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# Prevalence of low vitamin D status in an urban district in Sri Lanka: a population-based study

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## Abstract

**Background** Vitamin D deficiency (VDD) is conventionally associated with inadequate sunlight exposure. Ironically, recent evidence suggests a rising prevalence in urban areas of tropical regions like Sri Lanka, where comprehensive data are unavailable. This study aimed to estimate the prevalence of low vitamin D status in urban adults and its impact on serum calcium.

**Methods** A population-based cross-sectional study was conducted among 1260 adults aged 35–74 years, living in Colombo, the most urban district in Sri Lanka. They were recruited from 63 administrative divisions, using multi-stage, probability-proportionate-to-size, cluster sampling. Non-fasting venous blood was collected without tourniquet. Low vitamin D (< 30.0 ng/mL), VDD (< 20 ng/mL) and vitamin D insufficiency (20.0–29.9 ng/mL) were determined using chemiluminescence assay method, and serum calcium using Calcium Gen2 reagent.

**Results** Among the population (53.3% females; mean age = 51.8 years), the prevalence of low vitamin D was 93.9% (95% CI: 92.5–95.2). This was primarily due to VDD (67.5%; 95% CI: 64.9.0–70.1%), with some insufficiency (26.4%; 95% CI: 24.0–28.9%). Most VDD cases (53.9.0%) were 'mild' (10.0- < 20.0 ng/mL) in severity, with fewer 'moderate' (12.8%) and 'severe' (0.8%) cases. Prevalence of VDD was highest in females, aged 35–44-years, living in 'highly urban' areas and of Tamil ethnicity. Further, VDD showed a decreasing trend with older age groups, while it was significantly more prevalent in females than males (72.6% vs. 61.7%; $p < 0.01$), across all age groups. Low serum calcium levels were observed in 9.8% of adults with low vitamin D, compared to 22.4% with normal vitamin D, implying that there could be factors other than vitamin D in maintaining serum calcium levels.

**Conclusions** Colombo District, representing urban settings in Sri Lanka faces a high prevalence of low vitamin D, primarily VDD, with higher rates in females, younger individuals and highly urban areas. These findings challenge assumptions about tropical regions being guaranteed of optimal vitamin D levels; and underscore the need for national vitamin D supplementation and food fortification programs, especially in high-risk urban settings in South Asian countries like Sri Lanka.

**Keywords** Vitamin D, Low, Deficiency, Insufficiency, Sri Lanka, Urban

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## Background

Vitamin D is primarily responsible for calcium homeostasis in the body [1]. In cases of deficiency (i.e., below 20 ng/mL), it precipitates reduced serum calcium concentrations, thereby leading to skeletal disorders in children as well as in adults [1]. In recent times, notably during the COVID-19 pandemic, vitamin D deficiency (VDD) gained more prominence based on emerging evidence of its extra-skeletal effects. Vitamin D exerts its influence on the immune and cardiovascular systems, intestines, brain, muscles and pancreas [1, 2]. Consequently, lower respiratory tract infections, cardiovascular diseases, autoimmune diseases, certain cancers and neurodegenerative diseases like dementia have shown associations with decreased vitamin D levels, even in cases of vitamin D insufficiency (VDI) (i.e., below 30 ng/mL) [2]. Recent studies suggest that optimal vitamin D levels may serve as a preventive measure against chronic non-communicable diseases (NCD) [2, 3], underscoring its critical role as both a primary and secondary preventive strategy in the context of emerging health challenges.

Vitamin D deficiency is predominantly attributed to inadequate exposure to sunlight. As a result, though VDD is prevalent globally [1, 4–14], people living in tropical regions, such as South Asia where there is sunlight available for more than 12 h a day [15], have been assumed to exhibit lower VDD prevalence and consequently fewer health impacts. Yet, there is a growing body of evidence indicating that VDD is becoming more prevalent even in such regions [10–14]. In this backdrop, South Asia, home to several low-income countries, is particularly vulnerable to the adverse consequences of VDD, signifying a pressing public health issue requiring immediate attention.

Despite its importance, VDD in South Asia has not received much attention thus far [16]. In Sri Lanka, a country in South Asia located just 7°N above the equator, the abundance of ultra-violet B (UVB) radiation with minimal seasonal variations of weather and having over 75% of adults engaged in outdoor agricultural activities appear to seemingly ensure sufficient vitamin D levels [17]. However, this should be further examined, particularly in light of the shifting behaviours of adults towards a sedentary lifestyle, which is more pronounced in urban cities, resulting in decreased exposure to sunlight compared to previous decades.

To date, epidemiological studies on VDD among Sri Lankan adults in urban areas remain notably scarce, with existing literature often limited to small sample studies of specific demographics such as males [18], females [19], 3–5-year-old children [20, 21], adolescents [22] and pregnant mothers [23]. Such studies do not adequately represent the broader adult population at risk of VDD in Sri Lanka, leading to widely varying prevalence estimates. Further, the existing prevalence estimates for Sri Lanka are available in relation to skeletal health effects of vitamin D, neglecting its numerous extra-skeletal implications, especially in the context of the rising burden of NCDs, in parallel with an aging population in Sri Lanka [24]. Currently, there is no established vitamin D supplementation programme in place. Therefore, it is imperative to assess the magnitude of the burden of VDD comprehensively using rigorous methodologies. This study aimed to fill this knowledge gap by estimating the prevalence of low vitamin D including its impact on serum calcium among adults in the most urban district in Sri Lanka. The findings will enable to provide critical baseline data for health policy makers to develop and implement preventive strategies; and could be applied in other countries of similar socio-cultural and economic backgrounds.

## Materials and methods

### Study design and setting

This was a population-based cross-sectional study conducted in Colombo District, which is the most populous district in Sri Lanka comprising people of diverse ethnic and socio-economic backgrounds. It includes the commercial capital and represents the most urban district, with the highest urban population percentage in the country [25]. For administrative purposes, the district is divided into 557 *grama-niladhari* divisions (GND). Of these, 344 GNDs (61.8%) are part of the urban sector, representing densely populated areas with sedentary lifestyles. The remaining 38.2% are in less urbanised areas, where populations are relatively more physically active [24, 25]. The urban sector is further divided into 'highly urban' (the City of Colombo) and 'urban' (outside the City of Colombo) areas.

### Study population

The study population comprised adults aged 35–74 years residing in Colombo District for more than one year. Those who were on drugs that influence serum vitamin D levels, such as corticosteroids, hormonal contraceptives, anticonvulsants, rifampicin, cholestyramine, diuretics and vitamin D supplements; pregnant and lactating women; those having fat mal-absorption syndromes such as cystic fibrosis and inflammatory bowel diseases including Crohn's and chronic diseases such as skin, liver, renal and endocrine disorders confirmed through medical records; and those with mental illnesses were excluded from the study.

### Sample size and sampling technique

The minimum sample calculated was 383 [26] to detect an expected prevalence of VDD of 47.4% (based on a previous study among 30–60-year-old residents of Kandy District) [27], Z value of 1.96 and absolute precision of 5%. The sample was increased to 1260 to account for a design effect of 2.9 (for an intra-class correlation coefficient of 0.1 considered in the absence of evidence from previous studies and cluster size of 20 [28]) and 10% non-response.

This number was obtained from 63 GNDs (each GND defined as a cluster of 20 adults) by adopting a multi-stage cluster sampling technique. In the first stage, the number of clusters to be selected from the 'highly urban', 'urban' and 'less urban' sectors, was calculated as 15, 34 and 14, respectively, proportionate to the population of each sector of Colombo District. In the second stage, the required GNDs were identified based on probability-proportionate-to-size (PPS) technique using updated population lists available at the Department of Census and Statistics of adults living within each GND [24]. In the third stage, 20 households within each cluster were identified systematically using a road map, with the first house selected randomly, and the subsequent households identified to the right-hand side of the first house consecutively. During the final stage, one eligible adult per household was selected using simple random sampling. In order to ensure representation of all age categories of the district, recruitment of the 20 individuals in each cluster was carried out until the required quota of each five-year age category was fulfilled, as per the existing age-specific population of Colombo District. Sampling of the participants was carried out on all days of the week, so as to capture the working adults and males during sampling.

### Data collection

The data collection team consisting of medical graduates visited the households. Visits to clusters to check eligibility, obtain informed written consent and data collection commenced from January 2022 to July 2022. A pre-tested questionnaire was administered to collect basic demographic and socio-economic characteristics of the sample. Thereafter, a trained nurse obtained a 4 mL non-fasting venous blood sample without using a tourniquet into a plain blood collection tube as per the World Health Organization Guidelines [29]. The samples kept at room temperature were transported within 2 h to the laboratory, where the samples were centrifuged and the sera frozen at -20 °C until analysis. Only one cycle of freeze-thawing was allowed.

The total serum 25(OH) D levels was measured by chemiluminescence assay method using 'DiaSorin LIAISON 25-OH D, Stillwater, Minnesota, USA' assay. This is a direct competitive chemiluminescence immunoassay with a dynamic range between 4–150 ng/mL, a functional sensitivity of ≤ 4 ng/mL and specificity of 100% for 25(OH) $D_2$ and 25(OH) $D_3$. The precision of this test method was evaluated by determining intra-assay coefficients of variation (CV%) which were 4.8% for control 1 (low control) and 4.09% for control 2 (high control). The corresponding values for inter-assay CV% were 5.7% and 5.9%. The method can be considered valid as demonstrated by CV% of < 10%, according to Kaplan, 2010 [30].

The sera obtained were also analysed for serum total calcium levels using Calcium Gen 2 (CA2) reagent (chromophore 5-nitro-5'-methyl-(1,2-bis(o-aminophenoxy) ethan-N,N,N',N'-tetraacetic acid [NM-BAPTA] method) on the Cobas c501 fully automated analyser (Roche Diagnostic Corp., Germany). The precision of this test method was evaluated by determining the intra-assay CV% using Bio-Rad Lyphocheck Assayed Chemistry QC, which were 0.77% for control 1 (low control) and 1.38% for control 2 (high control). The corresponding values for inter-assay CV% were 1.2% and 1.41%.

The assays and the Cobas c501 automatic biochemistry system were done by well-trained medical laboratory technologists under the supervision of an expert in the field of medical laboratory accreditation.

### Data analysis and definitions used

The Statistical Package for Social Sciences (SPSS) version 22 was used for data analysis. Based on the vitamin D level, participants were divided into 'low' (< 30 ng/mL) and 'normal' (≥ 30 ng/mL) levels. 'Low' was further divided into VDD (< 20 ng/mL) and VDI (20.0–29.9 ng/mL). Further, the skeletal and extra-skeletal benefits of vitamin D were assessed based on the cut-off values of ≥ 20.0 ng/mL and ≥ 30.0 ng/mL, as recommended by the Endocrine Society for Health [31] and the Medical Research Institute (the national reference laboratory in Sri Lanka) [32]. Crude and specific as well as age- and sex-stratified weighted prevalence estimates were calculated with 95% confidence interval (CI) in relation to VDD, VDI and low vitamin D. Further, Lips classification of severity was used to categorize VDD into mild (10.0- < 20.0 ng/mL), moderate (5.0- < 10.0 ng/mL) and severe (< 5.0 ng/mL) categories [33]. Corrected serum calcium levels were assessed in the range of 8.6–10.2 mg/dL and classified as 'low' (< 8.6 mg/dL), 'normal' (8.6–10.2 mg/dL) and 'high' (> 10.2 mg/dL). Chi-squared test was used to assess the significance of associations with vitamin D status.

The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Review Committee of the Postgraduate Institute of Medicine of the University of Colombo (protocol number ERC/PGIM/2020/206). Informed written consent was obtained from all participants prior to data collection. The participation in the study was voluntary, with no penalty and effect on medical care or loss of benefits. Those who were found to have low vitamin D levels were referred to the closest endocrine clinic of state sector hospital and were advised on the options available for improving their vitamin D level.

## Results

A total of 1260 adults participated in the study (response rate 100%). Their basic characteristics are given in Table 1. The mean age of sample was 51.8 years (SD = 10.5 years) and showed a slight female predominance ($n$ = 672; 53.3%). These characteristics were compatible with the age and sex composition of Colombo District.

The mean serum 25(OH)D level was 17.4 ng/mL (SD = 7.2) with median of 16.6 ng/mL (IQR 21.6–12.5 ng/mL). The minimum level was 4.1 ng/mL and the maximum was 55.3 ng/mL. The crude prevalence of low vitamin D level was 93.9% (95% CI: 92.5, 95.2). This encompassed 67.5% (95% CI: 64.9, 70.1%) of adults with VDD representing those without skeletal health benefits; and 26.4% (95% CI: 24.0, 28.9%) with VDI. The weighted prevalence based on age and sex composition of Colombo District was 67.9% (95% CI: 65.0–70.1%) for VDD and 26.1% (95% CI: 24.0–28.9%) for VDI.

When stratified by age, the prevalence of low vitamin D including VDD was highest in the 35–44-year age group and showed a decreasing trend towards older age groups (Table 2). Further, the prevalence estimates for low vitamin D including VDD were highest among females, those living in the highly urban areas and of Tamil ethnicity. In relation to VDD, it was significantly more prevalent in females compared to males ($p < 0.001$); in highly urban areas compared to less urban areas followed by urban areas ($p < 0.001$); and in Tamils compared to Muslims followed by Sinhalese ($p < 0.001$).

When both age and sex were considered in the prevalence of VDD (Fig. 1), males aged 45–54 years and females aged 35–44 years had the highest prevalence, while the lowest prevalence was noted in both males and females in the 65–74 age group.

Of those with VDD ($n$ = 851), the majority had mild VDD (53.9%; 95% CI: 51.2, 56.7%) compared to 12.8% having moderate VDD and only 0.8% having severe VDD (Table 3). Mild VDD was most prevalent among females and those aged 35–44 years, in contrast to severe VDD mostly observed among males and those aged 45–64-years, and moderate VDD in females and those aged 35–44 years.

**Table 1** Characteristics of the sample of adults of Colombo District ($N$ = 1260)

| Characteristic | No | % |
|---|---|---|
| **Age** | | |
| 35 – 44 years | 378 | 30.0 |
| 45 – 54 years | 378 | 30.0 |
| 55 – 64 years | 315 | 25.0 |
| 65 – 74 years | 189 | 15.0 |
| **Residential sector** | | |
| Highly urban | 300 | 23.8 |
| Urban | 680 | 54.0 |
| Less urban | 280 | 22.2 |
| **Ethnicity** | | |
| Sinhalae | 1016 | 80.6 |
| Tamil | 128 | 10.2 |
| Muslim | 116 | 9.2 |
| **Current marital status** | | |
| Single | 49 | 3.9 |
| Married | 1118 | 88.7 |
| Separated / divorced | 20 | 1.6 |
| Widowed | 73 | 5.8 |
| **Highest educational level** | | |
| Grade 1–5 | 58 | 4.6 |
| Grade 6–11 | 698 | 55.4 |
| Grade 12–13 | 365 | 29.0 |
| Diploma/Degree | 121 | 9.6 |
| **Current employment status** | | |
| Employed | 686 | 54.4 |
| Unemployed* | 574 | 45.6 |
| **Categories of employment ($n$ = 686)** | | |
| Professionals | 160 | 23.3 |
| Sales and services | 187 | 27.3 |
| Agriculture-related** | 36 | 5.2 |
| Skilled labourers | 205 | 29.9 |
| Manual Labourers*** | 74 | 10.8 |
| Other | 24 | 3.5 |
| **Income categories LKR** | | |
| ≤ 10,000 | 55 | 4.4 |
| 10,001 – 30,000 | 336 | 26.6 |
| 30,001 – 80,000 | 665 | 52.8 |
| 80,001 – 100,000 | 98 | 7.8 |
| > 100,000 | 106 | 8.4 |

*Includes housewives ($n$ = 376)

**Includes those engaged in rubber tapping, vegetable farming and paddy work (paddy work encompasses work related to rice farming, harvesting and processing)

***Includes domestic workers and sanitary workers not engaged in agricultural work

**Table 2** Distribution of the prevalence of vitamin D levels among adults of Colombo District by their basic characteristics ($n = 1184$)

| Variable | Prevalence estimates of vitamin D* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Deficiency (< 20 ng/mL) | | | Insufficiency (20.0 – 29.9 ng/mL) | | | Low vitamin D (< 30.0 ng/mL) | | |
| | No | PE | 95% CI | No | PE | 95% CI | No | PE | 95% CI |
| **Age** | | | | | | | | | |
| 35 – 44 | 266 | 70.3 | 65.5–74.9 | 93 | 24.6 | 20.3–29.3 | 359 | 94.9 | 92.3–96.9 |
| 45 – 54 | 261 | 69.1 | 64.1–73.7 | 95 | 25.1 | 20.8–29.8 | 356 | 94.2 | 91.3–96.3 |
| 55 – 64 | 211 | 66.9 | 61.5–72.2 | 82 | 26.0 | 21.3–31.3 | 293 | 93.0 | 89.6–95.6 |
| 65 – 74 | 113 | 59.8 | 52.4–66.8 | 63 | 33.3 | 26.6–40.5 | 176 | 93.1 | 88.5–96.3 |
| **Sex** | | | | | | | | | |
| Female | 488 | 72.6 | 69.1–75.9 | 153 | 22.8 | 19.6–26.1 | 641 | 95.4 | 93.5–96.8 |
| Male | 363 | 61.7 | 57.7–65.7 | 180 | 30.6 | 26.9–34.5 | 543 | 92.3 | 89.9–94.4 |
| **Residential sector****| | | | | | | | | |
| Highly urban | 251 | 83.7 | 78.9–87.7 | 44 | 14.6 | 10.8–19.2 | 295 | 98.3 | 96.2–99.5 |
| Urban | 412 | 60.6 | 56.8–64.3 | 216 | 31.8 | 28.3–35.4 | 628 | 92.4 | 90.1–94.2 |
| Less urban | 188 | 67.1 | 61.3–72.6 | 73 | 26.1 | 21.0–31.6 | 261 | 93.2 | 89.6–95.9 |
| **Ethnicity** | | | | | | | | | |
| Sinhala | 666 | 65.5 | 62.5–68.5 | 280 | 27.6 | 24.8–30.4 | 946 | 93.1 | 91.4–94.6 |
| Tamil | 105 | 82.0 | 74.3–88.3 | 21 | 16.427.6 | 10.5–23.9 | 126 | 98.4 | 94.5–99.8 |
| Muslim | 80 | 68.9 | 59.7–77.2 | 32 | 27.6 | 19.7–36.6 | 112 | 96.5 | 91.4–99.1 |
| **All** | **851** | **67.5** | **64.9–70.1** | **333** | **26.4** | **24.0–28.9** | **1184** | **93.9** | **92.5–95.2** |

*PE* Point estimates

*Deficiency (< 20 ng/mL), Insufficiency (20.0 – 29.9 ng/mL) and Low level (< 30.0 ng/mL)

**Highly urban areas represented by the City of Colombo and urban areas by areas in the urban sector outside the City of Colombo

With regards to serum calcium levels, the mean and median levels were 9.4 mg/dL (SD = 1.2) and 9.5 mg/dL (IQR: 0.6), respectively in the sample. Approximately, 10.6% ($n = 133$) of the adults had a low serum calcium level, with the highest proportion seen among females (54.9%) and among 35–44-year-olds (33.1%) (Table 4). Only the difference in relation to gender was significant ($p = 0.019$). When assessing the impact of low vitamin D on serum calcium levels (Table 4), only 9.8% ($n = 116$) of those with low vitamin D levels had serum calcium below the normal range, compared to 22.4% who did not have low vitamin D levels. This difference was significant ($p = 0.002$). It further shows that this significance is mainly attributed by the significant differences seen among the females (9.7% vs. 35.5%; $p < 0.001$).

## Discussion

To the best of our knowledge, this is the first ever population-based study conducted to estimate the prevalence of VDD among adults studied in a relatively large sample in high-risk urban areas in Sri Lanka.

The study revealed a striking finding: despite the abundant sunshine in this tropical region, a significant public health concern persists, with a crude prevalence estimate of low vitamin D levels at 93.9% (95% CI: 92.5, 95.2%). The finding signifies the potential risk the adults have for both skeletal and extra-skeletal health effects. This low vitamin D level is primarily driven by a substantial prevalence of VDD, which stands at 67.5% (95% CI: 64.9, 70.1%), accompanied by some degree of insufficiency at 26.4% (24.0, 28.9%). Encouragingly, the majority of VDD cases fall into the 'mild' severity category, accounting for 53.9% of the cases. Being a tropical country, Sri Lanka typically has sunlight and warm weather throughout the year with minimal seasonal variation, relative to countries in the temperate zone. Further, despite variations in rain pattern, cloud cover and UV index, results showed that there was no significant difference in the median serum 25(OH)D level in the samples collected during January, May–July (monsoon rains) and other months ($p > 0.05$). Therefore, the estimates of low vitamin D emphasize the importance of addressing it in this population, where sunlight availability does not seem to guarantee sufficient vitamin D levels.

Comparatively, the reported VDD prevalence in developed countries using the same cut-off value (< 20.0 ng/mL) ranged from 20 to 32%. For instance, in the USA, the prevalence was 24% in 2016, 32% in Canada in 2012/2013, and 31% in Australia in 2012 [5–7]. Further, in Northern European populations, it averaged below

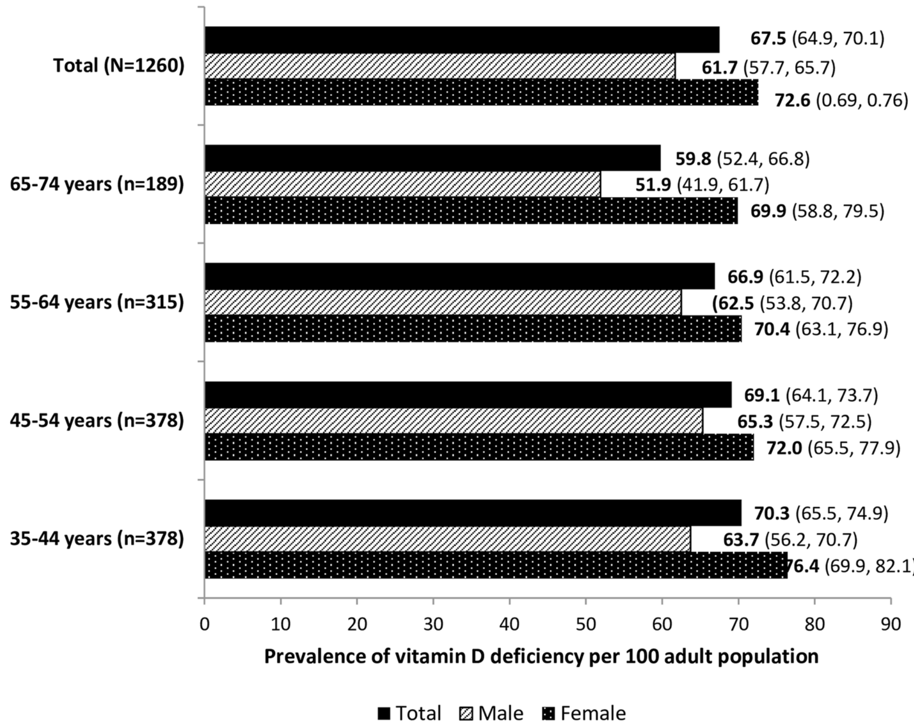


**Fig. 1** Age- and sex-specific prevalence of vitamin D deficiency among adults of Colombo District

*Footnote:* The prevalence estimates of vitamin D deficiency (< 20.0 ng/mL) are given in bold and the 95% confidence intervals are indicated within parentheses

20%, and in Western, Eastern and Southern European countries, it ranged from 30 to 60% [34]. This relatively lower burden of VDD in developed countries, despite the inadequate exposure to its major determinant- sunlight, may be attributed to well-established national vitamin D supplementation and food fortification programs that enabled such countries to control VDD encountered in the past [8]. On the contrary, when considering Asian populations living in developed countries, VDD prevalence appeared to remain high (82% to 94%) compared to their native counterparts, also suggesting a genetic vulnerability to VDD among Asians [9].

The present study's findings align more closely with VDD and VDI prevalence estimates from Asia including South Asian countries. India, for example, reports some of the highest VDD and VDI prevalence rates in the South Asian region, with 98% VDD in North India, 85% in Eastern India (Odisha coastal region) and 97% in South India [10–12]. Similar trends have been observed in Pakistan and Thailand as well [13, 14].

Several factors are likely to contribute to the high prevalence of low vitamin D including VDD among Sri Lankan adults. In contrast to ancient times, contemporary sun-avoidance practices such as wearing hats, using umbrellas and adopting protective clothing, especially in hot climates, have become widespread in modern societies of Asia, including Sri Lanka. This trend is particularly prominent in densely urbanized areas, where occupational preferences, transportation choices and recreational activities often favour indoor settings, as part of their sedentary lifestyles shaped by socio-cultural perspectives. Additionally, Sri Lankans typically have Fitzpatrick skin types 4–5, which require longer sun exposure than Caucasians to produce the same amount of vitamin D [16, 35]. Low consumption of vitamin D-rich dairy products in Sri Lanka may also exacerbate the issue [36]. Additionally, the staple diet in Sri Lanka, rice, contains phytate, which reduces calcium absorption from the intestines. This reduction in calcium levels could trigger the parathyroid gland to release parathyroid hormone, leading to increased bone resorption and decreased circulating 25(OH)D levels.

Furthermore, the study reveals that women are significantly more likely to have low vitamin D (predominantly in relation to VDD) than men ($p < 0.001$). However, there was no significant gender difference noted in relation to the severity of VDD (0.7 vs. 0.9). This gender disparity is in concurrence with global VDD prevalence and trends of Asian women's clothing pattern such as saris which cover most of the body. Further, it could be due

**Table 3** Distribution of the severity among adults with vitamin D deficiency of Colombo District by their basic characteristics ($n=851$)

| Variable | Prevalence estimates of the severity of vitamin D deficiency* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mild | | | Moderate | | | Severe | | |
| | No | PE | 95% CI | No | PE | 95% CI | No | PE | 95% CI |
| **Age** | | | | | | | | | |
| 35 – 44 | 213 | 56.3 | 51.2–61.4 | 51 | 13.5 | 10.2–17.4 | 2 | 0.5 | 0.06–1.9 |
| 45 – 54 | 209 | 55.3 | 50.1–60.4 | 48 | 12.7 | 9.5–16.5 | 4 | 1.1 | 0.3–2.7 |
| 55 – 64 | 169 | 53.7 | 47.9–59.3 | 38 | 12.1 | 8.7–16.2 | 4 | 1.3 | 0.4–3.2 |
| 65 – 74 | 89 | 47.1 | 39.8–54.5 | 24 | 12.7 | 8.3–18.3 | 0 | 0.0 | 0.0–0.0 |
| **Sex** | | | | | | | | | |
| Female | 385 | 57.3 | 53.5–61.1 | 98 | 14.6 | 12.0–17.5 | 5 | 0.7 | 0.2–1.7 |
| Male | 295 | 50.2 | 46.1–54.3 | 63 | 10.7 | 8.3–13.5 | 5 | 0.9 | 0.3–1.9 |
| **Residential sector**** | | | | | | | | | |
| Highly urban | 147 | 49.0 | 43.2–54.8 | 94 | 31.3 | 26.1–36.9 | 10 | 3.3 | 1.6–6.0 |
| Urban | 372 | 54.7 | 50.9–58.5 | 40 | 5.9 | 4.2–7.9 | 0 | 0.0 | 0.0–0.0 |
| Less urban | 161 | 57.5 | 51.5–63.4 | 27 | 9.6 | 6.5–13.7 | 0 | 0.0 | 0.0–0.0 |
| **Ethnicity** | | | | | | | | | |
| Sinhala | 558 | 54.9 | 51.8–58.0 | 104 | 10.2 | 8.4–12.3 | 4 | 0.4 | 0.1–1.0 |
| Tamil | 67 | 52.3 | 43.3–61.2 | 34 | 26.6 | 19.2–35.1 | 4 | 3.1 | 0.9–7.8 |
| Muslim | 55 | 47.4 | 3.81–56.9 | 23 | 19.8 | 13.0–28.3 | 2 | 1.7 | 0.2–6.1 |
| **All** | 680 | **53.9** | **51.2–56.7** | **161** | **12.8** | **10.9–14.8** | **10** | **0.8** | **0.4–1.5** |

*PE* Point estimates

*Mild (10.0- < 20.0 ng/mL), Moderate (5.0- < 10.0 ng/mL) and Severe (< 5.0 ng/mL)

**Highly urban areas represented by the City of Colombo and urban areas by areas in the urban sector outside the City of Colombo

**Table 4** Relationship of serum calcium levels among adults by their vitamin D status ($N=1260$)

| Vitamin D level* | Serum calcium levels in mg/dL | | | | | | | | Significance |
|---|---|---|---|---|---|---|---|---|---|
| | Mean (SD)** | Median (IQR)+ | Low (< 8.6) | | Normal (8.6—10.2) | | High (> 10.2) | | |
| | | | No | % | No | % | No | % | |
| **Females** | | | | | | | | | $\chi^2=20.4$ df = 2 **p < 0.00** |
| Low | 9.3 (1.01) | 9.5 (0.6) | 62 | 9.7 | 543 | 84.7 | 36 | 5.6 | |
| Normal | 8.7 (1.24) | 9.2 (1.6) | 11 | 35.5 | 19 | 61.3 | 1 | 3.2 | |
| **Males** | | | | | | | | | $\chi^2=0.93$ df = 2 p = 0.63 |
| Low | 9.4 (1.07) | 9.6 (0.6) | 54 | 9.9 | 435 | 80.1 | 54 | 9.9 | |
| Normal | 9.2 (1.3) | 9.4 (0.8) | 6 | 13.3 | 36 | 80.0 | 3 | 6.7 | |
| **All** | | | | | | | | | $\chi^2=12.1$ df = 2 **p = 0.002** |
| Low | 9.4 (1.04) | 9.5 (0.6) | 116 | 9.8 | 978 | 82.6 | 90 | 7.6 | |
| Normal | 8.9 (1.3) | 9.4 (0.9) | 17 | 22.4 | 55 | 72.4 | 4 | 5.3 | |

* Low (< 29.9 ng/mL) and Normal (≥ 30.0 ng/mL) vitamin D levels

** SD denotes standard deviation

+ IQR denotes interquartile range

to intentional sun avoidance behaviours of women, often linked to cultural and body image perceptions where fair skin of women is deemed a beauty standard [16]. Recent climate change leading to increased ambient temperature has also made venturing outdoors uncomfortable for women, due to increased sweating, premature skin aging and skin darkening [37, 38].

Surprisingly, the study also indicates that younger age groups (35–44 years) have higher VDD prevalence compared to older age groups (65–74 years), contrary to the expected norm. This may be due to lower rates of vitamin D supplementation [39] or less opportunity or preference for outdoor sun exposure among younger individuals. A recent study conducted among young adults in Sri Lanka has shown that more than 60% adopt at least one sun avoidance behaviour when outdoors [40].

In terms of ethnicity, the study found the highest prevalence of VDD among Tamils (82.0%). This trend may be attributed to their predominantly vegetarian diet and conservative clothing choices. In contrast, Muslims, who also adhere to traditional clothing styles, exhibited improved vitamin D levels in the study. Although there is no clear explanation, to some extent, this may be owing to their higher consumption of fats, oils and spreads, meat and poultry. Interestingly, effect of long-term fasting conducted for religious purpose has also been implicated in this regard [41, 42].

Previous community-based studies in Sri Lanka have also reported high VDD prevalence rates among adults in relatively urban areas, such as Kandy Municipal Council area (47.4%) [27] and in one underserved settlement area in Colombo District (58.8%) [43], conducted almost 10–15 years ago, reinforcing the current study's findings. Notably, the highly urban area exhibited the highest VDD prevalence; however, rural dwellers did not have the lowest prevalence. This is contrary to what was expected, i.e., occupational sun exposure due to agriculture-based outdoor occupations of rural dwellers, leading to a lower prevalence of VDD. In the present-day context, even rural farmers commonly adopt protective measures like wearing long-sleeved clothing and brimmed hats to shield themselves from pesticides during farming activities, resulting in reduced sunlight exposure among this group. This may explain this discrepancy to some extent.

Finally, the study identified that 9.1% of participants had serum total calcium levels below the reference range, with the highest observed among the elderly (65–74 years). Low calcium levels showed no significant gender disparity, although females had a slight preponderance. The majority of those with VDD maintained normal serum calcium levels, possibly due to the predominance of mild VDD cases. Further, among those with VDD, 6.9% had high calcium levels, possibly an incidental finding or due to secondary hyperparathyroidism where low calcium levels lead to increased stimulation of the parathyroid glands, which could lead to bone resorption and adverse consequences [44]. However, further clinical and biochemical tests are needed to interpret these results accurately. Further, as 22.4% ($n = 17$) of those who had normal vitamin D levels showed low serum calcium, other causes of hypocalcaemia such as inadequate dietary intake, pancreatitis, lactose intolerance and disorders of the parathyroid gland should be explored [44].

### Strengths and limitations of the study

There were several strengths in the methodology of this study related to adequate sample size, representativeness of the sample of urban settings in Sri Lanka and high response rate. Sample was stratified by the age- and sector-distribution of Colombo District. Although stratification by sex distribution of the district was not considered during sampling, selection bias was unlikely, as the sample showed a slight female preponderance compatible with census data of the district. Further, sampling was done on weekends and Sundays, so that both working adults and males were available at the time of sampling. Standard protocols were adopted during sample collection, transportation, storage and processing. The use of chemiluminescence assay method with a wide functional sensitivity range (4–150 ng/mL) and 100% detection of both serum $25(OH)D_2$ and $25(OH)D_3$ presented as a single value enabled an accurate estimation of true positives for VDD, minimising misclassification. Quality control indicators of vitamin D and calcium tests were within acceptable limits indicating satisfactory precision and reliability; however, gold standard methods would have further improved the measurements.

## Conclusions and recommendations

Study findings reveal that nine out of every ten adults living in urban settings have vitamin D deficiency or insufficiency, which is alarmingly high for a country with year-round sunlight, which should naturally facilitate sufficient vitamin D synthesis in the body. This low vitamin D level was widespread, cutting across all age groups, genders, ethnicities and residential areas. Importantly, even though VDD was staggeringly high, it generally presented as a mild form in the backdrop of normal serum calcium levels. Findings underscore the need for vitamin D supplementation and food fortification. However, further research is needed to explore the factors influencing low vitamin D in this population.

### Abbreviations

| | |
|---|---|
| CI | Confidence intervals |
| CV | Coefficient of variation |
| COVID-19 | Coronavirus disease 2019 |
| DE | Design effect |
| GND | Grama niladhari division |
| IQR | Interquartile range |
| NCD | Non-communicable diseases |
| PE | Point estimates |
| PPS | Probability-proportionate-to-size |
| SD | Standard deviation |
| SPSS | Statistical Package for Social Sciences |
| USA | Unites States of America |
| UVB | Ultraviolet B |
| VDD | Vitamin D deficiency |
| VDI | Vitamin D insufficiency |

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**Authors' contributions**
R.S. and C.A. conceptualized the study. R.S. was the principal investigator involved in collection and analysis of data, drafting the manuscript and was supervised by C.A. and N.G. C.A. and N.G. revised the document critically for content. All authors were involved in interpretation of data. All authors read and approved the final manuscript.

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**Availability of data and materials**
All relevant data supporting the findings are found within the manuscript. Our data are not available within the Supporting Information files, as no prior permission has been granted from the participants or health authorities for uploading data files. In acknowledging the importance of contributing to the open access policies of the journal, we have provided a non-author point of contact to field data access queries: erc@med.cmb.ac.lk. Reasonable requests submitted to this non-author point of contact are considered on a case-by-case basis and once permission is granted, we will share the data requested.

## Declarations

**Ethics approval and consent to participate**
The study was conducted in accordance with the 1964 Declaration of Helsinki and approved by the Ethics Review Committee of the Postgraduate Institute of Medicine of the University of Colombo (protocol number ERC/PGIM/2020/206 approved on 18/01/2021). Informed written consent was obtained from all participants prior to data and serum sample collection. The participation in the study was voluntary and the right of the participant to withdraw from the study at any time without penalty and effect on medical care or loss of benefits was informed and their rights were respected. Those who were found to have low vitamin D levels were referred to the closest Endocrine Clinic of state sector hospital and were advised on vitamin D-rich food that can be consumed and sensible sun exposure.

**Consent for publication**
Not applicable.

**Competing interests**
The authors declare no competing interests.

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**References**
1. Holick MF. Vitamin D deficiency. N Engl J Med. 2007;357(3):266–81. https://doi.org/10.1056/nejmra070553.
2. Wang H, Chen W, Li D, Yin X, Zhang X, Olsen N, et al. Vitamin D and chronic diseases. Aging Dis. 2017;8(3):346. https://doi.org/10.14336/ad.2016.1021.
3. Shoben AB, Kestenbaum B, Levin G, Hoofnagle AN, Psaty BM, Siscovick DS, et al. Seasonal variation in 25-hydroxyvitamin D concentrations in the cardiovascular health study. Am J Epidemiol. 2011;174(12):1363–72. https://doi.org/10.1093/aje/kwr258.
4. Cui A, Zhang T, Xiao P, Fan Z, Wang H, Zhuang Y. Global and regional prevalence of vitamin D deficiency in population-based studies from 2000 to 2022: A pooled analysis of 7.9 million participants. Front Nutr. 2023;10. Available from: https://doi.org/10.3389/fnut.2023.1070808
5. Berger C, Greene-Finestone LS, Langsetmo L, Kreiger N, Joseph L, Kovacs CS, et al. Temporal trends and determinants of longitudinal change in 25-hydroxyvitamin D and parathyroid hormone levels. J Bone Miner Res. 2012;27(6):1381–9. https://doi.org/10.1002/jbmr.1587.
6. Schleicher RL, Sternberg MR, Lacher DA, Sempos CT, Looker AC, Durazo-Arvizu RA, et al. The vitamin D status of the US population from 1988 to 2010 using standardized serum concentrations of 25-hydroxyvitamin D shows recent modest increases. Am J Clin Nutr. 2016;104(2):454–61. https://doi.org/10.3945/ajcn.115.127985.
7. Daly RM, Gagnon C, Lu ZX, Magliano DJ, Dunstan DW, Sikaris KA, et al. Prevalence of vitamin D deficiency and its determinants in Australian adults aged 25 years and older: a national, population-based study: Vitamin D deficiency in Australian adults. Clin Endocrinol (Oxf). 2012;77(1):26–35. https://doi.org/10.1111/j.1365-2265.2011.04320.x.
8. Hassan-Smith ZK, Hewison M, Gittoes NJ. Effect of vitamin D deficiency in developed countries. Br Med Bull. 2017;122(1):79–89. https://doi.org/10.1093/bmb/ldx005.
9. Pal BR, Marshall T, James C, Shaw NJ. Distribution analysis of vitamin D highlights differences in population subgroups: preliminary observations from a pilot study in UK adults. J Endocrinol. 2003;179(1):19–29. https://doi.org/10.1677/joe.0.1790119.
10. Marwaha RK, Tandon N, Garg MK, Kanwar R, Narang A, Sastry A, et al. Vitamin D status in healthy Indians aged 50 years and above. J Assoc Physicians India. 2011;59:706–9.
11. Rattan R, Sahoo D, Mahapatra S. Prevalence of Vitamin D deficiency in adults in the coastal regions of Odisha. India IOSR J Pharm Biol Sci. 2016;11:49–52.
12. Majumdar V, Nagaraja D, Christopher R. Vitamin D status and metabolic syndrome in Asian Indians. Int J Obes (Lond). 2011;35(8):1131–4. https://doi.org/10.1038/ijo.2010.232.
13. Sheikh A, Saeed Z, Jafri SAD, Yazdani I, Hussain SA. Vitamin D levels in asymptomatic adults-A population survey in Karachi, Pakistan. PLoS One. 2012;7(3):e33452. https://doi.org/10.1371/journal.pone.0033452.
14. Chailurkit L-O, Aekplakorn W, Ongphiphadhanakul B. Regional variation and determinants of vitamin D status in sunshine-abundant Thailand. BMC Public Health. 2011;11(1). Available from: https://doi.org/10.1186/1471-2458-11-853
15. Harinarayan CV, Holick MF, Prasad UV, Vani PS, Himabindu G. Vitamin D status and sun exposure in India. Dermatoendocrinol. 2013;5(1):130–41. https://doi.org/10.4161/derm.23873.
16. Nimitphong H, Holick MF. Vitamin D status and sun exposure in southeast Asia. Dermatoendocrinol. 2013;5(1):34–7. https://doi.org/10.4161/derm.24054.
17. Wacker M, Holick MF. Sunlight and Vitamin D: A global perspective for health. Dermatoendocrinol. 2013;5(1):51–108. https://doi.org/10.4161/derm.24494.
18. Madusanka MAIS, Dissanayake M, Akalanka HMK, Bandara T. A cross-sectional study on the vitamin D status in a group of indoor and outdoor workers in Galle, Sri Lanka. Kandy Med J. 2022;31(2):35–42. https://doi.org/10.4038/sljm.v31i2.339.
19. Rodrigo M, Hettiarachchi M, Liyanage C, Lekamwasam S. Low serum vitamin D among community-dwelling healthy women in Sri Lanka. Health. 2013;05(12):1997–2003. https://doi.org/10.4236/health.2013.512270.
20. Hettiarachchi M, Liyanage C. Coexisting micronutrient deficiencies among Sri Lankan pre-school children: a community-based study: Micronutrients and deficiency status of Sri Lankan pre-school children. Matern Child Nutr. 2012;8(2):259–66. https://doi.org/10.1111/j.1740-8709.2010.00290.x.

21. Marasinghe E, Chackrewarthy S, Abeysena C, Rajindrajith S. Micronutrient status and its relationship with nutritional status in preschool children in urban Sri Lanka. Asia Pac J Clin Nutr. 2015;24(1):144–51. Available from: https://www.airitilibrary.com/Publication/alDetailedMesh?DocID=09647058-201503-201503180028-201503180028-144-151. Cited 16 Sep 2023.
22. Jayatissa R, Lekamwasam S, Ranbanda JM, Ranasingha S, Perera AG, De Silva KH. Vitamin D deficiency among children aged 10–18 years in Sri Lanka. Ceylon Med J. 2019;64(4):146. https://doi.org/10.4038/cmj.v64i4.8991.
23. Anusha K, Hettiaratchi U, Gunasekera D, Prathapan S, Liyanage G. Maternal vitamin D status and its effect on vitamin D levels in early infancy in a tertiary care centre in Sri Lanka. Int J Endocrinol. 2019;2019:1–6. https://doi.org/10.1155/2019/9017951.
24. Department of Census and Statistics. Census of Population and housing 2011. 94.94.83:8041. 2012. Available from: https://203.94.94.83:8041/index.php?fileName=FinalReportE&gp=Activities&tpl=3. Cited 16 Sep 2023.
25. Weeraratne B. Re-Defining Urban Areas in Sri Lanka - Working Paper Series No.23. Colombo, Sri Lanka: Institute of Policy Studies; 2016. Available from: https://www.ips.lk/wp-content/uploads/2017/01/RE-DEFININGURBAN-AREAS-INSRI-LANKA_ips_E_Book.pdf.
26. Lwanga SK LS. Sample size determination in health studies: a practical manual. World Health Organization. 1991. Available from: https://apps.who.int/iris/handle/10665/40062. Cited 16 Sep 2023.
27. Meyer HE, Holvik K, Lofthus CM, Tennakoon SUB. Vitamin D status in Sri Lankans living in Sri Lanka and Norway. Br J Nutr. 2008;99(5):941–4. https://doi.org/10.1017/s0007114507844138.
28. Bennet S, Woods T, Liyanage WM, Smith DL. A simplified general method for cluster-sample surveys of health in developing countries. World Health Stat Q. 1991;44(3):98–105.
29. World Health Organization. WHO guidelines on drawing blood: best practices in phlebotomy. World Health Organization. 2010. Available from: https://www.who.int/publications/i/item/9789241599221. Cited 16 Sep 2023.
30. Kaplan LA, Pesce AJ. Clinical Chemistry: Theory, Analysis. Correlation. Mosby: Elsevier; 2010.
31. Holick MF, Binkley NC, Bischoff-Ferrari HA, Gordon CM, Hanley DA, Heaney RP, et al. Evaluation, treatment, and prevention of vitamin D deficiency: An endocrine society clinical practice guideline. J Clin Endocrinol Metab. 2011;96(7):1911–30. https://doi.org/10.1210/jc.2011-0385.
32. Medical Research Institute. https://www.mri.gov.lk/. Accessed 8 Aug 2024.
33. Lips P. Which circulating level of 25-hydroxyvitamin D is appropriate? J Steroid Biochem Mol Biol. 2004;89–90:611–4. https://doi.org/10.1016/j.jsbmb.2004.03.040.
34. Lips P, de Jongh RT, van Schoor NM. Trends in vitamin D status around the world. JBMR Plus. 2021;5(12). Available from: https://doi.org/10.1002/jbm4.10585
35. Webb A, Kazantzidis A, Kift R, Farrar M, Wilkinson J, Rhodes L. Colour counts: Sunlight and skin type as drivers of vitamin D deficiency at UK latitudes. Nutrients. 2018;10(4):457. https://doi.org/10.3390/nu10040457.
36. Jayawardena R, Byrne NM, Soares MJ, Katulanda P, Hills AP. Food consumption of Sri Lankan adults: an appraisal of serving characteristics. Public Health Nutr. 2013;16(4):653–8. https://doi.org/10.1017/s1368980012003011.
37. Chen H-Y, Yarnal C, Chick G, Jablonski N. Egg white or sun-kissed: A cross-cultural exploration of skin color and women's leisure behavior. Sex Roles. 2018;78(3–4):255–71. https://doi.org/10.1007/s11199-017-0785-4.
38. Morrissey H, Subasinghe S, Ball P A, Lekamwasam S, & Waidyaratne E. (2019). Sunlight exposure and serum vitamin D status among community dwelling healthy women in Sri Lanka. Ejpmr, 2019,6(9), 109–113. https://wlv.openrepository.com/handle/2436/622686
39. Francis TV, Sooriyaarachchi P, Jayawardena R. Usage of nutritional supplements to improve immunity during the COVID-19 pandemic: An online survey. Clin Nutr Open Sci. 2022;43:6–19. https://doi.org/10.1016/j.nutos.2022.04.003.
40. Liyanage G, Jayathunga S, Amarasekara T. Vitamin D knowledge and sun exposure practices among Sri Lankan healthcare undergraduates. PLoS One. 2022;17(12):e0279480. https://doi.org/10.1371/journal.pone.0279480.
41. Tewani GR, Silwal K, Sharma G, Yadav D, Siddiqui A, Kriplani S, et al. Effect of medically supervised prolonged fasting therapy on vitamin D, B12, body weight, body mass index, vitality and quality of life: A randomized control trial. Nutr Metab Insights. 2022;15:117863882211305. Available from: https://doi.org/10.1177/11786388221130560
42. Żychowska M, Rola R, Borkowska A, Tomczyk M, Kortas J, Anczykowska K, et al. Fasting and exercise induce changes in serum vitamin D metabolites in healthy men. Nutrients. 2021;13(6):1963. https://doi.org/10.3390/nu13061963.
43. Subasinghe CJ, Gunawardane K, Ediriweera D, Somasundaram NP. Prevalence of vitamin D deficiency/insufficiency and its metabolic associations in an urban setting in Sri Lanka: data from Colombo urban study. Sri Lanka J Diabetes Endocrinol Metab. 2019;9(2):16. https://doi.org/10.4038/sjdem.v9i2.7394.
44. Tinawi M. Disorders of calcium metabolism: Hypocalcemia and hypercalcemia. Cureus. 2021; Available from: https://doi.org/10.7759/cureus.12420


## Publisher's Note