



Decreasing prevalence of vitamin D deficiency in the central region of Saudi Arabia (2008-2017)

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ABSTRACT

Objective: Widespread vitamin D deficiency (serum 25-hydroxyvitamin D < 50 nmol/L) in Saudi Arabia (SA) has been documented, yet a time trend is needed to establish where the prevalence is headed. This study aims to fill this gap.

Study Design and Setting: This cross-sectional series (N = 7360) were conducted in the central region of SA from 2008 to 2017. Participants of all ages were taken from multiple cohorts that included the Biomarker Screening in Riyadh (2008–2010; N = 1460), the Osteoporosis Registry (2014–2017; N = 1225), Gestational Diabetes Mellitus cohort (2014–2017, N = 281), Vitamin D School Project (2011–2017; N = 3039) and Prediabetes cohort (2012–2017; N = 1355) master databases.

Results: Vitamin D deficiency in SA has a 10-year prevalence of 73.2%. Between 2008–2017, the prevalence of vitamin D deficiency decreased from 87.1% to 64.7% for participants aged 18–40 years (p-trend < 0.001), and from 86.2% to 45.7% in participants aged > 40 years (p-trend < 0.001). During this period, vitamin D deficiency in females decreased from 80.1% to 69.6% (p-trend < 0.001), whereas in males, it decreased from 93.2% to 49.3% (p-trend < 0.001). Serum 25(OH)D was observed to have an overall increase of 2.2 ± 0.1 nmol/l ($p < 0.001$) along with the seasonally adjusted annual increase of 1.3 ± 0.2 nmol/l from 2008 to 2017 ($p < 0.001$).

Conclusion: The decreasing trend in vitamin D deficiency in SA across all demographics suggests successful public health campaigns over time. It will be interesting to investigate further whether the general improvement in the vitamin D status at the community level also translated in lesser incidences of vitamin D-related diseases over time.

1. Introduction

Vitamin D is a seco-steroid hormone essential for skeletal health since it promotes intestinal calcium absorption and stimulates strengthening of the bones [1]. A severe and persistent vitamin D deficiency can cause bone softening and skeletal deformation, i.e., rickets in infancy and childhood and osteomalacia in adults [1]. Vitamin D deficiency can also contribute to the progression of osteoporosis in the

elderly. In recent years, associations between low levels of vitamin D and various chronic diseases, such as T2DM, obesity, cancer, and cardiovascular disease, have been reported in observational studies [2–6]. However, there is no evidence of a causal relation [7–10].

Vitamin D deficiency has long been recognized as a serious health issue in Saudi Arabia (SA), as reflected by the vast research interest in Saudi clinical and academic areas. Widespread prevalence of vitamin D deficiency in all groups, including elderly, women, men, pregnant

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women and their neonates, school children, and toddlers, have been documented in SA [11]. Al-Daghri et al. [11] conducted a meta-analysis of 13 studies published from 2011 to 2016 with an overall sample size of 24,399 participants including neonates, pregnant/lactating women, adults, children and adolescents. Meta-analysis of these studies revealed a pooled prevalence of vitamin D deficiency (< 50 nmol/l) as 81.0 % (95 % CI: 68.0 %–90.0 %) [11]. Another meta-analysis study with a pooled sample of 20,787 participants, based on 16 studies published between 2008 and 2015, estimated the prevalence of vitamin D deficiency (<50 nmol/l) in SA as 63.5 % [12]. Studies carried out before 2010 reported a wide range of prevalence from 28 % to 81 % in Saudi men, women and adolescents [13–15]. Attempts have also been made to increase awareness about vitamin D deficiency and its correctional strategies [16]. It is important to identify the on-going trends in the population's vitamin D status, which can provide crucial information for discussions on how the population has fought back in its battle against vitamin D deficiency.

Over the past decades, several studies from mostly Western nations have evaluated the trends of vitamin D status over time [17–23]. Unfortunately this vital information is missing in the Saudi population. This study is an assessment of vitamin D deficiency in the Saudi Arabian population spanning ten years conducted between 2008 and 2017. This study is the first to report vitamin D trends in the Middle East based on a nationwide representative sample collected from the central region of Saudi Arabia.

2. Materials and methods

2.1. Subjects

The series of cross-sectional studies were conducted between January 2008 and December 2017 in central region of Saudi Arabia. Participants for this study were selected from multiple cohorts. The 2008–2010 database was taken from the project involving province-wide biomarker screening in Riyadh (2008–2010; N = 1460), a project of King Saud University, Ministry of Health, and the Chair for Biomarkers of Chronic Diseases (CBCD) (previously the Biomarkers Research Program, BRP), where participants were randomly recruited from their homes [24,25]. Participants from 2011 to 2017 were also taken from multiple cohorts including the Osteoporosis Registry (2014–2017; N = 1225) [26], Gestational Diabetes Mellitus cohort (2014–2017, N = 281) [27], Vitamin D School Project (2011–2017; N = 3039) [28] and Prediabetes cohort (2012–2017; N = 1355) [29] master databases. Vitamin school study was a project of King Saud University, Ministry of Education and the CBCD, where they were recruited from different schools in Riyadh. Whereas, GDM, prediabetes and Osteoporosis registry were the project of the Chair for Biomarkers of Chronic Diseases (CBCD). The younger subjects (n = 3267) were from school surveys and biomarker screening in Riyadh region. The adults (n = 2480) subjects were from multiple cohorts including biomarker screening in Riyadh region, vitamin D school study, prediabetes project, gestational diabetes mellitus project and osteoporosis registry. The elderly (n = 1613) population were from biomarker screening in Riyadh region, osteoporosis registry and prediabetes project.

2.2. Anthropometrics

Anthropometrics included body weight, and height rounded off to the nearest 0.1 kg or 0.5 cm, while hip and waist circumferences were measured using standard tape. Average diastolic and systolic blood pressure values were 2 separate measurements (in mmHg).

2.3. Assessment of circulating 25(OH)D

Blood samples collected were centrifuged and processed on the same day in CBCD at King Saud University in Riyadh, SA. Total 25(OH) D

levels were calculated using COBAS e-411 with a limit of detection (LOD) and interassay coefficient of variation of 5 nmol/L and 8.0 % respectively. The assay was validated by using standardization [30,31]. Vitamin D status was categorized as 25(OH)D \geq 75 nmol/L as desirable, 50.0–74.9 nmol/L as sufficiency, 25–49.9 nmol/L as deficiency and < 25 nmol/L considered as severe deficiency [16].

2.4. Statistical analysis

Statistical Package for Social Sciences (SPSS) version 21.0 was used to conduct statistical analysis. Descriptive statistics, including mean \pm standard deviation (SD), were used to present continuous variables while frequencies and percentages were used to show categorical variables. Inferential statistics, including independent sample *t*-test and ANOVA, were used to check the mean differences. Furthermore, regression analysis was also used to quantify the relationship between time and serum 25(OH)D. A *p*-value <0.05 was considered statistically significant.

3. Results

3.1. Demographic characteristics

Table 1 shows the participants clinical and demographic characteristics. A total of 7360 subjects participated in this study. There were 2999 male and 4361 female participants. Mean age of the participants was 28.2 ± 15.3 years, with 25 % of them being under 14 years old or younger, while 25 % were older than 39 years. Male participants were significantly younger, with lower BMI but higher waist-hip ratio, than female participants (*p* < 0.001). Male participants also had significantly higher systolic blood pressure and serum 25(OH)D concentration while lower diastolic blood pressure as compared to female participants (*p* < 0.001).

3.2. The prevalence of vitamin D deficiency and severe deficiency in the overall population

The mean 25(OH) D concentrations, according to participant sex, are shown in Table 2. The overall mean 25(OH) D was significantly higher in males (41.6 ± 21.6) than females (39.5 ± 25.6 , *p* < 0.001). The lowest mean 25(OH) D concentration was observed in females under 18 years (30.3 ± 16.8), while the highest was observed in females aged over 40 years (53.8 ± 29.4). Both male and female participants aged over 40 years had a significantly higher mean 25(OH) D concentration than younger participants. Blood samples gathered in summer season showed significantly higher mean serum 25(OH)D concentrations in both males and females (47.0 ± 24.4 and 50.5 ± 28.9 , respectively) as compared to samples collected in the winter in both males and females (42.0 ± 20.3 and 38.4 ± 24.2 , respectively, *p* < 0.001).

The overall vitamin D deficiency in Saudi Arabia was 73.2 %. Fig. 1 shows vitamin D deficiency and severe deficiency, in both sexes according to age groups. Females aged under 18 years had a higher prevalence of both vitamin D deficiency and severe deficiency, with 89.7 % and 44.8 % of subjects, respectively. Females aged between 18–40 years were 72.8 % deficient and 37.8 % severely deficient. However, females above 40 years of age had a significantly lower prevalence of deficiency and severe deficiency, with 51.2 % and 19.1 %, respectively, than younger female participants. Males aged under 18 years and between 18 and 40 years also had higher prevalence of vitamin D deficiency, 76.8 % and 73.9 %, respectively, as compared to vitamin D deficiency, which was lower in older male participants affecting 61.3 %. Similarly, the severe deficiency was also found to be lower in male participants aged over 40 years affecting 15.6 %, as compared to 22.7 % and 20.8 % in subjects aged less than 18 years and 18–20 years, respectively.

Table 1
Demographic and clinical characteristics.

Parameters	Overall	Sex		Age		
		Males	Females	< 18 years	18–40 years	> 40 years
N	7360	2999	4361	3111	2480	1767
Age (Years)	28.2 ± 15.3	26.3 ± 14.7	29.5 ± 15.5*	14.2 ± 1.8	30.7 ± 6.5 ^A	50.4 ± 8.0 ^{AB}
Male	2999 (40.7)	2999 (40.7)	–	1404 (45.1)	1011 (40.8) ^A	582 (32.9) ^{AB}
Female	4361 (59.3)	–	4361 (59.3)	1707 (54.9)	1469 (59.2) ^A	1185 (67.1) ^{AB}
BMI (kg/m ²)	26.1 ± 6.6	25.2 ± 6.2	26.7 ± 6.8*	22.3 ± 5.3	28.4 ± 5.9 ^A	30.6 ± 5.5 ^{AB}
WHR	0.86 ± 0.10	0.89 ± 0.08	0.83 ± 0.09*	0.85 ± 0.08	0.85 ± 0.09	0.88 ± 0.09 ^{AB}
Systolic BP (mmHg)	118.1 ± 15.7	120.0 ± 14.6	116.8 ± 16.2*	115.3 ± 14.2	118.5 ± 14.1 ^A	123.0 ± 19.2 ^{AB}
Diastolic BP (mmHg)	73.9 ± 11.7	73.3 ± 10.9	74.3 ± 12.3*	70.7 ± 11.1	74.1 ± 10.2 ^A	80.2 ± 12.8 ^{AB}
25(OH) D (nmol/l)	40.3 ± 24.1	41.6 ± 21.6	39.5 ± 25.6*	34.3 ± 18.1	39.8 ± 24.7 ^A	51.8 ± 28.0 ^{AB}
Vitamin D Deficiency	5390 (73.2)	2183 (72.8)	3207 (73.5)	2609 (83.9)	1816 (73.2)	964 (54.6)
Severe Deficiency	2165 (29.4)	620 (20.7)	1545 (35.4)	1083 (34.8)	765 (30.8)	317 (17.9)

Note: Data presented as Mean ± SD; N(%) for categorical variables; vitamin D (nmol/l) < 50 nmol/l is considered as deficient.

* indicates significant differences from males; Superscript A and B indicates significant differences from < 18 years and 18–40 years respectively; P < 0.05 considered significant.

Table 2
Mean 25(OH) D concentrations in different age group and seasons according to sex.

	Males	P-values	Females	P-values
Age Group				
< 18 years	39.1 ± 18.4		30.3 ± 16.8	
18–40 years	41.6 ± 23.2	<0.001	38.6 ± 25.6	<0.001
>40 years	47.6 ± 24.5 ^{AB}		53.8 ± 29.4 ^{AB}	
Season				
Winter	42.0 ± 20.3	<0.001	38.4 ± 24.2	<0.001
Summer	47.0 ± 24.4		50.5 ± 28.9	

Note: Data presented as Mean ± SD, p < 0.05 considered significant. Superscript A and B indicates significant difference from <18 years and 18–40 years.

3.3. Vitamin D trends

Fig. 2 shows the prevalence of vitamin D deficiency and severe deficiency between 2008 and 2017 for all participants. It showed that the overall vitamin D deficiency and severe deficiency decreased from 86.6 % and 48.8 % in 2008, to 59.0 % and 16.7 %, respectively, in 2017.

The prevalence of vitamin D deficiency and severe deficiency across 2008 and 2017, according to sex and age groups are shown in Table 3. Table 4 shows the mean 25(OH) D concentrations between 2008 and 2017, according to sex and age groups. The average serum 25(OH)D in 2008 was 36.1 ± 19.9 and 24.6 ± 15.7 nmol/l in males and females

respectively. In 2017, the average serum 25(OH)D increased to 45.5 ± 25.3 and 55.2 ± 30.5 nmol/l in males and females, respectively. The prevalence of vitamin D deficiency and the severe deficiency also improved in 2017 in both male and female participants, as shown in Table 3. Regression analysis also showed a significantly higher trend with an increment of 1.3 ± 0.1 nmol/l in males and 3.0 ± 0.2 nmol/l in females every year. This increasing trend in vitamin D concentration remained significant in both genders after adjusting for the season of blood collection, age and BMI (Table 6).

The average serum 25(OH)D in 2008 for participants aged < 18 years was 30.2 ± 17.7 nmol/l that increased to 38.0 ± 18.1 in 2015 but decreased to 30.9 ± 22.0 in 2016. However, the average serum 25(OH) D in participants aged between 18–40 years increased from 27.9 ± 18.7 in 2008 to 46.5 ± 26.0 in 2017. Similarly, the average serum 25(OH)D in participants aged more than 40 years increased from 34.8 ± 21.7 in 2008 to 60.1 ± 31.8 in 2017. Regression analysis also showed a significantly higher trend with the highest increment observed in participants aged older than 40 years with 3.2 ± 0.3, followed by 1.8 ± 0.2 nmol/l in participants aged between 18–40 years, while the smallest increment of 0.9 ± 0.2 nmol/l was observed in participants aged below 18 years. This increasing trend in 25(OH)D concentration was still significant in all age groups after adjusting for the season of blood collection, age, bmi and gender (Table 6).

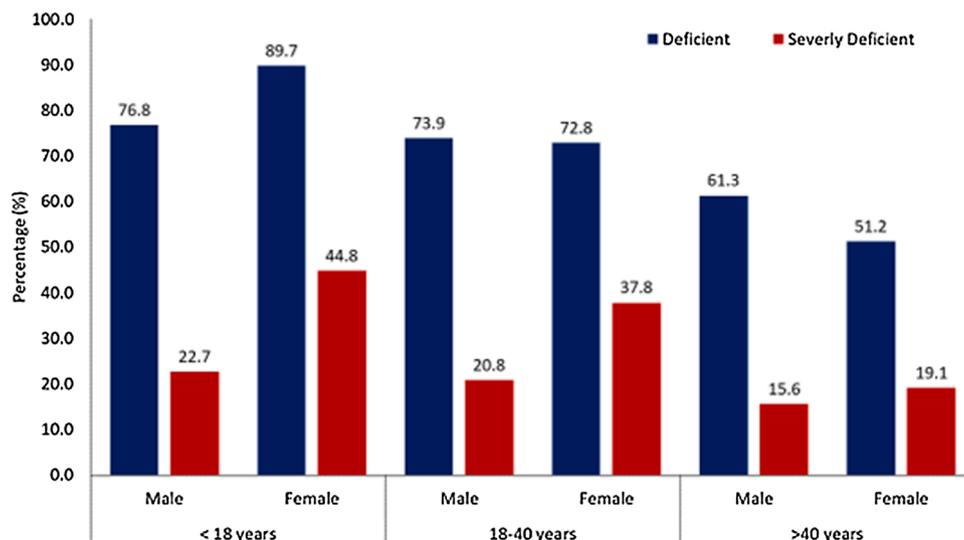


Fig. 1. Deficiency and Severe Deficiency in males and females according to Age.

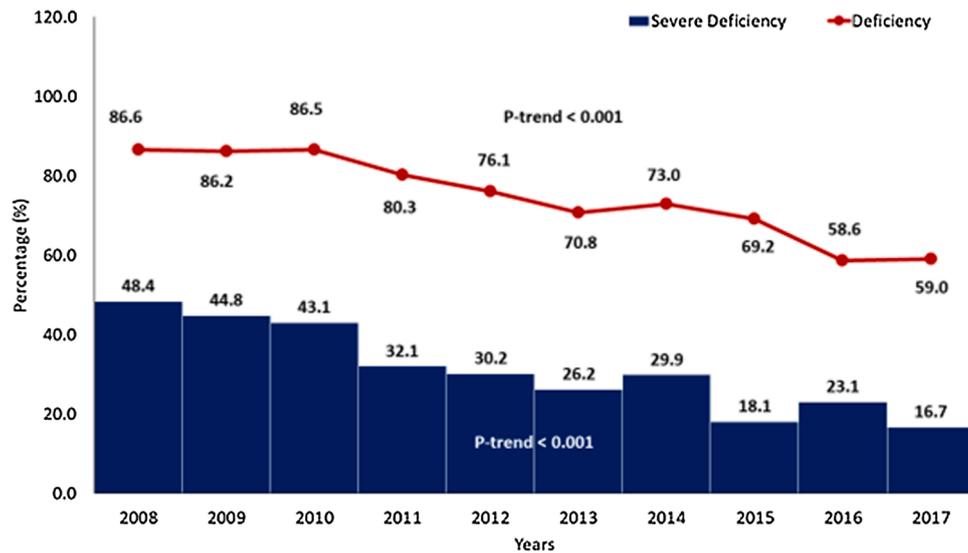


Fig. 2. Vitamin D Deficiency and Severe Deficiency (%) during 2008 – 2017 in Saudi Arabia.

Table 3

Vitamin D Deficiency (<50 nmol/l) and Severe Deficiency (<25 nmol/l) from 2008 – 2017 according to Sex and Age.

Year	Sex		Age		
	Females (N = 4361)	Males (N = 2999)	≤ 18 Years (N = 3111)	19–40 Years (N = 2480)	> 40 Years (N = 1767)
Vitamin D Deficiency (25(OH)D <50 nmol/l)					
2008	193 (80.1)	220 (93.2)	230 (86.5)	108 (87.1)	75 (86.2)
2009	188 (80.3)	168 (93.9)	205 (85.8)	99 (91.7)	52 (78.8)
2010	233 (81.2)	249 (92.2)	294 (86.5)	110 (90.2)	78 (82.1)
2011	172 (75.8)	385 (82.4)	341 (87.0)	151 (73.7)	65 (67.0)
2012	255 (66.4)	496 (82.3)	403 (84.0)	215 (77.1)	133 (58.3)
2013	397 (76.8)	280 (63.8)	300 (81.5)	231 (78.0)	146 (50.0)
2014	121 (80.7)	554 (71.5)	453 (84.0)	126 (69.6)	96 (46.8)
2015	262 (67.7)	387 (70.2)	377 (78.7)	152 (70.4)	120 (49.4)
2016	181 (58.0)	327 (58.9)	6 (75.0)	378 (66.4)	124 (42.8)
2017	181 (69.6)	141 (49.3)	–	246 (64.7)	75 (45.7)
P-value*	<0.001	<0.001	0.001	<0.001	<0.001
Severe Deficiency (25(OH)D <25 nmol/l)					
2008	150 (63.6)	81 (33.6)	127 (47.7)	71 (57.3)	33 (37.9)
2009	109 (60.9)	76 (32.5)	104 (43.5)	53 (49.1)	28 (42.4)
2010	154 (57.0)	86 (30.0)	149 (43.8)	55 (45.1)	36 (37.9)
2011	181 (38.8)	42 (18.5)	129 (32.9)	67 (32.7)	27 (27.8)
2012	248 (41.1)	50 (13.0)	164 (34.2)	91 (32.6)	43 (18.9)
2013	139 (31.7)	111 (21.5)	98 (26.6)	102 (34.5)	50 (17.1)
2014	230 (29.7)	47 (31.3)	199 (36.9)	51 (28.2)	27 (13.2)
2015	124 (22.5)	46 (11.9)	108 (22.5)	36 (16.7)	26 (10.7)
2016	165 (29.7)	35 (11.2)	5 (62.5)	162 (28.5)	33 (11.4)
2017	45 (15.7)	46 (17.7)	–	77 (20.3)	14 (8.5)
P-value*	<0.001	<0.001	<0.001	<0.001	<0.001

Note: Data presented as frequencies (%).

* indicate P-value for trend.

4. Discussion

This study showed that despite some improvement, low levels of 25 (OH)D remain a serious public health issue in SA. We observed that young adolescents less than 18 years suffer had the highest prevalence of vitamin D deficiency as compared to elderly who had the lowest, which is consistent with other studies [32–35]. Similar results have also been reported in other countries including United Kingdom, China, South Korea and Thailand [32–35]. Since ageing is associated with decreased vitamin D production in the skin, adequate sun exposure becomes extremely important for achieving optimal vitamin D status. Vitamin D deficiency in the young Saudi population may affect the overall bone health negatively due to the importance of this period in achieving peak bone mass [33].

Al-Mogbel [36] noted that females are prone to vitamin D deficiency because of the absence of outdoor activities, however both male and female participants in this study had similar vitamin D deficiency affecting 72.8 % and 73.5 % of the subjects, respectively. Despite abundance of sun light throughout the year, direct exposure is limited in SA population due to high daytime temperatures which hinder people from practicing various activities outdoors [36]. Furthermore, the use of types of clothing that prevent the exposure of the skin to sunlight and the dark skin color in most Arab communities, increases the amount of time needed to produce enough active vitamin D. In addition, the lack of public awareness of the importance of sunlight and healthy food culture in these communities, have also added to the low levels of serum 25(OH) D in SA (Table 5).

The most notable observation in this study is the increasing levels of

Table 4
25(OH)D (nmol/L) concentration from 2008–2017 according to Sex and Age.

Year	Overall	Sex		Age		
		Females	Males	≤ 18 Years	19–40 Years	> 40 Years
2008	30.4 ± 18.8	24.6 ± 15.7	36.1 ± 19.9	30.2 ± 17.7	27.9 ± 18.7	34.8 ± 21.7
2009	31.7 ± 19.7	25.7 ± 15.4	36.2 ± 21.4	31.4 ± 18.0	29.9 ± 21.3	35.5 ± 22.8
2010	31.6 ± 18.4	25.9 ± 14.4	36.9 ± 20.1	32.1 ± 18.9	28.9 ± 17.9	33.0 ± 16.8
2011	37.1 ± 22.2	35.8 ± 24.1	39.9 ± 17.5	33.7 ± 16.7	41.1 ± 28.3	42.4 ± 24.7
2012	38.3 ± 21.7	34.5 ± 21.7	44.3 ± 20.5	34.2 ± 16.6	38.4 ± 24.8	46.8 ± 24.6
2013	42.2 ± 24.6	44.8 ± 28.6	40.0 ± 20.4	37.3 ± 18.3	36.4 ± 22.4	54.2 ± 29.2
2014	41.1 ± 24.8	41.9 ± 25.6	36.7 ± 19.5	34.1 ± 19.1	42.6 ± 25.6	58.2 ± 28.6
2015	43.9 ± 22.3	43.5 ± 24.3	44.3 ± 19.2	38.0 ± 18.1	42.8 ± 21.0	56.3 ± 25.8
2016	47.5 ± 27.0	45.7 ± 27.4	50.6 ± 26.0	30.9 ± 22.0	42.2 ± 25.0	58.2 ± 27.7
2017	50.6 ± 28.5	55.2 ± 30.5	45.5 ± 25.3	–	46.5 ± 26.0	60.1 ± 31.8
Slope	2.2 ± 0.1	3.0 ± 0.2	1.3 ± 0.1	0.9 ± 0.2	1.8 ± 0.2	3.2 ± 0.3
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Slope	1.3 ± 0.2	1.6 ± 0.3	0.8 ± 0.3	0.8 ± 0.3	1.1 ± 0.3	2.5 ± 0.4
P-value	<0.001	<0.001	0.006	0.004	0.001	<0.001

Note: Data presented as mean ± SD; Slope and p-values are calculated using linear regression analysis. Slope is adjusted for season.

serum 25(OH)D concentration between 2008 and 2017 across all groups, except younger participants aged below 18 years. Contrary to our findings, a declining trend in 25(OH)D level was noted by Park et al. in the South Korean population, where the vitamin D deficiency prevalence in 2014 rose to 75.2 % and 82.5 % from 51.8 % and 68.2 in 2008, respectively, in both male and female participants [33]. Park et al. [33] also acknowledged that, contrary to their observations in the South Korean population, recent findings from western countries have shown a normalizing trend in vitamin D status [18,20,23]. Schleicher et al. [23] reported modest increases of 5–6 nmol/L in serum 25(OH)D between 2007 and 2010. In our study, the overall increase in mean serum 25(OH)D levels was 20.2 nmol/L from 2008 to 2017. A Finnish study conducted between 2000 and 2011 also reported a rise of 18 nmol/L in adults, with mean serum 25 (OH)D level increasing from 48 to 65 nmol/L [20]. However, the increase in serum 25(OH)D in our study was more prominent in female participants with an increase of 30.6 nmol/L compared to 9.4 nmol/L in males. A population-based study from Canada also reported a similar trend, between 1995–2007, with an increase of serum 25 (OH)D levels of 9.3 nmol/L in females and 3.5 nmol/L in males [18]. Vitamin D deficiency also declined by 9.9 % from the initial prevalence of 29.7 % during the same period [18]. Our results also saw a decline of 25 (OH)D levels <50 nmol/L from 86.6% to 59.0%.

Researchers attributed this recent surge in 25(OH)D concentration, evident in western nations, to raised health awareness and increased vitamin D supplementation [17,19,23]. In SA, several studies have been done to assess the level of awareness and knowledge regarding vitamin D deficiency. In a recent survey, Aljefree et al. [37] observed that participants were aware of the effects of vitamin D deficiency on bone health and how to overcome it through different sources including exposure to sunlight and by including vitamin D supplementation in their diet. Al-Johani et al. [38] also reported a recent increase in the use of vitamin D and other mineral supplements among Saudi medical

Table 5
Age and Sex distribution according to Year.

Year	Age	Male	Female
2008	26.0 ± 16.1	243 (50.6)	237 (49.4)
2009	25.3 ± 15.7	237 (57.0)	179 (43.0)
2010	24.8 ± 15.8	293 (52.0)	271 (48.0)
2011	23.5 ± 12.4	235 (33.2)	473 (66.8)
2012	26.7 ± 15.7	394 (37.6)	654 (62.4)
2013	28.7 ± 15.0	572 (56.1)	447 (43.9)
2014	25.3 ± 14.6	737 (42.7)	990 (57.3)
2015	27.6 ± 16.2	389 (41.3)	552 (58.7)
2016	36.9 ± 12.1	312 (36.0)	555 (64.0)
2017	35.5 ± 11.3	260 (47.6)	286 (52.4)

Note: Data presented as Mean ± SD for age while N(%) for sex.

students. This increased awareness about 25(OH) deficiency, vitamin D supplement intake and the use of food products, such as Vitamin D fortified milk reflects the improvement in 25(OH)D levels during 2008–2017 in the Saudi population. Schleicher et al. [23] also linked the improvement in serum 25 (OH)D concentration between 2007 and 2010 with the increasing use of large doses of vitamin D supplements.

Furthermore, Al-Daghri et al. [39] also observed that Saudi adolescents and adults supplemented with vitamin D tablets and fortified milk experienced significant increases in 25(OH)D level. They reported that oral vitamin D supplementation was the most effective strategy, followed by the use of vitamin D fortified milk. Another study was done by Al-Daghri et al. [40] in a similar cohort, comprising only adolescents, reaffirmed the importance of oral vitamin D supplementation in improving serum 25(OH)D concentrations. However, milk fortified with vitamin D showed mixed results with one of the four milk brands found to be as effective as an oral vitamin D tablet. In contrast, other brands were either associated with modest increases or even decreases 25(OH) D level. Authors of the study attributed the absence of improvement in vitamin D with (a) insufficient quantity of vitamin D added to milk (0.5 µg/100 mL), and (b) girls consumed inadequate amounts of milk. Al-Raddadi et al. [41] also reported low intake of vitamin D fortified dairy products and supplements among female adolescents. The lack of improvement of vitamin D in Saudi adolescents in the present study as compared to adults might be due to lack of use of vitamin D supplements or their preference of milk products with insufficient amount of vitamin D. Since the high prevalence of vitamin D deficiency in adolescent predicts an increased prevalence of bone diseases including osteoporosis and fracture [41]. Therefore, along with the promotion of healthy lifestyle changes, there is a need of systematic fortification of food with vitamin D, particularly milk provided to children and adolescents to overcome vitamin D deficiency.

The study acknowledges some limitations. The cross-sectional nature of the study prevents causal analysis. Expatriates, who form a bulk of the population living in SA, were excluded, and the overall picture of vitamin D deficiency over time in the country is limited to citizens. Lastly, important covariates such as sun exposure, dietary vitamin D intake and supplementations were missing and this was due to the nature of objectives of the databases where the population was taken. This may potentially explain some inconsistencies in the trend. The study nevertheless is one of the largest of its kind to track trends of vitamin D deficiency in the Kingdom.

5. Conclusions

In conclusion, vitamin D deficiency is still prevalent in Saudi Arabia. However, there is an increasing trend in serum 25(OH)D concentrations from 2008 to 2017 in both men and women, particularly those above 18

Table 6

Age, BMI and gender adjusted 25(OH)D (nmol/l) concentration from 2008-2017 according gender and age groups.

Year	Overall	Sex*		Age		
		Females	Males	≤ 18 Years	19–40 Years	> 40 Years
2008	30.7 ± 1.0	25.4 ± 1.5	35.9 ± 1.3	30.2 ± 1.1	29.0 ± 2.1	31.7 ± 2.8
2009	31.4 ± 1.1	27.5 ± 1.7	35.7 ± 1.3	30.6 ± 1.2	29.9 ± 2.3	30.5 ± 3.3
2010	32.0 ± 1.0	26.8 ± 1.4	36.9 ± 1.2	31.7 ± 1.0	28.5 ± 2.1	30.6 ± 2.7
2011	39.4 ± 0.9	37.3 ± 1.0	40.6 ± 1.3	34.2 ± 0.9	40.1 ± 1.9	46.2 ± 3.3
2012	39.4 ± 0.7	35.1 ± 0.9	44.2 ± 1.0	36.3 ± 0.8	38.4 ± 1.6	45.9 ± 1.9
2013	41.6 ± 0.7	40.8 ± 1.1	40.3 ± 0.9	35.2 ± 1.2	36.6 ± 1.4	54.7 ± 1.7
2014	39.4 ± 1.0	43.8 ± 0.8	42.9 ± 0.8	35.6 ± 1.1	37.6 ± 2.3	50.6 ± 2.8
2015	43.0 ± 0.8	41.8 ± 1.1	44.0 ± 1.0	38.0 ± 0.8	43.2 ± 1.6	51.9 ± 2.4
2016	44.7 ± 0.8	40.4 ± 1.0	50.0 ± 1.2	24.4 ± 7.7	43.4 ± 1.0	57.9 ± 1.7
2017	48.2 ± 1.0	51.6 ± 1.4	44.9 ± 1.3	–	48.8 ± 1.3	57.3 ± 2.2
Slope	1.8 ± 0.1	2.3 ± 0.2	1.3 ± 0.2	1.1 ± 0.1	1.9 ± 0.2	3.2 ± 0.3
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Season Adjusted Slope	1.2 ± 0.2	1.6 ± 0.3	0.9 ± 0.3	1.0 ± 0.3	1.3 ± 0.3	2.3 ± 0.5
P-value	<0.001	<0.001	0.005	<0.001	<0.001	<0.001

Note: Data presented as mean ± SD; Slope and p-values are calculated using linear regression analysis;

* indicates adjustment for age, and BMI only.

years. This improvement can be attributed to raised health awareness and increased vitamin D supplementation among adults. Lack of increase in adolescent may be the result of lack of sun exposure, vitamin D supplements and vitamin D fortified products. There is a need to encourage and promote positive behavior change among everyone, particularly adolescents.

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Author contributions

NMA, NA, YA, MA, SS and MSA designed the study. MGAA and MNKK performed sample and data analysis. SDH wrote the manuscript. All authors reviewed the manuscript.

Declaration of Competing Interest

All authors declare no competing interest.

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