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A Mathematical Model for Estimating the Weight of Human Beings Using Some Anthropometric Parameters (A Case Study of Taraba State of Nigeria's Community)

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Abstract

The research is concerned with the development of a mathematical model for estimating the body weight of human beings in relation to some of their anthropometric parameters (height and waist sizes). The model was optimized to know whether it is possible for humans to have a maximum or minimum body weight. However, the optimization result showed that there is no specific body weight that could be called a maximum or minimum. Emphasis was laid mainly on a particular proportion of Nigerians from the north- west geopolitical zone (as a case study) in order to be able to make generalizations about the entire country and beyond. Hence, the population sample for the research was the Taraba State of Nigeria's Community. Moreover, several recommendations were made at the end of the model analysis which when adhered to, would bring about some medical breakthroughs to the entire human populace.

Keywords: Weight; height; waist size; Nigerians; nature of equation; optimized; model parameter; body weight estimated; anthropometric measurement; anthropometric parameters.

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1 Introduction

Estimating human weight is so important in every country today. Many disease conditions make it impossible to gauge patients' weight. This anthropometric measurement is essential to calculate medicament dose and doses. Anthropometrics measures is the single most universally applicable, inexpensive and non-invasive method available for the assessment of size, proportion and composition of human body [1,2]. Thus, it would also be important to discuss in the cause of this work various mathematical approaches to estimate weight already used worldwide and a mathematical look at this anthropometric measurement in particular, is essential. Weight estimation is essential to address the problem of obesity and weight stigmatisation. The fact remains that, obsessed people are regularly blamed for their weight, with common perception that weight stigmatisation is justifiable and may motivate individuals to adopt healthier behaviours. Unknown to them that weight stigma is not a beneficial public health tool for reducing obesity; rather it threatens health, generates health disparities, and interferes with effective obesity intervention efforts [3]. That is why despite the stigma, the obsessed and overweight individuals are lazy, weak-willed, unsuccessful, unintelligent and have poor weight-loss treatment [4,5].

Moreover, it has been observed that due to peculiarities about generations, certain immunity, resistances and prevalence a generation A, might claim/achieve over an ailment, it is difficult for another immediate/next generation to enjoy such. For instance, HIV, Jaundice, and other diseases that have existed in the world for over centuries now are just having a higher spreading and penetration power of late. A country's attention is supposed to be drawn to this reality because the healthy living of a nation's citizens is a fundamental and necessary condition for a healthy and prosperous economy [6].

Similarly, findings have shown that resistances/immunities demonstrated by people are as a result of their geographical locations. This is evident in the variation between the resistance/immunity an African can show over that of American in terms of the water they drink, the food they eat and the diseases they could fight and win. Hence it is notable to remark here that, for effectiveness in medication prescriptions and special intervention, each generation of human beings has to be studied in isolation considering their geographical locations and body response rates while addressing parameters such as popular food taken, body weight, body mass index, sleeping and exercising cultures and so on.

Meanwhile, we need to employ the knowledge of mathematical modelling for this task in our hands because; mathematical modelling is the aspects of mathematics that connects the learning of its principles, concepts and procedures to the real world phenomena [6].

According to [7], mathematical models are useful experimental tools for building and testing theories, accessing quantitative conjectures, answering specific questions, determining sensitivities to changes in parameter values, and estimating key parameters from data. But, [8] advised that the closer mathematical model assumptions are to reality of dynamics, the more difficult the mathematical analysis, hence the need to simplify assumptions without losing track of the situation or dynamics at hand.

Thus, the need for this research and the choice of using mathematical modelling approach cannot be over emphasized.

1.1 Relevance of the Study

The study of the weight and body mass index of human beings is important to enable one know when he is becoming/about to be obese in order to take all the necessary dietary and regular-exercise precautions.

Secondly, the study is also useful for one to identify whether his weight is too small or too high for his corresponding height.

Equally, it can be used for the development of weight scale for human beings.

Also, since mathematical modelling is useful for proper medication dosage [9], then; this mathematical model for weight of people developed in this research work could be instrumental for deciding the proper medication dosage and nutritional evaluation for a patient based on estimated weight. This model is especially useful in many of the remote interior settings in the world, in which reliable weighing scale is not easily available, because of transport issues, but a soft ruler/tape rule is of course a useful tool instead.

1.2 Relevance of the Study over Others

The study is peculiar to a certain geopolitical area in Nigeria and can be adopted for use in other areas with similar characteristics of human beings.

As an addendum, without a weight scale (which sometimes may be expensive) either in the hospital or at home, if an individual could identify his weight, waist size and height, he could as well estimate his body weight using the model developed in this work.

2 Methodology

Under this section, we shall consider the following subheadings like: Formulation of the model itself, Basic assumptions needed to give us a model that conforms to reality, establish a relationship between our model parameters, and evaluate the resulting model equations' constants.

2.1 Formulation of the Model

In similar manner, this section will also address the following subtopics as they unfold.

2.1.1 Basic assumptions

2.1.1.1 Weight versus height

A very tall person must have longer bones. And it is remarkable that length of bones accounts for the possible weight of the bones. Hence, an increase in the height (H) of a person gives rise to a corresponding increase in his body weight (W). Hence, it is then suffices to remark that the body weight of a person is directly proportional to its height since any increase in one leads to a corresponding increase in the other. Hence mathematically,

$$W \propto H$$
$$\Rightarrow W = k_1 H \qquad (2.1)$$

2.1.1.2 Weight (W) versus waist size (W_S)

A man, who uses his waist belt calibrated at a certain 40cm mark, has a weight of W_1 measured. After a short while some natural and physiological factors like (illness hunger, dehydration and so on) came upon him, and his belt calibrated at the 40cm mark could no longer size him. Hence for a perfect comfort and fitness in his dressing and his waist size (W_S), he reduced his belt calibration `to yet another 35 cm mark in order for his belt to fit/size him. But when his waist size (W_S) got reduced, he went and take a new measurement of his weight (W) and discovered that his body weight has likewise reduced in kg. Thus it can be postulated that, the weight (W) of a person is directly proportional to his waist size (W_S) since a decrease in one leads to a corresponding decrease in the other; and vice versa. Hence mathematically,

$$W \propto W_S;$$
$$\Rightarrow W = k_2 W_S \tag{2.2}$$

2.1.2 First establishment of model parameter relationship

From our respective postulations above, adding equation (2.1) and (2.2) gives

$$2W = k_1 H + k_2 W_S$$
$$\therefore W = AH + BW_S \tag{2.3}$$

Where: $A = \frac{k_1}{2}$ and $B = \frac{k_2}{2}$

Where: H = Height of an Individual
W_S = Waist size of an Individual
W = Weight of an Individual
And A, B are the Model constants.

2.1.3 Nature of equation's basic assumption

Under this heading, the nature of equation view was given to the relationship that existed between the variables of the model. Hence, a relationship graph was plotted for weight, height and waist size and considering equation (2.1) and (2.2), it can be observed also that:

- The relationship between the human weight, W and height (H) is a Linear equation relationship.

$$\therefore W = aH + C_1 \quad (where\ C_1\ is\ a \text{ constant}) \tag{2.4}$$

- The relationship between the human weight W and his waist size W_S is a linear relationship also.

  Therefore,

$$W = bW_S + C_2 \quad (where\ C_2\ is\ a \text{ constant}) \tag{2.5}$$

2.1.4 Second establishment of model parameter relationship

From our respective equations above, adding equation (2.4) and (2.5) gives

$$W = a'H + b'W_S + C$$
$$(where\ C\ is\ a\ \text{constant}\ and\ a' = \tfrac{1}{2}a,\ b' = \tfrac{1}{2}b, C = C_1 + C_2) \quad (2.6)$$

2.1.5 General establishment of model parameter relationship

From our respective postulations above, if we add equations (2.3) and (2.6) in a similar way, we have,

$$2W = (A + a')H + (B + b')W_S + C$$
$$\therefore W = \alpha H + \beta W_S + \gamma \quad (2.7)$$

Where: H = Height of an Individual human being
W_S = Waist size of an Individual human being
W = Weight of an Individual human being
$\alpha, \beta\ and\ \gamma$ are the Model constants.

2.2 Analysing the Model to Evaluate Its Equation Constants

To evaluate the constants in the model above, equation (2.7) is going to be differentiated partially with respect to $\alpha, \beta\ and\ \gamma$ respectively. To do this, we have to minimize the model using *least squares method* as follows: From (2.7) we let,

$$Z_{\min} = \min \sum (W_i - \alpha H - \beta W_S - \gamma)^2 \quad i = 1, 2, 3, \ldots, n \quad (2.8)$$

$$\frac{\partial Z}{\partial \alpha} = -2\sum (W_i - \alpha H_i - \beta W_{Si_i} - \gamma) H_i = 0 \quad (2.9)$$

$$\frac{\partial Z}{\partial \beta} = -2\sum (W_i - \alpha H_i - \beta W_{Si_i} - \gamma) W_{Si_i} = 0 \quad (2.10)$$

$$\frac{\partial Z}{\partial \gamma} = -2\sum (W_i - \alpha H_i - \beta W_{Si_i} - \gamma) = 0 \quad (2.11)$$

Hence from (2.9)

$$-2\sum (W_i - \alpha H_i - \beta W_{Si_i} - \gamma) H_i = 0 \quad (2.12)$$

$$\therefore\ \alpha \sum H_i^{\,2} + \beta \sum W_{Si} H_i + \gamma \sum H_i = \sum W_i H_i \quad (2.13)$$

Also from (2.10)

$$-2\sum (W_i - \alpha H_i - \beta W_{Si_i} - \gamma) W_{Si} = 0 \quad (2.14)$$

$$\therefore\ \alpha\sum H_i W_{Si} + \beta\sum (W_{Si})^2 + \gamma\sum W_{Si} = \sum W_i W_{Si} \qquad (2.15)$$

Hence from (2.11)

$$-2\sum (W_i - \alpha H_i - \beta W_{Si_i} - \gamma) = 0 \qquad (2.16)$$

$$\therefore\ \alpha\sum H_i + \beta\sum W_{Si} + 10\gamma = \sum W_i \qquad (2.17)$$

i = 1, 2, 3, …, n. But, for this research, n = 10.

Meanwhile Equations (2.13), (2.15) and (2.17) are to be solved simultaneously for values of $\alpha, \beta\ and\ \gamma$ respectively.

2.2.1 Research instrument used

The research instrument used is known as the random sampling technique. This is a situation where a certain sample of the Taraba State's community members was randomly made to represent the entire population of the university community in the research. However, during the study, only the set of questionnaires for persons that are not 'deprived' by nature leading to dwarfism, obesity etc were considered. Such natural situation stated above may affect the authenticity of our research model and may not allow the model results to conform to reality. Also, in the questionnaire there are questions designed to checkmate fake responses. Wherever any element of fake response is discovered, the questionnaire is ignored accordingly.100 copies of questionnaire were distributed. But only 10 copies which satisfied our acceptability test were considered. We attached a fake response (F.R.) test/acceptability test to each questionnaire such which any one that became successful was considered for the research.

Table 1. Questionnaire and measured data gathered from Federal University Wukari community of Nigeria

Weight(kg)	Height, H(m)	Waist size, W_s (inches)
55	1.58	32
60	1.68	31
61	1.7	31
63	1.72	33
65	1.72	31.5
68	1.73	32
68	1.76	32
70	1.77	32
75	1.8	33
80	1.9	32

2.3 Evaluation of the Equation Constants Using the Questionnaire Data in Table 3

Solving equation (2.13), (2.15) and (2.17) in the section above simultaneously, where from the Table 1 above.

Table 2. Multiplication values of the figures in Table 1 above

Weight (kg)	Height H (m)	Waist size W_s (inches)	H^2 (m^2)	W_s^2	WH	W_sH	WW_s
55	1.58	32	2.4964	1024	86.9	50.56	1760
60	1.68	31	2.8224	961	100.8	52.08	1860
61	1.7	31	2.89	961	103.7	52.7	1891
63	1.72	33	2.9584	1089	108.36	56.76	2079
65	1.72	31.5	2.9584	992.25	111.8	54.18	2047.5
68	1.73	32	2.9929	1024	117.64	55.36	2176
68	1.76	32	3.0976	1024	119.68	56.32	2176
70	1.77	32	3.1329	1024	123.9	56.64	2240
75	1.8	33	3.24	1089	135	59.4	2475
80	1.9	32	3.61	1024	152	60.8	2560
$\sum W =$ 665	$\sum H =$ 17.36	$\sum W_{Si} =$ 319.5	$\sum H_i^2 =$ 30.199	$\sum (W_{Si})^2 =$ 10212.25	$\sum W_i H_i =$ 1159.78	$\sum W_{Si} H_i =$ 554.8	$\sum W_i W_{Si} =$ 21264.5

Using the data collected for equations (2.13), (2.15) and (2.17) as evaluated in Table 2, we have:

$\sum W_i = 665$, $\sum H_i = 17.36$, $\sum W_{Si} = 319.5$, $\sum H_i^2$ = 30.199,
$\sum (W_{Si})^2$ = 10212.25, $\sum W_i W_{Si}$ = 21264.5, $\sum W_i H_i$ = 1159.78, $\sum W_{Si} H_i$ = 554.8

$$\therefore 30.199\alpha + 554.8\beta + 17.36\gamma = 1159..78 \tag{2.18}$$

$$554.8\alpha + 10212.25\beta + 319.5\gamma = 21264.5 \tag{2.19}$$

$$17.36\alpha + 319.5\beta + 10\gamma = 665 \tag{2.20}$$

Hence, solving (2.18), (2.19) and (2.20) above gives,

$$\alpha = 82.98607497 = \frac{41493}{500},$$
$$\beta = 1.294215599 = \frac{647}{500},$$
$$\gamma = -118.9140145 = \frac{-59457}{500}.$$

Also, putting the values of α, β *and* γ *in equation* (2.7) *yields*,

$$\therefore W = \frac{41493H + 647W_S - 59457}{500}; W \geq 0 \quad or \ W \in [0,1) \tag{2.21}$$

Thus, equation (2.21) is the developed model for estimating weight of human beings (Nigerian to be specific).

3 Results and Discussion

In the concluding part of the previous chapter, data were collected in order to be able to evaluate our emerging model equation constants. Thus, our new model equation now as in equation (2.21) is,

$$\therefore W = \frac{41493H + 647W_S - 59457}{500}; W \geq 0 \quad or \ W \in [0,1)$$

3.1 Optimization of the Model

This approach is a technique for programming/optimizing an objective function or a model in order to know whether a model conforms to reality or not. Thus, the first part of our optimization process is the determination of the model's critical values as below:

From (2.7),

$$\left.\begin{aligned} W &= \alpha H - \beta 1 W_S + \gamma \\ \therefore \quad W &= \frac{41493\ H + 647\ W_S - 59457}{500} \end{aligned}\right\} \tag{3.0}$$

$$\frac{\partial W}{\partial H} = \alpha \tag{3.1}$$

$$\frac{\partial W}{\partial W_S} = \beta \tag{3.2}$$

But at optimal level,

$$\frac{\partial W}{\partial H} = \frac{\partial W}{\partial W_S} = 0$$

$$Hence\ at\ optimal\ \ level,$$

$$H = 0$$

$$W_S = 0$$

Putting values of $H\ and\ W_S$ into equation (3.0) gives,

$$W < 1\ kg$$

Thus, our critical values are: $W < 1\ kg$, $H = 0\, metres\ and\ W_S = 0\, Inch.$

The above critical values do not conform to reality since human being cannot have weight 0kg or height 0meter. And thus, there is no genuine information derivable about the extreme values of the model which is a confirmation of equation (3.3) below after the analysis.

3.2 Observation on the Nature of the Models' Extreme Values

This stage is necessary in order to know whether the model's extreme point $W_{o,}$ is a minimum or a maximum.

Generally, given a function f(x, y) that obeys the continuity of the partial derivatives and we

Let: $A = \frac{\partial^2 f}{\partial x^2}$; $B = \frac{\partial^2 f}{\partial x \partial y}$; and $C = \frac{\partial^2 f}{\partial y^2}$; then,

1) If B^2 – AC< 0, then f(x, y) has extreme value at (x_o, y_o) and minimum if A > 0 and it is maximum if A < 0
2) IfB^2 – AC > 0, or AC<B^2 then f(x, y) has no extreme value. That is, it has a saddle point at (x_o, y_o).
3) If B^2 – AC = 0, then no information is derivable about its extreme values.

Similarly, importing the same idea in our reduced model equation variables,

$$\frac{\partial \mathrm{W}}{\partial \mathrm{H}} = \alpha \ , \ \frac{\partial W}{\partial W_S} = \beta$$

$$\frac{\partial^2 \mathrm{W}}{\partial \mathrm{H}^2} = 0$$

$$\frac{\partial^2 W}{\partial {W_S}^2} = 0$$

$$\frac{\partial^2 W}{\partial H W_S} = \frac{\partial}{\partial H}\left(\frac{\partial W}{\partial W_S}\right)$$

$$\therefore \frac{\partial^2 W}{\partial H W_S} = 0$$

From our general argument above,

$$B^2 - AC = 0 \tag{3.3}$$

It means W has no information derivable about its extreme values or it has no local *extremum* or has no specific optimal value (that is, there is no specific minimum or maximum value for weight of human beings in the range of values $W \geq 0 \quad or \ W \in [0,1)$).

3.3 Validation of our Model

After the model became ready, the researcher conducted a pilot test using some people living in Taraba State community (the area of the research) to see whether or not the model conforms to reality. The test confirms that the model is suitable for the people since the absolute difference between the model data generated and the actual measurement done for the people is approximately less than five unit (as in Table 3 below). This little difference in measurement however, is due to the fact that, the parameters considered by the researcher are not the whole parameters associated with the study of weight of a human being.

This confirms the view of [10] that, model parameter relationships are inexact. The reason being that, the solution is dependent on the parameters decided to be considered by the modeller. In the same vein, the model is developed and validated in Nigeria, if considered logical could be used to make a universal generalization about the weight of every other person in the world.

Moreover, the table below gives a validation of the questionnaire data to see whether the model really measures what it claims to measure in order to be able to conclude if the model conforms to reality or not.

Table 3. Table for validation of our model

Questionnaire data on weight (kg)	Model data on weight (kg)	Absolute difference/Error
55	53.6	Less than 2 units
60	60.6	Less than 1 units
61	62.3	Less than 2 units
63	66.5	Less than 4 units
65	64.6	Less than 1 units
68	66.1	Less than 2 units
68	68.6	Less than 1 units
70	69.4	Less than 1 units
75	73.2	Less than 2 units
80	80.2	Less than 1 units

3.4 Discussion of Results

From our optimization result in equation (3.3) above, it was noticed at various levels of our model analysis that there is no particular weight of human beings that can be called the maximum or minimum weight. This is consequent upon obtaining neither minimum nor maximum value as the model's extreme/optimal value as evident in equation (3.3) above. This tends to substantiate the reason why the award for the world heaviest/weightiest man keeps on changing and never constant. For instance, [11] weighed 463 kg, [12] weighed 544 kg, [13] weighed 545 kg, [14] weighed 500 kg and so on. It then means that a person's weight value cannot be constant as he does not have maximum or minimum value. Equally, the developed model equation is relevant as compared to other existing models because, this model gives rise to simplicity of measures and can be utilized in remote areas in the absence of physically produced weight scales if tape rule for measuring height and waist sizes could be made available. It is also relevant in checkmating cases of false report of data from the available weight machines.

4 Conclusion

In view of the fact that immunity/resistance to health conditions and ailments varies from generation to generations and geographical location to geographical locations, then this research recommends that new, repeated and consistent researches be made about respective communities members' weight, body mass index (BMI), weight loss, reactions to treatment/illness/conditions and other body compositions in order to overhaul reasons behind why so many persistent medical conditions posses solitary characteristics that need to be treated alike.

Finally, the weight model developed in this research work possesses a higher level of correlation as deducted from the result obtained in the model validation section above. Hence the model could be recommended as one of the standard measure for determining the weight of Nigerians and other human beings alike.

Competing Interests

Authors have declared that no competing interests exist.

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