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Mathematical models for better determination of food security in Nigeria: A case study of Bauchi state, North-Eastern, Nigeria

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Abstract
Foods play a fundamental role for growth and development of human body including animals. Food security remains the cardinal agenda of every serious government. The prices of available food commodities must be affordable to every citizen and that were determined by the cost of the food commodities. As prices of agricultural commodities keep increasing, the availability of food becomes limited to every household in Nigeria, especially in the North-Eastern region. The research was aimed at determining the mathematical model that was perfect for determining the food security in the study area. Time series equations and Non-linear equation were used to compare the prices of the selected agricultural commodities. Price is considered because, price play a vital role to food security in the country. This research covers the entire local governments of Bauchi state including the metropolis and the crop considered included; Maize, Rice and Soybeans. Twenty local governments (20) local governments of Bauchi state were visited to collect data on averaged price of three selected commodities per mudu (i.e. Maize, Rice and Soybeans) through direct interaction as well as from Bauchi state statistical year book from 2013 to date across the state from national bureau of statistics Bauchi. Standard method for determining a linear trend is the method of least square that used for linear regression was used to model the selected agricultural commodities. The findings revealed that the Non-linear equation method has a minimal error compared to the least square method; this was explained that Non-linear equation is the better model for determining food security in Bauchi state.

Keywords: Food security, price, compare, commodities, agriculture

1. Introduction
Food insecurity has emerged as a global challenge particularly in African region and it is a great obstacle to sustainable development. According to the Food and Agriculture organization of the United Nations (FAO) about 870 million people are undernourished worldwide of which 30% are found in sub- Saharan African which Nigeria is inclusive. The availability of sufficient quantities of food of appropriate quality, supplied through domestic production or imports (including food aid). Access by individuals to adequate resources (entitlements) for acquiring appropriate foods for a nutritious diet. Entitlements are defined as the set of all commodity bundles over which a person can establish command given the legal, political, economic and social arrangements of the community in which they live (including traditional rights such as access to common resources) Utilization of food through adequate diet, clean water, sanitation and health care to reach a state of nutritional well-being where all physiological needs are met. This brings out the importance of non-food inputs in food security. To be food secure, a population, household or individual must have access to adequate foods regularly. They should not risk losing access to food as a consequence of sudden shocks (e.g. an economic or climatic crisis) or cyclical events (e.g. seasonal food insecurity). The concept of stability can therefore refer to both the availability and access dimensions of food security.
Foods must be available at all times and also be accessible to the entire citizens. Moreover, there must be a quality of nutritious foods and stability for the entire populations.

Food utilization which includes; (Food safety, Hygiene and manufacturing practices should be applied regularly. The primary agricultural production, harvesting, storage, food processing; transportation, retail, households, Diet quality and diversity needs should also be considered in every developing nation. Food security refers to the ability of the household to secure, either from its own production or through purchases, adequate food for meeting the dietary needs of all members of the household. Food security describes a country's access to food of sufficient quantity and quality at all times either from domestic production or world food markets. Accordingly, a country is considered food secure at the macro level if domestic food production is sufficient to meet the domestic food demand, if the country's external balance and currency reserves allow for importing sufficient food (also in times of global food price spikes), or both.

The World Food Summit a definition that involved food security not only at national level but at household and individual level. It was defined as: "when all population at all times has physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life". Food and Agricultural Organization (FAO) indicated that agricultural activities contributes to poverty alleviation by reducing food prices, creating employment, improving farm income and increasing wages.

Nigeria was blessed as it is, with abundant agro-ecological resources and diversity, has become one of the largest food importers in sub-Saharan Africa.

Nigeria needs to come up with food policy which is lacking in order to alleviate crisis is food security. A world where all enjoy freedom from want, and progressively realize their right to adequate food and nutrition can only be realized through far reaching transformations, supported by policies and programmes promoting sustainable development in all its three dimensions. One of the motivations for this study is from the USAID (2016) projection and declaration of food security for now and the next 2030, The declaration shows that, the U.S. Government's global hunger and food security initiative, Feed the Future, has been working with its partners around the world to help countries overcome agriculture and nutrition challenges with entrepreneurship, partnership and innovation.

Statement of Problem

There is a global increase in food insecurity across the globe. Sub-Sahara Africa considered as the highest victim of such circumstances. This may lead to migration, hunger and severe diseases among humans and other animals. Nigeria has experienced series of food crisis challenges particularly in the North-Eastern, Nigeria. This with the hope of designing a new mathematical model that will address and determine the food insecurity challenges in the North-Eastern, Nigeria.

Methodology

The method adopted in this research work was to look for a suitable mathematical model that will be perfect for determining the food security in Bauchi State. Twenty local Governments of Bauchi State were considered as the study areas. Various markets were visited and data were generated. Data on averaged price of three selected commodities (Rice, Maize, and Soy-beans) per mudu were collected through direct interaction as well as from Bauchi State Statistical year Book from 2012 to date across State National Bureau of Statistics Bauchi.

Trends by Regressions

The research work considered the standard method for determining a linear trend which was the method of least square that was purely used for linear regression in order to check the model selected on agricultural commodities.

This is accomplished by replacing the variables x by the variable t in

$$Y = \alpha + \beta x \text{ to } Y_t = \alpha + \beta t$$

Which was

$$\bar{Y}_t = \alpha + \beta t$$

The estimates for α and β i.e. a and b are then

$$b = \sum \frac{t_i y_i - \overline{my}}{\sum t_i^2 - m^{-2}}$$

Here

$$\bar{t} = \frac{\sum t}{n}$$

and $a = \bar{y} - b\bar{t}$

In this research work, I assigned the values of x to the yeas so that$\sum x = 0$.

The equation of the least square was written as

$$Y = \bar{Y} + \left(\frac{\sum xy}{\sum x^2}\right) x = \bar{Y} + b \quad \ldots (1)$$

On the basis of the equation aboved, the following models for three selected food commodities in Bauchi State were obtained.

$$Y_R = 431 + 39.3t \quad \ldots (2)$$

$$Y_M = 290 + 37.6t \quad \ldots (3)$$

$$Y_S = 264 + 34.6t \quad \ldots (4)$$

2.2 Non-Linear Models

Local Rice

The non-linear price of the local Rice $P_L(t)$, certify the equation below

$$P_R(t) = at^2 + bt + c, \quad \ldots (5)$$

Thus, minimizing the cumbersome data for $P_L(t)$ using Least Square method were as follows;

$$Z_{min} = min \sum_{i=1}^{11} (P_R(t) - at_i^2 - bt_i - c)^2$$

$$\frac{\partial Z}{\partial a} = -2 \sum_{i=1}^{11} (P_R(t) - at_i^2 - bt_i - c) * t_i^2 = 0$$

(At turning point)

$$\Longrightarrow \sum_{i=1}^{11} P_R(t) t_i^2 = a \sum_{i=1}^{11} t_i^4 + b \sum_{i=1}^{11} t_i^3 + c \sum_{i-1}^{11} t_i^2 \ldots (6)$$

$$\frac{\partial Z}{\partial b} = -2 \sum_{i=1}^{11} (P_R(t) - at_i^2 - bt_i - c) * t_i^2 = 0$$

(At turning point)

$$\Rightarrow \sum_{i=1}^{11} P_R(t)t_i = a\sum_{i=1}^{11} t_i^3 + b\sum_{i=1}^{11} t_i^2 + c\sum_{i-1}^{11} t_i^1 \ldots (7)$$

Similarly,

$$\frac{\partial Z}{\partial c} = -2\sum_{i=1}^{11}(P_R(t) - at_i^2 - bt_i - c) * t_i^2 = 0$$

(at turning point)

$$\Rightarrow \sum_{i=1}^{11} P_R(t)t_i = a\sum_{i=1}^{11} t_i^2 + b\sum_{i=1}^{11} t_i + c\sum_{i-1}^{11} 1 \ldots (8)$$

Model for Maize

We suppose that the non-linear price of the maize $P_M(t)$, certified the equation below;

$$P_M(t) = et^2 + ft + g; \quad \ldots (9)$$

Thus, minimizing the cumbersome data for $P_M(t)$ using Least Square method were

$$Z_{min} = min\sum_{i=1}^{11}(P_M(t) - et_i^2 - ft_i - g)^2$$

$$\frac{\partial Z}{\partial e} = -2\sum_{i=1}^{11}(P_M(t) - et_i^2 - ft_i - g) * t_i^2 = 0$$

(At turning point)

$$\Rightarrow \sum_{i=1}^{11} P_M(t)t_i^2 = e\sum_{i=1}^{11} t_i^4 + f\sum_{i=1}^{10} t_i^3 + g\sum_{i-1}^{11} t_i^2 \ldots (10)$$

$$\frac{\partial Z}{\partial f} = -2\sum_{i=1}^{11}(P_M(t) - et_i^2 - ft_i - g) * t_i = 0$$

(At turning point)

$$\Rightarrow \sum_{i=1}^{11} P_M(t)t_i = e\sum_{i=1}^{11} t_i^3 + f\sum_{i=1}^{10} t_i^2 + g\sum_{i-1}^{11} t_i^1 \ldots (11)$$

$$\frac{\partial Z}{\partial g} = -2\sum_{i=1}^{11}(P_M(t) - et_i^2 - ft_i - g) * 1 = 0$$

(At turning point)

$$\Rightarrow \sum_{i=1}^{11} P_M(t) = e\sum_{i=1}^{11} t_i^2 + f\sum_{i=1}^{11} t_i^1 + g\sum_{i-1}^{11} 1 \quad \ldots (12)$$

Model for Soy-beans

It suggested that the non-linear price of the Soy-beans $P_S(t)$, certify the equation below;

$$P_S(t) = At^2 + Bt + C; \quad \ldots (13)$$

Thus minimizing the cumbersome data for $P_S(t)$ using Least Square method were;

$$Z_{min} = min\sum_{i=1}^{11}(P_S(t) - At_i^2 - Bt_i - C)^2$$

$$\frac{\partial Z}{\partial A} = -2\sum_{i=1}^{11}(P_S(t) - At_i^2 - Bt_i - c) * t_i^2 = 0$$

(At turning point)

$$\Rightarrow \sum_{i=1}^{11} P_S(t)t_i^2 = A\sum_{i=1}^{11} t_i^4 + B\sum_{i=1}^{11} t_i^3 + c\sum_{i-1}^{11} t_i^2 \quad \ldots (14)$$

$$\frac{\partial Z}{\partial B} = -2\sum_{i=1}^{11}(P_S(t) - At_i^2 - Bt_i - c) * t_i = 0$$ (At turning point)

$$\Rightarrow \sum_{i=1}^{11} P_S(t)t_i = A\sum_{i=1}^{11} t_i^3 + B\sum_{i=1}^{11} t_i^2 + c\sum_{i-1}^{11} t_i \quad \ldots (15)$$

$$\frac{\partial Z}{\partial C} = -2\sum_{i=1}^{11}(P_S(t) - At_i^2 - Bt_i - c) * 1 = 0$$ (At turning point)

$$\Rightarrow \sum_{i=1}^{11} P_S(t) = A\sum_{i=1}^{11} t_i^2 + B\sum_{i=1}^{11} t_i^1 + c\sum_{i-1}^{11} 1 \quad \ldots (16)$$

Table 1: Shows data on average prices of three selected food commodities per mudu (i.e. bowl used in measurement) in Bauchi State

Items	YEARS										
	2022	2021	2020	2019	2018	2017	2016	2015	2014	2013	2012
Local Rice	700	620	500	470	500	380	350	300	310	300	300
Maize	450	420	450	380	350	270	250	200	170	150	100
Soybeans	500	400	350	280	300	250	220	200	130	150	120

Source: Direct Interview with the local marketers cross the state and Bauchi Statistical Year Book.

Tabular presentation of the results of the commodities

Table 2: Shows computational details for Local Rice Using Least Square Method

X(year)	**Y(price)**	**t = year − 2012**	**$Y_R = 431 + 39.3t$**	**e**	**|e|**
2022	700	5	627.5	72.5	72.5
2021	620	4	588.2	31.8	31.8
2020	500	3	548.9	-48.9	48.9
2019	470	2	509.6	-39.6	39.6
2018	500	1	470.3	29.7	29.7
2017	380	0	431	-51	51
2016	350	-1	391.7	-41.7	41.7
2015	310	-2	352.4	-42.4	42.4
2014	310	-3	313.1	-3.1	3.1
2013	300	-4	273.8	26.2	26.2
2012	300	-5	234.5	-204.5	204.5
					$\sum\|e\| = 591.4$

Table 3: Shows computational details for Local Rice using Non Linear equation method.

T	$P_R(t)$	t^2	t^3	t^4	$t^2P_R(t)$	$tP_R(t)$
0	700	0	0	0	0	0
1	620	1	1	1	620	620
2	500	4	8	16	2000	100
3	470	9	27	81	4230	1410
4	500	16	64	256	8000	2000
5	380	25	125	625	9500	1900
6	350	36	216	1296	12600	2100
7	310	49	343	2401	15190	2170
8	310	64	512	4096	19840	2480
9	300	81	729	6561	24300	2700
10	300	100	1000	10000	30000	3000
$\sum_{i=1}^{11} t = 55$	$\sum_{i=1}^{11} P_R(t) = 4740$	$\sum_{i=1}^{11} t^2 = 385$	$\sum_{i=1}^{11} t^3 = 3025$	$\sum_{i=1}^{11} t^4 = 25333$	$\sum_{i=1}^{11} t^2P_R(t) = 126280$	$\sum_{i=1}^{11} tP_R(t) = 18480$

Using Table 3. Shows above, equation (6), (7), & (8) becomes

$$\left.\begin{aligned} 126280 &= 25333a + 3025b + 385c \\ 18480 &= 3025a + 385b + 55c \\ 4740 &= 385a + 55b + 11c \end{aligned}\right\} \quad \ldots (17)$$

Solving the system (17), we get

$a = 14.7 \quad b = -194.1 \quad c = 888.1$

And therefore, the model for Local Rice was given as;

$$P_R(t) = 14.7t^2 - 194.1t + 888.1 \quad \ldots (18)$$

Table 4: Shows validation of the model for Local Rice

X(year)	t	$P_R(t)$ prices	$P_R(t)$for model data	|e| Absolute error
2022	0	700	888.1	188.1
2021	1	620	708.7	88.7
2020	2	500	558.1	58.7
2019	3	470	438.1	31.9
2018	4	500	346.9	153.1
2017	5	380	285.1	94.9
2016	6	350	252.7	97.3
2015	7	310	249.7	60.3
2014	8	310	276.1	33.3
2013	9	300	331.9	31.9
2012	10	300	417.1	117.1
				$\sum \|e\| = 955.3$

The minimal absolute error makers the least square method with 591.4 error were preferable over the Non-linear equation with 955.3 error formulated above.

Table 5: Shows computational details of Maize for Least Square Method

$X(year)$	$Y(price)$	$t = year - 2012$	$Y_M = 290 + 37.6t$	e	$\|e\|$
2022	450	5	478	-28	28
2021	420	4	440.4	20.4	20.4
2020	450	3	402.8	-47.2	47.2
2019	380	2	365.2	14.8	14.8
2018	350	1	327.6	22.4	22.4
2017	270	0	290	-20	20
2016	250	-1	252.4	-2.4	2.4
2015	200	-2	214.8	-14.8	14.8
2014	170	-3	177.2	-7.2	7.2
2013	150	-4	139.6	10.4	10.4
2012	100	-5	102	-2	2
					$\sum \|e\| = 189.6$

Table 6: Shows computational details for Maize model

T	$P_M(t)$	t^2	t^3	t^4	$t^2P_M(t)$	$tP_M(t)$
0	450	0	0	0	0	0
1	420	1	1	1	420	420
2	450	4	8	16	1800	900
3	380	9	27	81	3420	1140
4	350	16	64	256	5600	1400
5	270	25	125	625	6750	1350
6	250	36	216	1296	9000	1500
7	200	49	343	2401	9800	1400
8	170	64	512	4096	10880	1360
9	150	81	729	6561	12150	1350
10	100	100	1000	10000	10000	1000
$\sum_{i=1}^{11} t = 55$	$\sum_{i=1}^{11} P_M(t) = 3190$	$\sum_{i=1}^{11} t^2 = 385$	$\sum_{i=1}^{11} t^3 = 3025$	$\sum_{i=1}^{11} t^4 = 25333$	$\sum_{i=1}^{11} t^2P_M(t) = 69820$	$\sum_{i=1}^{11} tP_M(t) = 11820$

Substituting the data collected into equation (10), (11), & (12) give rise to the following equations

$$\left.\begin{aligned} 69820 &= 25333e + 3025f + 385g \\ 11820 &= 3025e + 385f + 55g \\ 3190 &= 385e + 55f + 11g \end{aligned}\right\} \quad \ldots (19)$$

Solving equations (19), we have

$e = -0.6 \quad f = -31.4 \quad g = 468.5$

And therefore our model for the price of Maize is given as:

$$P_M(t) = -0.6t^2 - 31.4t + 468.5 \quad \ldots (20)$$

Table 7: Shows validation of the model for Maize

$X(year)$	t	$P_M(t)$ *prices*	$P_M(t)$ *for model data*	$\lvert e\rvert$ *Absolute error*
2022	0	450	468.5	18.5
2021	1	420	436.5	16.5
2020	2	450	403.3	46.7
2019	3	380	368.9	11.1
2018	4	350	333.3	16.7
2017	5	270	296.5	26.5
2016	6	250	258.5	8.5
2015	7	200	219.3	19.3
2014	8	170	178.3	8.9
2013	9	150	137.3	12.7
2012	10	100	94.5	5.5
				$\sum \lvert e\rvert = 190.9$

Remarks: The minimal absolute error makes the Least Square Method with 189.6 error to be preferable over the Non-linear model with 190.9 error formulated above.

Table 8: Shows computational details for Soybeans Using Least Square Method

$X(year)$	$Y(price)$	$t = year - 2012$	$Y_S = 290 + 37.6t$	e	$\lvert e\rvert$
2022	500	5	437	-63	-63
2021	400	4	402.4	2.4	2.4
2020	350	3	367.8	17.8	17.8
2019	280	2	333.2	53.2	53.2
2018	300	1	298.6	-1.4	1.4
2017	250	0	264	14	14
2016	220	-1	229.4	9.4	9.4
2015	200	-2	194.8	-5.2	5.2
2014	130	-3	160.2	30.2	30.2
2013	150	-4	125.6	-24.4	24.4
2012	120	-5	91.0	-29	29
					$\sum \lvert e\rvert = 250$

Table 9: Shows computational details for Soybeans

T	$P_S(t)$	t^2	t^3	t^4	$t^2P_S(t)$	$tP_S(t)$
0	500	0	0	0	0	0
1	400	1	1	1	400	420
2	350	4	8	16	1400	700
3	280	9	27	81	2520	840
4	300	16	64	256	4800	1200
5	250	25	125	625	6250	1250
6	220	36	216	1296	7920	1320
7	200	49	343	2401	9800	1400
8	130	64	512	4096	8320	1040
9	150	81	729	6561	12150	1350
10	120	100	1000	10000	12000	1200
$\sum_{i=1}^{11} t = 55$	$\sum_{i=1}^{11} P_S(t) = 3190$	$\sum_{i=1}^{11} t^2 = 385$	$\sum_{i=1}^{11} t^3 = 3025$	$\sum_{i=1}^{11} t^4 = 25333$	$\sum_{i=1}^{11} t^2P_S(t) = 65560$	$\sum_{i=1}^{11} tP_S(t) = 10700$

Substituting the collected data into the equation (14), (15) & (16) we get

$$\left.\begin{aligned} 65560 &= A25333 + 3025B + 385C \\ 10700 &= 3025A + 385B + 55C \\ 2900 &= 385A + 55B + 11C \end{aligned}\right\} \quad \ldots (21)$$

Solving the above equation (i.e. 21), we have

$A = 2.4 \qquad B = -58.6 \qquad C = 472.4$

And therefore, the model for the price of Soy-beans was given as:

$$P_S(t) = 2.4t^2 - 58.6t + 472.4 \quad \ldots (22)$$

Table 10: Shows validation of the model for Soy-beans.

X(year)	t	$P_S(t)$ prices	$P_S(t)$for model data	|e| Absolute error
2022	0	500	472.4	27.6
2021	1	400	416.2	16.2
2020	2	350	364.8	14.8
2019	3	280	318.2	38.2
2018	4	300	276.4	23.6
2017	5	250	239.4	10.6
2016	6	220	207.2	12.8
2015	7	200	179.8	20.2
2014	8	130	157.2	27.2
2013	9	150	139.4	10.6
2012	10	120	126.4	6.4
				$\sum \|e\| = 208.2$

The minimal absolute error makes the Non-linear model with 208.2 error were preferable over the Least Square Method with 250 error formulated above.

Discussion

The result from the Least Square Method computation for Local Rice shows that total absolute error of 519.4, the total absolute error from the Non-linear Model was 955.3. The Least Square Method has a minimal error compare to Non-linear Model which makes the Least Square Model better than the Non-linear Model. From Table 5 and Table 7, the total error obtained from Least Square Model was 189.6, while from Nonlinear Model were 190.9, which makes the Least Square Model better than the Non-linear Model. From Table 8 and Table 10, the absolute error for Least Square Model was 250, compare it to that of Non-linear Model with 208.2, the Non-linear Model is better than Least Square Model.

Conclusion

Food security remains the fundamental agenda for every responsible Nation. Food insecurity can lead to hunger, war and possible migration. Therefore, priority should be given massive production of agricultural products in the North-Eastern, Nigeria.

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