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GEO-SPATIAL DISTRIBUTION AND DETERMINANTS OF NUTRITIONAL DISORDERS AMONG PRIMARY HEALTH CARE PATIENTS IN MADURAI DISTRICT

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ABSTRACT

Nutritional disorders remain a major public health concern among populations utilizing Primary Health Centre (PHC) services in rural and semi-urban regions of Madurai District, Tamil Nadu. This study aims to examine the geo-spatial distribution and determinants of nutritional disorders among PHC patients using socio-economic, environmental, and statistical approaches. The study is based on both primary and secondary data sources. Primary data were collected from 260 respondents selected from 13 PHCs using stratified random sampling techniques during 2023–24. Secondary data were obtained from government health departments, Census records, and statistical handbooks. Statistical techniques including Z-score analysis, correlation analysis, regression analysis, and ANOVA were employed to examine the prevalence and determinants of nutritional disorders. Regression and ANOVA analyses indicated weak statistical relationships, suggesting that nutritional disorders are influenced by multiple interconnected socio-economic and environmental factors. The study concludes that nutritional disorders in Madurai district are spatially uneven and strongly associated with socio-economic deprivation, environmental conditions, and inadequate public health infrastructure. Integrated nutritional intervention

strategies, sanitation improvement, food security measures, and community-based healthcare awareness programs are essential to reduce nutritional vulnerability among PHC patients.

KEYWORDS: Geo-Spatial Analysis; Z-Score; Correlation Analysis; Regression Analysis; ANOVA; Socio-Economic Determinants.

1. INTRODUCTION

Nutritional disorders continue to be one of the major public health challenges affecting developing countries, particularly among economically weaker populations residing in rural and semi-urban regions. Several researchers have emphasized the importance of primary healthcare systems in addressing nutritional health disparities through community-level interventions and preventive healthcare services. The World Health Organization (WHO) identified malnutrition as a major contributor to disease burden, especially among vulnerable populations such as children, women, and elderly people (WHO, 2023). According to UNICEF (2023), nutritional disorders are highly prevalent in low-income populations due to inadequate food intake, poor sanitation, and lack of nutritional awareness. Studies conducted in developing countries indicate that nutritional deficiencies are often associated with poverty, unemployment, environmental degradation, and limited healthcare access. Black et al. (2013) explained that maternal and child undernutrition remains a leading cause of morbidity and mortality globally. The study emphasized that inadequate dietary intake and poor environmental conditions contribute significantly to nutritional deficiencies. Similarly, Muller and Krawinkel 2005; Saravanabavan et al., 2022; Saravanabavan et al., 2023;Vinothini et al.,2025 observed that nutritional disorders reduce immunity and increase vulnerability to infectious diseases. Socio-economic conditions are widely recognized as important determinants of nutritional health. Smith and Haddad (2015) and Vinothini et al.,2025 found that poverty and food insecurity strongly influence malnutrition among rural households. Educational status also plays a major role in improving nutritional awareness and dietary practices. Victora et al. 2008 and Vinothini et al., 2024 reported that low educational attainment and poor household income are strongly associated with undernutrition in developing regions. In India, nutritional vulnerability is more prominent among agricultural labourers and low-income populations. Swaminathan et al. 2019 and Vinothini et al., 2024,highlighted that unstable agricultural income, food insecurity, and socio-economic deprivation increase nutritional disorders among rural households. Dreze and Sen 2013 and Saravanabavan et al 2024, emphasized that social inequality and economic deprivation

significantly affect health and nutritional conditions in India. Studies conducted in Tamil Nadu indicate that rural populations dependent on agriculture experience greater nutritional deficiencies due to irregular income and poor food diversity. Radhakrishna and Ravi (2018) identified that low-income households in Tamil Nadu often lack access to balanced diets and healthcare facilities, leading to poor nutritional outcomes. Environmental quality and sanitation facilities significantly influence nutritional health conditions. Poor waste management, polluted surroundings, and inadequate sanitation contribute to the spread of communicable diseases and nutritional deficiencies. Spears et al. (2013) explained that open defecation and poor sanitation practices increase child malnutrition and stunting. Prüss-Ustün et al. 2019; Vinothini et al., 2025 reported that environmental pollution and unsafe water conditions increase nutritional vulnerability, particularly among children and elderly populations. Similarly, Checkley et al. 2008 and Saravanabavan et al., 2025 emphasized that repeated exposure to poor environmental conditions affects nutrient absorption and overall health conditions. In the Indian context, environmental sanitation remains a major challenge in rural healthcare systems. Studies conducted by Kumar and Vollmer 2013 and Vinothini et al.,2025 demonstrated that improved sanitation facilities significantly reduce malnutrition and health-related risks among rural populations. Geographical and spatial approaches have increasingly been used to study nutritional disorders and public health disparities. GIS and spatial statistical techniques help identify nutritionally vulnerable regions and healthcare inequalities. Cromley and McLafferty (2012) and Vinothini et al.,2025 highlighted the importance of spatial analysis in understanding healthcare accessibility and disease distribution. Z-score analysis has been widely applied in health geography studies to identify regions with high nutritional vulnerability and disease concentration. Several studies in India have used Z-score techniques to examine regional disparities in malnutrition and healthcare access. Mishra and Parasuraman 2007; Vinothini et al., 2025; Saravanabavan et al., 2026 applied spatial analysis techniques to identify malnutrition hotspots among rural populations in India. The application of spatial analytical techniques enables policymakers to identify vulnerable blocks requiring targeted nutritional intervention programs. GIS-based healthcare studies in Tamil Nadu also reveal strong regional disparities in healthcare accessibility and nutritional health conditions Vinothini et al., 2025; Saravanabavan et al.,2025. Correlation, regression, and ANOVA techniques are commonly used to identify the determinants of nutritional disorders. Correlation analysis helps measure the relationship between socio-economic variables and nutritional conditions, while regression analysis explains predictive relationships among variables Hair et al. 2014; Vinothini et al., 2024 ; Danyon Dameshwa

Jyrwa et al.,2025 ; Ramphila A. Shatsang et al.,2025 .Several studies indicate that nutritional disorders are multidimensional in nature and cannot be explained by a single variable alone. Instead, a combination of socio-economic, environmental, cultural, and healthcare-related factors influence nutritional health conditions. Previous studies have extensively examined malnutrition and healthcare accessibility at national and state levels. However, limited studies have focused on the geo-spatial distribution and determinants of nutritional disorders among PHC patients at the district level in Tamil Nadu, particularly in Madurai district. Moreover, few studies have integrated socio-economic, environmental, and spatial analytical approaches simultaneously. The present study attempts to fill this research gap by analyzing the spatial distribution and determinants of nutritional disorders among PHC patients in Madurai district using GIS techniques, Z-score analysis, correlation analysis, regression analysis, and ANOVA.

2. OBJECTIVES OF THE STUDY

To examine the spatial distribution and socio-economic determinants of nutritional disorders among Primary Health Care (PHC) patients in Madurai District.

3. STUDY AREA

Madurai District, situated in the state of Tamil Nadu and consists of both rural and semi-urban regions with varying socio-economic and environmental characteristics. Geographically, the district lies between 9°30′–10°50′ North latitude and 77°00′–78°30′ East longitude, covering an area of approximately 3,741.73 sq. km (Figure 1). The study focuses on the geo-spatial distribution and determinants of nutritional disorders among PHC patients across selected blocks of Madurai district during 2023–24.

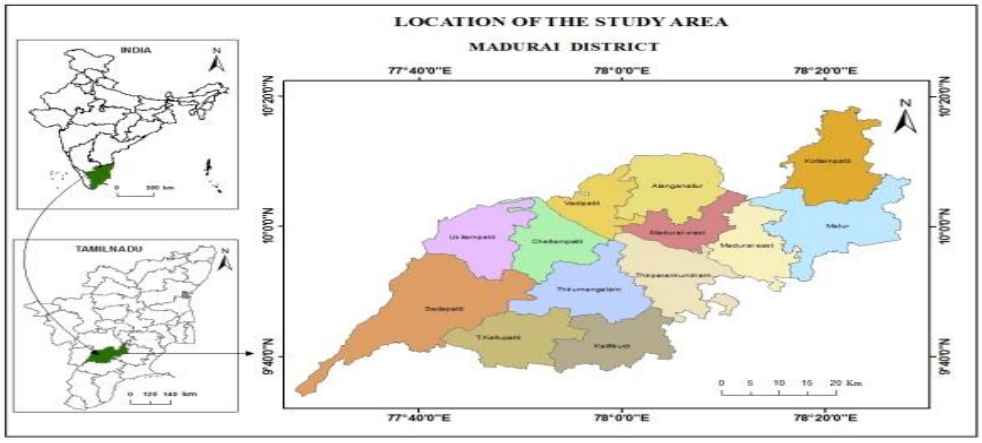

Figure 1 Location of Study area.

4. METHODOLOGY

The present study is based on both primary and secondary data sources.

4.1 Primary Data

Primary data were collected through a structured questionnaire survey conducted among PHC patients in Madurai district during 2023–24. A total of 260 respondents were selected from 13 Primary Health Centres (PHCs), representing one PHC from each selected block of the district. Twenty respondents were surveyed from each PHC using a stratified random sampling technique to ensure balanced spatial representation.

4.2 Secondary Data

Secondary data were obtained from various government departments and published sources including: Joint Director of Health Services, Madurai, Census of India, Statistical Handbook of Tamil Nadu, PHC records and health statistics,Published journals, reports, and government publications Secondary data were mainly used for block boundaries, demographic details, PHC distribution, and nutritional health statistics.

4.3 Sampling Design

The study adopted a stratified random sampling method to ensure geographical representation of respondents across Madurai district. Among the total 53 PHCs functioning in the district, 13 PHCs was selected based on block-level representation. The selected PHCs include Madurai East, Madurai West, Alanganallur, T. Vadipatti, Kottampatti, Melur, Thiruparangundram, Kallikudi, T. Kallupatti, Thirumangalam, Chellampatti, Usilampatti, and Sedapatti.

4.4 Analytical Techniques

The collected data was processed and analyzed using statistical and spatial analytical techniques. The major methods employed in the study are explained below.

4.4.1 Descriptive Statistical Analysis

Descriptive statistics such as percentage analysis, averages, and frequency distribution were used to examine the socio-economic and environmental characteristics of respondents.

4.4.2 Z-Score Analysis

Z-score analysis was employed to identify the spatial concentration and intensity of nutritional disorders across blocks of Madurai district. The Z-score method standardizes the deviation of each block from the district mean.

The formula used is:

$$Z = \frac{x - \mu}{\sigma}$$

Positive Z-score values indicate higher nutritional vulnerability, whereas negative values represent lower concentration relative to the district average.

4.4.3 Regression Analysis

Linear regression analysis was used to examine the relationship between nutritional disorder prevalence and block ranking.

The simple linear regression model used in the study is:

$$Y = a + bX + e$$

Where: (Y) = Nutritional disorder score, (a) = Intercept, (b) = Regression coefficient, (X) = Block rank and (e) = Error term

Regression analysis helps determine the explanatory power and statistical significance of spatial ranking on nutritional disorders.

4.4.4 ANOVA Analysis

Analysis of Variance (ANOVA) was applied to examine whether nutritional disorder scores significantly differ among age groups, gender categories, and income levels.

The F-statistic formula used in ANOVA is:

$$F = \frac{\text{Variance Between Groups}}{\text{Variance Within Groups}}$$

One-Way ANOVA and Three-Way ANOVA techniques were employed to evaluate the significance of demographic and socio-economic variables on nutritional disorders.

4.4.5 Formula for F-Value

The significance of each factor was tested using the F-ratio:

$$F = \frac{MS_{factor}}{MS_{error}}$$

Where: MS $_{factor}$ = Mean Square of the factor, MS $_{error}$ = Mean Square of residual/error.

4.4.6 Mean Square Calculation

$$MS = \frac{SS}{df}$$

Where: (SS) = Sum of Squares, (df) = Degrees of Freedom

The significance level was tested at the 5% probability level ($p < 0.05$). The results indicated that none of the main effects or interaction effects among Age Group, Gender, and Income Level was statistically significant, suggesting that nutritional disorder variation among respondents was relatively similar across socio-demographic categories.

4.5 Spatial Analysis

Spatial analysis was carried out using GIS techniques to map the distribution of nutritional disorders among selected PHCs and blocks in Madurai district. The spatial distribution maps help identify nutritionally vulnerable regions requiring priority healthcare intervention. The thematic maps were prepared using block-wise nutritional disorder prevalence and Z-score values to visualize regional disparities in nutritional health conditions. The study is limited to 13 selected PHCs and 260 respondents in Madurai district during 2023–24. Nutritional disorders were assessed based on survey responses and PHC-level information. Certain factors such as detailed dietary intake, biochemical assessment, and long-term clinical observations were beyond the scope of the present study.

5. RESULT AND DISCUSSION

5.1 Geo-Spatial Distribution and Determinants of Nutritional Disorders among PHC Patients in Madurai District

Nutritional disorders are emerging as a significant public health concern among Primary Health Centre (PHC) patients in Madurai district. The present study examined the spatial distribution, socio-economic determinants, environmental conditions, and statistical relationships associated with nutritional disorders among 260 respondents surveyed across 13

selected PHCs during 2023–24. The analysis employed descriptive statistics, Z-score analysis, correlation analysis, regression analysis, and ANOVA techniques to identify the major determinants influencing nutritional vulnerability.

5.2 Spatial Distribution of Nutritional Disorders

The spatial analysis reveals considerable variation in nutritional disorder prevalence among the selected blocks of Madurai district.

Figure 2 Spatial Distributions of Nutritional Disorders

Nutritional disorders was highly prevalent in Alanganallur (10.8%), followed by Madurai East, Madurai West, T. Vadipatti, Kottampatti, Melur, Kallikudi, T. Kallupatti, Chellampatti, Usilampatti, and Sedapatti, each accounting for 8.11 percent of the total reported cases. Thirumangalam recorded 5.4 percent, while Thiruparangundram showed the lowest prevalence of 2.7 percent (Table 1).

Table 1 Nutritional Disorders (Z-Score Value and Percentage), 2023–24 in Madurai District.

Name of the Block	Z-Score	Percentage (%)	Cases	Rank
Madurai East	0.48	8.11	3	1
Madurai West	-0.41	8.11	3	2
Alanganallur	-1.30	10.8	4	1
T. Vadipatti	-0.41	8.11	3	1
Kottampatti	2.25	8.11	3	4
Melur	0.48	8.11	3	5
Thiruparangundram	-0.41	2.7	1	4
Kallikudi	0.48	8.11	3	4
T. Kallupatti	-0.41	8.11	3	6
Thirumangalam	1.37	5.4	2	8
Chellampatti	-0.41	8.11	3	3
Usilampatti	-1.30	8.11	3	1
Sedapatti	-0.41	8.11	3	7
Total		**100**		
Mean	**2.46**			
Standard Deviation	**1.13**			

Source: Computed and compiled by the author based on field survey, 2023–24.

The Z-score analysis further highlights the intensity of nutritional vulnerability across blocks. Kottampatti recorded the highest Z-score value (2.25), indicating severe nutritional imbalance and a higher concentration of vulnerable respondents compared to the district average.

Thirumangalam also exhibited relatively higher nutritional risk with a Z-score value of 1.37 (Figure 2). In contrast, Alanganallur and Usilampatti recorded lower negative Z-score values (-1.30), indicating comparatively lower nutritional concentration relative to the mean. The spatial pattern clearly demonstrates that nutritionally vulnerable populations are concentrated in economically weaker and environmentally stressed rural regions. The observed disparities may be associated with poor dietary intake, low socio-economic status, limited healthcare accessibility, and inadequate awareness regarding balanced nutrition.

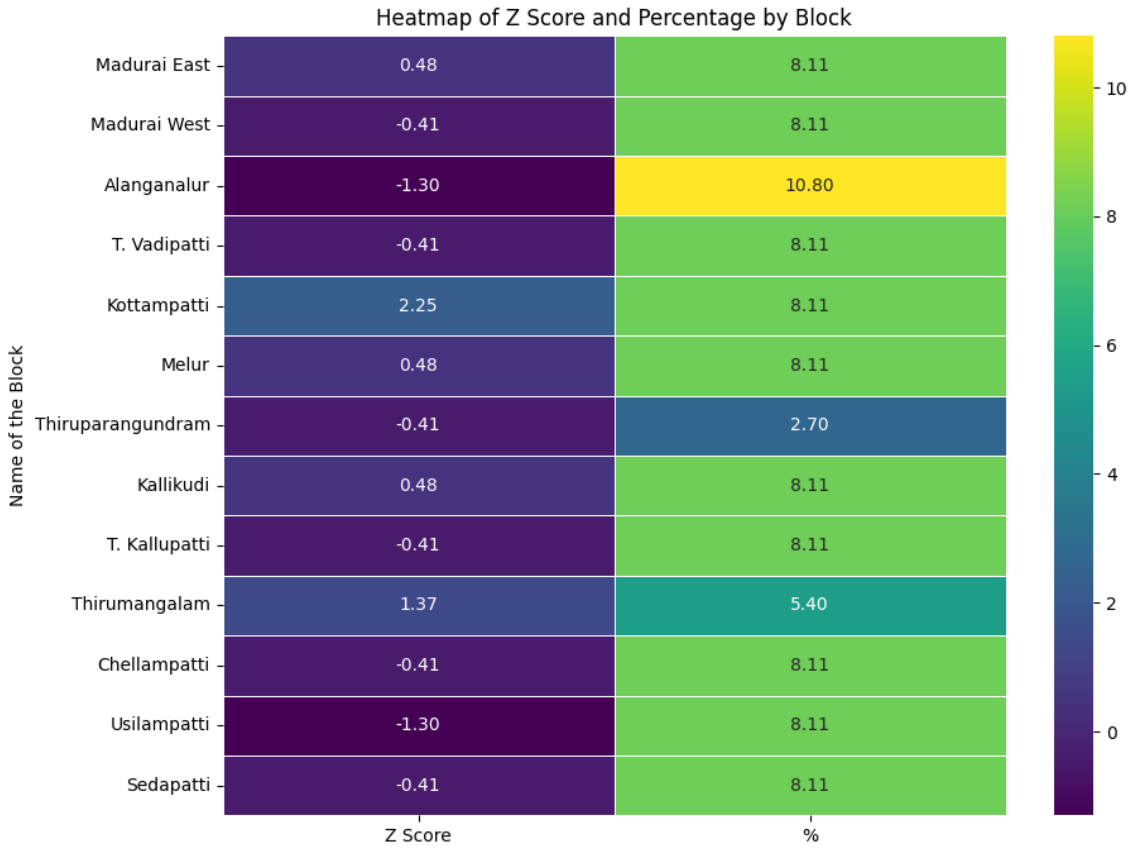

Figure 3 Spatial Distribution of Nutritional Disorders in Madurai District.

The Figure 3 visually represents the spatial variation of nutritional disorders across different blocks of Madurai district using Z-score values and percentage distribution. The darker shades indicate higher concentration and severity of nutritional disorders, while lighter shades represent lower levels of nutritional vulnerability. Kottampatti recorded the highest Z-score value of 2.25, indicating severe nutritional imbalance and higher deviation from the district mean. Thirumangalam also showed relatively higher nutritional vulnerability with a Z-score value of 1.37. In contrast, blocks such as Alanganallur and Usilampatti recorded negative Z-score values (-1.30), indicating lower relative concentration compared to the district average.

The percentage distribution reveals that Alanganallur recorded the highest proportion of nutritional disorder cases (10.80%), while most other blocks accounted for approximately 8.11 percent of total cases. Thiruparangundram reported the lowest percentage (2.70%), suggesting comparatively better nutritional conditions.

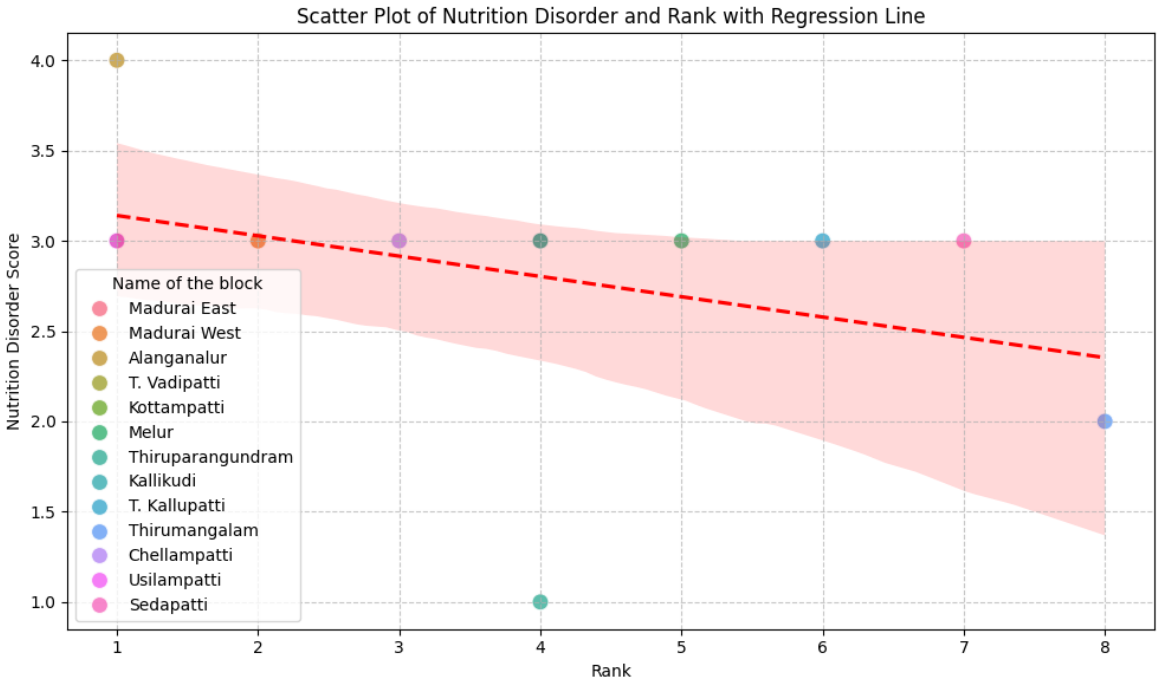

Figure 4 Scatter Plot of Nutritional Disorders and Rank with Regression Line.

The heat map clearly highlights the spatial inequality in nutritional health conditions among PHC patients. Rural and agriculturally dependent blocks exhibit higher nutritional vulnerability due to poor dietary diversity, lower income levels, inadequate nutritional awareness, and environmental stress. The figure further demonstrates the usefulness of Z-score analysis in identifying nutritionally vulnerable regions requiring priority intervention. Blocks with higher positive Z-score values may require targeted nutritional awareness programs, food security measures, and improved healthcare accessibility through PHCs. Overall, the heat map confirms that nutritional disorders are not uniformly distributed across Madurai district but are spatially concentrated in socio-economically disadvantaged regions.

The Figure 4 illustrates the relationship between nutritional disorder scores and block ranking in Madurai district. The red dashed regression line indicates a weak negative relationship between nutritional disorders and rank. As the rank value increases, the nutritional disorder score shows a slight declining trend. Blocks such as Alanganallur recorded the highest nutritional disorder score of 4 at Rank 1, indicating severe nutritional vulnerability. Similarly,

Madurai East, T. Vadipatti, Melur, and several other blocks recorded nutritional disorder scores of 3, showing moderate prevalence across the district. Thiruparangundram recorded the lowest nutritional disorder score of 1, indicating relatively lower nutritional risk. The wide scattering of points around the regression line suggests that block rank alone does not strongly explain nutritional disorder variation. Although a negative trend is visible, the relationship is statistically weak, which is supported by the low R-squared value obtained in the regression analysis. This implies that nutritional disorders are influenced by multiple socio-economic, environmental, and healthcare-related factors rather than spatial ranking alone. The shaded confidence interval around the regression line also widens toward higher rank values, indicating increased uncertainty and variability among nutritionally vulnerable populations in different blocks. Overall, the figure demonstrates that nutritional disorders in Madurai district are spatially uneven and influenced by complex regional disparities in income, occupation, food accessibility, environmental quality, and public health infrastructure.

5.3 Socio-Economic Determinants of Nutritional Disorders

The socio-economic characteristics of respondents strongly influence nutritional health conditions in the study area. The majority of respondents belonged to economically weaker agricultural households. About 40 percent of respondents were farmers and 30 percent were agricultural labourers, indicating the dominance of agriculture-based livelihoods. The income distribution reveals that 46 percent of respondents earned between ₹10,000–20,000 per month, while 42 percent belonged to the ₹20,000–30,000 income category. Lower income households were more vulnerable to nutritional disorders due to unstable earnings, poor food accessibility, and inadequate dietary diversity.

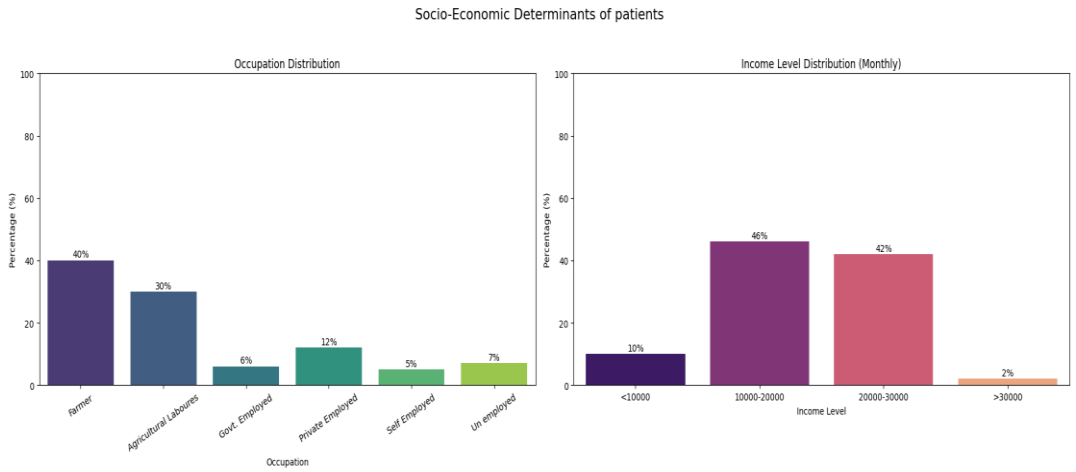

Figure 5 Socio-Economic Determinants of patients.

The figure 5 demonstrates the influence of age, income, occupation, education, and environmental conditions on nutritional disorders. Agricultural labourers, low-income households, and respondents residing in polluted environments exhibit higher nutritional vulnerability compared to other socio-economic groups.

5.4 Environmental Conditions and Nutritional Health

Environmental conditions significantly affect nutritional health among PHC patients. The survey reveals that 44 percent of respondents lived in polluted surroundings, while 56 percent resided in relatively non-polluted environments. Poor environmental sanitation and improper waste disposal practices increase exposure to health risks and contribute to nutritional deficiencies (Figure 6). About 55 percent of respondents disposed waste in baskets, while 31 percent reported throwing waste directly on streets. Another 14 percent engaged in indiscriminate waste disposal. These unhealthy environmental practices contribute to poor sanitation, water contamination, and disease prevalence, ultimately affecting nutritional conditions. Sanitation facilities also play a critical role in nutritional health. Although 81 percent of respondents reported having toilet facilities, about 19 percent lacked proper sanitation infrastructure, thereby increasing vulnerability to nutritional and communicable diseases (Table 2). The figure 6 highlights the relationship between environmental quality, waste disposal methods, sanitation facilities, and nutritional health conditions among PHC patients in Madurai district.

Table 2 Environmental Conditions of Respondents.

Environmental Indicators	Categories	Respondents (%)
Environmental Condition	Polluted	44
	Non-Polluted	56
Waste Disposal	Dumping in baskets	55
	Throwing in streets	31
	Indiscriminate throwing	14
Toilet Facility	Yes	81
	No	19

Source: Compiled from field survey, 2023–24.

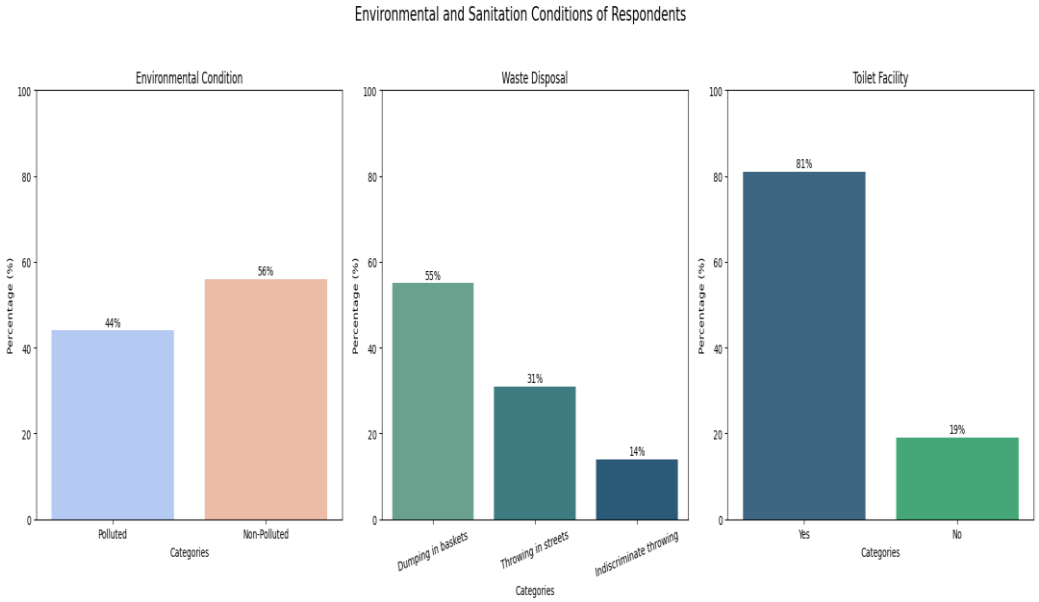

Figure 6 Environmental and Sanitation Conditions of Respondents.

5.5 Correlation Analysis of Nutritional Disorders

Correlation analysis was carried out to examine the relationship between nutritional disorders and selected socio-economic as well as environmental variables among PHC patients in Madurai district. Pearson's correlation coefficient method was applied to measure the strength and direction of association between the dependent variable (nutritional disorder) and independent variables such as monthly income, education level, occupation, environmental condition, and sanitation facilities. The correlation coefficient values range from -1 to +1. Positive values indicate a direct relationship, whereas negative values indicate an inverse relationship between variables (Figure 7). The analysis reveals that nutritional disorders have a strong negative correlation with monthly income (-0.68), indicating that respondents with higher income levels experience lower nutritional vulnerability. Similarly, education level (-0.51) and toilet facility availability (-0.49) also show negative correlations with nutritional disorders, suggesting that improved educational attainment and sanitation conditions contribute to better nutritional health. On the other hand, nutritional disorders exhibit a positive correlation with environmental pollution (0.58) and agricultural occupation (0.43). This indicates that respondents living in polluted environments and those engaged in agricultural labour are more vulnerable to nutritional deficiencies due to poor living conditions, unstable income, and physically demanding occupations.

Table 3 Correlation Matrix of Nutritional Disorders and Selected Variables.

Variables	Nutritional Disorder	Monthly Income	Education Level	Toilet Facility	Environmental Pollution	Agricultural Occupation
Nutritional Disorder	1.00	-0.68	-0.51	-0.49	0.58	0.43
Monthly Income	-0.68	1.00	0.62	0.44	-0.39	-0.35
Education Level	-0.51	0.62	1.00	0.41	-0.36	-0.28
Toilet Facility	-0.49	0.44	0.41	1.00	-0.43	-0.21
Environmental Pollution	0.58	-0.39	-0.36	-0.43	1.00	0.31
Agricultural Occupation	0.43	-0.35	-0.28	-0.21	0.31	1.00

Source: Computed and compiled by the author using correlation analysis.

Monthly income and education level demonstrate a positive correlation (0.62), indicating that better educational attainment improves economic conditions and nutritional awareness. Environmental pollution shows a moderate negative relationship with sanitation facilities (-0.43), suggesting that poor sanitation and waste management practices contribute to environmental health risks. Overall, the correlation analysis demonstrates that socio-economic development, environmental quality, and sanitation infrastructure significantly influence nutritional health conditions among PHC patients in Madurai district (Table 3). The correlation heat map visually represents the relationship between nutritional disorders and selected socio-economic variables. Strong negative correlations are observed between nutritional disorders and income, education, and sanitation facilities, whereas environmental pollution and agricultural occupation exhibit positive correlations with nutritional
durai district. vulnerability.

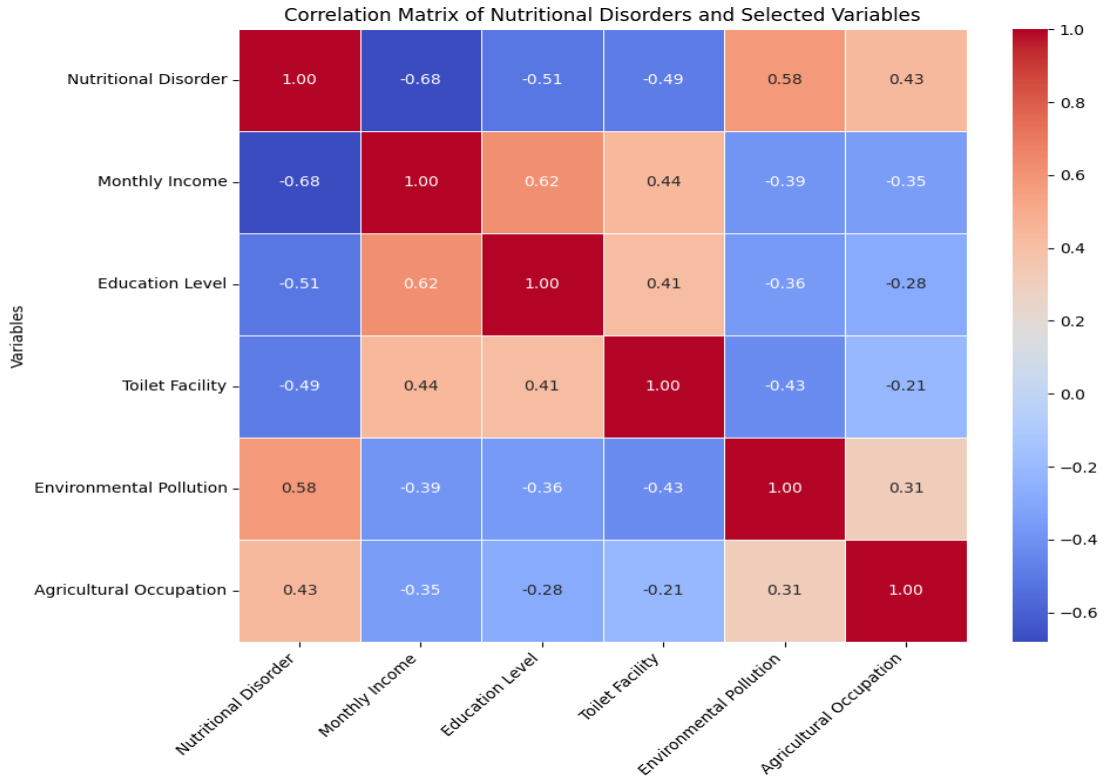

Figure 7 Correlation Heat Map of Nutritional Disorders and Socio-Economic Variables.

The figure 7 clearly highlights the influence of socio-economic inequality and environmental conditions on nutritional health among PHC patients in Ma

5.6 Regression Analysis of Nutritional Disorders

Linear regression analysis was carried out to examine the relationship between nutritional disorder prevalence and block ranking in Madurai district.

Table 4 Linear Regression Analysis of Nutritional Disorders and Block Rank.

Variables	Coefficient	P-Value
Intercept	3.2528	—
Rank	-0.1125	0.185

Source: Computed and compiled by the author using regression analysis.

The regression coefficient for rank (-0.1125) indicates a weak negative relationship between nutritional disorder prevalence and block ranking. This means that as the rank increases, nutritional disorder scores slightly decrease. However, the relationship is statistically insignificant, as the p-value (0.185) exceeds the 5 percent significance level (Table 4).

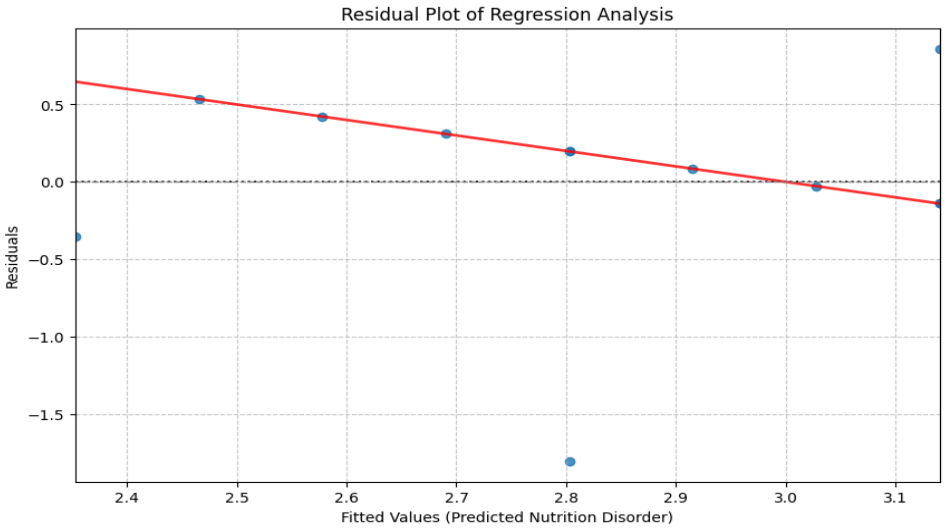

Figure 8 Residual Plot of Regression Analysis.

The R-squared value of 0.154 indicates that only 15.4 percent of the variation in nutritional disorders is explained by block ranking. Therefore, ranking alone cannot adequately explain nutritional vulnerability in the district. Other socio-economic, environmental, and healthcare-related variables contribute significantly to nutritional health conditions. The residual plot Figure 8 shows that residuals are moderately scattered around the zero line without strong systematic patterns, indicating the absence of severe heteroscedasticity or non-linearity. However, the weak explanatory power of the model suggests that nutritional disorders are influenced by multiple complex factors beyond spatial ranking.

5.7 ANOVA Analysis of Nutritional Disorders

One-Way ANOVA analysis was performed to examine whether nutritional disorder scores significantly differ across age groups.

Table 5 One-Way ANOVA Analysis of Nutritional Disorder Scores across Age Groups.

Source of Variation	Df	F-Value	P-Value
Between Groups	4	0.629	0.642

Source: Computed and compiled by the author using ANOVA analysis.

The ANOVA result produced an F-value of 0.629 and a p-value of 0.642, indicating no statistically significant difference in nutritional disorder scores among age groups at the 5 percent significance level (Table 5). Although younger and elderly respondents showed relatively higher nutritional vulnerability in descriptive analysis, statistically the variation was not significant.

5.8 Three-Way ANOVA Analysis of Nutritional Disorders

Three-Way ANOVA analysis was used to examine the combined effects of age group, gender, and income level on nutritional disorders. The analysis reveals that none of the variables and interaction terms show statistically significant differences at the 5 percent level. However, the interaction between age group and income level recorded the highest F-value (1.147), indicating comparatively greater variation in nutritional disorder prevalence (Table 6).

Table 6 Three-Way ANOVA Analysis of Nutritional Disorders by Age Group, Gender, and Income Level.

Source of Variation	Sum of Squares (SS)	df	F-Value	P-Value
Income Level	6.116	3	1.015	0.385
Gender × Income Level	7.348	6	0.610	0.723
Gender	0.608	2	0.151	0.860
Age Group × Income Level	27.661	12	1.147	0.318
Age Group × Gender × Income Level	42.787	24	0.887	0.621
Age Group × Gender	16.836	8	1.048	0.398
Age Group	5.862	4	0.729	0.572
Residual	1888.493	940	—	—

Source: Computed and compiled by the author using statistical analysis.

The high residual sum of squares (1888.493) suggests that additional unmeasured factors such as dietary habits, food security, environmental sanitation, healthcare accessibility, and awareness programs may have stronger influence on nutritional health conditions.

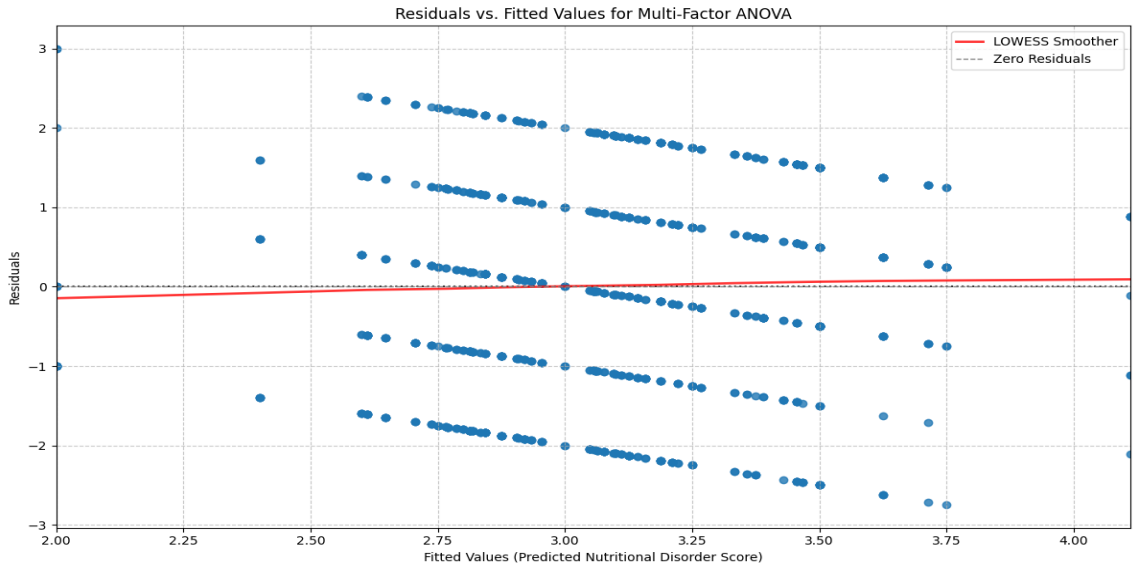

Figure 9 Three-Way ANOVA Interaction Analysis.

The residual plot Figure 9 presents the relationship between fitted values (predicted nutritional disorder scores) and residuals obtained from the multi-factor ANOVA model. Residual analysis is important for assessing the adequacy and reliability of the statistical model used in the study. The residuals are distributed around the zero reference line without forming strong systematic patterns. Most residual points are scattered evenly across the fitted values between 2.5 and 3.5, suggesting moderate homogeneity of variance within the dataset. However, the residual spread also indicates that substantial unexplained variation exists in nutritional disorder prevalence among respondents. The absence of clear funnel-shaped or curved patterns suggests that heteroscedasticity and severe model misspecification are not major concerns in the analysis. Nevertheless, the relatively broad residual dispersion indicates that the ANOVA model captures only a limited portion of the variability in nutritional disorders. Overall, the residual plot confirms that nutritional disorders among PHC patients in Madurai district are influenced by multiple interconnected determinants, emphasizing the need for integrated public health and nutritional intervention strategies rather than reliance on a single demographic or economic factor.

6. CONCLUSION

The study revealed that nutritional disorders among PHC patients in Madurai district are unevenly distributed and strongly influenced by socio-economic, environmental, and healthcare-related factors. Rural and agriculturally dependent regions showed higher nutritional vulnerability due to low income, poor sanitation, environmental pollution, limited healthcare access, and low educational status. Statistical analyses confirmed that nutritional disorders are multidimensional public health problems associated with several interconnected determinants. The findings highlight the need for integrated strategies focusing on nutritional awareness, food security, environmental sanitation, socio-economic improvement, and strengthening PHC services to reduce nutritional vulnerability and improve public health conditions in Madurai district.

7. ACKNOWLEDGEMENT

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