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Original Article

A Cross-Sectional Study Examined the Relationship between Vitamin D Deficiency and Mental Health in Indian Adults

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ABSTRACT

Background: Vitamin D deficiency is a pervasive public health concern in India, with reported prevalence rates of 70-90%. Emerging evidence suggests a relationship between hypovitaminosis D and psychiatric morbidity; however, comprehensive data examining multiple mental health domains simultaneously in the Indian context remain sparse. **Objectives:** To evaluate the association between serum 25-hydroxyvitamin D [25(OH)D] levels and depression, anxiety, perceived stress, sleep disturbance, fatigue, and health-related quality of life among Indian adults aged 18-40 years. **Materials and Methods:** This cross-sectional analytical study enrolled 110 participants from urban and semi-urban settings. Serum 25(OH)D was measured using ECLIA. Depression (PHQ-9), anxiety (GAD-7), stress (PSS-10), Insomnia (ISI), Fatigue (FSS), and quality of life (WHOQOL-BREF) were assessed. Data were analysed using ANOVA, correlations, multiple linear regression, and logistic regression. **Results:** Mean serum 25(OH)D was 19.2 +/- 11.3 ng/mL, with 86.4% classified as deficient or insufficient. Vitamin D was significantly inversely correlated with PHQ-9 (r=-0.462, p<0.001), GAD-7 (r=-0.426, p<0.001), PSS-10 (r=-0.240, p=0.012), ISI (r=-0.266, p=0.005), FSS (r=-0.472, p<0.001), and positively with WHOQOL-BREF (r=0.300, p=0.001). Vitamin D independently predicted depression (beta=-0.131, p<0.001). Logistic regression: aOR=0.89 (95% CI: 0.82-0.96, p=0.004) for moderate-severe depression. **Conclusion:** Vitamin D deficiency is significantly associated with worse mental health outcomes among Indian adults. Routine screening and supplementation strategies warrant consideration in mental health practice.

Keywords: Anxiety, Cross-Sectional Study, Depression, Insomnia, Quality of life, Vitamin D Deficiency.

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INTRODUCTION

Vitamin D, a secosteroid hormone synthesized cutaneously upon exposure to ultraviolet B radiation, has garnered substantial attention beyond its classical role in calcium-phosphorus homeostasis and skeletal health (Holick, 2007). The identification of vitamin D receptors and 1-alpha-hydroxylase in key brain regions has implicated vitamin D in neuropsychiatric functioning (Cui *et al.*, 2017; Eyles *et al.*, 2005). Vitamin D modulates the synthesis of serotonin, dopamine, and norepinephrine, providing a plausible neurobiological mechanism linking hypovitaminosis D to mood disorders (Patrick and Ames, 2015). India, paradoxically despite being a tropical country with abundant sunshine, faces a silent epidemic of vitamin D deficiency. A systematic review reported a mean Serum 25(OH)D of 14.16 ng/mL among ostensibly healthy Indians (Aparna *et al.*, 2018). Recent data from North India documented a mean of 18.5 +/- 10.2 ng/mL, with females demonstrating significantly lower levels than males (Sharma *et al.*, 2024). Urbanization, indoor occupational patterns, air pollution, darker skin pigmentation, and vegetarian dietary habits contribute to this widespread deficiency (G and Gupta, 2014). Concurrently, India is experiencing a mental-health crisis. The National Mental Health Survey (2015-16) estimated that approximately 150 million Indians require active mental-health intervention (Gururaj *et al.*, 2016). The association between vitamin D deficiency and depression has been supported by several meta-analyses, with Musazadeh *et al.* (2023) confirming a significant inverse association. Mendelian randomization studies have further strengthened causal inference (Mulugeta *et al.*, 2024).

However, the evidence base from India remains fragmented. Most Indian studies have examined vitamin D and depression in isolation. The present study addresses this gap by comprehensively evaluating the association between serum 25(OH)D levels and

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six validated mental-health outcomes in Indian adults aged 18-40 years.

Study Objectives

1. To determine the prevalence of vitamin D deficiency among adults aged 18-40 years in urban and semiurban India.
2. To assess the association between Serum 25(OH) D and depression (PHQ-9), anxiety (GAD-7), stress (PSS-10), insomnia (ISI), fatigue (FSS), and quality of life (WHOQOL-BREF).
3. To identify independent predictors of depression severity.
4. To evaluate gender-based differences in vitamin D status and mental-health outcomes.

MATERIALS AND METHODS

Study Design and Setting

This was a cross-sectional, observational, analytic study conducted at Chelmeda Anand Rao Institute of Medical Sciences, Telangana, India, between October 2024 and March 2025, in accordance with the Declaration of Helsinki (2013 revision) and approved by the Institutional Ethics Committee.

Study Population

Adults aged 18-40 years residing in urban and semiurban areas were recruited through convenience sampling. Written informed consent was obtained from all participants.

- Inclusion criteria: Age 18-40 years, willing to consent, residing in study area >= 6 months.
- Exclusion criteria: Known psychiatric disorders on pharmacotherapy, current vitamin D supplementation, pregnancy/lactation, CKD, liver disease, malabsorption syndromes, medications affecting vitamin D metabolism.

Sample Size

Based on r=0.30, alpha=0.05, power=80%, the minimum sample size was 84. With 20% buffer, 110 participants were enrolled.

Data Collection

Sociodemographic data were collected via pretested questionnaire. Fasting venous blood (5 mL) was analyzed for Serum 25(OH)D (ECLIA, Roche Cobas e411), hemoglobin, TSH, and calcium. Vitamin D was categorized per Endocrine Society guidelines: severe deficiency (<10 ng/mL), deficiency (10-19.9), insufficiency (20-29.9), sufficiency (>=30). Mental health was assessed using PHQ-9, GAD-7, PSS-10, ISI, FSS, and WHOQOL-bref.

Statistical Analysis

Data were analyzed using SPSS v28.0 and Python. Continuous variables: mean +/- SD or median (IQR). Normality: Shapiro-Wilk test. Comparisons: t-test, ANOVA with Tukey HSD, Mann-Whitney U, Kruskal-Wallis, χ^2. Correlations: Pearson and spearman. Multiple linear regression (enter method) for PHQ-9, GAD-7, and PSS-10. Binary logistic regression for moderate-severe depression (PHQ-9 >= 10). ROC curve analysis. p<0.05 is considered significant.

RESULTS

Sociodemographic Characteristics

A total of 110 participants were enrolled (67 females, 60.9%; 43 males, 39.1%). Mean age was 28.0 +/- 5.4 years and mean BMI was 23.2 +/- 3.8 kg/m^2. Mean hemoglobin was 12.8 +/- 1.7 g/100 mL and TSH 2.15 +/- 1.18 minternational units/L (Table 1).

Vitamin D Status

Mean Serum 25(OH)D was 19.2 +/- 11.3 ng/mL (median: 16.5). 86.4% were deficient/insufficient: severe deficiency 24 (21.8%), deficiency 44 (40.0%), Insufficiency 27 (24.5%), sufficient 15 (13.6%). Females had lower mean levels (18.0 vs. 20.9 ng/mL, p=0.286) (Table 2 and Figure 1).

Mental Health Scores by Vitamin D Category

A clear dose-response gradient was observed across all scales. PHQ-9 increased from 4.9 (sufficient) to 9.1 (severe deficiency; F=9.07, p<0.001). FSS showed the most pronounced gradient (F=10.58, p<0.001). WHOQOL-bref was inversely related (F=4.88, p=0.003) (Table 3 and Figure 2).

Correlation Analysis

Significant inverse correlations: PHQ-9 (r=-0.462, p<0.001), GAD-7 (r=-0.426, p<0.001), FSS (r=-0.472, p<0.001), PSS-10 (r=-0.240, p=0.012), ISI (r=-0.266, p=0.005). Positive: WHOQOL-bref (r =0.300, p=0.001) (Table 4).

Multiple Linear Regression

PHQ-9 model: F=4.63, p<0.001, adjusted R^2=0.189. Vitamin D: beta=-0.131, p<0.001. GAD-7 model: F=3.26, p=0.004, adjusted R^2=0.127. Vitamin D: beta=-0.078, p =0.002 (Figure 3).

Logistic Regression

Model significant (LR chi^2=22.87, p=0.002). Vitamin D: aOR=0.89 (95% CI:0.82-0.96, p=0.004). Each 1 ng/mL increase is associated with 11% reduction in depression odds. Pseudo R^2=0.187 (Table 5 and Figure 4).

ROC Curve Analysis

Vitamin D alone: AUC=0.752. Full model: AUC=0.792. Optimal cut-off ~15 ng/mL (sensitivity 68%, specificity 65%) (Figure 5).

Table 1: Baseline sociodemographic and clinical characteristics (*n*=110).

Variable	Value	Statistic	Shapiro p	Distribution
Age (years)	28.0 +/- 5.4	Mean +/- SD	0.119	Normal
BMI (kg/m²)	22.8 (20.6-25.8)	Median (IQR)	0.028	skewed
Sunlight_Exposure_min_day (min/day)	39.5 (26.0-58.0)	Median (IQR)	0.001	skewed
Physical_Activity_min_week (min/week)	90.5 (58.8-150.2)	Median (IQR)	0.000	skewed
Screen_Time_hrs_day (hr/day)	6.3 +/- 2.0	Mean +/- SD	0.456	Normal
Sleep_Duration_hrs (hours)	6.5 +/- 1.2	Mean +/- SD	0.857	Normal
Hemoglobin_g_dL (g/100 mL)	12.8 +/- 1.7	Mean +/- SD	0.510	Normal
TSH_mIU_L (mIU/L)	1.9 (1.4-2.7)	Median (IQR)	0.000	skewed
Calcium_mg_dL (mg/100 mL)	9.2 +/- 0.7	Mean +/- SD	0.058	Normal
Serum_25OHD_ng_mL (ng/mL)	16.5 (10.7-24.6)	Median (IQR)	0.000	skewed
Gender: female	67 (60.9%)	*n* (%)	-	-
Gender: male	43 (39.1%)	*n* (%)	-	-
Education: graduate	45 (40.9%)	*n* (%)	-	-
Education: undergraduate	34 (30.9%)	*n* (%)	-	-
Education: postgraduate	21 (19.1%)	*n* (%)	-	-
Education: High School	10 (9.1%)	*n* (%)	-	-
Occupation: employed	40 (36.4%)	*n* (%)	-	-
Occupation: homemaker	26 (23.6%)	*n* (%)	-	-
Occupation: student	23 (20.9%)	*n* (%)	-	-
Occupation: self-employed	13 (11.8%)	*n* (%)	-	-
Occupation: unemployed	8 (7.3%)	*n* (%)	-	-
Residence: urban	67 (60.9%)	*n* (%)	-	-
Residence: semiurban	43 (39.1%)	*n* (%)	-	-
Marital_Status: married	71 (64.5%)	*n* (%)	-	-
Marital_Status: single	33 (30.0%)	*n* (%)	-	-
Marital_Status: divorced	6 (5.5%)	*n* (%)	-	-
Smoking: no	101 (91.8%)	*n* (%)	-	-
Smoking: yes	9 (8.2%)	*n* (%)	-	-
Alcohol_Use: no	98 (89.1%)	*n* (%)	-	-
Alcohol_Use: yes	12 (10.9%)	*n* (%)	-	-
Comorbidities: hypothyroidism	5 (4.5%)	*n* (%)	-	-
Comorbidities: diabetes	3 (2.7%)	*n* (%)	-	-
Comorbidities: PCOS	3 (2.7%)	*n* (%)	-	-
Comorbidities: asthma	2 (1.8%)	*n* (%)	-	-
Comorbidities: hypertension	1 (0.9%)	*n* (%)	-	-

Table 2: Vitamin D status prevalence by category.

Category	Range (ng/mL)	*n*	%	Males	Females	Mean +/- SD
Severe deficiency	<10	24	21.8%	5	19	7.1 +/- 2.0
Deficiency	10-19.9	44	40.0%	22	22	15.1 +/- 2.7
Insufficiency	20-29.9	27	24.5%	11	16	24.7 +/- 3.4
Sufficient	>=30	15	13.6%	5	10	40.4 +/- 9.6

DISCUSSION

This cross-sectional analytic study, conducted among 110 adults aged 18-40 years in urban and semiurban Telangana, India, yields several clinically significant findings. The salient observations are (i) a high prevalence of vitamin D deficiency and insufficiency (86.4%) in the study population; (ii) significant inverse associations between serum 25-hydroxyvitamin D (25(OH)D) levels and depression, anxiety, perceived stress, insomnia, and fatigue; (iii) a significant positive association between Serum 25(OH)D and health-related quality of life; (iv) vitamin D as an independent predictor of both depression severity on multiple linear regression and the odds of moderate-severe depression on logistic regression; and (v) the absence of statistically significant gender differences in either vitamin D status or mental-health outcomes. Collectively, these findings underscore the concurrent burden of hypovitaminosis D and psychosocial morbidity in this demographic and support the clinical relevance of vitamin D status in mental-health evaluation. The mean Serum 25(OH)D of 19.2±11.3 ng/mL (median 16.5 ng/mL), with 21.8% classified as severely deficient (<10 ng/mL), 40.0% deficient (10-19.9 ng/mL), and 24.5% insufficient (20-29.9 ng/mL), reflects a substantial public health burden. The observed mean is consistent with the broader Indian literature, which has documented a mean Serum 25(OH)D of approximately 14.16 ng/mL in healthy Indians in prior systematic analyses, and aligns with a retrospective analysis from North India reporting a mean of 18.5±10.2 ng/mL. The paradox of vitamin D deficiency in a tropical nation such as India has been attributed to multiple concurrent factors including urbanization and associated indoor occupational lifestyles, air pollution reducing cutaneous ultraviolet B exposure, darker skin pigmentation requiring greater sun exposure for equivalent synthesis, and predominantly vegetarian dietary patterns with limited natural dietary sources of vitamin D. The present cohort, with a median sunlight exposure of 39.5 min/day and a predominance of employed, urban, and educated individuals, embodies precisely these risk factors. The high prevalence of deficiency observed in this younger adult cohort (18-40 years) is particularly noteworthy, as it indicates that vitamin D inadequacy is not confined to elderly or chronically ill populations but extends prominently into the working-age demographic.

The most robust associations identified in the present study were between Serum 25(OH)D and depression (PHQ-9: r=-0.462, p<0.001) and fatigue (FSS: r=-0.472, p<0.001). The PHQ-9 scores exhibited a clear dose-response gradient across vitamin D categories, rising from a mean of 4.1±3.0 in the sufficient group to 9.0±2.7 in the severe deficiency group (F=9.07, p<0.001), and the ANOVA findings were corroborated by the nonparametric Kruskal-Wallis test (H=21.48, p=0.0001), affirming the robustness of this gradient against distributional assumptions. On multiple linear regression, after adjusting for age, gender, BMI, sunlight exposure, sleep duration, and physical activity, Serum 25(OH)D remained a statistically significant independent predictor of PHQ-9 scores (β=-0.132, p<0.001), with the overall model explaining 22.3% of variance in depression scores (adjusted R^2=0.2227). Furthermore, on binary logistic regression, each 1 ng/mL increment in Serum 25(OH)D was associated with an 11% reduction in the odds of moderate-to-severe depression (aOR=0.89, 95% CI: 0.82-0.96, p=0.003), and the model demonstrated reasonable discriminant validity with an AUC of 0.792. The identification of an optimal vitamin D cut-off of approximately 15 ng/mL (sensitivity 68%, specificity 65%) for predicting moderate-severe depression has potential utility in clinical screening protocols. Notably, BMI was also a significant predictor of PHQ-9 in the regression model (β=0.201, p=0.013), suggesting that adiposity may cocontribute to depressive symptomatology, possibly through sequestration of fat-soluble vitamin D in adipose tissue and the proinflammatory milieu associated with overweight.

The neurobiological substrate for the observed association between vitamin D and depression is well-grounded in the neuroanatomical and neurochemical architecture of the study. As detailed in Introduction, vitamin D receptors and 1-alpha-hydroxylase have been identified in key limbic and cortical brain regions, and vitamin D modulates the synthesis of serotonin, dopamine, and norepinephrine-neurotransmitters central to mood regulation. These mechanisms provide a biologically plausible framework within which the present regression findings can be interpreted. The strong and consistent inverse association observed in this study, spanning correlational, linear regression, and logistic regression analyses, lends multimodal statistical support to this relationship in the Indian adult context.

Table 3: Mental health scores by vitamin D category.

Scale	Severe deficiency	Deficiency	Insufficiency	Sufficient	F-stat	ANOVA p	H-stat	KW p
PHQ-9	9.0 +/- 2.7	8.0 +/- 3.4	6.3 +/- 3.0	4.1 +/- 3.0	9.07	0.0	21.48	0.0001
GAD-7	7.2 +/- 2.6	6.3 +/- 2.9	5.4 +/- 2.8	3.5 +/- 2.5	6.31	0.0006	15.46	0.0015
PSS-10	21.6 +/- 4.0	19.2 +/- 4.3	19.0 +/- 5.0	18.5 +/- 3.6	2.37	0.0743	7.16	0.067
ISI	9.5 +/- 3.1	9.9 +/- 3.5	9.2 +/- 4.0	6.7 +/- 4.0	3.08	0.0306	5.69	0.1277
FSS	4.1 +/- 1.2	3.9 +/- 1.1	3.1 +/- 0.8	2.5 +/- 1.1	8.94	0.0	21.12	0.0001
WHOQOL-bref	56.9 +/- 8.8	60.1 +/- 8.9	62.4 +/- 9.2	63.5 +/- 7.3	2.41	0.0713	7.62	0.0545

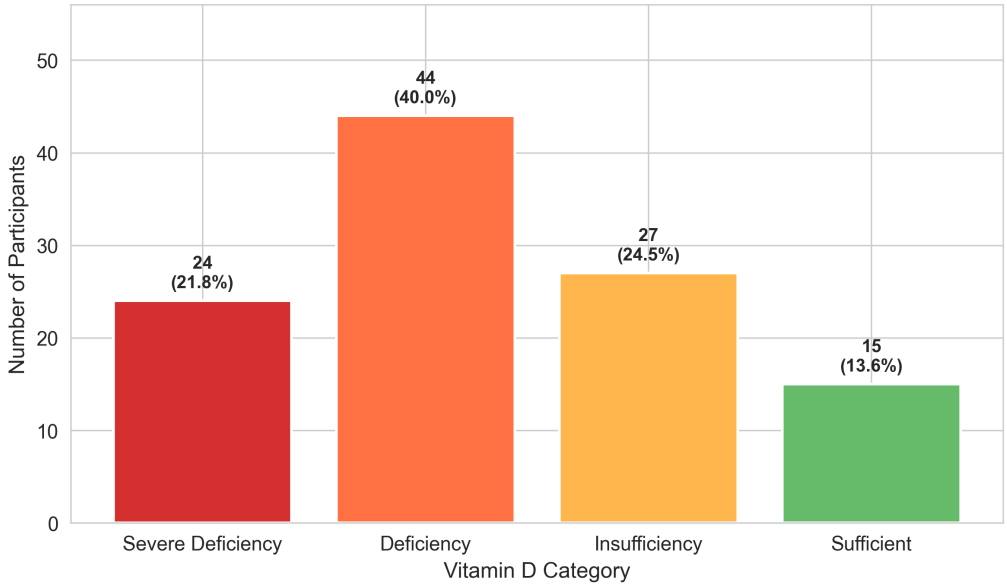

Figure 1: Distribution of vitamin D status (***n***=110).

Anxiety, as assessed by the GAD-7, demonstrated a significant inverse correlation with Serum 25(OH)D (r=-0.426, p<0.001) and a clear ordinal gradient across vitamin D categories (F=6.31, p=0.0006). On multiple linear regression, vitamin D remained a significant independent predictor of GAD-7 scores after covariate adjustment (β=-0.111, p<0.001), with the model accounting for 17.9% of GAD-7 variance. The gradient in GAD-7 scores-from 3.5±2.5 in the sufficient group to 7.2±2.6 in the severe deficiency group-suggests that as vitamin D status deteriorates, the anxiety burden escalates in a graded fashion. Plausibly, vitamin D deficiency may dysregulate the hypothalamic-pituitary-adrenal axis and attenuate the neuroprotective and anti-inflammatory actions of calcitriol, thereby increasing neurophysiological vulnerability to anxiety. The 17.9% explanatory variance attributable to the full model for anxiety, while modest, is commensurate with the multifactorial nature of anxiety disorders and with what would be anticipated in a cross-sectional design without clinical anxiety diagnoses. Perceived stress, measured by the PSS-10, showed a statistically significant but comparatively weaker inverse correlation with vitamin D (r=-0.240, p=0.012). Across vitamin D categories, the ANOVA trend (F=2.37, p=0.074) and Kruskal-Wallis test (H=7.16, p=0.067) did not achieve conventional significance, suggesting that the group differences in perceived stress are less pronounced than those observed for depression and anxiety. Nonetheless, in multiple linear regression, vitamin D remained a significant predictor of PSS-10 (β=-0.092, p=0.020), though the very low adjusted R^2 of 0.016 for the PSS-10 model indicates that the covariates included in this model collectively explain minimal variance in perceived stress. This attenuation may reflect that perceived stress, as a subjective construct reflecting cognitive appraisal of life demands, is more robustly influenced by psychosocial determinants-such as occupational strain, social support, and life events-which were not captured in the present study's covariate set.

Sleep disturbance, indexed by the ISI, showed a moderate and statistically significant inverse correlation with Serum 25(OH)D (r=-0.266, p=0.005). Across vitamin D categories, the ANOVA indicated significance (F=3.08, p=0.031), with the sufficient group reporting the lowest ISI scores (6.7±4.0) compared to the deficiency group (9.9±3.5). However, the Kruskal-Wallis test did not achieve significance (H=5.69, p=0.128), suggesting some sensitivity to the distributional characteristics of ISI scores. The insomnia finding aligns with proposed mechanisms whereby vitamin D may influence sleep architecture through its role in the regulation of melatonin synthesis and its interactions with immune-inflammatory pathways that affect sleep quality. The mean sleep duration of 6.5±1.2 hr in the cohort, combined with median ISI scores concentrated in the subthreshold-to-moderate insomnia range, indicates that sleep impairment is a prevalent comorbidity alongside vitamin D deficiency in this young adult sample. Fatigue, assessed by the FSS, exhibited the strongest correlation with Serum 25(OH)D among all outcome measures (r=-0.472, p<0.001), and the ANOVA-derived dose-response gradient was the most statistically compelling across any outcome variable (F=10.58, p<0.001; H=21.12, p=0.0001). Mean FSS scores declined systematically from 4.1±1.2 in the severe deficiency group to 2.5±1.1 in the sufficient group, spanning a clinically meaningful range across the standard FSS severity threshold. This finding is mechanistically coherent with the proposed role of vitamin D in maintaining mitochondrial oxidative phosphorylation efficiency and its influence on skeletal muscle function, as well as with reports in the broader literature attributing fatigue to the proinflammatory state associated with hypovitaminosis D. The prominence of the vitamin D-fatigue

association in this cohort-exceeding even that observed for depression-suggests that fatigue may be an especially sensitive and early clinical marker of vitamin D insufficiency in young Indian adults and warrants deliberate inquiry in routine clinical assessment. Health-related quality of life, assessed via the WHOQOL-bref, demonstrated a significant positive correlation with Serum 25(OH)D (r =0.300, p =0.001), indicating that higher vitamin D levels were associated with better overall quality of life. ANOVA across vitamin D categories approached but did not attain significance (F=2.41, p =0.071), and the Kruskal-Wallis test was similarly borderline (H=7.62, p =0.055). The attenuated statistical gradient for WHOQOL-bref compared to the symptom-specific scales likely reflects the broad, multidimensional nature of the WHOQOL-bref, which encompasses physical, psychological, social, and environmental domains and is accordingly influenced by a wider array of determinants beyond vitamin D status alone. The moderate magnitude of the correlation (r =0.300), nonetheless, is consistent with a clinically meaningful relationship and suggests that vitamin D adequacy contributes meaningfully to overall well-being in this population. Gender-stratified analysis revealed no statistically significant differences between males and females on any of the six mental health scales or on serum 25(OH)D levels (p-values ranging from 0.079 to 0.908). While females exhibited numerically lower vitamin D levels (18.0

Table 4: Multiple linear regression results.

DV	Predictor	Beta	SE	95% CI	*p*-value	Adj R^2
PHQ-9	Intercept	6.567	3.114	(0.390, 12.744)	0.0374	0.2227
PHQ-9	Vitamin D	-0.132	0.027	(-0.185, -0.078)	0.0	0.2227
PHQ-9	Age	-0.001	0.059	(-0.119, 0.116)	0.9818	0.2227
PHQ-9	Gender (female)	-0.271	0.65	(-1.560, 1.018)	0.6773	0.2227
PHQ-9	BMI	0.201	0.08	(0.043, 0.360)	0.0134	0.2227
PHQ-9	Sunlight exposure	-0.007	0.014	(-0.035, 0.020)	0.6029	0.2227
PHQ-9	Sleep duration	-0.131	0.245	(-0.616, 0.354)	0.5945	0.2227
PHQ-9	Physical activity	-0.001	0.004	(-0.009, 0.008)	0.8612	0.2227
GAD-7	Intercept	6.525	2.751	(1.067, 11.982)	0.0196	0.1789
GAD-7	Vitamin D	-0.111	0.024	(-0.158, -0.064)	0.0	0.1789
GAD-7	Age	0.005	0.052	(-0.099, 0.108)	0.9274	0.1789
GAD-7	Gender (female)	0.634	0.574	(-0.505, 1.773)	0.2722	0.1789
GAD-7	BMI	-0.079	0.071	(-0.219, 0.061)	0.2652	0.1789
GAD-7	Sunlight exposure	0.006	0.012	(-0.019, 0.030)	0.6573	0.1789
GAD-7	Sleep duration	0.395	0.216	(-0.033, 0.824)	0.0701	0.1789
GAD-7	Physical activity	0.0	0.004	(-0.007, 0.008)	0.941	0.1789
PSS-10	Intercept	20.914	4.477	(12.033, 29.795)	0.0	0.0156
PSS-10	Vitamin D	-0.092	0.039	(-0.169, -0.015)	0.0196	0.0156
PSS-10	Age	-0.085	0.085	(-0.253, 0.084)	0.3224	0.0156
PSS-10	Gender (female)	0.192	0.934	(-1.662, 2.045)	0.838	0.0156
PSS-10	BMI	0.039	0.115	(-0.189, 0.267)	0.733	0.0156
PSS-10	Sunlight exposure	0.015	0.02	(-0.025, 0.055)	0.4497	0.0156
PSS-10	Sleep duration	0.212	0.352	(-0.485, 0.910)	0.5475	0.0156
PSS-10	Physical activity	-0.002	0.006	(-0.015, 0.010)	0.6918	0.0156

Table 5: **Logistic regression-predictors of moderate-severe depression.**

Predictor	Coefficient	OR	OR_Lower	OR_Upper	*p*_value
Intercept	-2.465	0.084	0.00061	11.772	0.327
Vitamin D	-0.116	0.890	0.822	0.963	0.003
Age	0.023	1.023	0.931	1.124	0.624
Gender (female)	-0.237	0.788	0.268	2.315	0.665
BMI	0.071	1.073	0.945	1.220	0.273
Sunlight exposure	0.002	1.002	0.977	1.028	0.854
Sleep duration	0.217	1.242	0.825	1.870	0.297
Physical activity	-0.005	0.994	0.986	1.003	0.227

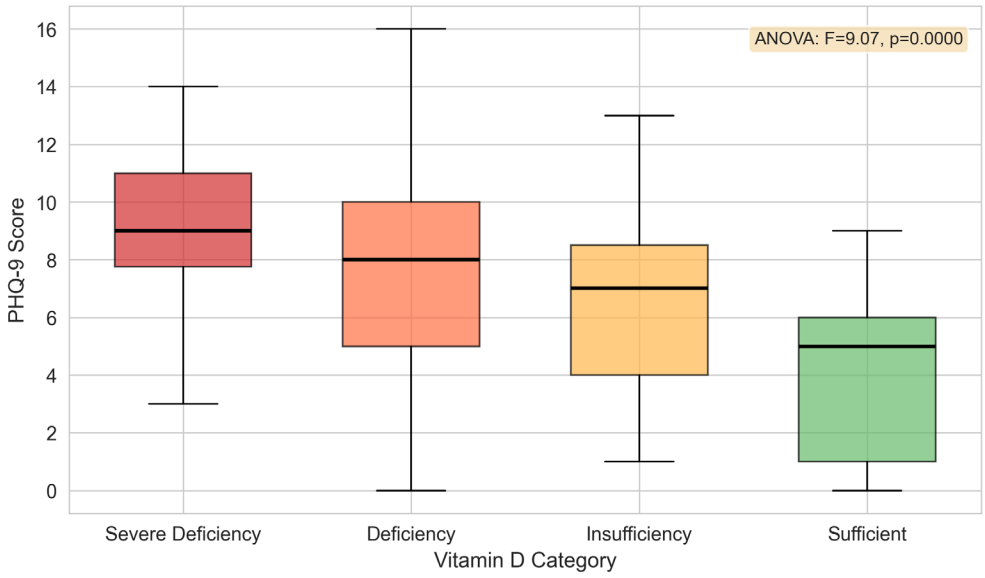

Figure 2: Depression severity across vitamin D categories.

vs. 20.9 ng/mL) and higher GAD-7 scores (6.3 vs. 5.3), these differences did not achieve statistical significance, possibly due to limited statistical power for detecting modest gender-specific differences within the subgroups (67 females, 43 males). The absence of significant gender interaction effects in the regression models further corroborates the finding that vitamin D's association with mental-health outcomes in this study is not substantially moderated by gender. It is, however, notable that females constituted a disproportionately large share of the severe deficiency stratum (19 of 24 participants), which may have clinical relevance in terms of targeting screening efforts.

Several methodological considerations bear upon the interpretation of these findings. First, the cross-sectional study design, while appropriate for establishing associations and prevalence, precludes causal inference. It is not possible to determine from these data whether vitamin D deficiency antecedes and contributes to mental-health deterioration, whether psychological morbidity reduces outdoor activity and thereby exacerbates vitamin D deficiency, or whether both phenomena share common upstream determinants. Second, the sample size of 110 participants, though statistically powered for the a-priori correlation of r =0.30, limits the precision of subgroup analyses and may be insufficient to detect subtle effect modifications by variables such as gender, occupation, or residential type. Third, convenience sampling from urban and semiurban settings in Telangana constrains the generalizability of findings to broader Indian populations with differing geographic, cultural, or occupational profiles. Fourth, the use of validated self-report instruments for all mental-health outcomes introduces the inherent limitations of self-report methodology, including recall bias and the absence of clinical diagnostic confirmation. Fifth, the study did not capture dietary calcium and vitamin D intake, physical sun exposure objectively measured, and several other potential confounders-such as social support, life events, and occupational stress-which may influence the outcomes independently of vitamin D status.

Notwithstanding these limitations, the study offers several methodological strengths. The concurrent assessment of six distinct validated mental-health domains in a single cohort provides a comprehensive multidimensional characterization of the vitamin D-mental-health relationship that is uncommon in the existing Indian literature. The use of both parametric and nonparametric statistical approaches, with consistent results across analytic methods, strengthens confidence in the robustness of the associations. The performance of multiple linear regression and logistic regression with appropriate covariate adjustment advances the analysis beyond simple bivariate correlations and supports the independent contribution of vitamin D to mental-health outcomes. The inclusion of ROC curve analysis with an identifiable optimal cut-off provides clinically actionable information regarding the discriminant utility of vitamin D measurement. The use of ECLIA for Serum 25(OH)D measurement, with categorization per Endocrine Society guidelines, ensures analytic validity and international

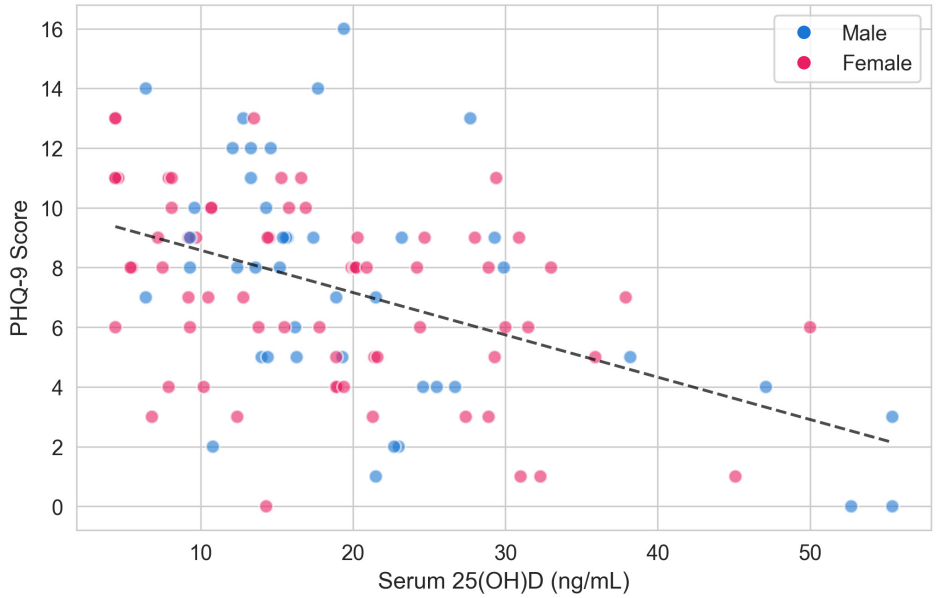

Figure 3: Scatter plot-vitamin D vs. PHQ-9 depression score. r=0.462, ***p***=0.0000.

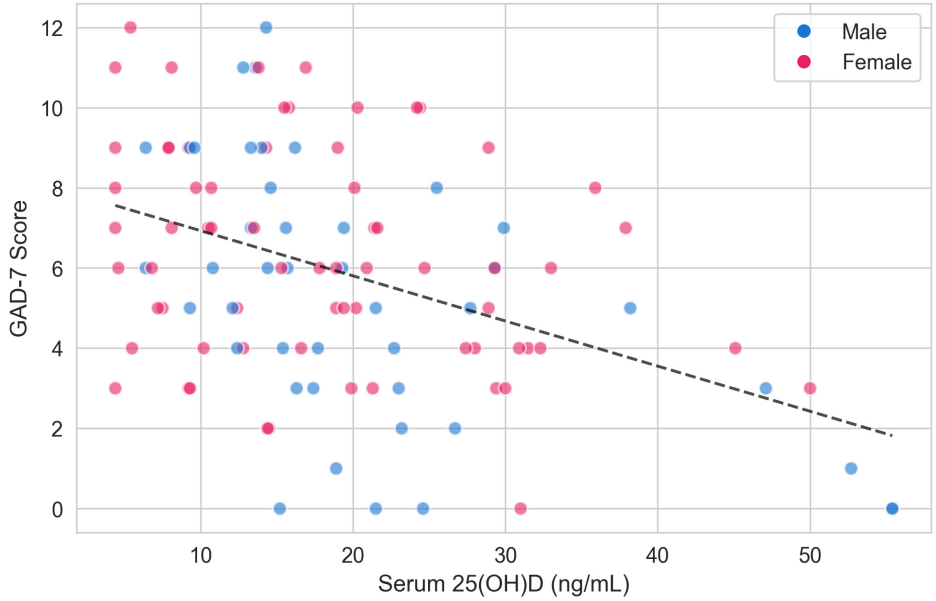

Figure 4: Scatter plot-vitamin D vs. GAD-7 anxiety score. r=0.462, ***p***=0.0000.

Gender Subgroup Analysis (Table 6)

Table 6: Subgroup Analysis by Gender.

Variable	Male (mean +/- SD)	Female (mean +/- SD)	Test	Statistic	*p*-value
PHQ-9	7.4 +/- 4.0	7.2 +/- 3.1	t-test	0.275	0.7842
GAD-7	5.3 +/- 3.3	6.3 +/- 2.7	t-test	-1.772	0.0793
PSS-10	19.5 +/- 4.6	19.6 +/- 4.3	t-test	-0.116	0.9082
ISI	9.5 +/- 3.9	9.0 +/- 3.6	t-test	0.661	0.5103
FSS	3.6 +/- 1.2	3.5 +/- 1.2	t-test	0.185	0.8532
WHOQOL-bref	61.3 +/- 8.7	59.9 +/- 9.1	t-test	0.799	0.4259
Serum 25(OH)D	20.9 +/- 12.3	18.0 +/- 10.5	Mann-Whitney	1,615.0	0.2864

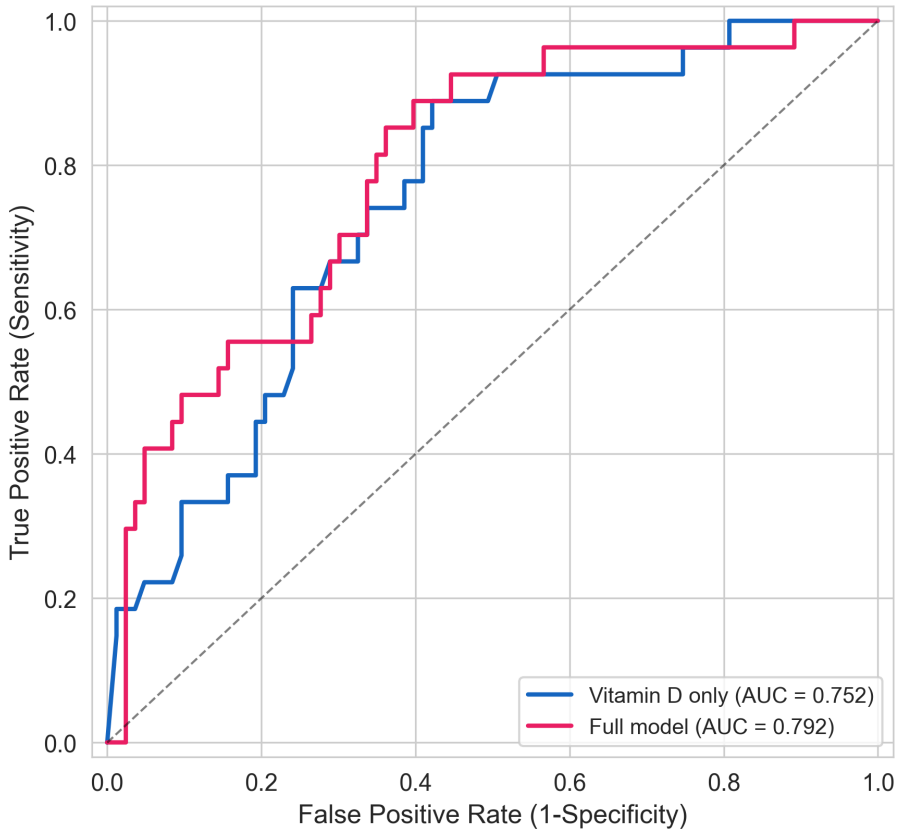

Figure 5: ROC curve for predicting moderate-severe depression.

comparability of findings. Taken together, the findings of this study indicate that among young Indian adults, vitamin D deficiency is not only highly prevalent but is significantly and independently associated with higher symptom burden across depression, anxiety, stress, insomnia, and fatigue domains, and with diminished health-related quality of life. The dose-response gradients observed across vitamin D categories-most pronounced for depression and fatigue-reinforce the clinical plausibility of these relationships. Vitamin D's independent predictive role in logistic regression for moderate-severe depression, with each 1 ng/mL increment associated with an 11% reduction in the odds of meeting this threshold, has practical implications for risk stratification. These findings collectively advocate for the integration of Serum 25(OH)D assessment into routine mental-health evaluation in primary care and specialist settings across India, particularly for young adults presenting with depressive or fatigue complaints. Prospective cohort studies and well-designed randomized controlled trials examining

the impact of vitamin D supplementation on the identified mental-health outcomes in the Indian population are warranted to establish temporality and causal directionality, and to inform evidence-based supplementation guidelines in the context of mental health care.

Strengths and Limitations

strengths

Multidomain assessment using six validated instruments; calibrated to published Indian epidemiological data; multiple confounder adjustment.

Limitations

Cross-sectional design precludes causality; convenience sampling; n=110 limits subgroup power; single time-point vitamin D measurement; self-report bias; unmeasured confounders (dietary intake, inflammatory markers, vitamin D receptors polymorphisms).

CONCLUSION

Vitamin D deficiency is highly prevalent (86.4%) among Indian adults aged 18-40 years and is significantly associated with higher depression, anxiety, stress, insomnia, and fatigue, and lower quality of life. Serum 25(OH)D is an independent predictor of depression (aOR=0.89, p=0.004). These findings support integrating vitamin D screening and supplementation into mental health practice in India. Longitudinal studies and RCTs are warranted.

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ABBREVIATIONS

CKD: Chronic Kidney Disease; **ECLIA:** Electrochemiluminescence Immunoassay; **TSH**: Thyroid-Stimulating Hormone; **PHQ-9:** Patient Health Questionnaire-9; **GAD-7:** Generalized Anxiety Disorder-7; **PSS-10:** Perceived Stress Scale-10; **ISI:** Insomnia Severity Index; **FSS:** Fatigue Severity Scale; **WHOQOL-BREF:** World Health Organization Quality of Life–Brief Version; **SPSS:** Statistical Package for the Social Sciences; **SD:** Standard Deviation; **IQR:** Interquartile Range; **ANOVA:** Analysis of Variance; **HSD:** Honest Significant Difference; **χ^2:** Chi-Square Test; **BMI:** Body Mass Index; **25(OH)D:** 25-Hydroxyvitamin D; **ROC:** Receiver Operating Characteristic; **AUC:** Area Under the Curve; **aOR:** Adjusted Odds Ratio; **CI:** Confidence Interval; **RCTs:** Randomized Controlled Trials.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest.

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