Exploring the Multifaceted Interplay of Diet Diversity, Body Mass Index, and Micronutrient Deficiencies Among Adolescents in India

Tarique Anwar[1], Dr. Sayeed Unisa[2], Dr. Wahengbam Bigyananda Matei[3], Jagriti Gupta[4]
[1,4]Student, Population Studies, International Institute for Population Sciences (IIPS), Mumbai
[2]Retired Professor & former Head, Department of Mathematical Demography and Statistics (IIPS), International Institute for Population Sciences, Mumbai
[3]Junior Research Scientist (GENDER Project), International Institute for Population Sciences (IIPS), Mumbai.

***Abstract*—This study examines the Body Mass Index (BMI) distribution among adolescents aged 10-19 years, analysing the influence of socio-demographic factors, diet diversity index (DDI), and micronutrient deficiencies. Findings reveal that thinness is more prevalent among boys than girls, especially in the 10-14 age group. Socioeconomic factors, such as parental education, wealth index, and urban-rural residence, significantly affect BMI distribution, with higher education and wealth linked to increased normal and overweight BMI categories. Adolescents with higher diet diversity are less likely to have high BMI, while deficiencies in Vitamin A, B-12, iodine, and folate show varied associations with BMI levels. Notably, boys with folate deficiency and girls with iodine deficiency have higher odds of elevated BMI. The study underscores the complex interplay between nutritional status and socioeconomic determinants in shaping adolescent BMI trends.**

***Index Terms*—Adolescent BMI, Socioeconomic Factors, Diet Diversity Index (DDI), Micronutrient Deficiencies, Nutritional Status**

I. INTRODUCTION

Acquiring all micronutrients from one or two food groups is not enough and requires regular intake of several foods and food groups in sufficient quantity and variety to satisfy the nutritional needs (NIN,2010). Micronutrient deficiencies are most prevalent in areas where the diet lacks variety, as is the case for many individuals in developing countries (kennedy et.al, 2003).
When people cannot afford to diversify their diets with adequate amounts of fruits, vegetables or animal-source foods that contain large amounts of micronutrients, deficiencies are inevitable. (FAO,2003)
In addition, a minimum amount of fat or vegetable oil is required in the diet for adequate absorption of the fat-soluble vitamins A, D, E and K (Kennedy, Nantel & Shetty, 2003).
Situations of food insecurity, where populations do not have enough to eat, will also inevitably for a developing country like India which is predominantly cereal pulse-based vegetarian diet with minimal amounts of flesh foods, contrary to popular assumption, cereals appear to be the major source of iron and zinc, owing to the sheer volume of intake (Nair et.al, 2016).
For vitamin C, fruits and vegetables are the sole source, and for folate, a mixture of all food groups contributes (Nair et.al, 2016). Strategies other than dietary diversification have the disadvantage of targeting the known factors. Dietary diversification has an advantage of being closer to the population psyche and culture but also bears the challenge of breaking the inertia of habituation (Nair et.al, 2016). Once made viable, dietary diversification is a strategy which is sustainable without external support and has the ability to simultaneously combat multiple micronutrient deficiencies (Tontisirin, Nantel & Bhattacharjee, 2002).
Diversity previously has been defined as the number of different foods or food groups consumed over a given reference period (Ruel, 2003). It includes a wide

range of food groups, both within and across levels, where enhanced availability, accessibility, and consumption of sufficient quantities and suitable varieties of safe, high-quality food are essential prerequisites. Dietary diversity had long been recognized as an important component of diet quality. (Kennedy, Razes, Ballard & Dop, 2010).

Micronutrient malnutrition remains one of the largest nutritional problems worldwide, affecting people in both developed and developing countries (WHO,2002). The nutrient density of the diet given to young children is often insufficient to meet their nutrient requirements, and increasing the diversity of foods provided to young children, particularly meat, poultry, fish, eggs, fruits and vegetables, is recommended to improve micronutrient intakes (Dewey, 2003).

Despite the intuitive link between increasing diversity of the diet and increased nutrient intake, the relationship between dietary diversity and adequate micronutrient intake has not yet been sufficiently validated across different cultural settings and in different age groups (Ruel, 2003).

Age, gender and race/ethnicity have been markers of dietary inequality for achieving adequate health within and across countries (Vaccaro & Huffman, 2013). Micronutrient intake is categorized as either a 'deficiency,' characterized by significant clinical ramifications, or an 'insufficiency,' representing a suboptimal level with consequences that may not be immediately apparent (Vaccaro & Huffman, 2013). Severe deficiencies of micronutrients, often observed in developing nations, result in severe, life-threatening outcomes, while micronutrient insufficiencies, more prevalent in developed countries, may lead to less pronounced consequences. Inequalities of health across race/ethnicity and genders may be attributed, in part, to disparities in micronutrient intake (Vaccaro & Huffman, 2013).

The prevalent issue of micronutrient deficiency stems from a deficient food system that fails to adequately supply essential micronutrients to meet the nutritional requirements of the population (Pritwani & Mathur, 2015). To foster sustainable growth and development in countries like India, addressing this issue is imperative. The global problem of micronutrient malnutrition arises from the incapacity of food systems to adequately supply essential micronutrients to fulfil the population's nutritional requirements (Pritwani & Mathur, 2015). For Sustainable growth and development in developing countries the problem of malnutrition of needs prompt attention (Pritwani & Mathur, 2015).

Everyone requires a varied selection of foods to fulfill their essential nutrient needs, and the importance of maintaining a diverse diet has been acknowledged for a considerable time. Lack of diversity in food is a particularly severe problem among poor populations in the developing world, where diets are predominantly based on starchy staples (Rice) and barely include animal products and only seasonal fruits and vegetables. (Lodha, 2015) For vulnerable infants and young children, the problem is particularly critical because they need energy- and nutrient-dense foods to grow and develop both physically and mentally and to live a healthy life (Dewey, 2003). For these reasons, dietary diversity is now included as a specific recommendation in the recently updated guidance for complementary feeding of the breast-fed child aged 6 to 23 months. (Kennedy, 2009)

Dietary diversification (DD) is a standard and recommended strategy to counter nutritional problems due to food insecurity and inadequate consumption of different essential micronutrients (Kennedy, 2009). Dietary diversity is believed to be essential to nutrient adequacy as there is no single food that contains all of the essential nutrients required to carry on good health (Kennedy, 2009). Consuming a wide range of foods among and within food groups is a recommended strategy to help guarantee adequate intake of micronutrients (Kennedy, 2009). Hence, Dietary diversity is prominent element of quality diets and the counsel to consume a variety of foods appears in many nutritional guidelines. (Kennedy, 2009) Wearisome diets, mainly based on grains, roots and tubers are found in areas of high food insecurity and add-on to the burden of malnutrition (FAO/WHO, 2002).

The essential nutrients which fulfil the one’s nutritional requirements are not all available in a single food but come from a diet composed of a number and variety of foods (Hsu-Hage & Wahlqvist, 1996). Commonly healthy diets are supposed to be those that are the most varied in nature. Diverse diets have been shown to protect against chronic diseases (Vecchia et al, 1997), as well as being associated with prolonged longevity (Kant et al, 1995) and improved health status (Hodgson et al, 1994).

A study summarises that converting the diet from monotonous to one containing more variety of foods has been found to increase intake of energy as well as micronutrients in developing countries (Hoddinott & Yohannes, 2002; Hatloy et.al, 1998; Ruel et.al, 2004; Steyn et.al, 2006; Onyango et.al, 1998). Intake of a diverse range of foods has been a recommendation to achieve adequate nutrient intake and this recommendation found in the many dietary guidelines of various countries (Kennedy, 2009). The exact number of foods or food groups that one should try to consume over any given period is not commonly described in most dietary guidelines. Like, dietary guideline of Japan recommends to consume 30 different food items per day (Truswell, 1987) While the US promote to consume a variety of nutrient rich foods and beverages within and among 5 basic food groups, with at least one item from each food group consumed daily {the 5 USDA food groups are: cereals, vegetables, fruit, dairy, and protein source foods like meat, fish, poultry, eggs, nuts, beans} (USDA, 2005).

A study conducted in Mali found that the contribution of each food group to nutrient intake depends on two key factors: the quantity consumed and the nutrient density of the food. They found that consumption of grain contributed slightly less than half of the energy intake, and 1/3 of vitamin B_6 and zinc. Further, nuts and seeds supplied 10 % intake of thiamine and folate. Vitamin C rich vegetables also supplied 1/3 of folate and over ten % of Vitamin A. Similarly, milk and yogurt supplied more than 20 % of Vitamin B_{12}, Vitamin A. Surprisingly eggs did not supply > 5 % of any micronutrient. Flesh food group (red meat and large fish) supplied 2/3 of Vitamin $B_{12\ \text{and}}$ > 20 % of intakes of Zinc. Dark green leafy vegetables supplied less than one percent of total energy intake, but 36 percent of vitamin A intake and ten percent or more of intakes of folate and calcium (Kennedy et.al, 2011).

A recent review of six studies concluded the correlation between DD and individual micronutrients. Four out of six studies had positive correlation between DD and Vitamin A and zinc, three studies included Vitamin B_{12}, two or fewer results are available for another micronutrient. (Roman-Vinas et. al, 2009). No consistent pattern is seen across studies in terms of a lower or higher correlation for any individual micronutrient (Kennedy, 2009). In another study related to dietary intake for children 6-23 months of age in ten different countries found positive correlation coefficient of DD bases on seven food group with increases mean micronutrient intake. Many other studies in children (Hatloy, Torheim & Oshaug, 1998; ; Ruel et.al, 2004), adolescents (Mirmiran, 2004) as well as among adults (Ahn, Engelhardt & Joung, 2006; Sodjinou et.al, 2009; Torheim et.al, 2004) have found similar positive associations.

II. SOURCE OF DATA

The study uses data from the Comprehensive National Nutrition Survey (CNNS 2016-2018) India.The age criteria of the survey was pre-schoolers (0–4 years), school-age children (5–9 years) and adolescents (10–19 years) through interviews, a comprehensive set of anthropometric measures and biochemical indicators (CNSS, 2018).

III. SAMPLE DESIGN AND SIZE

The CNNS was carried out via a multi-stage survey design that included households in both rural and urban areas across all 30 states of India. Three target population groups were surveyed: young children (ages 0–4), school-age children (ages 5–9), and adolescents (ages 10–19). A minimum sample size of 1000 for anthropometric and 500 for biochemical indicators was defined for each age group in each state, considering design effects and optimising the sample power with the available resources (CNSS, 2018).

The projected sample was estimated to consist of 122,100 children and adolescents from 2035 primary sampling units (PSUs) nationwide (CNSS, 2018).. For the anthropometric measurements and household survey, a sample size of 40,700 persons was planned for each age group, whereas 20,350 individuals were included in the biological samples for each age group. Using a multi-stage sampling approach, the CNNS selected a representative sample of households and individuals aged 0 to 19 across 30 states. For each state, the rural sample was selected in two phases. Probability proportional to size (PPS) sampling was used in the first stage to select Primary Sampling Units (PSUs), followed by the random systematic selection of households within each PSU in the second stage.

For all participants in the CNNS, a household and individual questionnaire was employed.

Furthermore, to find out the sex differential of the issue, we have done the whole analysis for boys and girls separately.

IV. DIET DATA OVERVIEW

Data from the Comprehensive National Nutrition Survey (CNNS) 2016-2018 will be used for the analysis. The household dietary diversity score (HDDS) is meant to reflect, in a snapshot form, the economic ability of a household to access a variety of foods (Vaasudevan, Thomas & Kurpad, 2022). Studies have shown that increased dietary diversity is associated with socio-economic status and household food security (household energy availability) (Hoddinot and Yohannes, 2002; Hatloy et al., 2000).

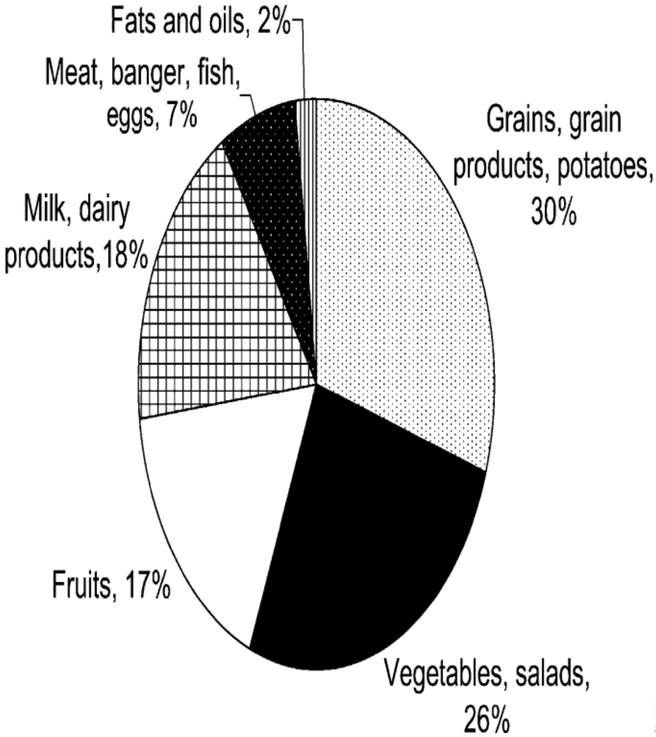
In CNNS 2016, Separate questionnaires were structured based on WHO-FAO's dietary diversity questionnaire for the different age groups; children aged 0–4 years, children aged 5–9 years, adolescents aged 10–14 years and adolescents aged 15–19 years (CNSS, 2018). for older children, daily and seven-day food frequency questions on consumption of key food items were used to assess dietary diversity (CNSS, 2018). To assess dietary diversity for children aged 5 to 9 years and adolescents aged 10–19 years, the consumption of a variety of food groups at least once a day and once per week was assessed (CNSS, 2018). Dietary diversity comprises 10 distinct food items or groups, including Cereals, Milk and Curd, Pulses or Beans, Green Leafy Vegetables, Fruits, Roots and Tubers, Other Vegetables, Chicken or Meat, Fish, and Eggs.

V. DIET DIVERSITY INDEX

We have calculated a new diet diversity score on the basis of the guideline of the German Nutritional Society. We have used the modified version of the Berry-Index so that the index rises if the distribution of foods moves in favour of healthier products (Drescher, Thiele & Mensink, 2007) In this analysis, we derived health values from actual food guidelines of the German Nutrition Society (DGE) (Drescher, Thiele & Mensink, 2007). (Drescher, Thiele & Mensink, 2007) The visual representation of the DGE food guidelines is illustrated by a nutrition circle and a food pyramid (See appendix Fig 2.). The nutrition circle (See appendix Fig 1.) illustrates the shares of food groups that should be consumed in terms of weight. These shares are calculated on the basis of the DGE reference values for nutrient intake. Exemplary diets are constructed to achieve the reference values for nutrient intake on average over a 7-d period. In accordance with the sides of the food pyramid, these shares can be summed up in 3 groups: 73% plant foods, 25% animal foods, 2% fats and oils (Drescher, Thiele & Mensink, 2007).

We made use of these guidelines to create health values for foods (Drescher, Thiele & Mensink, 2007). This explicit valuation of foods is our own interpretation of the DGE guidelines (Drescher, Thiele & Mensink, 2007)The constructed health values are dependent on the position of foods in the pyramid as well as on the affiliation to a main food group (plant foods, animal foods, fats, and oils(Drescher, Thiele & Mensink, 2007)The health value of the main food groups (G_b) was assessed according to the percentage consumption recommendation shown in the nutrition circle(Drescher, Thiele & Mensink, 2007). For the assessment of food subgroups (G_w), the qualitative dimension of the pyramid sides had to be quantified (Drescher, Thiele & Mensink, 2007) It was assumed that each side is divided into 5 different subgroups, because the pyramid is an isosceles triangle, it was further supposed that the 5 subgroups have the same heights on all sides(Drescher, Thiele & Mensink, 2007). The percentage of each subgroup within the upper group was calculated with geometric calculations. The combination of the subgroup shares (G_w) with the main group shares (G_b) yield health factors (hf 1⁄4 G_w "G_b) for 15 different subgroups (Drescher, Thiele & Mensink, 2007). (See appendix Table 1.).

Using these health factors, the health value of an individual's food basket was assessed by multiplying the quantitative shares of single foods in terms of weight (s_i) on total quantities with their corresponding health factor (hf_i). The output is called health value hv 1⁄4 +hf_i " s_i. The maximum health value that can be achieved is 0.26. Thus, division of hv by its maximum ensures that hv is bounded between 1 and nearly 0 (Drescher, Thiele & Mensink, 2007).



2.1 Health factors for 15 food groups derived from thenutrition circle and the food pyramid of the DGE

Food Groups	Share of Sub food groups, %	Health Factor
Plant Food (73%)		0.73 X
Vegetables/fruits/leaf salads/juices	36	0.36 = 0.2628
Wholemeal products/paddy	28	0.28 = 0.2044
Potatoes	20	0.20 = 0.1460
White-meal products/peeled rice	12	0.12 = 0.0876
Snacks and sweets3	4	0.04 = 0.0292
Animal foods (25%)		0.25 X
Fish/low-fat meat/low-fat meat products	36	0.36 =0.090
Low-fat milk/low-fat dairy products	28	0.28 = 0.070
Milk/dairy products	20	0.20 = 0.050
Meat products, sausages, eggs	12	0.12 = 0.030
Bacon	4	0.04 =0.010
Fats and oils (2%)		0.002X
Oilseed rape/walnut oil	36	0.36 = 0.0072
Wheat germ oil/soybean oil	28	0.28 = 0.0056
Corn oil/sunflower oil	20	0.20 =0.0040
Margarines/butter	12	0.12 = 0.0024
Lard/vegetable fat	4	0.04 0.0008

VI. METHODOLOGY

Descriptive statistics, bivariate analysis are used to find the expected results.

We have used the level of BMI (Thin, Normal and Overweight) as the dependent variable, while the confounding variables are the same as previous objectives.

In binary logistic regression, the outcome Y has two levels. If we have an outcome with more than two levels, and the levels are ordered then ordinal logistic regression model is used.

The **ordinal logistic regression model**, as parameterized for an outcome Y with levels ℓ=1,2,...,L is

$$ln(P(Y \leq \ell)P(Y > \ell)) = \zeta\ell - \eta 1X1 - \eta 2X2 - \cdots - \eta kXk$$

for each level ℓ=1,2,...,L−1. This equation is applicable only for levels up to L−1, as extending it to L would result in P(Y>L)=0 in the denominator. Pronounced "zeta," the letter ζ, and "eta," the letter η, are used in this context. Similar to binary logistic regression, the left-hand side represents the log-odds of a probability. However, instead of the probability of an outcome being at one level, it denotes the cumulative probability of an outcome being at any level up to and including a specified level.

VII. RESULTS

A. Level of Body Mass Index (BMI) among Adolescent

The table shows the percentage of boys and girls in two age groups (10-14 years and 15-19 years) falling into each BMI category. In the 10-14 years age group, a higher percentage of boys are categorized as Thin (88.26%) compared to girls (80.61%). However, the percentage of boys and girls in the Normal and Overweight categories is similar in this age group. In the 15-19 age group, a higher percentage of girls are categorized as Normal (46.86%) compared to boys (40.87%). Boys have a slightly higher percentage of Overweight individuals (3.94%) compared to girls (2.98%). The distribution of BMI varies based on school attendance. The majority of boys and girls who attended school are thin, with a lower percentage of normal and overweight. However, among boys and girls who did not attend school, a slightly higher percentage fall into the thin category. The data examines the distribution of BMI based on whether individuals live in urban or rural areas. Urban areas have a higher percentage of Normal and Overweight individuals than rural areas, with a higher percentage of thin individuals. The data shows that as a mother's education level increases from Illiterate to Literate, the percentage of thin individuals decreases, while the percentage of Normal and Overweight individuals increases for both boys and girls. The BMI distribution varies based on the mother's work status. Boys and girls with "Not working" mothers have a slightly higher percentage of thin individuals compared to those with "Working" mothers, who have a higher percentage of Normal and Overweight individuals. Similar to the mother's education, as the father's education level increases from Illiterate to Literate, the percentage of Thin individuals decreases, while the percentage of Normal and Overweight individuals increases for both boys and girls. The BMI distribution differs based on the wealth index of the individuals. "Poor" individuals have the highest percentage of thin individuals, while "rich" individuals have the highest percentage of Normal and Overweight individuals for both boys and girls. The data shows variations in BMI distribution across different caste groups. The percentage of thin individuals is highest among "SC" and "ST" boys and girls, while the percentage of Normal and Overweight individuals is highest among "Others" boys and girls. BMI distribution varies among different religious groups. "Hindu" boys and girls have a higher percentage of Normal and Overweight individuals compared to "Muslim" and "Others" boys and girls, who have a higher percentage of thin individuals. BMI distribution differs based on different regions. Boys and girls from the "Central" region have the highest percentage of thin individuals, while those from the "Northern" region have the highest percentage of Normal and Overweight individuals.

Table 1. Distribution of Body Mass Index (BMI) among Adolescents aged 10-19 years in India

Background Characteristics	Body Mass Index (BMI)					
	Boys			Girls		
Age	Thin	Normal	Overweight	Thin	Normal	Overweight
10-14 years	88.26	10.44	1.31	80.61	17.42	1.97
15-19 Years	55.19	40.87	3.94	50.16	46.86	2.98
Attended School						
Yes	74.32	23.27	2.41	67.04	30.51	2.45

No	77.35	20.37	2.28	63.88	34.14	1.98
Place of residence						
Urban	65.16	30.54	4.29	59.07	37.11	3.82
Rural	77.54	20.69	1.77	69.48	28.56	1.96
Mother's Education						
Illiterate	76.96	21.32	1.72	68.61	29.94	1.46
literate	69.12	27.03	3.85	63.1	32.36	4.54
Mother's work status						
Not working	72.49	24.44	3.07	65.33	32.13	2.54
Working	77.52	21.14	1.34	69.6	28.18	2.22
Father's Education						
literate	73.88	23.53	2.59	67.55	29.76	2.69
Illiterate	75.76	22.26	1.98	65.66	32.56	1.78
Father's work status						
Not working	72.93	26.45	0.63	63.79	35.51	0.7
Agricultural worker	76.82	21.39	1.79	70.67	27.57	1.75
Non-Agricultural worker	73.12	24.04	2.84	65.27	31.86	2.87
Wealth Index						
Poor	82.71	16.75	0.54	72.3	27.02	0.68
Middle	75.5	22.37	2.13	70.56	27.24	2.2
Rich	65.08	30.38	4.53	59.35	36.32	4.33
Caste						
SC	78.08	19.3	2.62	66.85	30.7	2.45
ST	77.74	21.17	1.1	67.98	30.73	1.29
OBC	72.74	25.1	2.17	66.09	31.32	2.58
Others	72.21	24.73	3.05	67.83	29.56	2.6
Religion						
Hindu	74.92	22.91	2.17	66.67	30.84	2.49
Muslim	75.05	22.27	2.68	69.61	28.4	1.99
Others	62.78	30.91	6.31	62.15	35.26	2.6
Regions						
Northern	72.96	24.79	2.25	70.45	27.79	1.76
Central	81.71	17.53	0.76	66.68	31.61	1.71
Eastern	76.61	20.8	2.59	70.1	27.91	2
North-eastern	63.12	34.97	1.91	58.56	38.54	2.91
Western	70.2	25.18	4.62	65.46	30.19	4.35
Southern	62.87	33.07	4.06	61.48	34.64	3.88
Total	74.43	23.16	2.41	66.88	30.7	2.42

B. Level of BMI by DDI and micronutrient deficiency among adolescent

Table shows the effect of DDI and Micronutrient deficiency on Body Mass Index. The table shows that 85% of boys aged 10-14 with diet diversity are thin, and 2 % are overweight. Similarly, 78% of girls in the same age group with high diversity are thin, and 1.71 % are overweight. 92% of boys age 10-14 years and having high diet diversity are thin, and nearly 1 % are overweight. Similarly, 83% of girls in the same age group with high diet diversity are thin, and 2.3 % are overweight.

While those not having Vitamin-A deficiency, 86% of boys are thin, and 1.6 % are overweight compared to that 79% of girls are thin, and 2.2% are overweight. 91 % of Boys in the age group of 10-14 with Vitamin-A deficiency are thin, and 0.8 % are overweight, while 83% of girls with Vitamin-A deficiency are thin, and 2.7% are overweight. Among those without Iodine deficiency, 89% of boys are thin, and only 0.9% are overweight in the same age group, 81% of girls are thin, and 2% are overweight. However, in the same age group of 10-14 years, 84% of boys having Iodine deficiency are thin, and 2% are overweight. Similarly, 77.6% of girls in similar situations are thin, and 2.2% are overweight. In the same age group, those not having Vitamin B-12 deficiency, 87% of boys are thin, and 1% are overweight, and 82% of girls are thin, and nearly 2% are overweight. Whereas, having a deficiency of Vitamin B-12 in the age group of 10-14 years 90% of boys are thin and 0.6 % are overweight, whereas 77% of girls are thin and 1.6% are overweight. Likewise, among those not having folate deficiency 90% of boys are thin, and 1.2 % are overweight and 85% of girls are thin, and 1.5% are overweight. Whereas in the same age group of 10-14 years, 84% of boys having folate deficiency are thin and 1.2 % are overweight compared to that, 73% of girls are thin but 2.5% are overweight.

Now, moving to the 15-19 years age group, having low DDI, 56% of boys are thin and 5% are overweight, while 51% of girls are thin and 4.5 % are overweight. In the same age group having high DDI 57.5% of boys are thin, and nearly 3% are overweight; in comparison to that, 51% of girls are thin and 2.2% are overweight. Again, 57% of Boys in the age group of 15-19 with among those not having Vitamin-A deficiency, 54% of boys are thin and 4.3 % are overweight compared to that 47% of girls are thin, and 3.2% are overweight. While those with Vitamin-A deficiency, 57% of boys are thin, 0.8 % are overweight while 56% of girls are thin and 1.8% are overweight. Now, in the same age group of 15-19 years, without Iodine deficiency, 55% of boys are thin, and only 3.7% are overweight, 51% of girls are thin, and nearly 3% are overweight. However, in the same age group, 53.6% of girls having Iodine deficiency are thin, and 4.3% are overweight; meanwhile, 43% of girls are thin, and 3.4% are overweight. In the like manner, 15-19 age group, of those not having Vitamin B-12 deficiency, 57% of boys are thin and 5% are overweight and 53% of girls are thin and 2.4% are overweight, whereas, having Vitamin B-12 deficiency in the same age group 52% of boys are thin and 3.4 % are overweight, and, 44% of girls are thin and 4 % are overweight. Likewise, among those not having folate deficiency; 57% of boys are thin and 3.8 % are overweight, and 49% of girls are thin and 2.5% are overweight, compared to that, 51% of boys having folate deficiency are thin and 4.5 % are overweight, and, 49% of girls are thin but 4.4% are overweight.

Table 2. Prevalence of BMI by DDI and micronutrient deficiency among adolescent age 10-19 years

	10 - 14 Years						15 - 19 Years					
	Boys			Girls			Boys			Girls		
		BMI			BMI			BMI			BMI	
	Thin	Normal	Overweight	Thin	Normal	Overweight	Thin	Normal	Overweight	Thin	Normal	Overweight
DDI												
Low	85.41	12.61	1.98	78.33	19.95	1.71	55.63	39.12	5.25	50.79	44.67	4.54
Moderate	87.08	12.04	0.88	79.6	18.54	1.86	52.6	44	3.39	48.37	49.26	2.37
High	92.23	6.74	1.03	83.61	14.09	2.3	57.56	39.45	2.99	51.17	46.63	2.2
Vitamin A Deficiency												
Non-Deficient	85.85	12.54	1.61	79.22	18.56	2.22	53.87	41.74	4.39	47.01	49.72	3.27
Deficient	90.95	8.23	0.82	82.92	14.33	2.75	57.05	42.11	0.84	56.66	41.49	1.85
Iodine Deficiency												
Non-Deficient	89.06	9.99	0.95	81.08	16.83	2.09	54.89	41.35	3.77	51.45	45.59	2.96
Deficient	84.39	13.59	2.02	77.64	20.13	2.23	53.64	42	4.36	42.97	53.57	3.47
Vitamin B12 Deficiency												
Non-Deficient	86.84	11.91	1.25	82.26	15.75	1.99	56.71	38.35	4.94	52.9	44.66	2.44
Deficient	90.18	9.18	0.63	77.08	21.28	1.64	51.81	44.76	3.42	43.64	52.17	4.19
Folate Deficiency												
Non-Deficient	89.73	9.05	1.22	84.88	13.6	1.51	56.6	39.55	3.85	48.98	48.51	2.5

Deficient	83.69	15.05	1.26		72.66	24.79	2.55		50.71	44.79	4.5		49.35	46.17	4.49

C. Effect of DDI and micronutrient deficiency on BMI among adolescents

This finding shows the odds of BMI among adolescents age group of 10-19 years. It shows that boys in the age group 10-14 years with high levels of diet diversity are less likely to have higher BMI. Similarly, this remains true for the girls of the same age group who have high diet diversity also have less likelihood of achieving high BMI, which also remains true for girls with low diet diversity but in contrast. the boys with a low diet diversity level are likelier to have high BMI. In the case of Vitamin-A deficiency, boys and girls in the age group of 10-14 are both less likely to have high BMI. Contrasting to this, in the case of Vitamin B-12 deficiency, boys and girls of the same age group of 10-14 show 1.15 and 1.26 OR, which indicating that both are more likely to have higher BMI than and girls without deficiency.

Meanwhile, in the same age group of 10-14, the Odds Ratio for boys with iodine deficiency (Less than 300) compared to those without iodine deficiency (300 and above) is 1.02. This suggests that boys with iodine deficiency have approximately the same odds of higher BMI as boys without iodine deficiency, whereas, Odds Ratio of 1.19 compared to girls without iodine deficiency implies that girls with iodine deficiency are 1.19 times more likely to have higher BMI compared to girls without iodine deficiency.

In the case of Folate deficiency for boys aged 10-14 years, The Odds Ratio for boys with Folate Deficiency compared to those without folate deficiency is 1.37. This means that boys with Folate Deficiency are more likely to have higher BMI compared to boys without folate Deficiency. Similarly, for girls of the same age group o, an odd ratio of 1.24 suggests that those with folate deficiency are also more likely to have higher BMI than those without folate deficiency.

The other half of the table shows the association of DDI and BMI for the age group of 15-19 where boys and girls with high DDI are not significant, but girls with high DDI are more likely to have higher BMI as compared to those having low DDI having Odds Ratio 1.02. Most importantly in this age group, girls having low DDI denoted by a 0.75 Odds ratio (which is also significant) are less likely to have higher BMI. Further, in the age group of 15-19, the Odds ratio in the case of boys and girls both there shows no statistical significance which denies an association between Vitamin-A deficiency and BMI. However, in the same age group, boys with Vitamin-A deficiency are less likely to have higher levels of BMI in comparison to those with no deficiency of Vitamin-A. In the table, for boys aged 15-19 years, the odds ratio for vitamin B-12 deficiency is 1.08. This indicates that boys with vitamin B12 deficiency have 1.08 times the odds of higher BMI compared to boys without deficiency, and for the same age group of girls Odds Ratio of 1.24 compared to those without deficiency. This means that girls with vitamin B12 deficiency are 1.24 times as likely to have higher BMI compared to girls without deficiency. But both the cases are insignificant, which implies no association between Vitamin B-12 and BMI in this analysis.

The age group of 15-19 years of girls with iodine deficiency have an Odds Ratio of 1.36 compared to those without iodine deficiency. This means that girls with iodine deficiency are 1.36 times as likely to have higher BMI compared to girls without iodine deficiency. In the same age group of boys, this case is insignificant, but both boys and girls are more likely to have higher levels of BMI for those with Iodine deficiency (300 and above). The table for folate and BMI association suggest that, in the age group 15-19 years, folate deficiency is significantly associated with an Odds ratio of 0.74 for girls implying a lesser likelihood of high BMI in girl but not in boys, which shows 1.11 Odds ratio for boys which is insignificant.

Table 3. Effect of DDI and micronutrient deficiency on BMI among adolescents age 10-19 years

	10 - 14 Years										15 - 19 Years									
	Boys					Girls					Boys					Girls			
	OR A		95% CI			OR A		95% CI			OR A		95% CI			OR A		95% CI	
DDI																			
Low	1.01		0.76	1.32		0.95		0.73	1.24		0.93		0.71	1.21		0.75	**	0.58	0.98
Moderate ®																			

High	0.75	**	0.56	0.99		0.91		0.71	1.16		0.97		0.75	1.26		1.02		0.79	1.31
Vitamin A Deficiency																			
Non-Deficient ®																			
Deficient	0.89		0.64	1.23		0.81		0.61	1.09		0.58	***	0.40	0.85		1.07		0.79	1.45
Iodine Deficiency																			
Non-Deficient ®																			
Deficient	1.02		0.79	1.30		1.19		0.94	1.49		1.21		0.96	1.51		1.36	***	1.08	1.72
Vitamin B12 Deficiency																			
Non-Deficient ®																			
Deficient	1.15		0.88	1.50		1.26		0.96	1.64		1.08		0.86	1.36		1.24		0.97	1.58
Folate Deficiency																			
Non-Deficient ®																			
Deficient	1.37	**	1.07	1.74		1.24	**	0.99	1.55		1.11		0.89	1.40		0.74	**	0.59	0.93
cut 1	2.30		1.22	3.38		0.75		0.06	1.44		0.77		0.06	1.48		0.59		-0.11	1.28
cut 2	4.73		3.61	5.84		3.54		2.80	4.27		3.57		2.82	4.32		3.77		3.04	4.51

Note: OR-Odds Ratio; CI-Confidence Interval; *** p-value < 0.01 & ** 0.01 < p-value < 0.05; [A] Adjusted for attended school, place of residence, mother's education, father's education, mother's work status, father work's status, wealth index, caste, and religion

VIII. DISCUSSION

The findings presented in this study contribute valuable insights into the intricate interrelationships among diet diversity, micronutrient deficiency, and Body Mass Index (BMI) among adolescents in India. Understanding these dynamics is critical for designing effective interventions to address malnutrition and its associated health consequences in this vulnerable population. Our analysis of BMI distribution among adolescents aged 10-19 years revealed notable disparities influenced by various demographic and socio-economic factors. Gender, age, parental education, household wealth, caste, religion, and geographic region all observed to be significant determinants of BMI status. These findings underscore the multifaceted nature of malnutrition, which is shaped by complex interactions between biological, socio-economic, and environmental factors. The prevalence of BMI by diet diversity and micronutrient deficiency provided further insights into the complex relationship between dietary intake, nutrient status, and BMI. Notably, adolescents with high diet diversity tended to exhibit higher rates of thinness, while those with certain micronutrient deficiencies, such as Vitamin A, B-12, and folate, displayed distinct patterns of BMI distribution. These findings resemble the findings of existing research (Jaiswal et.al., 2021) and highlight the importance of addressing both dietary diversity and specific nutrient deficiencies in combating malnutrition among adolescents.

Moreover, our analysis of the association between diet diversity, micronutrient deficiency, and BMI revealed significant relationships that varied across age groups and genders. While high diet diversity appeared to act as protective effects against higher BMI in younger adolescents, the association was less clear in older age groups. Similarly, the impact of micronutrient deficiencies on BMI varied, with some deficiencies showing significant associations while others did not. These findings underscore the need for targeted interventions tailored to specific age groups and nutritional needs.

In conclusion, our findings highlight the complex interplay between diet diversity, micronutrient deficiency, and BMI among adolescents in India. Addressing malnutrition in this population requires comprehensive strategies that encompass promotion of dietary diversity, targeted nutrient supplementation, and socio-economic empowerment. By understanding the underlying determinants of malnutrition and tailoring interventions accordingly, targeted policy towards improving the nutritional status of the adolescents in India would ensure to bring down the prevalence of malnourishment and bring about a status of wellbeing among the adolescents.

There are certain limitations of this study, including the reliance on cross-sectional data, which precludes causal inference. Additionally, the use of self-reported dietary intake and reliance on proxy measures for assessing nutrient status may introduce measurement error. Future research employing longitudinal designs and more robust measures of dietary intake and nutrient status could provide further insights into these relationships.

IX. CONCLUSION

In summary, the comprehensive analysis presented in Tables 5.1 to 5.3 sheds light on the intricate interplay between various demographic factors, dietary habits, and nutritional deficiencies concerning body mass index (BMI) among adolescents aged 10-19 years in India.

Table 5.1 illustrates significant disparities in BMI distribution across different age groups, genders, educational backgrounds of parents, socioeconomic status, and geographic regions. These findings underscore the need for tailored interventions addressing diverse socio-economic determinants to foster healthier BMI outcomes among adolescents.

Furthermore, Table 5.2 provides valuable insights into the impact of dietary diversity and micronutrient deficiencies on BMI, highlighting the importance of promoting balanced nutrition to mitigate the risk of malnutrition and support optimal BMI levels among adolescents.

Lastly, Table 5.3 offers critical information on the odds of BMI among adolescents, emphasizing the role of dietary diversity and specific micronutrient deficiencies in shaping BMI outcomes. These findings underscore the significance of targeted interventions addressing nutritional gaps to enhance BMI outcomes and overall health among adolescents.

Overall, this analysis underscores the complexity of factors influencing BMI among adolescents and underscores the importance of multifaceted approaches integrating nutrition education, socioeconomic support, and healthcare interventions to promote healthier BMI outcomes in this population.

REFERENCES

[1] NIN, N. (2010). requirements and recommended dietary allowances for Indians. A Report of the Expert Group of Indian Council of Medical Research, National Institute of Nutrition, ICMR, Hyderabad.

[2] Kennedy, G., Nantel, G., & Shetty, P. (2003). The scourge of" hidden hunger": global dimensions of micronutrient deficiencies. Food Nutrition and Agriculture, (32), 8-16.

[3] World Health Organization (WHO). (2003). Food and Agriculture Organization of the United Nations (FAO). Vitamin A. Human Vitamin and Mineral Requirements. Report of a Joint FAO/WHO Expert Consultation, Bangkok, Thailand. Rome: FAO/WHO.

[4] Kennedy, G., Nantel, G., & Shetty, P. (2003). The scourge of" hidden hunger": global dimensions of micronutrient deficiencies. Food Nutrition and Agriculture, (32), 8-16.

[5] Nair, M. K., Augustine, L. F., & Konapur, A. (2016). Food-based interventions to modify diet quality and diversity to address multiple micronutrient deficiency. Frontiers in public health, 3, 277

[6] Tontisirin, K., Nantel, G., & Bhattacharjee, L. (2002). Food-based strategies to meet the challenges of micronutrient malnutrition in the developing world. Proceedings of the Nutrition Society, 61(2), 243-250.

[7] Ruel, M. T. (2003). Operationalizing dietary diversity: a review of measurement issues and research priorities. The Journal of nutrition, 133(11), 3911S-3926S.

[8] Kennedy, G., Razes, M., Ballard, T., & Dop, M. C. (2010). Measurement of dietary diversity for monitoring the impact of food-based approaches. In International symposium on food and nutrition security, Rome.

[9] Dewey, K. (2003). Guiding principles for complementary feeding of the breastfed child.

[10] Vaccaro, J. A., & Huffman, F. G. (2013). Race/ethnicity-, gender-and age-specific differences in micronutrient intakes of US adults

with and without diabetes. International journal of food sciences and nutrition, 64(2), 175-184.
[11] Pritwani, Richa & Mathur, Pulkit. (2015). Strategies to Combat Micronutrient Deficiencies: A Review. International Journal of Health Sciences & Research. 3625.
[12] World Health Organization (WHO). (2003). Food and Agriculture Organization of the United Nations (FAO). Vitamin A. Human Vitamin and Mineral Requirements. Report of a Joint FAO/WHO Expert Consultation, Bangkok, Thailand. Rome: FAO/WHO.
[13] Wahlqvist, M. L., & Hsu-Hage, B. (1996). Food variety of adult Melbourne Chinese: A case study of a population in transition. Dietary patterns of selected countries, tea and coffee: metabolic consequences. World review of nutrition and dietetics, 79.
[14] La Vecchia, C., Muñoz, S. E., Braga, C., Fernandez, E., & Decarli, A. (1997). Diet diversity and gastric cancer. International Journal of Cancer, 72(2), 255-257.
[15] Kant, A. K., Schatzkin, A., & Ziegler, R. G. (1995). Dietary diversity and subsequent cause-specific mortality in the NHANES I epidemiologic follow-up study. Journal of the American College of Nutrition, 14(3), 233-238.
[16] Hodgson, J. M., Hsu-Hage, B. H. H., & Wahlqvist, M. L. (1994). Food variety as a quantitative descriptor of food intake. Ecology of food and nutrition, 32(3-4), 137-148.
[17] Hoddinott, J., & Yohannes, Y. (2002). Dietary diversity as a food security indicator (No. 583-2016-39532).
[18] Hatløy, A., Torheim, L. E., & Oshaug, A. (1998). Food variety—a good indicator of nutritional adequacy of the diet? A case study from an urban area in Mali, West Africa. European Journal of Clinical Nutrition, 52(12), 891-898.
[19] Ruel, M., Graham, J., Murphy, S., & Allen, L. (2004). Validating simple indicators of dietary diversity and animal source food intake that accurately reflect nutrient adequacy in developing countries. Report submitted to GL-CRSP.
[20] Steyn, N. P., Nel, J. H., Nantel, G., Kennedy, G., & Labadarios, D. (2006). Food variety and dietary diversity scores in children: are they good indicators of dietary adequacy? Public health nutrition, 9(5), 644-650.
[21] Onyango, A., Koski, K. G., & Tucker, K. L. (1998). Food diversity versus breastfeeding choice in determining anthropometric status in rural Kenyan toddlers. International journal of epidemiology, 27(3), 484-489.
[22] Truswell, A. S. (1987). Evolution of dietary recommendations, goals, and guidelines. American journal of clinical nutrition (USA).
[23] USDA. Dietary guidelines for Americans 2005 [monograph on the Internet]. Washington: USDA [cited March 1, 2006].
[24] Kennedy, G., Fanou, N., Segheiri, C., Arimond, M., Koreissi, Y., Dossa, R., & Brouwer, F. J. K. I. D. which food groups are associated with probability of adequate intake of 11 micronutrients in the diets of women in urban mali? evaluation of dietary diversity scores for assessment of micronutrient intake and food security in developing countries, 69.
[25] Román-Vinas, B., Barba, L. R., Ngo, J., Martínez-González, M. Á., Wijnhoven, T. M., & Serra-Majem, L. (2009). Validity of dietary patterns to assess nutrient intake adequacy. British Journal of Nutrition, 101(S2), S12-S20.
[26] Hatløy, A., Torheim, L. E., & Oshaug, A. (1998). Food variety—a good indicator of nutritional adequacy of the diet? A case study from an urban area in Mali, West Africa. European Journal of Clinical Nutrition, 52(12), 891-898.
[27] Ruel, M., Graham, J., Murphy, S., & Allen, L. (2004). Validating simple indicators of dietary diversity and animal source food intake that accurately reflect nutrient adequacy in developing countries. Report submitted to GL-CRSP.
[28] Mirmiran, P., Azadbakht, L., Esmaillzadeh, A., & Azizi, F. (2004). Dietary diversity score in adolescents-a good indicator of the nutritional adequacy of diets: Tehran lipid and glucose study. Asia Pacific journal of clinical nutrition, 13(1), 56-60.
[29] Chul Ahn, B., Engelhardt, K., & Joung, H. (2006). Diet variety is associated with socio-economic factors. Ecology of food and nutrition, 45(6), 417-430.
[30] Sodjinou, R., Agueh, V., Fayomi, B., & Delisle, H. (2009). Dietary patterns of urban adults in Benin: relationship with overall diet quality and socio-demographic characteristics. European journal of clinical nutrition, 63(2), 222-228.

[31] Torheim, L. E., Ouattara, F., Diarra, M. M., Thiam, F. D., Barikmo, I., Hatløy, A., & Oshaug, A. (2004). Nutrient adequacy and dietary diversity in rural Mali: association and determinants. European journal of clinical nutrition, 58(4), 594-604.