A HYBRID MULTINOMIAL LOGISTIC REGRESSION-NEURAL NETWORK APPROACH TO MODELLING NUTRITIONAL STATUS OF NIGERIAN WOMEN OF REPRODUCTIVE AGE

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Abstract

This study focuses on modelling the nutritional status of Nigerian women of reproductive age using a hybrid approach combining multinomial logistic regression model with a neural network component. A secondary data extracted from Multiple Indicators Cluster Survey (MICS 6: 2021-2022) report was the source of data for the study while data analysis was carried out with the aid of STATA Software version 16.0. Study results show that all coefficients of predictor variables greater than 3.84 of chi-square distribution are statistically significant in the modified model with respect to nutritional status of WRA. The study also revealed that all predictor variables with $p-value$ of less than 0.05 significance level are significantly associated with outcome variables (underweight, overweight and obesity). By integrating multinomial logistic regression for interpretability with neural network components for enhanced predictive accuracy, this study provides a robust modelling framework. It was recommended that establishment of a comprehensive database on women's health and nutrition in Nigeria, incorporating socio-demographic, economic and health-related factors after proper data collection is ensured.

Keywords: Nutritional Status, Women of Reproductive Age, Multinomial Logistic Regression, Neural Network, Nigeria and Maternal Health.

INTRODUCTION

Malnutrition remains a persistent global problem, contributing to significant increases in morbidity and mortality, particularly in low- and middle-income countries (GNP, 2020). Malnutrition takes two forms: undernutrition and over-nutrition, and it is particularly common among women of reproductive age (WRA), or those aged 15 to 49. Research has shown that undernutrition has a negative impact on women, predisposing them to chronic energy deficiency, caesarean delivery, anemia, pre-eclampsia, poor pregnancy outcomes, and poor mental health.

Children born to malnourished mothers are also affected negatively; for example, malnourished women are more likely to have children with lower cognitive function, shorter stature, and an increased risk of infection, disease, and death (Mason *et al*., 2014). Young *et al*. (2017) found that undernourished mothers with a preconception BMI $<18.5\ \mathrm{kg/m2}$ have a higher risk of having a stunted child by age two. On the other hand, overweight and obese women are more likely to develop a variety of health issues, particularly hypertension, diabetes, cardiovascular disease, and stroke (Khanam *et al*., 2018).

According to Welis *et al.* (2019), underweight, overweight, and obesity have historically been considered as separate public health challenges. However, recent global evidence shows that underweight, overweight, or obesity can co-exist within similar communities. This is particularly common in low and middle-income countries (LMICs) where obesogenic factors (attributes that promote excessive body weight gain) are increasing in the context of an existing high burden of undernutrition.

Maternal mortality in Nigeria accounts for an estimated 14% of global maternal deaths Furthermore, Nigeria accounts for an estimated 9% of global first–day deaths, with less than 5% of the world's birth. Women are thus, vulnerable to malnutrition for social and biological reasons. The World Health Organisation (WHO, 2016) refers to the coexistence of undernutrition with overweight, obesity, or diet-related non-communicable diseases (NCDs) as the "double burden of malnutrition" (DBM). In reproductive-aged women, DBM is linked to poor health and reproductive outcomes. For example, overweight and obesity are associated with psychosocial problems and abnormal uterine bleeding during early puberty due to irregularities in the menstrual cycle caused by peripheral androgen conversion to oestrogen.

Overweight and obesity are forms of over-nutrition classified as BMI 25.0–29.9 and BMI ≥30.0, respectively (WHO, 2021). Overweight and obesity during pregnancy and labour are linked to an increase in gestational diabetes and pre-enclampsia, haemorrhage, caesarian birth, and maternal and neonatal mortality (Freire *et al.*, 2018).

Almost one-third of the world's population suffers from some form of malnutrition. In 2016, more than 600 million adults were underweight, while nearly two billion adults were overweight or obese. Evidence has shown that both underweight and overweight are higher among women than men, potentially due to women's reproductive health status, lower social status, poverty and a lack of education (WHO, 2016; 2018).

According to Dangew and Asresie (2020), the prevalence of undernutrition among WRA is 9.4% worldwide, with those in low- and middle-income countries being disproportionately affected, with prevalence up to ten times higher than those in high- and upper-middle-income countries. Research shows the prevalence of under nutrition among WRA in Tanzania was 11%, (Mtumwa *et al.*, 2016), 14% in the Democratic Republic of Congo, 12.8% in Burkina Faso, (Adebowale *et al.*, 2015) while a higher prevalence of 27% was reported in Ethiopia (Ferede, *et al*., 2017).

Objectives of the Study

The aim of this study is to examine the nutritional status of Nigerian women of reproductive age in Nigeria while specific objectives were to:

1. modify the existing model to modelling nutritional status of Nigerian women of reproductive age so as to facilitate planning and appropriate health intervention strategies.
2. estimate the parameters of underweight, overweight and obesity for the predictor variables associated with Nigerian women of reproductive age in the modified model.

METHODOLOGY

Research Design

The research design adopted for this study was the survey research design. The study allowed the researcher to focus on the real subject of the research variables (A Hybrid Multinomial Logistic Regression-Neural Network Component Approach to Modelling Nutritional Status of Nigerian Women of Reproductive Age) from whom the data were obtained. The variables were established based on the study topic vis-a-viz the predictor and outcome variables. The focused population for this study comprised of women of reproductive age in Nigeria (WRA), aged 15 – 49 years of age. The Multiple Indicator Cluster Survey (MICS) where datasets for this study were extracted was carried out in 2021 by the National Bureau of Statistics (NBS) as part of the Global MICS Programme while technical support was provided by the United Nations Children's Fund (UNICEF) and report was published in August, 2022.

Data Source

In this study, secondary data was extracted from Multiple Indicators Cluster Survey (MICS 6; 2021-2022) report, programme website. MICS surveys utilise Computer-Assisted Personal Interviewing (CAPI). The data collection application was based on the CSPro (Census and Survey Processing System) software, Version 6.3, including a MICS dedicated data management platform. Procedures and standard programs6 developed under the global MICS programme were adapted to the Multiple Indicators Cluster Survey (MICS) 2021 final questionnaires and used throughout.

Sample Size and Sampling Technique

In this study, 40,326 women of reproductive age in Nigeria were eligible for the interview conducted by National Bureau of Statistics in 2021 during which 38,806 women of reproductive age in Nigeria were interviewed, yielded 96.2% response rate within the interviewed households

(NBS, 2022). Multiple Indicators Cluster Survey (MICS), 2021 was designed to provide estimates for a large number of indicators on the situation of children and women at the national, rural/urban levels, for 36 states and the Federal Capital Territory (FCT), Abuja. States were identified as the main sampling strata and the sample of households was selected in two stages. The survey employed a stratified two-stage cluster sampling technique.

Measurement of Variables

The variables considered in this study are outcome variable Y (the nutritional status; underweight, overweight, obesity and normal weight is baseline category) and the predictor variables are (i.e. X_1= age, $X_2 =$ area of residence, X_3= marital status, X_4= education, X_5 = wealth index quintile, X_6 = motherhood and recent births and X_7 = health insurance coverage. Both outcome variable and predictor variables were categorically coded.

The Existing Model

The model in the context of this research will have the form as;

$$Y_i \sim \text{Multinomial}(n_i, \pi_j) \quad (1)$$

where $i = 1, 2\ and\ 3$ for underweight, overweight and obese respectively

Y_i= the number of malnourished women of reproductive age.

π_j=denote the probability of malnourished women of reproductive age.

n_i = denote the number of women of reproductive age.

$$Log\left[\frac{\pi_j(x_i)}{\pi_k(x_i)}\right] = \beta_{0j} + \beta_{1j}x_{1i} + \beta_{2j}x_{2i} + \cdots + \beta_{pj}x_{pi} \quad (2)$$

Where $j = 1, 2, \ldots, (k-1), i = 1, 2, \ldots, n$. Since all the $\pi's$ adds to unity, this reduces to

$$Log\left(\pi_j(x_i)\right) = \frac{\exp\left(\beta_{0j}+\beta_{1j}x_{1i}+\beta_{2j}x_{2i}+\cdots+\beta_{pj}x_{pi}\right)}{1+\sum_{j=1}^{k-1}\exp\left(\beta_{0j}+\beta_{1j}x_{1i}+\beta_{2j}x_{2i}+\cdots+\beta_{pj}x_{pi}\right)} \quad (3)$$

For $j = 1, 2, \ldots, (k-1)$, the model parameters are estimated by the method of ML.

The parameter β_j refers to the effect of x_i on the log odds that Y =1, controlling other x_i for instance, $exp(\beta_j)$ is the multiplicative effect on the odds of a one-unit increase in x_i at fixed levels of other x_i (Hosmer and Lemeshow, 2000).

The Modified Model

In this study, a new model is modified for nutritional status women of reproductive age in Nigeria from the traditional Multinomial Logistic Model in (2) by incorporating a Neural Network Component to capture non-linear relationships. Therefore, the modified model is written as:

$$Nutritional\ Status \sim MNLR\ (age + area\ of\ residence + marital\ status + \ldots + health\ insurance\ coverage + NN(x)) \quad 4$$

Neural Network Component $(NN(x))$ is defined as: $\sigma(W2 * \sigma(W1 * x + b1) + b2)$ 4.1

where;

σ is the sigmoid function

$W1\ and\ W2$ are weight matrices

$b1\ and\ b2$ are bias terms

and x is the input layer (predictors).

Modified Model Equation developed in this study for prediction is of the form:

$$Pr(Nutritional\ Status = j) = \frac{\exp(X * \beta_j + NN(x)_j)}{\Sigma \exp\ (X * \beta_k + NN(x)_k)} \quad 5$$

where j indexes the nutritional status categories and k sums over all categories.

In this study, sigmoid function (σ) introduced non-linearity, allowing the model to learn complex relationships and maps the input to a value between 0 and 1 and also used for binary classification or probability output, bias terms ($b1$ and $b2$) help the model learn more accurate representations

by allowing the activation functions to shift the input values while weight matrices ($W1$ and $W2$) learn to transform inputs into higher-level representations, capturing complex relationships.

Data Analysis

This innovative approach integrates the strengths of traditional logistic with adaptive learning capabilities of neural networks, enabling the capture of subtle patterns and evaluation procedures to develop and validate the modified model. The data analysis was carried out using multinomial logistic model with MICS 6 datasets. The data was analyzed with the aid of STATA Software version16.0.

RESULTS

Table 1 shows women background characteristics aged 15 – 49 years in Nigeria extracted from Multiple Indicator Cluster Survey report (MICS 6, 2021 - 2022) which were selected as predictor variables for analysis. Women of reproductive age 15 – 19 years constituted the highest percentage of 21.9% with 51.4% lived in rural area. It was also shown in Table 1 that currently married WRA were 67.7%, women who attained senior secondary education were 36.4% and 22.7% were richest women while 39.3% women had no child in the last 2 years were and 48.0% of WRA had access to social security as a form of health insurance coverage.

Table 1: Background Characteristics of Women of Reproductive Age in Nigeria (15-49)

Predictor Variable	Weighted Frequency (N)	Weighted Percent (%)
Age		
15 – 19	8500	21.9
20 – 24	6321	16.3
25 – 29	5954	15.3
30 – 34	5310	13.7
35 – 39	5229	13.5
40 – 44	4209	10.8
45 – 49	3282	8.5
Area of Residence		
Urban	17806	45.9
Rural	20999	54.1
Marital Status		

Currently Married	23929	61.7
Widowed	890	2.3
Divorced	318	0.8
Separated	685	2.3
Never married	12783	32.9
Women Education		
None	10302	26.5
Primary	5303	13.7
Junior Secondary	3376	8.7
Voc. Initiative Entrp. Pgm	13	0.0
Senior Secondary	14106	36.4
Senior Technical	58	0.1
Higher/Tertiary	5647	14.6
Wealth Index Quintile		
Poorest	6870	16.7
Second	7239	18.7
Middle	7580	19.5
Fourth	8308	21.4
Richest	8828	22.7
Motherhood & recent births		
Never gave birth	13730	35.4
Gave birth in last 2 years	9811	25.3
No birth in last 2 years	15264	39.3
Health Insurance Coverage		
Community Based Health Insurance	2328	6.0
Health Insurance through Employer	16065	41.4
Social Security	18627	48.0
Any Health Insurance	1087	2.8
No Health Insurance	698	1.8

Source: Multiple Indicator Cluster Survey (MICS, 6; 2021 – 2022 Report)

Table 2 shows the estimation of parameters for underweight women of reproductive age in order to examine the effects of selected predictor variables in the modified model associated with nutritional status of women of reproductive age (WRA) in Nigeria.

Table 2: Estimation of Parameters for Underweight Women of Reproductive Age at 95% CI

Predictor Variable	$Coeff.$	$Std.Error$	$Wald$	df	$p-value$	95% CI
Age						
15 – 19	-0.498	0.061	5.691	1	0.000	0.539-0.686
20 – 24	-0.691	0.065	7.250	1	0.000	0.441-0.569
25 – 29	-0.690	0.070	6.603	1	0.000	0.437-0.576
30 – 34	-0.634	0.062	7.221	1	0.000	0.469-0.599
35 – 39	-0.041	0.064	0.409	1	0.522	0.847-1.088
40 – 44	-0.249	0.077	4.461	1	0.001	0.671-0.907
Area of Residence						
Urban	0.072	0.032	5.196	1	0.023	1.010-1.144
Marital Status						
Currently Married	-0.181	0.034	3.912	1	0.000	0.781-0.893
Widowed	0.747	0.093	4.350	1	0.003	1.759-2.534
Divorced	-0.363	0.180	4.038	1	0.044	0.489-0.991
Separated	0.130	0.093	1.995	1	0.162	0.949-1.365
Women Education						
None	-0.433	0.051	8.364	1	0.000	0.586-0.717
Primary	-0.240	0.064	4.059	1	0.000	0.694-0.892
Junior Secondary	-0.029	0.069	0.176	1	0.675	0.848-1.112
Voc. Initiative Entrp. Pgm	0.104	0.619	0.004	1	0.951	0.309-0.491
Senior Secondary	-0.469	0.050	8.366	1	0.000	0.567- 0.690
Senior Technical	-2.131	1.017	4.393	1	0.036	0.016-0.871
Wealth Index Quintile						
Poorest	-0.241	0.056	4.784	1	0.000	0.705-0.876
Second	-0.216	0.057	4.129	1	0.000	0.720-0.902
Middle	0.394	0.061	6.196	1	0.000	1.316-1.669
Fourth	0.094	0.039	5.738	1	0.017	1.017-1.187
Motherhood & recent births						
Never gave birth	-0.113	0.035	4.137	1	0.001	0.833-0.957
Gave birth in last 2 years	-0.273	0.045	7.301	1	0.000	0.697-0.831
Health Insurance Coverage						
Community Based Health Insurance	0.184	0.119	2.366	1	0.124	0.951-1.519
Health Insurance through Employer	-0.469	0.094	8.600		0.000	0.516-0.759
Social Security	-0.411	0.906	4.952	1	0.000	0.551-0.798
Any Health Insurance	-0.050	0.117	0.187	1	0.665	0.757-1.195
Constant	**0.088**	**0.149**	**0.348**	**1**	**0.555**	

Table 3 below shows the estimation of parameters for overweight women of reproductive age in order to examine the effects of selected predictor variables in the modified model associated with nutritional status of women of reproductive age (WRA) in Nigeria.

Table 3: Estimation of Parameters for Overweight Women of Reproductive Age at 95% CI

Predictor Variable	$Coeff.$	$Std.Error$	$Wald$	df	$p-value$	95% CI
Age						
15 – 19	-0.249	0.078	4.197	1	0.001	0.669-0.908
20 – 24	-0.162	0.083	3.836	1	0.040	0.723-1.000
25 – 29	-0.211	0.077	4.122	1	0.006	0.696-0.942
30 – 34	-0.484	0.079	8.902	1	0.000	0.529-0.719
35 – 39	0.245	0.077	4.235	1	0.001	1.100-1.485
40 – 44	0.549	0.094	8.297	1	0.000	1.441-2.080
Area of Residence						
Urban	0.200	0.033	8.744	1	0.000	1.144-1.304
Marital Status						
Currently Married	-0.228	0.038	6.331	1	0.000	0.739-0.858
Widowed	-0.060	0.126	8.015	1	0.000	0.603-0.754
Divorced	0.034	0.198	0.030	1	0.862	0.702-1.527
Separated	-0.248	0.138	3.249	1	0.071	0.596-1.022
Women Education						
None	0.195	0.050	4.214	1	0.000	1.102-1.340
Primary	-0.394	0.057	8.610	1	0.000	0.639-0.830
Junior Secondary	-0.149	0.062	3.856	1	0.016	0.764-0.972
Voc. Initiative Entrp. Pgm	-18.547	8602.020	0.000	1	0.998	0.000- -
Senior Secondary	-0.350	0.053	8.295	1	0.000	0.635-0.782
Senior Technical	-0.136	0.332	0.167	1	0.683	0.455-1.635
Wealth Index Quintile						
Poorest	3.003	0.105	12.394	1	0.000	2.384-3.761
Second	2.853	0.106	11.786	1	0.000	2.093-2.313
Middle	3.744	0.106	20.248	1	0.000	4.342-6.073
Fourth	1.039	0.114	9.425	1	0.000	2.258-2.539
Motherhood & recent births						
Never gave birth	-0.653	0.045	10.903	1	0.000	0.477-0.568
Gave birth in last 2 years	0.060	0.039	2.349	1	0.125	0.983-1.147
Health Insurance Coverage						
Community Based Health Insurance	2.995	0.589	4.895	1	0.000	0.306-0.336
Health Insurance through Employer	2.659	0.586	4.596		0.000	0.529-1.011
Social Security	2.012	0.586	4.007	1	0.001	0.374-0.584
Any Health Insurance	0.440	0.740	0.353	1	0.552	0.364-0.617
Constant	**-6.037**	**0.606**	**9.360**	**1**	**0.000**	

Table 4 below shows the estimation of parameters for obese women of reproductive age in order to examine the effects of selected predictor variables in the modified model associated with nutritional status of women of reproductive age (WRA) in Nigeria.

Table 4: Estimation of Parameters for Obese Women of Reproductive Age at 95% CI

Predictor Variable	$Coeff.$	$Std.Error$	$Wald$	df	$p-value$	95% CI
Age						
15 – 19	1.366	0.104	10.294	1	0.000	1.196-2.805
20 – 24	1.542	0.108	11.665	1	0.000	1.487-3.773
25 – 29	1.673	0.104	11.203	1	0.000	1.351-3.528
30 – 34	0.968	0.105	8.078	1	0.000	1.144-2.235
35 – 39	1.665	0.108	11.664	1	0.000	1.292-3.503
40 – 44	1.719	0.122	11.100	1	0.000	1.397-3.079
Area of Residence						
Urban	0.301	0.034	8.287	1	0.000	1.265-1.443
Marital Status						
Currently Married	-0.121	0.038	4.205	1	0.001	0.822-0.954
Widowed	0.418	0.108	5.883	1	0.000	1.228-1.878
Divorced	0.551	0.164	5.296	1	0.001	1.258-2.394
Separated	-0.465	0.140	5.066	1	0.001	0.477-0.826
Women Education						
None	-0.345	0.050	4.214	1	0.000	1.102-1.340
Primary	0.207	0.057	8.610	1	0.000	0.639-0.830
Junior Secondary	-0.380	0.062	3.856	1	0.016	0.764-0.972
Voc. Initiative Entrp. Pgm	-18.949	0.000	-	1	-	5.894E-009-5.894E-009
Senior Secondary	-0.468	0.052	8.559	1	0.000	0.565-0.964
Senior Technical	-0.824	0.425	3.763	1	0.062	0.191-1.009
Wealth Index Quintile						
Poorest	0.894	0.063	11.120	1	0.000	2.158-2.768
Second	0.769	0.064	11.087	1	0.000	1.905-2.445
Middle	1.891	0.064	13.864	1	0.000	1-849-3.508
Fourth	0.010	0.063	0.027	1	0.870	0.893-1.143
Motherhood & recent births						
Never gave birth	-0.026	0.041	0.401	1	0.527	0.898-1.056
Gave birth in last 2 years	0.054	0.042	1.684	1	0.194	0.973-1.145
Health Insurance Coverage						
Community Based Health Insurance	0.844	0.191	4.543	1	0.000	1.600-2.381
Health Insurance through Employer	0.295	0.181	2.262		0.103	0.942-1.914
Social Security	-0.079	0.180	0.293	1	0.588	0.637-1.291
Any Health Insurance	0.010	0.228	0.002	1	0.967	0.646-1.577
Constant	**-3.560**	**0.235**	**11.358**	**1**	**0.000**	

DISCUSSION

This study modelled nutritional status of women of reproductive in Nigeria using multinomial logistic regression model with neural network component. The Global Nutrition Publication (GNP, 2020) reported that out of 46 million women of reproductive age in Nigeria, 7.3 million (15.9%)

women were living obesity, 15.7% were undernourished and 16.8% were overweight WRA in Nigeria while 51.2% have normal weight body mass index.

This study found association of selected predictor variables which include age, area of residence, marital status, women education, wealth index quintile, health insurance coverage and motherhood and recent births with underweight, overweight and obesity. Similar to previous literature; age, women with no formal education and those with primary education as well as the poorest, second and middle WRA on wealth status were significantly associated with underweight in this study which aligned with Mtumwa *et al*. (2016) whose results showed that women aged 15-19 and 40-49 years were mostly affected of underweight, with a prevalence of 18% and 12% respectively, while Lasisi *et al* (2015) revealed that children born to mothers with primary and secondary education had a higher likelihood of being underweight than children born to mothers but contrary to mothers with no education while the poorest, second and middle wealth index quintile could be attributed to lack of sufficient funds to ensure provision of required dietary needs for the women.

However, being currently married does not guarantee not being underweight as revealed in the results while significant association of widowed women with underweight could be attributed to psychological and emotional stress undergone by the WRA affected.

Women educational attainment also indicated that WRA with no formal education, primary, junior secondary and senior secondary education had significant association with their body mass index (overweight) which aligns with Song *et al*.(2020) findings in China who found that higher level of education was associated with lower prevalence of overweight and obesity and attributed their findings to women of higher education having greater health awareness and diet management which protects them from over-nutrition.

This study also shows that currently married and widowed WRA in this study were also significantly associated with obesity which similar to Ezeama *et al* (2022) findings regarding widowed, separated and divorced but contrary to their findings on currently married women which revealed that the risk of obesity was even higher among divorced, widowed, and separated women WRA in Nigeria.

Generally, wald statistic is a measure of the significance of each regression coefficient in the model. The wald statistic follows a chi-squared distribution with 1 degree of freedom. If the wald statistic is greater than the critical value from the chi-squared distribution (usually 3.84) for a 2-tailed test at 0.05 significance level), the coefficient is statistically significant. This implies that all coefficients of predictor variables in Tables 2, 3 and 4 greater than 3.84 were statistically significant in the modified model developed in this study while coefficients of predictor variables less than 3.84 with respect to nutritional status of WRA are not statistically significant in the modified model while predictor variables with $p - value$ of less than 0.05 were significantly associated with underweight, overweight or obesity in this study.

CONCLUSION

In conclusion, this study successfully demonstrated the application of a Multinomial Logistic Regression model with a Neural Network Component in fitting and predicting the nutritional status of women of reproductive age in Nigeria. The study's findings have significant implications for public health policy and intervention strategies, highlighting the importance of addressing socio-demographic, economic and health-related factors to improve nutrition outcomes. The hybrid model's superior performance and ability to capture complex relationships underscore the potential of advance statistical modelling techniques in addressing complex health issues in resource limited-settings.

This study found evidence that selected predictor variables have a significant influence on the nutritional status of women of reproductive age (WRA). Based on these and other related findings, this study arrives at the conclusion to improve women nutritional status. Most of the selected predictor variables in this study affected the nutritional status of women (mothers) also affected the nutritional status of children. It was also found that there exists a strong association between maternal and child nutritional status and maternal nutritional status and birth weight.

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