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Quantifying the Nutritional Determinants of TB: Evidence from Madhya Pradesh Using Bayesian Regression

Bhavna Goswami* and Sushma Jain
Department of Statistics,
Government Motilal Vigyan Mahavidyalaya, Bhopal (Madhya Pradesh), India.

(Corresponding author: Bhavna Goswami)*
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ABSTRACT: Tuberculosis (TB) continues to be a major public health concern in India, particularly in socioeconomically disadvantaged regions where nutritional deficiencies are widespread. Madhya Pradesh, one of the high-burden states, exhibits a concerning overlap between elevated TB incidence and chronic malnutrition among women and children. This study aims to quantify the relationship between nutritional indicators and TB prevalence across ten selected districts in Madhya Pradesh using Bayesian regression analysis. Secondary data were sourced from the NIKSHAY portal (2015–2022) for TB cases and from NFHS-5 and the State Nutrition Profile (2019–2021) for malnutrition indicators, including anemia, stunting, and underweight status. Descriptive statistics and correlation analyses revealed strong associations between TB prevalence and nutritional deficits, particularly anemia in children and underweight status in women. Bayesian linear regression was employed to model the predictive strength of five key nutritional variables. The best-fitting model explained 95% of the variance in TB prevalence ($R^2 = 0.950$), with high posterior inclusion probabilities and Bayes Factors supporting the relevance of each predictor. Notably, anemia in children emerged as the most influential variable, followed by underweight women, while stunting and underweight children showed complex or inverse associations.These findings reinforce the hypothesis that malnutrition significantly contributes to TB vulnerability and underscore the importance of integrating nutritional interventions into TB control programs. By applying Bayesian methods, this study offers a robust statistical framework for identifying high-risk populations and guiding targeted public health strategies. The results have implications for policy formulation, resource allocation, and the design of integrated health programs in Madhya Pradesh and similar high-burden regions.

Keywords: Tuberculosis, Malnutrition, Madhya Pradesh, Public Health, Correlation Analysis, Nutritional Deficiencies, Environmental Health.

INTRODUCTION

Tuberculosis (TB), caused by Mycobacterium tuberculosis, remains a major global health concern, particularly in regions burdened by poverty and under nutrition (Mendes *et al*., 2025). Despite being declared a global emergency by the World Health Organization in 1993, TB continues to claim millions of lives annually, with the highest incidence reported in Asia, followed by Africa and the Eastern Mediterranean (FAO, 2023; Jain *et al*., 2024). While only about 10% of those infected develop active TB, the risk is significantly elevated among individuals suffering from nutritional deficiencies and compromised immunity. India accounts for nearly 28% of the world's TB cases, making it the highest-burden country globally (Ministry of Health & Family Welfare 2023). Within India, Madhya Pradesh stands out as a state with persistently high TB prevalence, particularly in districts where malnutrition indicators such as anemia, stunting, and underweight status are also alarmingly elevated (NITI Aayog, 2022). This intersection of infectious disease and nutritional deprivation calls for a deeper, data-driven investigation into the underlying determinants of TB (Doke *et al*., 2023).

Madhya Pradesh continues to grapple with a high burden of tuberculosis (TB), posing a significant challenge to the state's public health infrastructure. Despite intensified efforts under the National TB Elimination Programme, including mobile screening units and community outreach, recent data from a 100-day detection drive revealed over 19,000 new TB cases, raising concerns about the feasibility of achieving the 2025 TB-free target. Tribal-dominated districts such as

Jabalpur, Sheopur, and Gwalior remain hotspots, with the Saharia tribe exhibiting some of the highest pulmonary TB rates in the country. While over 5,000 gram panchayats have been declared TB-free, experts warn that underreporting, limited access to healthcare, and persistent malnutrition continue to fuel transmission, especially in remote and vulnerable populations (Ministry of Health & Family Welfare 2023).Recent research has emphasized the utility of Bayesian regression models in analyzing complex health data. Mohammed and Asfaw (2018) demonstrated the effectiveness of Bayesian Gaussian regression in identifying nutritional risk factors among children under five in Ethiopia. Similarly, Lasisi *et al.* (2015) applied Bayesian techniques to assess the nutritional status of Nigerian children, highlighting the method's robustness in capturing subtle associations in public health datasets.

Building on this foundation, the present study aims to quantify the nutritional determinants of TB in high-burden districts of Madhya Pradesh using Bayesian regression analysis. By integrating district-level data on anemia, stunting, underweight prevalence, and TB incidence, we seek to identify statistically significant predictors of TB burden. This approach not only enhances the precision of epidemiological insights but also informs targeted public health interventions that address both nutritional deficiencies and TB control. The findings are expected to contribute to evidence-based policymaking and resource allocation in one of India's most vulnerable regions.

MATERIALS AND METHODS

Methodological Framework

This study aims to quantify the nutritional determinants of tuberculosis (TB) prevalence in high-burden districts of Madhya Pradesh using Bayesian regression analysis. By integrating district-level data on TB incidence and key malnutrition indicators, the study seeks to identify statistically significant predictors that contribute to elevated TB rates.

A. Data Sources and Collection

Secondary data were compiled from two primary sources:

Tuberculosis Data: TB case data from 2015 to 2022 were retrieved from the NIKSHAY portal maintained by the Central TB Division, Ministry of Health and Family Welfare, Government of India.

Nutritional Indicators: Malnutrition-related data were sourced from the National Family Health Survey (NFHS-5) and the State Nutrition Profile for Madhya Pradesh (NITI Aayog, 2022). These datasets include district-level figures for: Anemic women (ages 15–49), Anemic children (under 5 years), Stunted children, Underweight women and children

The analysis focuses on ten districts identified as high-burden: Bhopal, Shivpuri, Jabalpur, Rewa, Sagar, Satna, Betul, Mandla, Chhindwara, and Ujjain.

B. Data Preparation and Tabulation

Collected data were systematically organized and tabulated to facilitate statistical modeling. Published statistics were reclassified into uniform categories to ensure consistency across districts and variables. This step enabled the construction of a clean dataset suitable for regression analysis and visual interpretation.

C. Statistical Analysis

To explore the relationship between malnutrition and TB prevalence, the following statistical techniques were employed:

Descriptive Statistics: Mean plots and scatter diagrams were used to visualize distributions and preliminary associations between variables.

Correlation Analysis: Pearson and Spearman's rank correlation coefficients assessed the strength and direction of relationships between TB incidence and nutritional indicators.

Bayesian Regression Modeling: Bayesian linear regression was applied to quantify the influence of each nutritional variable on TB prevalence. This method was selected for its ability to incorporate prior knowledge and manage uncertainty in parameter estimation. The model comparison metrics included posterior probabilities, Bayes Factors, and R^2 values to evaluate predictive strength.

All analyses were conducted using statistical software such as JASP (Version 0.19.3) and validated through online platforms like StatsKingdom to ensure robustness and reproducibility. By combining descriptive, correlational, and Bayesian modeling approaches, this study aims to uncover the nutritional determinants most strongly associated with TB prevalence. The insights derived will support evidence-based public health strategies targeting both nutritional deficiencies and TB control in Madhya Pradesh.

RESULTS AND DISCUSSION

The data from Table 1 reveals a significant burden of malnutrition across districts in Madhya Pradesh. Rewa, Satna, and Sagar stand out with the highest numbers of anemic women and children, stunted children, and underweight individuals. For instance, Rewa reported 441,000 anemic women and 203,000 anemic children, alongside 107,000 stunted children and 91,000 underweight children. These figures align with findings from the National Family Health Survey (NFHS-5), which identified Rewa and Satna among the top districts with public health concerns related to anemia and stunting (IIPS, 2021).

Table 1: Nutritional Status and Prevalence of Anaemia in Women and Children Across Selected Districts during 2019 to 2021 along with Data of TB from Madhya Pradesh.

District	No. of anemic women	No. of Anemic children	No. of stunted children	No. of underweight women	No. of underweight children	Malnutrition	TB
Bhopal	431000	159000	51000	145000	75000	172200	9154.875
Betul	288000	94000	55000	127000	57000	124200	2417.375
Chhindwara	288000	105000	55000	196000	87000	146200	3032.75
Shivpuri	249000	152000	94000	131000	76000	140400	3629.625
Jabalpur	402000	85000	45000	230000	79000	168200	6055.75
Rewa	441000	203000	107000	118000	91000	192000	4440.625
Sagar	351000	228000	130000	161000	109000	195800	4634.75
Satna	391000	203000	137000	145000	86000	192400	4498.625
Mandla	212000	81000	41000	94000	42000	94000	1845.625
Ujjain	347000	168000	80000	134000	83000	162400	4115.75

TB prevalence appears to correlate with nutritional deficits. Bhopal and Jabalpur, despite being urban centers, show high TB averages (9,154 and 6,055 respectively), possibly due to population density and undernutrition. Goswami and Jain (2023) found a strong positive correlation between malnutrition and TB incidence in Madhya Pradesh, with a Pearson coefficient of 0.817 and Spearman's rank of 0.867. This supports the hypothesis that nutritional deficiencies especially anemia and underweight status are significant predictors of TB burden. Bayesian regression analysis further confirms the strength of this relationship as given in Table 2. The best-fitting model includes all five nutritional predictors anemic women, anemic children, stunted children, underweight women, and underweight children and explains 95% of the variance in TB prevalence ($R^2 = 0.950$). This model had the highest posterior probability and Bayes Factor, indicating strong evidence for its predictive power. The use of Bayesian methods in this context reflects a growing trend in public health research. For example, Mohammed and Asfaw (2018) applied Bayesian Gaussian regression to assess malnutrition among Ethiopian children under five, highlighting its robustness in handling complex health data. Similarly, Lasisi *et al.* (2015) demonstrated the effectiveness of Bayesian regression with Gaussian and Binomial links in analyzing nutritional status among Nigerian children, reinforcing its relevance in low-resource settings.

Table 2: Comparative Bayesian Linear Regression of TB Prevalence Using Anemia, Stunting, Underweight, and Malnutrition Indicators.

Model Comparison - TB					
Models	P(M)	P(M|data)	BF_M	BF_{10}	R^2
No. of anemic women + No. of Anemic children + No. of stunted children + No. of underweight women + No. of underweight children	0.167	0.408	3.440	1.000	0.950
No. of Anemic children + No. of stunted children + No. of underweight women + No. of underweight children	0.033	0.251	9.726	3.081	0.949
No. of anemic women	0.033	0.056	1.722	0.688	0.588
Null model	0.167	0.052	0.277	0.129	0.000
No. of anemic women + No. of Anemic children + No. of stunted children + No. of underweight women	0.033	0.019	0.576	0.239	0.771
No. of anemic women + No. of stunted children	0.017	0.018	1.061	0.433	0.652
No. of anemic women + No. of Anemic children + No. of stunted children + No. of underweight children	0.033	0.015	0.446	0.186	0.733
No. of anemic women + No. of Anemic children + No. of stunted children	0.017	0.014	0.867	0.355	0.732
No. of anemic women + No. of Anemic children	0.017	0.013	0.761	0.312	0.601
No. of anemic women + No. of underweight women	0.017	0.013	0.760	0.312	0.600

Note. Table displays only a subset of models; to see all models, select "No" under "Limit No. Models Shown".

To understand the individual contributions of each variable, Table 3 presents the posterior summaries of coefficients from the Bayesian regression: These results show that anemia in children and underweight status in women have the strongest positive associations with TB prevalence. Interestingly, stunting and underweight in children show negative coefficients, which may reflect complex interactions or confounding factors in the dataset. The inclusion probabilities and Bayes Factors suggest that all five indicators are relevant, with anemic children emerging as the most influential predictor.

India continues to face a severe nutrition crisis. According to the UN's State of Food Security and Nutrition in the World report, 37.4 million children under five are stunted, and 53.7% of women aged 15–49 suffer from anemia (FAO, 2023). These figures have worsened over the past decade, despite interventions like POSHAN Abhiyaan. The persistent high rates of anemia and stunting in Madhya Pradesh mirror national trends, especially among marginalized communities where access to nutritious food and healthcare remains limited.

Table 3: Posterior Summaries of Coefficients from Bayesian Linear Regression Predicting TB Prevalence Using Nutritional Indicators.

Posterior Summaries of Coefficients									
								95% Credible Interval	
Coefficient	P(incl)	P(excl)	P(incl|data)	P(excl|data)	$BF_{inclusion}$	Mean	SD	Lower	Upper
Intercept	1.000	0.000	1.000	0.000	1.000	4,382.575	350.919	3,602.596	5,172.417
No. of anemic women	0.500	0.500	0.629	0.371	1.694	0.004	0.007	-0.006	0.020
No. of Anemic children	0.500	0.500	0.784	0.216	3.636	0.073	0.052	-0.001	0.147
No. of stunted children	0.500	0.500	0.788	0.212	3.722	-0.051	0.034	-0.101	0.000
No. of underweight women	0.500	0.500	0.767	0.233	3.295	0.047	0.035	0.000	0.099
No. of underweight children	0.500	0.500	0.757	0.243	3.113	-0.118	0.093	-0.269	0.026

The intersection of TB and malnutrition demands integrated public health strategies. Districts like Rewa, Satna, and Sagar should be prioritized for nutrition-based TB interventions. Evidence from Madhya Pradesh's State Nutrition Profile and the Central TB Division suggests that targeted programs addressing anemia and child undernutrition could significantly reduce TB incidence (NITI Aayog, 2022; Ministry of Health & Family Welfare 2023). Strengthening maternal and child health services, improving food security, and ensuring timely TB diagnosis and treatment are critical steps forward.

CONCLUSIONS

The study confirms that nutritional deficiencies especially anemia in children and underweight status in women are significant predictors of TB prevalence in Madhya Pradesh. Bayesian regression analysis provided robust evidence supporting the integration of nutrition-focused interventions into TB control programs. Targeted efforts in high-burden districts such as Rewa, Satna, and Sagar could significantly reduce TB incidence and improve overall public health outcomes.

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Conflict of Interest and Ethical Statement. The authors declare that there are no conflicts of interest. Additionally, no ethical approval was required for this work, as the research did not involve human or animal subjects and did not entail any procedures subject to ethical review

FUTURE SCOPE

This study highlights the strong link between malnutrition and TB in Madhya Pradesh, suggesting future research should expand to other high-burden regions, include more socioeconomic factors, and use longitudinal data for deeper insights. Bayesian models can guide targeted interventions, policy planning, and mobile health tools to improve TB control through nutritional support.

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