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Systematic Review

A Systematic Review and Meta-Analysis of Vitamin D Status of Apparently Healthy Adults in Worldwide Regions

Alneil Hamza, Alyasa M. Elfaki, Mohamed N. Ibrahim, Sara Osman Yousif and Eman Fawzy Elazab

Clinical Laboratories Department, College of Applied Medical Sciences, Jouf University, Qurayyat, Saudi Arabia

Abstract

Plasma vitamin D, measured as 25-Hydroxyvitamin D [25(OH)D], is influenced by genetics, lifestyle, age, gender, skin pigmentation, sunlight exposure, latitude, sunscreen use, diet and supplementation. Globally, vitamin D deficiency is frequently reported among healthy populations, yet comprehensive analyses summarizing its prevalence are limited. This systematic review and meta-analysis aimed to assess 25(OH)D status among healthy adults across different regions worldwide. We systematically searched PubMed, Web of Science, ScienceDirect and Google Scholar for observational studies published in English between 2013 and 2024. Heterogeneity among studies was evaluated using Cochran's Q test and the I^2 statistic, with significance set at $p < 0.10$; I^2 values were interpreted as low (0-40%), moderate (30-60%), substantial (50-90%) and considerable (75-100%). Due to significant heterogeneity, a random-effects model was employed to estimate the prevalence of vitamin D deficiency. A total of 394,548 participants from 56 studies across 30 countries were included. The pooled prevalence of vitamin D deficiency was 55% (95% CI: 49.0-60.0%), with considerable heterogeneity ($Q < 0.001$; $I^2 = 100\%$). Subgroup analysis showed the highest deficiency in the Middle East (62%; 95% CI: 54-70%), followed by Asia (54%; 95% CI: 39-69%), Africa (43%; 95% CI: 24-63%), and Europe (43%; 95% CI: 23-63%). Weighted mean vitamin D levels ranged from 8.4 ± 0.5 ng/mL to 37.7 ± 10.8 ng/mL, with an overall mean of 20.14 ± 6.7 ng/mL. Regionally, the Middle East had the lowest recalculated weighted mean level (17.8 ng/mL), followed by Asia (20.4 ng/mL), Europe (26.8 ng/mL), "Others" (28.0 ng/mL) and Africa (29.2 ng/mL, influenced by one high outlier study). These findings reveal a high prevalence of vitamin D deficiency among healthy adults, particularly in the Middle East, but with the lowest mean levels observed in the Middle East and marked regional disparities, highlighting marked regional disparities.

Key words: Healthy adults, 25-Hydroxyvitamin D [25(OH)D], vitamin D deficiency, systematic review, meta-analysis

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Corresponding Author: Mohamed N. Ibrahim, Clinical Laboratories Department, College of Applied Medical Sciences, Jouf University, Qurayyat, Saudi Arabia

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Vitamin D is a very important fat-soluble vitamin, and its key role is in the metabolism of bones and calcium homeostasis. Besides its classical skeletal actions, vitamin D has very broad pleiotropic effects, acting as an anti-inflammatory, antiapoptotic and anti-fibrotic molecule, in which its significance has been demonstrated in cardiovascular, renal, and immune system in relation^{1,2}. Most of the people depend on the production of vitamin D through cutaneous synthesis, which is triggered by exposure to ultraviolet B (UVB) radiation, which transforms skin 7-dehydrocholesterol into cholecalciferol (vitamin D₃)³⁻⁵. This is hydroxylated repeatedly in the liver and the kidney to form the major circulating metabolite, 25-Hydroxyvitamin D [25(OH)D] and the active hormonal form, 1,25-Dihydroxyvitamin D [1,25(OH)₂D], respectively. It has been estimated that about 90 percent of the body's vitamin D comes from exposure to sunlight, while dietary intake contributes a minor proportion^{6,7}. The beta 25(OH)D response is viewed as the most accurate clinical measure of vitamin D status as it has a relatively long half-life of about 15 days and it incorporates both cutaneous synthesis and food intake^{6,7}.

The clinical levels to define the state of vitamin D in the body as recommended by the Endocrine Society and the Institute of Medicine classify serum levels of vitamin D to be the following: Adequate (>30 ng/mL or 75 nmol/L), less than adequate (20-29 ng/mL or 50-74 nmol/L) and deficient (<20 ng/mL or <50 nmol/L)^{8,9}. There is, however, an emerging agreement among professionals and multiple global recommendations that concentrations under 30 ng/mL could not be ideal in promoting wider non-skeletal health¹⁰⁻¹². Deficiency in vitamin D is linked to an increased vulnerability to adverse health conditions, including osteoporosis, fractures, muscular inactivity, cardiovascular disease, type 2 diabetes, some malignancies, autoimmune diseases, infectious diseases and greater all-cause mortality¹³⁻¹⁵. Hypovitaminosis D is caused by a lack of sufficient exposure to sunlight, a deficiency of vitamin D in the diet, or impaired absorption or metabolism and is also affected by personal factors like skin pigmentation, age, obesity, etc., as well as the sociocultural practices¹⁶⁻¹⁹.

Irrespective of the fact that many regions of the world have an adequate supply of solar radiation, vitamin D deficiency is a widespread worldwide health problem in the population²⁰⁻²². Ironically, the highest prevalence rates have been recorded in areas that receive plenty of sun, like the Middle East and North Africa, where cultural beliefs (e.g., modest dressing, minimal outdoor activities) and lifestyle factors greatly reduce the effective exposure to UVB radiation²⁰.

According to conservative estimates, it has been found that more than a billion individuals in the world have serum 25(OH)D levels below 20 ng/mL and the insufficiency (<30 ng/mL) affects an even larger proportion of the global population. These findings indicate a severe gap between environmental possibility and real vitamin D status and therefore, a global assessment should be updated and comprehensive. Although many regional studies and some meta-analyses have investigated the status of vitamin D in particular populations or continents^{21,22}.

Therefore, the present systematic review and meta-analysis had two primary objectives:

- To estimate the pooled prevalence of vitamin D deficiency (<20 ng/mL) and insufficiency (<30 ng/mL) in apparently healthy adult populations across major geographical regions
- To determine regional weighted mean serum 25-hydroxyvitamin D concentrations and identify areas with the greatest burden of hypovitaminosis D

MATERIALS AND METHODS

We used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to conduct this systematic review.

Search strategy: Various databases were searched, including PubMed, Web of Science, ScienceDirect and Google Scholar databases through July 2024 in English to find studies investigating the prevalence of vitamin D status in healthy adults published between 2013 and 2024. The systematic literature search was based on controlled vocabulary and specific text words were used for the search, with adaptations for each database. Search terms included "vitamin D" or "25-hydroxy vitamin D" and "prevalence" or "deficiency".

Inclusion and exclusion criteria: All the possible worldwide searched literature focused on vitamin D levels in healthy individuals published from 2013 to 2024 was included in this study. The exclusion of studies covers the studies related to vitamin D that included diseases of the thyroid gland, kidney, or liver; osteoporosis; stroke; lung emphysema; asthma; cancer; rheumatoid arthritis; multiple sclerosis; HIV; metabolic bone diseases; inflammatory diseases and other chronic diseases were excluded, as well as those that did not include usable data, or were a meta-analysis, review, or case report.

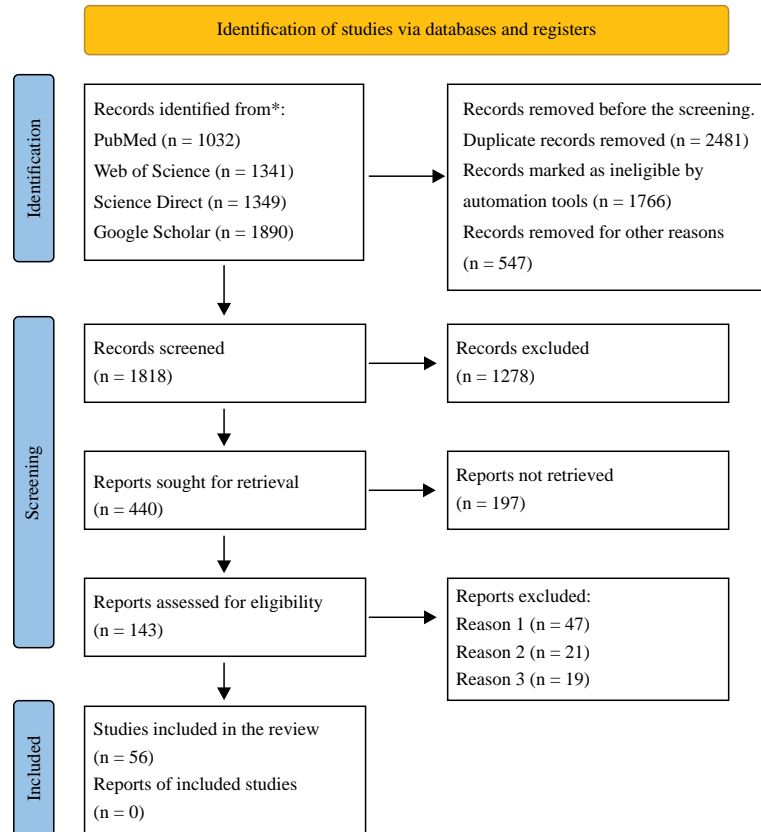


Fig. 1: Flowchart of study selection for inclusion trials in the systematic review

Study selection: The authors independently screened the articles based on their titles and abstracts and excluded studies that did not meet the eligibility criteria. A 5612 articles were selected for review using the above search strategy. The study selection process followed the PRISMA guidelines; the transition from initial identification to final inclusion of the 56 trials is summarized in Fig. 1. The 56 studies published between 2013 and 2024 were selected for analysis based on publication year, country, study population, design, sample size, measurement method and outcomes. The studies conducted in different countries were categorized under the respective zones, as per the classification of a worldwide geographical area (Table 1).

Statistical analysis: The statistical analyses were conducted using R and Jamovi software. The pooled prevalence of vitamin D deficiency (typically <20 ng/mL) and weighted mean 25(OH)D levels were calculated for each study where available. To evaluate the heterogeneity among the included studies, we used the Cochrane Q test and I^2 values greater than 50% signified moderate to high heterogeneity and $p < 0.10$ was considered statistically significant. Because of

the substantial heterogeneity, the pooled weighted mean difference and 95% CI were calculated using the random-effects model. The subgroup analysis was made to explore potential sources of observed heterogeneity among the included studies. Subgroup analysis was directed based on the following variables: Climate zone (Middle East, Asia, Europe, Africa and Others). The p-values for pooled effect sizes were considered statistically significant at the level of $p < 0.05$.

RESULTS

A methodical search in various databases did not produce less than 5612 records. Upon the elimination of duplicates, 1818 articles were filtered by title and abstract, with 1278 articles being excluded. The rest of the 440 articles ($n = 440$) were assessed in full-text and 184 articles were discarded due to different reasons (e.g., inappropriate population, inability to use the data, or study design). Among the number of records that were screened, 56 studies fit the eligibility criteria and were quantitatively synthesized (see Fig. 1 to see how those studies were selected). These specific trials have elaborate characteristics that are discussed further in Table 1.

Table 1: List of all 56 included studies with extracted variables

Study ID	Author (Year)	Country	Region	Sample Size	Mean age (Years)	Female (%)	Assay method	Deficiency cut-off (ng/mL)	Prevalence of deficiency (%)	Mean 25(OH)D (ng/mL)
1	Abdulmajeed <i>et al.</i> (2021)	Saudi Arabia	Middle East	10,070	39	52	CLIA	<20	46	22.1
2	Al Muhairi <i>et al.</i> (2013)	UAE	Middle East	315	18	100	ELISA	<20	20	28.5
3	Al Hayek <i>et al.</i> (2018)	Lebanon	Middle East	344	42.6	55	CLIA	<20	31	24.0
4	Arık <i>et al.</i> (2023)	Turkey	Middle East	121,727	39.4	55	CLIA	<20	72	18.5
5	Nakhaee <i>et al.</i> (2019)	Iran	Middle East	400	53.3	60	ELISA	<20	26	26.0
6	Lee <i>et al.</i> (2019)	Korea	Asia	179	52	50	CLIA	<20	74	18.0
7	Choi <i>et al.</i> (2017)	Korea	Asia	180,289	44.8	52	CLIA	<20	49	22.5
8	Abdelsalam <i>et al.</i> (2023)	Saudi Arabia	Middle East	2,153	43.5	48	CLIA	<20	42	23.0
9	Alsuwaida <i>et al.</i> (2013)	Saudi Arabia	Middle East	488	37.4	50	CLIA	<20	30	25.0
10	Al Anouti <i>et al.</i> (2022)	UAE	Middle East	550	35	100	CLIA	<20	67	19.0
11	AlFaris <i>et al.</i> (2019)	Saudi Arabia	Middle East	166	43	100	CLIA	<20	60	20.5
12	Albuloshi <i>et al.</i> (2022)	Kuwait	Middle East	237	65	55	CLIA	<20	63	19.8
13	Brîndus <i>et al.</i> (2021)	Romania	Europe	5,380	45.1	53	CLIA	<20	25	28.0
14	Borba <i>et al.</i> (2023)	Brazil	Others	1,004	37	52	LC-MS/MS	<20	15	31.0
15	Middendorf <i>et al.</i> (2019)	South Africa	Africa	242	20.4	50	CLIA	<20	12	35.0
16	Aljazzaf <i>et al.</i> (2023)	Libya	Africa	306	38.67	50	ELISA	<20	45	23.5
17	Saeed <i>et al.</i> (2021)	UAE	Middle East	287	19.9	55	CLIA	<20	85	16.0
18	Msalati <i>et al.</i> (2022)	Libya	Africa	100	19.5	50	ELISA	<20	74	18.5
19	Holick <i>et al.</i> (2007)	Pakistan	Asia	221	23	50	ELISA	<20	89	15.5
20	Arabi <i>et al.</i> (2021)	Lebanon	Middle East	466	45.3	55	CLIA	<20	39	24.5
21	Lin <i>et al.</i> (2021)	China	Asia	1,700	48.34	52	CLIA	<20	3	34.0
22	Kagotho <i>et al.</i> (2018)	Kenya	Africa	253	33	55	ELISA	<20	17	30.0
23	Ravelo <i>et al.</i> (2022)	Spain	Europe	33,601	59	52	CLIA	<20	48	24.0
24	Krasniqi <i>et al.</i> (2024)	Kosovo	Europe	297	65.3	55	CLIA	<20	46	24.5
25	Lee <i>et al.</i> (2019)	Taiwan	Asia	3,954	55.48	52	CLIA	<20	23	28.0
26	Kamacı <i>et al.</i> (2020)	Turkey	Middle East	100	20.18	55	ELISA	<20	91	14.0
27	Khazaei <i>et al.</i> (2018)	Iran	Middle East	102	42	55	ELISA	<20	73	19.0
28	El-Khateeb <i>et al.</i> (2019)	Jordan	Middle East	4,056	43.7	55	CLIA	<20	71	18.5
29	Husain <i>et al.</i> (2019)	Sudan	Africa	190	40.2	100	ELISA	<20	83	17.0
30	Hataysal <i>et al.</i> (2019)	Turkey	Middle East	2,007	42	55	CLIA	<20	68	19.5
31	Pradeep <i>et al.</i> (2017)	India	Asia	1,403	47	52	CLIA	<20	82	18.0
32	Golbahar <i>et al.</i> (2013)	Bahrain	Middle East	500	40	52	CLIA	<20	49	22.0
33	Ruram <i>et al.</i> (2019)	Zimbabwe	Africa	474	33	55	ELISA	<20	55	21.0
34	Sakyi <i>et al.</i> (2015)	Ghana	Africa	500	27.97	55	ELISA	<20	44	25.0
35	Niazi <i>et al.</i> (2019)	Iran	Middle East	70	37.5	100	ELISA	<20	46	22.0
36	Cigerli <i>et al.</i> (2013)	Turkey	Middle East	2,488	53.3	55	CLIA	<20	66	20.0
37	Ritu and Gupta (2014)	India	Asia	100	20.79	55	CLIA	<20	89	15.5
38	Bi <i>et al.</i> (2016)	Singapore	Asia	114	31.5	52	CLIA	<20	42	23.5
39	Khashayar <i>et al.</i> (2014)	Iran	Middle East	3,669	42.1	55	ELISA	<20	46	22.5
40	Forrest and Stuhldreher (2011)	Egypt	Africa	90	36.94	55	ELISA	<20	30	26.0
41	Walia <i>et al.</i> (2017)	India	Asia	150	19.46	100	ELISA	<20	53	21.0
42	Hinduja <i>et al.</i> (2022)	India	Asia	243	40	52	CLIA	<20	57	22.0
43	Bahlous <i>et al.</i> (2017)	Tunisia	Africa	196	36.9	55	CLIA	<20	48	24.0
44	Shafii <i>et al.</i> (2024)	Malaysia	Asia	120	33	100	CLIA	<20	77	18.5
45	Hu <i>et al.</i> (2023)	China	Asia	6,273	73.3	52	CLIA	<20	58	21.5
46	Rajebi <i>et al.</i> (2016)	Iran	Middle East	114	35.6	100	ELISA	<20	69	19.0
47	Hasanato <i>et al.</i> (2015)	Saudi Arabia	Middle East	178	22.2	100	CLIA	<20	71	18.5
48	Al-Kadi and Alissa (2014)	Saudi Arabia	Middle East	118	20.3	100	CLIA	<20	99	8.4
49	van Schoor and Lips (2011)	Iran	Middle East	100	23.6	55	ELISA	<20	77	18.0
50	Gill <i>et al.</i> (2014)	Australia	Others	2,413	50.6	52	CLIA	<20	23	28.0
51	Tønnesen <i>et al.</i> (2016)	Denmark	Europe	700	22	52	CLIA	<20	19	29.0
52	Cashman <i>et al.</i> (2016)	Pakistan	Asia	88	27	50	ELISA	<20	99	9.0
53	Sayed-Hassan <i>et al.</i> (2014)	Syria	Middle East	372	34	55	ELISA	<20	90	16.0
54	Bhatta <i>et al.</i> (2016)	Nepal	Asia	2,158	39.5	52	ELISA	<20	18	31.0
55	Yogal <i>et al.</i> (S2022)	Nepal	Asia	733	48.5	100	LC-MS/MS	<20	6	34.2
56	Shafqat <i>et al.</i> (2019)	Pakistan	Asia	460	42.7	52	ELISA	<20	73	19.5

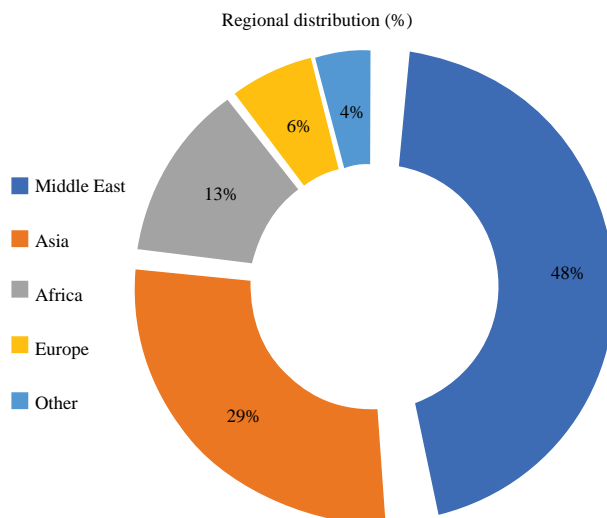


Fig. 2: Regional distribution % of studies on vitamin D deficiency

Table 2: Worldwide regions and the countries included under study

Regions	Countries
Middle East	Iran, Turkey, UAE, Bahrain, Saudi Arabia, Kuwait, Jordan, Lebanon, Syria
Asia	India, Pakistan, Nepal, Singapore, Malaysia, Korea, Taiwan, China
Africa	Egypt, Libya, Sudan, Tunisia, Ghana, Kenya, South Africa
Europe	Kosovo, Spain, Denmark, Romania
Others	Australia, Brazil

The majority of included studies (96%; 54/56) employed cross-sectional designs, with the remainder using case-control approaches that provided data on serum 25(OH)D levels in apparently healthy controls. The 56 studies, published between 2013 and 2024, encompassed a total of 394,548 participants (both men and women) across 30 countries. The mean age of participants was 39 ± 13 years, ranging from 18.0 to 73.3 years. Geographically, approximately 52% (29/56) of studies originated from Middle Eastern countries, 25% (14/56) from Asia, 12% (7/56) from Africa, 7% (4/56) from Europe and the remaining 4% (2/56) from other regions (e.g., Brazil and Australia) (Fig. 2, Table 2).

The pooled prevalence of vitamin D deficiency (<20 ng/mL) across all included studies was 55% (95% CI: 49.0-60.0%), with substantial heterogeneity ($I^2 = 100\%$, $p < 0.001$) (Fig. 3, Table 3). Subgroup analysis by region revealed the highest prevalence in the Middle East (62%; 95% CI: 54-70%), followed by Asia (54%; 95% CI: 39-69%), while Africa and Europe both showed a prevalence of 43% (95% CI: 24-63% and 23-63%, respectively).

Regional differences in serum 25(OH)D concentrations are presented in Fig. 4. Recalculated weighted mean levels were lowest in the Middle East (17.8 ng/mL), followed by Asia (20.4 ng/mL), Europe (26.8 ng/mL), "Others" (28.0 ng/mL) and Africa (29.2 ng/mL; influenced by one study reporting

markedly higher values). Overall, weighted mean 25(OH)D levels across studies ranged from 8.4 ± 0.5 ng/mL to 37.7 ± 10.8 ng/mL of the 56 included studies, 25 (45%) reported mean 25(OH)D levels exceeding 20 ng/mL, while only three studies (from South Africa, Iran and China) reported levels above 30 ng/mL.

DISCUSSION

This systematic review and meta-analysis demonstrate a substantial global burden of vitamin D deficiency among apparently healthy adults. The pooled findings indicate that hypovitaminosis D is highly prevalent worldwide, with marked regional variability. Similar patterns have been reported in previous population-based studies and regional assessments, which consistently describe vitamin D deficiency as a widespread public health issue across diverse populations and climatic zones^{23,24}.

Our findings are consistent with earlier regional syntheses. A higher prevalence of vitamin D deficiency has been reported in Turkey, reaching approximately 63% and in South Asian countries, where prevalence estimates approached 68% in earlier meta-analyses and large population studies^{25,26}. While these studies focused on specific geographic regions, the present analysis expands on this evidence by

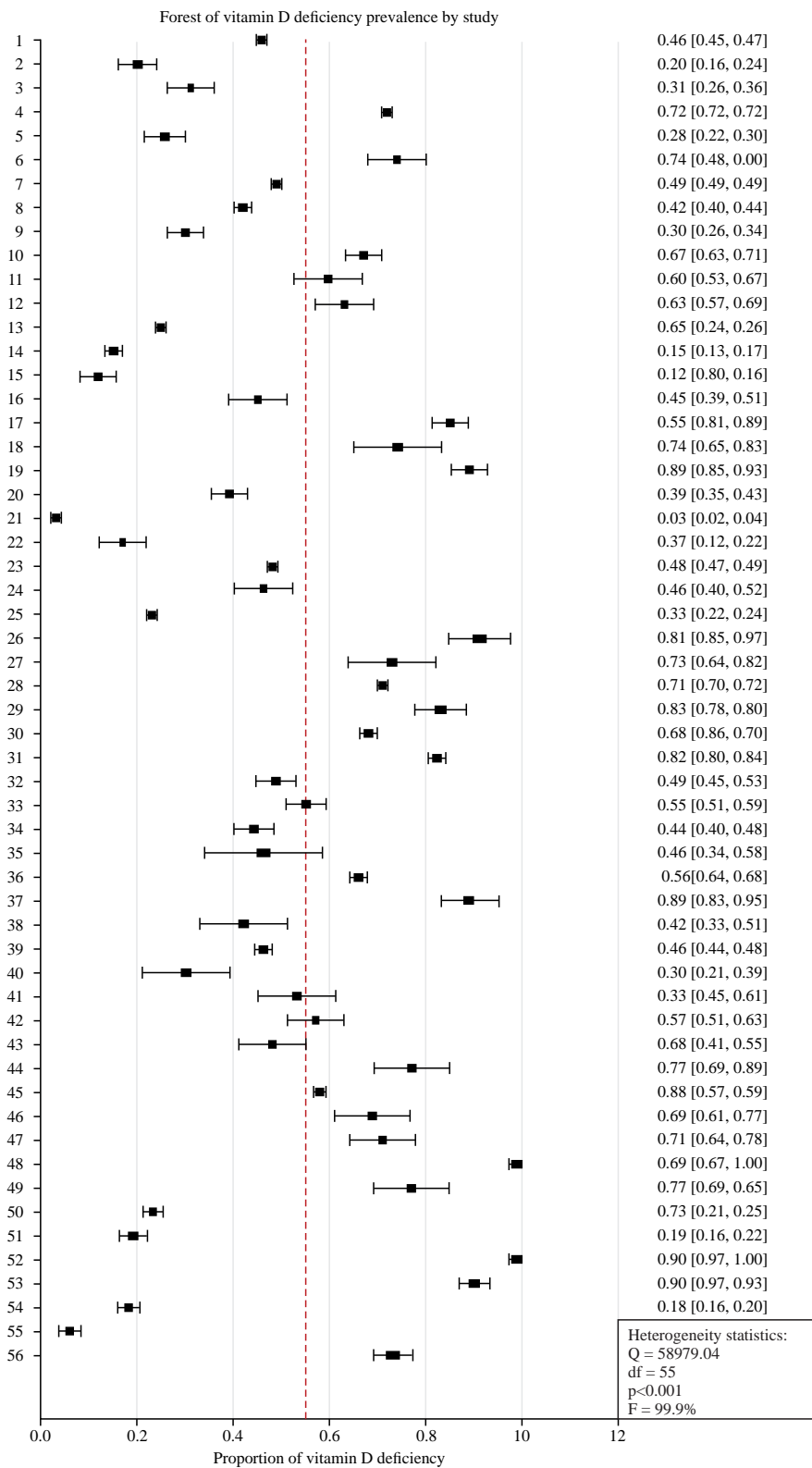


Fig. 3: Plot of the pooled prevalence of vitamin D deficiency (<20 ng/mL) in apparently healthy adults worldwide

Numbers on left side are reference numbers, The small black squares represent the point estimate (proportion) of vitamin D deficiency for each study, with the size of the square proportional to the study's weight in the meta-analysis. The horizontal lines through each square are the 95% confidence intervals for that study. The diamond at the bottom shows the overall pooled prevalence using the random-effects model (55%, 95% CI: 49.0-60.0%), with the width of the diamond representing the 95% CI of the pooled estimate. Heterogeneity: $\tau^2 = 0.0698$, $I^2 = 100\%$, $p < 0.001$

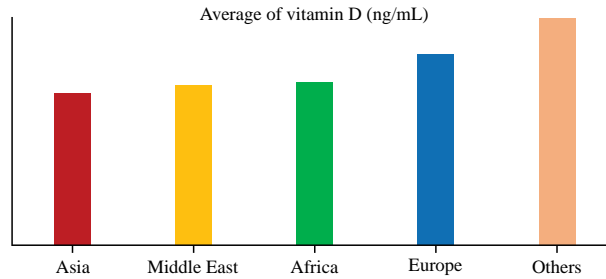


Fig. 4: Average of vitamin D levels by region

Table 3: Characteristics of the included studies evaluating the vitamin D status of apparently healthy adults

Ref no.	Authors	Year	Country	Sex	Age (years)	Total	Prevalence (%)
1	Abdulmajeed <i>et al.</i> (2021)	2021	Saudi Arabia	M/F	39	10070	46
2	Al Muhairi <i>et al.</i> (2013)	2013	UAE	M/F	18	315	20
3	Al Hayek <i>et al.</i> (2018)	2018	Lebanon	M/F	42.6	344	31
4	Arik <i>et al.</i> (2023)	2023	Turkey	M/F	39.38	121727	72
5	Nakhaee <i>et al.</i> (2019)	2019	Iran	M/F	53.28	400	26
6	Lee <i>et al.</i> (2019)	2019	Korea	M/F	52	179	74
7	Choi <i>et al.</i> (2017)	2022	Korea	M/F	44.8	180289	49
8	Abdelsalam <i>et al.</i> (2023)	2023	Saudi Arabia	M/F	43.5	2153	42
9	Alsuwaida <i>et al.</i> (2013)	2013	Saudi Arabia	M/F	37.43	488	30
10	Al Anouti <i>et al.</i> (2022)	2022	UAE	F	35	550	67
11	AlFaris <i>et al.</i> (2019)	2019	Saudi Arabia	F	43	166	60
12	Albuloshi <i>et al.</i> (2022)	2022	Kuwait	M/F	65	237	63
13	Brindus <i>et al.</i> (2021)	2024	Romania	M/F	45.1	5380	25
14	Borba <i>et al.</i> (2023)	2022	Brazil	M/F	37	1004	15
15	Middendorf <i>et al.</i> (2019)	2019	South Africa	M/F	20.4	242	12
16	Aljazzaf <i>et al.</i> (2023)	2023	Libya	M/F	38.67	306	45
17	Saeed <i>et al.</i> (2021)	2021	UAE	M/F	19.9	287	85
18	Msalati <i>et al.</i> (2022)	2022	Libya	M/F	19.5	100	74
19	Holick (2007)	2007	Pakistan	M/F	23	221	89
20	Arabi <i>et al.</i> (2021)	2021	Lebanon	M/F	45.3	466	39
21	Lin <i>et al.</i> (2021)	2021	China	M/F	48.34	1700	3
22	Kagotho <i>et al.</i> (2018)	2018	Kenya	M/F	33	253	17
23	Ravelo <i>et al.</i> (2022)	2022	Spain	M/F	59	33601	48
24	Krasniqi <i>et al.</i> (2024)	2024	Kosovo	M/F	65.3	297	46
25	Lee <i>et al.</i> (2019)	2019	Taiwan	M/F	55.48	3954	23
26	Kamacı <i>et al.</i> (2020)	2020	Turkey	M/F	20.18	100	91
27	Khazaei <i>et al.</i> (2018)	2018	Iran	M/F	42	102	73
28	El-Khateeb <i>et al.</i> (2019)	2019	Jordan	M/F	43.7	4056	71
29	Husain <i>et al.</i> (2019)	2019	Sudan	F	40.2	190	83
30	Hataysal <i>et al.</i> (2019)	2019	Turkey	M/F	42	2007	68
31	Pradeep <i>et al.</i> (2017)	2024	India	M/F	47	1403	82
32	Golbahar <i>et al.</i> (2013)	2013	Bahrain	M/F	40	500	49
33	Ruram <i>et al.</i> (2019)	2024	India	M/F	33	474	55
34	Sakyi <i>et al.</i> (2015)	2021	Ghana	M/F	27.97	500	44
35	Niazi <i>et al.</i> (2019)	2019	Iran	F	37.5	70	46
36	Cigerli <i>et al.</i> (2013)	2013	Turkey	M/F	53.3	2488	66
37	Ritu and Gupta (2014)	2014	India	M/F	20.79	100	89
38	Bi <i>et al.</i> (2016)	2016	Singapore	M/F	31.5	114	42
39	Khashayar <i>et al.</i> (2014)	2013	Iran	M/F	42.1	3669	46
40	Forrest and Stuhldreher (2011)	2011	Egypt	M/F	36.94	90	30
41	Walia <i>et al.</i> (2017)	2017	India	M/F	19.46	150	53
42	Hinduja <i>et al.</i> (2022)	2022	India	M/F	40	243	57
43	Bahlous <i>et al.</i> (2017)	2022	Tunis	M/F	36.9	196	48
44	Shafii <i>et al.</i> (2024)	2024	Malaysia	M/F	33	120	77
45	Hu <i>et al.</i> (2023)	2023	China	M/F	73.3	6273	58
46	Rajebi <i>et al.</i> (2016)	2014	Iran	F	35.6	114	69
47	Hasanato <i>et al.</i> (2015)	2015	Saudi Arabia	F	22.2	178	71
48	Al-Kadi <i>et al.</i> (2014)	2014	Saudi Arabia	F	20.3	118	99

Table 3: Continue

Ref no.	Authors	Year	Country	Sex	Age (years)	Total	Prevalence (%)
49	van Schoor and Lips (2011)	2011	Iran	M/F	23.6	100	77
50	Gill <i>et al.</i> (2014)	2014	Australia	M/F	50.6	2413	23
51	Tønnesen <i>et al.</i> (2016)	2016	Denmark	M/F	22	700	19
52	Cashman <i>et al.</i> (2016)	2016	Pakistan	M/F	27	88	99
53	Sayed-Hassan <i>et al.</i> (2014)	2014	Syria	M/F	34	372	90
54	Bhatta <i>et al.</i> (2016)	2016	Nepal	M/F	39.5	2158	18
55	Yogal <i>et al.</i> (2022)	2022	Nepal	F	48.5	733	6
56	Shafqat <i>et al.</i> (2019)	2017	Pakistan	M/F	42.7	460	73

The table includes all screened studies for transparency; however, 56 eligible studies met the inclusion criteria and were included in the reference list and analysis

providing a broader global perspective. Notably, the highest prevalence was observed in the Middle East, despite abundant year-round sunshine. This paradox highlights the importance of behavioral and sociocultural factors in determining vitamin D status, often outweighing environmental sunlight availability alone²⁷.

Several environmental factors regulate effective ultraviolet B (UVB) exposure and subsequent cutaneous vitamin D synthesis. Geographic Latitude plays a critical role, as regions located above approximately 35°N experience reduced solar zenith angles during certain months of the year, significantly limiting UVB penetration and vitamin D synthesis during late autumn and winter^{28,29}. Even in lower Latitudes and sun-rich regions, vitamin D production may be compromised by cloud cover, air pollution and reduced time spent outdoors, all of which impede adequate UVB exposure³⁰⁻³².

Beyond environmental constraints, vitamin D status is influenced by a complex interplay of demographic, biological and lifestyle determinants. Non-modifiable risk factors such as older age, female sex and increased skin pigmentation—resulting in reduced UVB penetration—have been consistently associated with lower serum 25(OH)D concentrations across populations³³⁻³⁶. In addition, sociocultural practices, including concealing clothing styles such as the niqab or hijab, preference for indoor activities, limited sun exposure and low intake of vitamin D-fortified foods or supplements, are particularly prevalent in regions such as the Middle East and South Asia and contribute significantly to deficiency risk^{37,38}. Several studies have demonstrated that conservative clothing practices alone may substantially increase the likelihood of vitamin D deficiency, even in sun-abundant environments³⁹⁻⁴².

Rapid urbanization worldwide has further altered lifestyle patterns, with an increasing proportion of time spent indoors. This shift has been associated with reduced opportunities for sunlight exposure and, consequently, lower vitamin D synthesis⁴³⁻⁴⁵. Urban living, high-rise housing and occupational settings that limit outdoor activity have been linked to lower serum vitamin D levels, particularly among working adults and students.

Regional evidence indicates that hypovitaminosis D remains highly prevalent across many Middle Eastern and African populations. Studies from Sub-Saharan Africa and the Middle East have reported that a substantial proportion of adults exhibit low serum 25(OH)D concentrations, despite favorable climatic conditions⁴⁶⁻⁵⁰. Identified risk factors in these developing regions include older age, female sex, malnutrition, darker skin pigmentation, limited sun exposure, conservative clothing practices and prolonged breastfeeding without vitamin D supplementation^{51,52}.

Dietary intake represents another important determinant of vitamin D status, particularly in populations with limited effective sun exposure. Low consumption of vitamin D-rich foods, such as fatty fish, fortified dairy products and eggs, as well as overall poor nutritional intake, has been consistently associated with vitamin D deficiency⁵³. Indeed, inadequate dietary intake, reduced sunlight exposure and impaired cutaneous synthesis are widely recognized as the three principal contributors to the global burden of hypovitaminosis D⁵⁴.

The interaction of these environmental, cultural and lifestyle factors likely explains the regional trends observed in this analysis. The high prevalence in the Middle East and Asia may be attributed to a combination of conservative clothing practices, predominantly indoor lifestyles, dietary habits and, in some urban areas, air pollution. In contrast, higher mean serum 25(OH)D levels observed in European populations may reflect the impact of public health measures, including voluntary or mandatory food fortification programs and greater use of vitamin D supplements. Similarly, higher mean levels reported in countries such as Australia and Brazil may be related to increased outdoor physical activity, lower skin pigmentation and established fortification or supplementation practices.

These findings underscore the urgent need for large-scale, context-specific public health strategies to address vitamin D deficiency globally. Recommended interventions include increasing awareness of the benefits of safe sun exposure, promoting dietary patterns rich in vitamin D and encouraging appropriate supplementation where necessary⁵⁵.

Importantly, the effectiveness of such interventions depends on their adaptation to local environmental, cultural and socioeconomic contexts⁵⁶. Continued surveillance and tailored public health responses are therefore essential to mitigate the persistent global burden of vitamin D deficiency.

CONCLUSION

This systematic review and meta-analysis of 56 studies involving 394,548 healthy adults from 30 countries (2013-2024) highlights a significant global burden of vitamin D deficiency [serum 25-hydroxyvitamin D <20 ng/mL]. The pooled prevalence was 55% (95% CI: 49.0-60.0%), with high heterogeneity ($I^2 = 100\%$, $p < 0.001$).

Subgroup analyses showed significant regional variations in prevalence, with the highest in the Middle East (62%; 95% CI: 54-70%) and Asia (54%; 95% CI: 39-69%), while Africa and Europe had lower rates (43%). The lowest mean 25(OH)D levels were in the Middle East (17.8 ng/mL), followed by Asia (20.4 ng/mL), Europe (26.8 ng/mL), "Others" (28.0 ng/mL) and Africa (29.2 ng/mL), influenced by a high outlier study.

The paradox of high vitamin D deficiency in sun-rich areas highlights the impact of sociocultural practices, urbanization, skin pigmentation and limited diet over sunlight availability. These findings emphasize the public health implications of vitamin D deficiency in seemingly healthy populations and support tailored interventions like promoting safe sun exposure, food fortification, targeted supplementation and routine screening in high-risk regions. Ongoing global surveillance and standardized research are crucial to tackling this preventable condition.

SIGNIFICANCE STATEMENT

This study highlights the widespread prevalence of vitamin D deficiency among healthy adults worldwide, with significant regional disparities. Identifying populations at highest risk, such as those in the Middle East and Asia, underscores the need for targeted public health strategies, dietary interventions and supplementation policies to improve vitamin D status and support overall health.

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