and household routines [63]. Notably, other household factors such as wealth index and maternal education, which were associated with DBM1 and DBM2 in unadjusted analyses, lost significance in the fully adjusted models (Tables 6–8), indicating that the effects of socioeconomic conditions on DBM may be mediated by other individual- and community-level factors. These findings highlight the complex interplay of household composition, parental characteristics, and socioeconomic context in shaping the risk of concurrent overweight/obesity and vitamin D deficiency among Colombian schoolchildren [63–66].

Our study indicates that the residential environment is a significant factor in the risk of double burden of malnutrition (DBM) among Colombian schoolchildren. Children living in large urban areas and small urban centers showed higher adjusted odds of DBM1 and DBM2 compared to those in major metropolitan cities, highlighting the role of neighborhood characteristics (Tables 6 and 7). Interestingly, our findings suggest that these associations are less pronounced for DBM3, where children with lower exposure to safe play areas and residing in smaller urban centers did not show a statistically significant increase in risk after adjusting for individual, household, and community-level factors (Table 8). This may reflect the broader prevalence of vitamin D insufficiency at the <50 nmol/L cutoff, indicating that other factors, such as diet, outdoor habits, and socioeconomic conditions, also contribute to DBM3 risk. Ensuring equitable access to safe outdoor spaces remains essential, but multifaceted interventions addressing physical activity, sunlight exposure, and nutritional support are critical to reduce the prevalence of all forms of DBM among Colombian schoolchildren.

According to data sourced from ENSIN 2015 [54], a substantial majority (63.8%) of Colombian children and adolescents inhabit neighborhoods equipped with parks, green spaces, recreational centers, or sports facilities conducive to physical play. Encouragingly, a reassuring 74.2% perceive these environments as safe, underscoring the potential of such spaces to foster regular physical activity and social interaction among the youth. Participation in community initiatives like Ciclovías and other physical activity programs further reflects a proactive approach aimed at promoting active lifestyles among Colombia's younger populace. With 7.7% of children and adolescents engaging in Ciclovía events and 20.4% of adolescents participating in other community-level physical activity

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programs in the past month, these initiatives represent crucial strides towards integrating physical activity into the daily routines of Colombia's youth.

However, despite these positive signals, our findings shine a light on a critical oversight in urban development and public health strategies within Colombia's largest cities, particularly concerning suburban areas [67]. These locales often grapple with insufficient infrastructure and resources to furnish safe and accessible play areas for children [68]. Discrepancies in the availability and quality of recreational facilities between urban cores and their suburban outskirts present a nuanced challenge. While municipal endeavors have made headway in ensuring play spaces throughout Colombia, it is evident that children residing on the fringes of large cities may not reap equal benefits from these advancements [68]. This disparity not only curtails opportunities for physical activity among a substantial portion of the population but also heightens the risk of nutritional imbalances [69]. The absence of suitable play environments in suburban areas fosters a sedentary lifestyle, predisposing individuals to overweight and obesity, while simultaneously amplifying the likelihood of malnutrition due to limited engagement in activities that foster holistic health and well-being [70]. Addressing these disparities necessitates a concerted effort to prioritize equitable access to recreational resources across all urban locales, ensuring that children, regardless of their residential context, can thrive in environments conducive to both physical activity and nutritional health.

Our study presents several significant strengths. Notably, it pioneers an examination of the factors correlating with the coexistence of low vitamin D levels and overweight among the Colombian school population. Employing a population survey approach, we scrutinized these factors at multiple levels, including the individual, intra-individual, and community levels.

However, it's crucial to acknowledge certain limitations. Chief among them are concerns surrounding the standardization and interpretation of vitamin D measurements. While ENSIN 2015 team utilized a chemiluminescence antibody immunoassay on an ADVIA Centaur XP analyzer from Siemens Health Care Diagnostics for assessing total serum 25(OH)D concentrations in Colombia, it's essential to recognize that chromatography-based assays, particularly those utilizing liquid chromatography-tandem mass spectrometry (LC-MS/MS), are widely regarded as the gold standard[42]. Discrepancies between these methods may lead to potential underestimations [40]. For instance, a study [40] assessment revealed intra-assay and total inaccuracies of 6.4% and 14.1% at 52.6 nmol/L, respectively, and 4.2% and 7.4% at 225 nmol/L with the ADVIA Centaur assay. Compared to LC-MS/MS, the ADVIA Centaur assay demonstrated an R^2 value of 0.893 alongside an average bias of -8.8%. Furthermore, the absence of consensus regarding cutoff points for defining vitamin D deficiency complicates result interpretation [42].

In summary, our study reveals a concerning double burden of malnutrition among Colombian schoolchildren, manifesting at the individual level. Our findings underscore the multifaceted nature of this issue, implicating factors across various domains, including the individual, interpersonal, and community levels. Highlighting the coexistence of lower levels of vitamin D and overweight/obesity, our research underscores the imperative for interventions addressing physical activity deficits among Colombian youth. Moreover, addressing the needs of mothers balancing child-rearing with professional aspirations is essential. We advocate for the enhancement of outdoor spaces tailored to facilitate physical activity and promote adequate sunlight exposure to bolster vitamin D levels among children. These multifaceted strategies are crucial steps toward addressing the complex interplay of factors contributing to the double burden of malnutrition in Colombia's youth.

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Informed Consent Statement: Not applicable. The study was based on publicly available, de-identified secondary data from the Encuesta Nacional de la Situación Nutricional en Colombia (ENSIN) 2015, which does not contain personal identifiers.

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Abbreviations

The following abbreviations are used in this manuscript:

25(OH)D	25-Hydroxyvitamin D (marker of vitamin D status)
ADVIA Centaur XP	A chemiluminescence antibody immunoassay analyzer from Siemens Health Care Diagnostics
BMI	Body Mass Index
C-MAFYCS	Measurement of Physical Activity and Sedentary Behavior (for children aged 3–5)
CDC	Centers for Disease Control and Prevention
CIs	Confidence Intervals
CV	Coefficient of variation
DEQAS	Vitamin D External Quality Assessment Scheme
DBM	Double Burden of Malnutrition
DBM1	Double Burden of Malnutrition 1: BMI-for-age Z score > 1 (overweight/obese) and Vitamin D < 30 nmol/L
DBM2	Double Burden of Malnutrition 2: BMI-for-age Z score > 1 (overweight/obese) and Vitamin D < 37.5 nmol/L
DBM3	Double Burden of Malnutrition 3: BMI-for-age Z score > 1 (overweight/obese) and Vitamin D < 50 nmol/L
DEQAS	Vitamin D External Quality Assessment Scheme
ENSIN	National Survey of Nutritional Situation (Encuesta Nacional de Situación Nutricional)
INS	National Institute of Health in Bogotá

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LC-MS/MS	Liquid Chromatography–Tandem Mass Spectrometry
NIST	National Institute of Standards and Technology
nmol/L	Nanomoles per liter
n	Number of cases
OR	Odds Ratio
PR	Prevalence ratio
Prev ± SE	Prevalence (%) ± Standard Error (%)
PSU	Primary Sampling Unit
Q1	Lowest 25% of wealth (poorest)
Q2	25–50% of wealth (low-middle)
Q3	50–75% of wealth (high-middle)
Q4	Highest 25% of wealth (richest)
R software	Statistical software R
Ref	Reference
SD	Standard Deviation
SE	Standard Error
SES	Socioeconomic Status
T2DM	Type 2 Diabetes Mellitus
VDSCP	Vitamin D Standardization Certification Program
WHO	World Health Organization
y	Years (age)
YRBSS	Youth Risk Behavior Surveillance System

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