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HIDDEN MARKOV MODEL FOR PREVALENCE OF MICRONUTRIENTS DEFICIENCY AMONG CHILDREN AND ADOLESCENTS IN INDIA

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ABSTRACT
There is a common problem of nutrient deficiencies in underdeveloped nations, which is also a problem in the countries among adolescents and children. According to United Nations Children's Fund (UNICEF), they are not receiving the vitamins they need. It is widely accepted that vitamins A, D, iron, iodine, zinc, and vitamin B12 are important micronutrients of human health in children and adolescents. A study is carried out to estimate prevalence of most important three preventable micronutrient deficiencies (vitamin A, vitamin D and zinc) in India. Hidden Markov models are explored for prevalence of above three deficiencies in India as a whole. The model has three hidden states and three observations. The Forward and Viterbi algorithms have been used to determine the probable observation and hidden states sequence, respectively. The model parameters have been optimised using the Baum-Welch algorithm. By calculating root mean square error (RMSE), the model has been evaluated for three age groups [(0-4), (5-9), and (10-19)]. Then, the RMSE of the model is calculated using the leave-one-out cross-validation method. Additionally, it is discovered that the RMSE of the optimised model was lower than the persistent forecast and standard deviation for their respective periods (2016–18).

Keywords: *Hidden Markov Model, Micronutrients, deficiencies, Children and Adolescents.*

1. INTRODUCTION
Nutrition is an essential component of human life and is required for living a healthy life. Macronutrients and micronutrients are the two types of nutrition. Although the number of micronutrients, vitamins, and minerals required in a balanced diet is minimal, they have a significant impact on a child's physical and mental development. Particularly, micronutrients are required for a variety of body activities, including physical growth, vision, reproduction, morphogenesis and immunity. The overall prevalence of VAD in India is 17.54 children who are exposed to longer duration of breast feeding have lower prevalence of VAD. Major states having children with VAD are Jharkhand, Mizoram, Madhya Pradesh, Andhra Pradesh, Telangana and Haryana and the studies conducted in South India has shown severe visual impairment which is one of the consequences of VAD in Andhra Pradesh by Krishnaiah et. al [11]. Poor diversity intakes of vitamin A rich foods (or) having a minimum dietary diversity are some causes of VAD in developing countries mostly among young children by Nelson KE et.al [12]. A few isolated studies have reported 7-55% prevalence of sub-clinical VAD, based on serum retinol levels in India among school-age children and adolescents (1-18 years) by Pant I et.al [13]. However, these studies were conducted between 15 and 30 years ago; dietary conditions in India have improved and further, serum retinol concentrations were not adjusted for inflammation, which can lower their values and overestimate the prevalence of subclinical VAD. Having the recent Comprehensive National Nutritional Survey (CNNS, 2016-2018) [7]. Vitamin D deficiencies during childhood are of major public health relevance in India and around the world. The physiology of vitamin D production and metabolism has been recently reviewed in details by Holick MF [14]. Many studies provide incomplete data regarding vitamin D deficiency risk factors, which include breast feeding without supplementation, dark skin pigmentation (or) race, female gender living at a northern latitude, lack of direct sun exposure and winter season, when serum vitamin D concentrations are at a nadir by Hickey L et.al.[15]. Susanna Y Hub et.al, [A2] had discussed the definitions, epidemiology, clinical impacts and treatment of vitamin D deficiency in children and young people. Vitamin A is necessary for the health and regeneration of respiratory and gastrointestinal epithelia, as well as for the proper functioning of the human immune system. Vitamin A deficiency can led to several health problems, especially infection susceptibility, stunting, eye health, and vision problems by Olson JA, et al.,[4]. According to a UNICEF report, vitamin A can increase a child's

survival chances by 12–24% by [5]. This deficiency has also been related to an increase in child mortality, due to detrimental impacts on the immunological system by Beaton GH [6].

2. Data Sources and Proposed methodology:

The Comprehensive National Nutrition Survey (CNNS) was a community based cross sectional survey conducted among Indian children and adolescents in 29 states and union territory of India from February 2016 to October 2018 in collaboration with UNICEF India and Population Council under the supervision of the ministry of Health and family welfare Government of India.

Hidden Markov Model (HMM) is in which the distribution that changes through time according to the states of a Hidden Markov Chain. The theory of HMM was proposed by Baum LE and Petrie T (1966) [1]. The 1st order Markov property in probability theory refers to a stochastic process in which the future state of the system was only related to the current state by M. H Davis (2018) [3]. Accordingly, each HMM is characterized by some basic components as follows:

$\lambda = \{N, V, A, B, \pi\}$

i. N is the number of states in the model and the discrete set S is often used to represent different hidden sates:

$S = \{S_1, S_2, ..., S_N\}$

ii. Observation symbols (M) of per state are respected by V as:

$V = \{V_1, V_2, ..., V_M\}$

iii. $A = \{a_{ij}\}$ is a N*N transition matrix, where a_{ij} denotes the transition probability of moving from S_i to S_j :

$a_{ij} = P\{q_{t+1} = S_j / q_t = S_t\}$ $1 \le i,j \le N$ and $\sum a_{ij} = 1$ for all j. Where the state sequence $q_1, q_2, ..., q_t$ in the Markov model and q_t identify the current state.

iv. $B = \{b_j(O_t)\}$ is a N*M emission matrix, where $\{b_j(O_t)\}$ denote the probability of observing O_t at state j. This matrix construction the following constraints should be satisfied:

$\{b_j(O_t)\} \ge 0$, $1 \le j \le N$, $1 \le O_t \le M$ and $\sum_{j=1}^{N} \{b_j(O_t)\} = 1$ for all t.

v. $\pi = \{\pi_i\}$ is the prior probability vector and π_i denote the probability of initial states in time zero.

$\pi_i = P\{q_1 = i\}$, $1 \le i \le N$ and $\sum_i \pi_i = 1$ for all i. Accordingly, we illustrate an HMM with parameter λ, where λ = {A, B, π }is our model. If we consider each new reportage as an observed symbol & state comprising of any of O = {Children (1-4) [C_1], Children (5-9) [C_2], Adolescents (10-19) [A]}and we consider that state Union Territory goes through the following hidden states: H = {Mild Health Problem (MHP), Moderate Health Problem (MDP), Severe Health Problem (SHP)}. We need to determine the parameter (λ) that best fit the training data where A is state-transition probability matrix, B is visible symbol probability matrix and π is probability distribution of hidden states at the initial state. The above details of procedures are given in the tutorial by Rabiner [2].

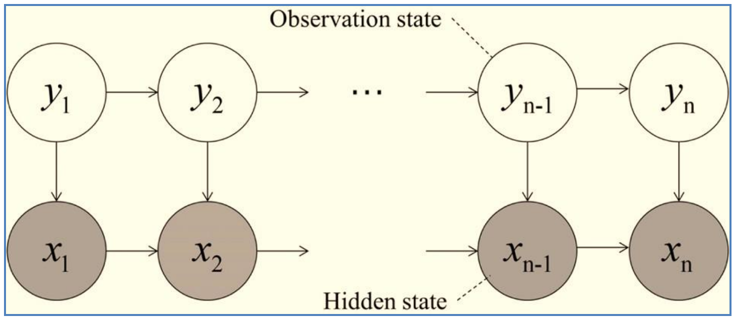

Figure 1: Pattern of an HMM

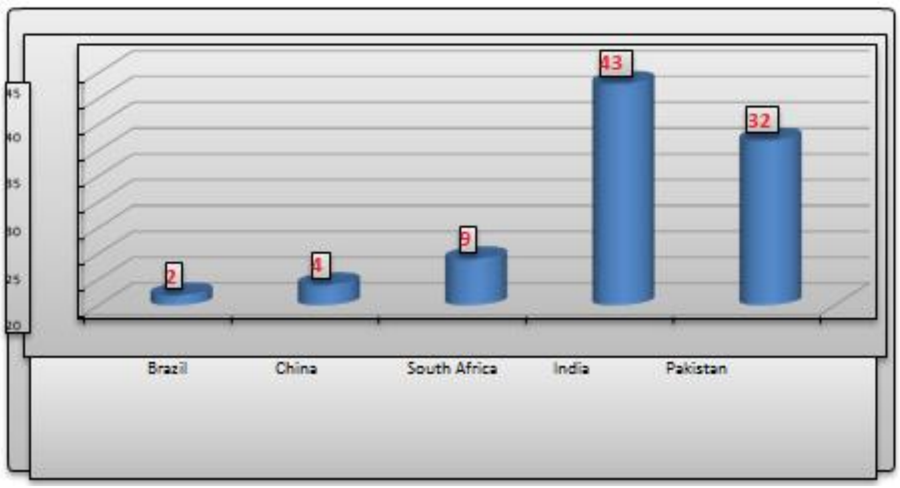

Figure 2: Underweight children in the developing countries (%).

According to Figure 1, India had nearly 43% of the world's underweight children, compared to 32% in Pakistan and 9% in South Africa. The foundational component of children's total mental and physical development is their nutritional status.

Table (1): Inferring Hidden States from our Observations.

State	Age: 1-4	Age: 5-9	Age: 10-19
MHP	L	M	H
MDP	M	H	L
SHP	H	M	L

We are making use of inferred states and derive state transitions. We applied this approach for data between 2016-18. Which detailed in table (2). Then, we estimate state transition values and observation values (see table 3 and 4).

State	Vitamin A				Vitamin D				Zinc			
	1-4	*5-9*	*10-19*	*Symbol*	*1-4*	*5-9*	*10-19*	*Symbol*	*1-4*	*5-9*	*10-19*	*Symbol*
Delhi	17.8	21.9	12.6	MDP	32.5	43.4	47.1	SHP	18.9	28.6	42.6	MDP
Haryana	26.1	24.2	8.9	SHP	27.6	45.5	53.8	SHP	6.2	9.1	19.4	MHP
Himachal Pradesh	5.9	11.4	3.3	MHP	4.6	15.4	17.6	MHP	41.1	37.7	51.6	SHP
Jammu & Kashmir	8.7	12.9	7.0	MHP	22.9	36.0	52.8	SHP	21.4	24.7	38.6	SHP
Punjab	17.2	22.9	12.8	MDP	52.1	76.1	68.0	SHP	21.0	25.2	51.8	SHP

Rajasthan	0	1.0	1.9	MHP	25.2	23.9	25.8	SHP	9.1	6.5	22.6	MHP
Uttarakhand	14.3	23.1	16.4	MDP	46.4	62.0	62.9	SHP	22.4	21.6	29.2	SHP
Chhattisgarh	26.6	29.3	25.7	SHP	10.5	18.5	21.6	MDP	18.6	17.1	36.2	MDP
Madhya Pradesh	27.1	13.4	13.2	SHP	7.7	19.7	23.0	MHP	22.3	12.3	19.9	SHP
Uttar Pradesh	17.1	28.7	18.8	MDP	13.2	12.3	19.4	MHP	22.1	18.3	26.3	SHP
Bihar	23.5	28.3	21.9	SHP	22.7	25.8	35.7	SHP	19.7	16.1	23.7	MDP
Jharkhand	43.2	42.3	29.8	SHP	19.2	20.0	29.6	MDP	28.4	21.9	49.8	SHP
Odisha	19.8	18.3	19.1	MDP	6.7	12.4	18.4	MHP	18.7	15.8	42.4	MDP
West Bengal	5.0	3.9	4.9	MHP	7.0	10.2	19.5	MHP	15.2	14.4	26.6	MDP
Arunachala Pradesh	14.8	14.7	9.5	MDP	7.3	14.3	21.9	MHP	8.4	9.2	20.1	MHP
Assam	21.4	16.6	14.3	SHP	1.1	4.0	7.1	MHP	27.1	18.2	33.9	SHP
Manipur	17.1	22.6	12.5	MDP	41.2	55.5	59.8	SHP	26.6	35.3	52.8	SHP
Meghalaya	6.3	9.9	5.6	MHP	2.1	5.8	6.6	MHP	14.3	23.3	49.3	MDP
Mizoram	39.2	46.8	21.5	SHP	5.5	9.0	13.4	MHP	4.6	5.0	6.8	MHP
Nagaland	0	0	0	MHP	2.2	4.1	7.4	MHP	0	2.1	4.3	MHP
Sikkim	2.7	5.4	4.7	MHP	14.2	18.3	18.8	MDP	22.4	17.8	36.8	SHP
Tripura	20.6	26.1	19.2	SHP	15.2	14.7	28.8	MDP	17.1	18.7	39.3	MDP
Goa	2.4	7.3	3.6	MHP	18.2	23.3	21.5	MDP	25.6	11.4	25.8	SHP
Gujarat	14.6	26.4	16.8	MDP	25.2	29.0	35.5	SHP	19.8	23.6	55.1	MDP
Maharashtra	9.4	8.9	8.1	MHP	12.8	17.6	22.1	MDP	12.3	8.1	25.1	MDP
Andhra Pradesh	20.8	22.8	13.0	SHP	4.9	10.3	15.9	MHP	10.0	9.4	20.6	MDP
Karnataka	9.6	14.5	8.5	MHP	4.8	8.5	15.6	MHP	20.1	19.8	46.8	SHP
Kerala	17.1	26.5	13.2	MDP	11.8	22.6	31.6	MDP	9.0	4.8	17.2	MHP
Tamil Nādu	13.1	10.0	14.3	MDP	1.4	5.4	9.8	MDP	20.1	21.8	46.3	SHP
Telangana	26.5	35.0	19.7	SHP	9.6	5.5	8.8	MHP	10.1	9.3	27.9	MHP

Table (3): Estimation of Hidden Markov model parameter A state Transition value for Vitamin deficiency.

Micronutrition's	Source	Target states				Target states				Target states		
	Mild health problem (MHP)	MHP	MDP	SHP	Moderate health problem (MDP)	MHP	MDP	SHP	Sever health problem (SHP)	MHP	MDP	SHP
Vitamin A		1	5	4		4	1	5		4	3	2
Vitamin D		8	2	3		4	3	1		2	3	4
Zinc		1	1	5		3	3	4		3	6	3

Table (4): Estimation of Hidden Markov model parameter B state Observation value for Vitamin deficiency.

Micronutrition's	MHP			MDP			SHP		
	Children (1-4)	Children (5-9)	Adolescents (10-19)	Children (1-4)	Children (5-9)	Adolescents (10-19)	Children (1-4)	Children (5-9)	Adolescents (10-19)
Vitamin A	45	71.3	42.7	162.9	215.1	146	275	284.8	187.2
Vitamin B	76.7	131.5	194.6	103.3	140.4	183.8	295.8	397.2	441.4
Zinc	47.4	46	118.3	144.8	151.5	305.8	320.6	286	509.6

Transition Probability Matrix for Vitamin A deficiency

$$\begin{bmatrix} 0.1 & 0.5 & 0.4 \\ 0.4 & 0.1 & 0.5 \\ 0.4 & 0.3 & 0.3 \end{bmatrix}$$

Transition Probability Matrix for Vitamin D deficiency

$$\begin{bmatrix} 0.6 & 0.2 & 0.2 \\ 0.5 & 0.4 & 0.1 \\ 0.2 & 0.3 & 0.5 \end{bmatrix}$$

Transition Probability Matrix for Zinc deficiency

$$\begin{bmatrix} 0.1 & 0.1 & 0.8 \\ 0.3 & 0.3 & 0.4 \\ 0.2 & 0.5 & 0.3 \end{bmatrix}$$

Observation Probability Matrix for Vitamin A deficiency

$$\begin{bmatrix} 0.28 & 0.45 & 0.27 \\ 0.19 & 0.33 & 0.49 \\ 0.23 & 0.22 & 0.55 \end{bmatrix}$$

Observation Probability Matrix for Vitamin D deficiency

$$\begin{bmatrix} 0.31 & 0.41 & 0.28 \\ 0.25 & 0.33 & 0.42 \\ 0.24 & 0.25 & 0.51 \end{bmatrix}$$

Observation Probability Matrix for Zinc deficiency

$$\begin{bmatrix} 0.37 & 0.38 & 0.25 \\ 0.26 & 0.35 & 0.39 \\ 0.29 & 0.26 & 0.45 \end{bmatrix}$$

3. Analyse and Results:

In the study, the HMM has been developed for quantitative prediction of vitamin deficiency in our country. The prevalence of micronutrients in India is shown in the following Figure. 3, 4, and 5.

3.1 Graphical Representation for Vitamin A deficiency in India:

Vitamin A deficiency children and adolescents are almost equal. Children in age group 0–4 and 5-9 years have the highest prevalence of vitamin A deficiency, while children in age group 10-19 years have the lowest prevalence (See. Fig. 3).

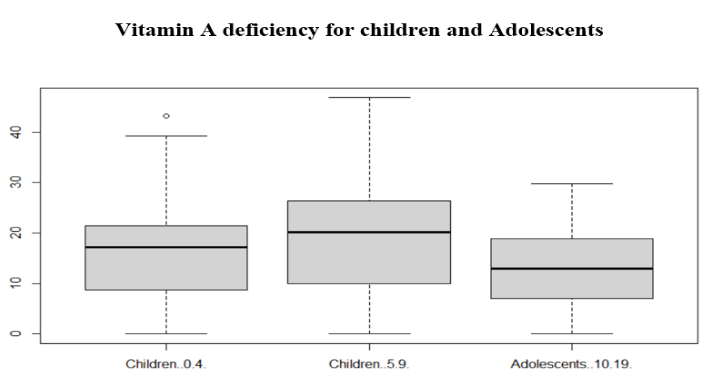

Figure 3. Graphical representation for vitamin A deficiency

3.2 Graphical Representation for Vitamin D deficiency in India:

Vitamin D deficiency children and adolescents are almost equal. Children in age group 0–4 and 5-9 years have the lowest prevalence of vitamin D deficiency, while children in age group 10-19 years have the highest prevalence (See. Fig. 4).

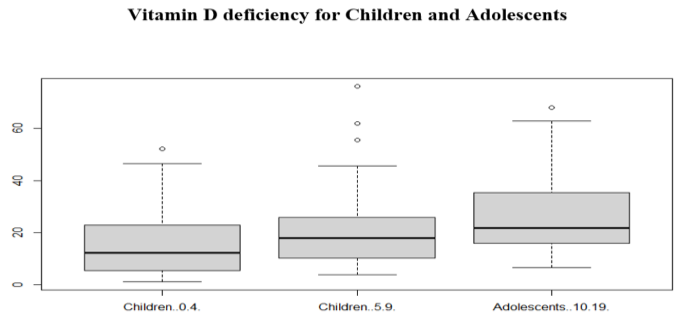

Figure 4. Graphical representation for vitamin D deficiency

3.3 Graphical Representation for zinc deficiency in India:

Zinc deficiency children and adolescents are almost equal. Children in age group 0–4 and 5-9 years have the lowest prevalence of Zinc deficiency, while children in age group 10-19 years have the highest prevalence (See. Fig. 5).

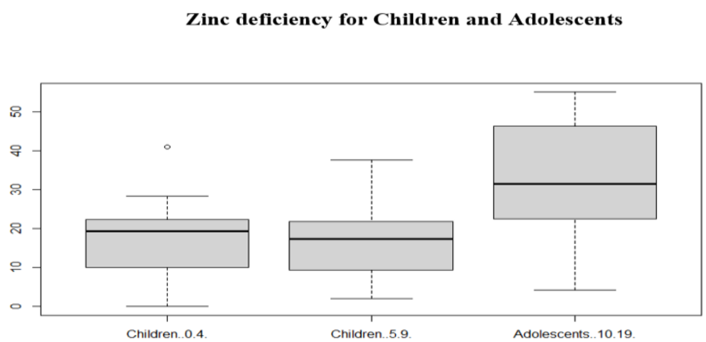

Figure 5. Graphical representation for zinc deficiency

From table (2) we can find out the status of three types of health problems (MHP, MDP, SHP) in the top ten most affected states in figure 7.

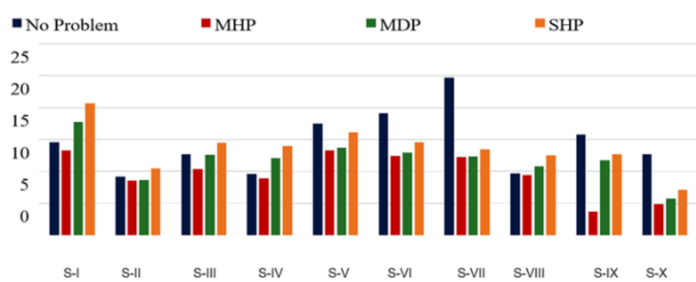

Figure 6. Nutrition's Analysis for top-ten states in India.

As per our calculation, figure 7, shows the fluctuation (on average) of vitamin A, vitamin D and zinc deficiency status for the three age groups (0-4, 5-9 and 10-19) we have taken in 2018-2020 and 2020-2022.

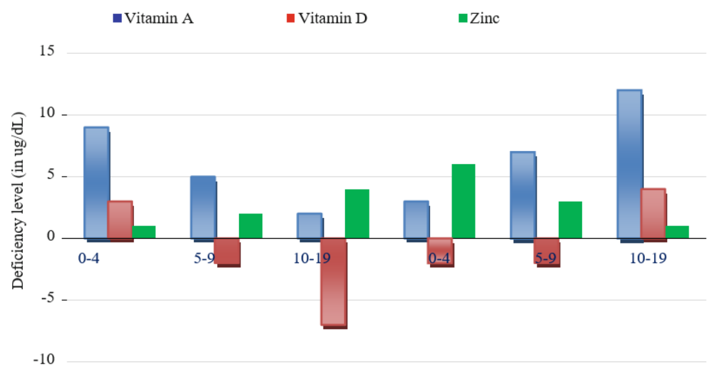

Figure 7. Average micronutrients deficiency for children and adolescents age groups (0-4, 5-9 and 10-19)

Table 5. Observed and model predicted cumulative prevalence probability percentage (with 95% CI) of Children and adolescents in India.

Micronutrition deficiency (CRP≤5mg/L)															
Age			**Children**				**Adolescents**			**Children**			**Adolescents**		
	Samples	**Diet**	**Vitamin A**	**Vitamin D**	**Zinc**	**Diet**	**Vitamin A**	**Vitamin D**	**Zinc**	**Vitamin A**	**Vitamin D**	**Zinc**	**Vitamin A**	**Vitamin D**	**Zinc**
0-4	240	70.6	16.45	13.89	10.86	76.0	0	0	0	17.79	15.04	11.52	0	0	0
5-6	290	65.6	16.39	14.26	10.45	35.1	0	0	0	18.10	15.48	11.54	0	0	0
7-9	360	75.7	16.86	14.65	10.23	38.2	0	**0**	0	18.27	15.10	12.09	0	0	0
10-12	430	76.4	0	0	0	13.5	14.87	12.56	9.41	0	0	0	15.86	12.94	8.76
13-15	480	81.4	0	0	0	16.7	15.63	12.43	8.95	0	0	0	16.22	13.22	9.28
16-18	460	77.7	0	0	0	80.0	15.06	11.23	9.56	0	0	0	16.06	13.42	9.45
19	370	78.6	0	0	0	29.4	14.44	11.02	9.06	0	0	0	16.33	12.66	9.23

In support of our study using simple random sampling technique, malnutrition surveys in rural and urban areas of 16 states in North, South, East and West are shown in figure 8 explains to us.

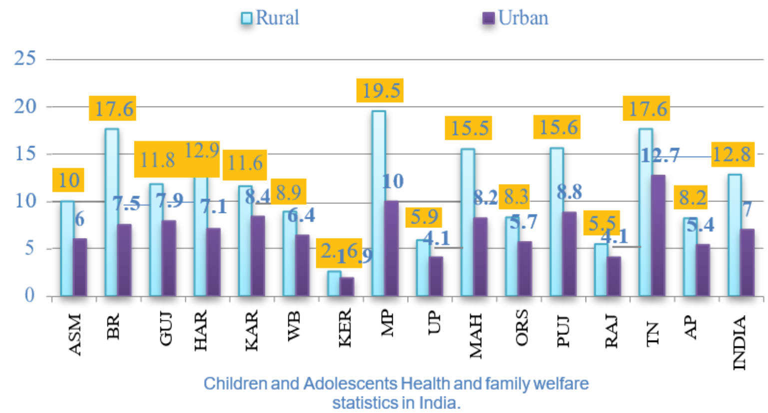

Figure 8. Health statistics for rural and urban area in India.

We have calculated the mortality rate of children who died due to micronutrient deficiency from 2016 to 2022 and projected it to 2024. Its information can be seen in Figure 9.

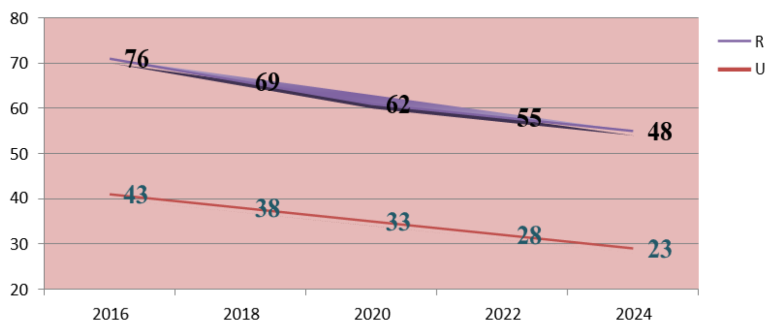

Figure 9: Presents the Child mortality rate by residence from 2016 to 2024.

DISCUSSION

Children in India lack vitamins due to socioeconomic and demographic inequalities. Increased parental education and longer breastfeeding periods may reduce vitamin insufficiency in children. Children who are stunted and anemic are shown to have higher rates of vitamin deficiencies. The study recommends focusing on the targeted child populations that are more likely to experience vitamin deficiencies and implementing focused group therapies. In this article, we have explored micronutrient deficiencies among children and adolescents in India. In this study, we use data of micronutrient deficiencies among children and adolescents from 30 specific states. With the information we have from the CNNS survey (2016–2018), we have predicted the next two years. We forecast the next two years using this Hidden Markov Model. However, three micronutrients (vitamin A, vitamin D, and zinc) Similarly, we divide it into age groups (0–4, 5–9, 10–19) and predict it as a hidden state (MHP, MDP, SHP). For this, we estimate the root mean square error for vitamin A, vitamin D, and zinc at age (0–4), vitamin A, vitamin D, and zinc at age (5–9), and vitamin A and vitamin D at age (10–19). Zinc is also calculated separately. Based on this, we also calculate the difference in Root Mean Square error between the next two years. Through this and the Hidden Markov Model forward and Backward algorithm method, we calculated for the next two years, i.e., 2018–2020 and 2020–2022, that vitamin A deficiency in 2018–2020 children was 16.56% and in adolescents was 15.04%. Similarly, vitamin A deficiency in 2020–2022, in children (15.04%) and adolescents (16.20%), Vitamin D deficiency in 2018–2020 children: 14.26%; adolescents: 11.81%; vitamin D deficiency in 2020–2022, children: 15.20%; adolescents: 13.06%. Zinc Deficiency in 2018–2020 Children: 10.51% and adolescents: 9.24% Zinc Deficiency in 2020–2022 Children: 11.7%, and adolescents: 9.18% (This is an Average Percentage) (See.

Table 5). Considering these, we have calculated the mortality rate of children who died due to micronutrient deficiency from 2016 to 2022 and projected it to 2024. This information can be seen in Figure 9. Through this study, we have found that micronutrient deficiencies are more common among children and less common among adolescents. Perticularly, it is more common in rural areas and slightly less common in urban areas (see fig. 8). This results in increased infant mortality due to micronutrient deficiency.

CONCLUSION

This study is a comprehensive effort to understand the state level analogy in the differential of selected children and adolescents. Additionally, we suggest in investing more on the targeted children and adolescents who are at more risk in developing micronutrients deficiency. Also, we proposed the hidden state of hidden Markov model to predicted the future hidden state of a micronutrition deficiency in our country. The study's key findings demonstrate the relationship between parental traits and child health and health care utilization, with the goal of informing policy makers and scholars in the field of public health research. Furthermore, advises the main careers (parents) should be well-informed about the value of immunizations for their children as well as their child's nutritional health.

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