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Original Research Article

A Regression Model for Predicting the Cost of Laterite- Quarry Dust Cement Blocks

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Abstract

This is part of a study investigating the structural properties of blocks produced from using different combination of laterite and quarry dust as full replacement for conventional river sand as aggregate. The use of alternative materials in blocks production and other concrete works is becoming increasingly popular across most developing countries. This work developed a mathematical model using Osadebe Regression Theory (ORT) for the prediction of cost/cum of laterite- quarry dust cement block. The lack of fit of the model was carried out using statistical tool (excel) and found to be adequate. The model will be very useful especially for commercial blocks producers and built experts in Nigeria and sub-Sahara African countries for construction cost estimation and profit projection.

Keywords: Regression model, Blocks, Cost, Osadebe Regression, Equation, Estimation, Construction.

INTRODUCTION

The execution of any construction project involved carrying out series of activities. These activities utilizes resources and materials that cost a lot of money. The total cost or estimation of a construction project or any other project depends on the overall cost of individual activities. To this end, Kumar (2016) posited that "the accuracy of an estimate can be improved once the nature of the project is clearly defined, and all quantities, quality of material and workmanship, logistics, etc., are well understood." Masonry unit or building blocks are major materials in the built industry. The use of sandcrete blocks as masonry or wall units, produced from an appropriate mix of convention river sand, cement and water in building construction have been reported to be over 90% (Amatobi *et al*., 2018). Continuous use of sandcrete blocks in construction have also been reported as one of the major reasons behind the high cost of providing shelter, especially for sub-Saharan Africans. This rising cost of building has made it necessary for experts in the built industry to utilize locally produced building materials in meeting the shelter needs of low- and mid-income earners (Labaran *et al*., 2020).

Blocks made from laterite and quarry dust are alternative to sandcrete blocks as they will assist in addressing the critical challenge of meeting the current demand for housing in most developing countries across the globe. Nigeria is blessed with huge deposits of laterite suitable for local utilization in the built industry, but regrettably, not much has been done to optimize its utilization (Ramachandra, 1983). Most of the utilization of laterite is found in geotechnical application in road improvement and landfilled. Quarry dust, a by-product of quarry activities produced during the crushing operations are not processed to meet specification requirements for use in building and are before now abandoned within the crusher units or its environ in heaps causing serious health hazards and other environmental issues (Chaoudhary, 2015). According to Wood and Merek (1993), ‘‘the physical properties, chemical composition and mineralogy of quarry dust are sources specific, but relatively consistent at each quarry location and may vary with the rock type, but the dust has the nature of cohesionless materials and is known to contained the particle size of conventional sand. These qualities makes it suitable replacement for sand in concrete and concrete related works’’.

The use of alternative materials in blocks production and other concrete works is becoming increasingly popular across most developing countries. The acceptance and used of alternative materials in block production has given rise to the surge in small –scale blocks manufacturing companies in most major cities of Nigeria. The fluctuating market system has also led to a lot of uncertainty in project costing. Knowledge of a cost model for estimation of materials cost is needed to reduce the risk associated with arbitrary estimation and it will also assist entrepreneurs in overall project cost projection. The paper presents a model for predicting the cost/cum of laterite quarry dust cement blocks. The model will assist in reducing the laborious effort in attempting to find out the cost for different mixes.

Review of Related Works

Globally, the use of alternative materials for blocks production to reduce the cost of construction projects as well as minimise the adverse environment effect associated with river sand mining is being advocated and is currently gaining impetus. A reduction in cost production cost up to 11.89% has been reported by Joshua and Lawal (2011) when laterite were used in block production. It has been observed that the overall cost of any project depends on the cost of the various activities that make up the project. Execution of individual activities also depends on the different materials constituents. The estimated project cost therefore depends on the materials cost. The construction industry has been described as one having the highest cases of cost volatility and that early cost planning and estimation response to construction projects cost volatility assures great success of the project (Egwunatum and Oboreh, 2015). Cost models as opined by SAVE international (2005) have been found to be a useful tool used to demonstrate the total cost of families of systems, components, or parts within a total complex product, system, structure or facility. Regressions models have been applied successfully by different authors for the determination of the cost and structural properties of concrete and concrete related works. A generalized unit rate cost model for pricing of concrete works was developed by Egwunatum and Oboreh (2015). They propose that other elements of building like blockwork, rendering, excavation, roof members, painting, etc. should also be modeled in their unit rate form and that the cost of a building can be known when the various quantities are multiplied by their unit rate cost and subsequently summed up with prime cost items. A building cost estimation model based on functional elements was developed by Hakan and Tas (2007). The external elements include, slab, doors and stairs, external and internal walls, windows, external and internal doors, roof, superstructure etc. some of these functional elements are made from blocks. A mathematical model for the strength of sandcrete blocks made from a combination of appropriate mix of cement, Rice Husk Ash and laterite was developed by Onuamah (2015). Many other researchers, (Lowe *et al.*, (2006), Chan and Park (2005), Trost and Oberlender (2003), Oberlender and Trost (2001), Ogunsemi and Jagboro (2006), Gunaydin and Dogan (2004)] have developed cost model for the estimation of project and building cost. Models have also been developed for the prediction of other properties of hollow block, [Onuamah and Osadebe (2015), Osuji and Egbon (2015), Okafor and Egbe 2017)]. From the review, it is obvious that none of these researchers have developed a model for the estimation of cost/cum for blocks or masonry unit made from laterite quarry dust cement. Also, literature in this aspect is scanty. This gap is what this work intends to address and will form the fulcrum of the research.

MATERIALS AND METHOD

MATERIALS

The following materials were used for this work: water, cement, laterite and quarry dust. For preparation of samples and curing, potable water supplied by the Cross River State Water Board (CRSWB) Limited was used. Portland Limestone cement (Unicem brand) grade 32.5N bought from a major vendor in Calabar, Nigeria, conforming to BS 12 was used for all the tests. The quarry dust used was obtained from the quarry site operated by SINO construction at Akamkpa, Cross River State. (Latitude 05^0 13.03' and Longitude 08^0 21.15'). The laterite used was obtained from an existing borrow pit at Akim- Akim in Odukpani Local Government Area, Cross River State (Latitude 05^0 07.48' and Longitude 08^0 20.5') while river sand obtained from Calabar river was used for the study.

METHOD

This work employs two methods; namely, analytical and experimental. The analytical method is concerned with the arrangement of points within the experimental region and choosing a second degree polynomial equation to represent the response surface over the entire region. The response in this case is the cost/cum of the laterite-quarry dust blocks. The response function is assumed to be multi-varied.

The response *y*, is expressed as a function of the actual proportions of the constituents of the mixture, Z_i by Osadebe (2003) [9]. The sum of all the quantities as expected of a mixture experiment must add up to 1. That is:

$$Z_1 + Z_2 + \cdots + Z_q = \sum_{I=1}^{q} Z_i = 1 \quad (1)$$

Osadebe assumed that $y = F(Z)$, is continuous and differentiable with respect to its predictors, and can be expanded in the region of a chosen point, $Z(0)$ using Taylor's series to yield the Osade equation as stated thus:

$$y(Z) = \sum_{i=1}^{q} \beta_i Z_i + \sum_{i \le j \le q}^{q} \beta_{ij} Z_i Z_j \quad (2)$$

Where

$$\beta_i = b_0 + b_i \dots\dots + b_{ii} \quad (3)$$

$$\beta_{ij} = b_{ij} - b_{ii} - b_{ij} \quad (4)$$

Which is defined if the unknown constant coefficients β_i and β_{ij} are uniquely determined.

If the number of constituents, q, is 4, and the degree of the polynomial, n, is 2 then the Osadebe regression equation is expressed thus:

$$y = \beta_1 Z_1 + \beta_2 Z_2 + \beta_3 Z_3 + \beta_4 Z_4 + \beta_{12} Z_1 Z_2 + \beta_{13} Z_1 Z_3 + \beta_{14} Z_1 Z_4 + \beta_{23} Z_2 Z_3 + \beta_{24} Z_2 Z_4 + \beta_{34} Z_3 Z_4 \quad (5)$$

The number of coefficients, N for a {4, 2} model is obtained from;

$$N = C_n^{(q+n-1)} = N = C_2^{(4+2-1)} = 10$$

The response function is generally given as:

$$y(Z) = \sum_{i=1}^{q} \beta_i Z_i + \sum_{i \le j \le q}^{q} \beta_{ij} Z_i Z_j \quad (6)$$

Determination of the Coefficients of the Osadebe's Regression Equation

The least number of experimental runs or independent responses necessary to determine the coefficients of the Osadebe regression coefficients is *N*.

The response is obtained from the N linear algebraic equations which can be written in matrix form as:

$$\boldsymbol{Z\beta} = \boldsymbol{y} \quad (7)$$

Where

$\boldsymbol{\beta}$ is a vector whose elements are the estimates of the regression coefficients.

$\boldsymbol{Z}$ is an *N x N* matrix whose elements are the mixture component proportions and functions of the component proportions.

$\boldsymbol{y}$ is a vector of the observations or responses at the various *N* observation points.

The regression coefficients for the model are obtained from:

$$\boldsymbol{\beta} = \boldsymbol{Z}^{-1}\boldsymbol{y} \quad (8)$$

Experimental Method

The pseudo proportion units were converted to actual mix proportion as indicated in table 1. The actual mix proportions; water (Z1), cement (Z2), quarry dust (Z3), and laterite (Z4), were measured by weight and used to produce machine vibrated laterite- quarry dust hollow blocks of size 450mm x 150mm x 225mm. The blocks were cured for 28 days after 24 hours of demoulding by sprinkling with water in the morning and evening. The densities of the block were computed using the relation by Duggal (2010) thus:

$$\boldsymbol{\rho = m/v} \quad (9)$$

ρ=density (Kg/m^3), m= mass (Kg), V= volume m^3

Cost of Production of 1m^3 of Laterite-Quarry Dust Mix

For the production of the blocks, two major costs, materials cost and that of labour and overhead were taken into consideration. To obtain the cost of material required to produce 1m^3 of each of the mixes, the products of the quantities of each constituent in a cubic meter of the mix and their respective current market price were summed up. The total cost was obtained by increasing the total cost of materials by 60% to carter for the costs of labour and overhead. The quantities of material in kilogram per cubic meter of the mixes were obtained based on the average densities obtained for the mixes.

Table 1 shows the prices of the material constituents while Table 2 shows the quantities of the constituents needed to produce 1m^3 of the mix. These quantities are based on the respective densities of the various mixes. It should be noted that the cost of the materials differ greatly from locations to locations.

Table 1: market prices of the materials for block making

S/No	Components	Cost per Kg (Naira)
1	Water	1.00
2	Cement	30.00
3	Quarry dust	2.00
4	Laterite	1.50

Source: (survey by researcher)

Table 2: Quantities of materials required for the production of 1m^3 of actual mix ratios

Run Order	Average density (kg/m^3)	Actual mix ratios				Quantity of material (Kg/m^3)			
		Water	Cement	Quarry dust	laterite	Water	Cement	Quarry dust	Laterite
1	1823	0.63	1	3.0	3.0	150.53	238.93	716.80	716.78
2	1890	0.72	1	5.6	2.4	140.00	194.44	1088.86	450.12
3	1962	0.54	1	5.4	0.6	140.50	260.19	1405.02	145.07
4	1899	0.67	1	7.2	0.8	131.55	196.34	1413.67	150.82
5	1909	0.77	1	4.0	4.0	150.45	195.38	781.53	746.37
6	1884	0.72	1	5.2	2.8	139.59	193.87	1008.12	525.14
7	1962	0.80	1	9.0	1.0	133.02	166.28	1496.51	154.49
8	1945	0.81	1	5.3	3.7	145.74	179.92	953.59	623.97

Run Order	Average density (kg/m³)	Actual mix ratios				Quantity of material (Kg/m³)			
		Water	Cement	Quarry dust	laterite	Water	Cement	Quarry dust	Laterite
9	1894	0.585	1	4.2	1.8	146.11	249.76	1048.99	432.62
10	1943	0.85	1	7.0	3.0	139.36	163.95	1147.68	461.52
11	1836	0.63	1	3.0	3.0	151.64	240.69	722.08	716.78
12	1860	0.90	1	5.0	5.0	140.69	156.32	781.59	765.97
13	1926	0.54	1	5.4	0.6	137.94	255.44	1379.37	145.07
14	1958	0.72	1	6.0	2.0	145.07	201.48	1208.89	375.10
15	1930	0.90	1	5.0	5.0	146.00	162.23	811.13	765.97
16	1961	0.63	1	5.5	1.5	143.14	227.20	1249.62	316.86
17	1959	0.80	1	9.0	1.0	132.84	166.06	1494.50	154.49
18	1883	0.72	1	5.6	2.4	139.45	193.68	1084.61	450.12
19	1972	0.674	1	4.3	2.7	153.24	227.36	977.63	567.45
20	1945	0.76	1	7.3	1.7	137.36	180.73	1319.37	288.02

Table 3 below shows the design matrix in the pseudo and real ratios along with the experimental test results for the cost.

Table 3: Pseudo and real ratios along with the experimental test results for the cost.

S/N	Pseudo components units				Actual mix ratio				Average response (y)
	Water (X1)	Cement (X2)	Quarry dust (X3)	Laterite (X4)	Water (X1)	Cement (X2)	Quarry dust (X3)	Laterite (X4)	Cost /Cum (Nmm⁻²)
1	0	1	0	0	0.63	1	3.0	3.0	9827.35
2	0.25	0.25	0.25	0.25	0.72	1	5.6	2.4	9784.14
3	1	0	0	0	0.54	1	5.4	0.6	12863.72
4	0.5	0	0.5	0	0.67	1	7.2	0.8	10969.65
5	0	0.5	0	0.5	0.77	1	4.0	4.0	8747.33
6	0.5	0	0	0.5	0.72	1	5.2	2.8	9484.10
7	0	0	1	0	0.80	1	9.0	1.0	10359.14
8	0.125	0.125	0.125	0.625	0.81	1	5.3	3.7	8881.01
9	0.5	0.5	0	0	0.58	1	4.2	1.8	11310.31
10	0	0	0.5	0.5	0.85	1	7.0	3.0	9074.90
11	0	1	0	0	0.63	1	3.0	3.0	9899.73
12	0	0	0	1	0.90	1	5.0	5.0	7565.81
13	1	0	0	0	0.54	1	5.4	0.6	12628.93
14	0	0.5	0.5	0	0.72	1	6.0	2.0	10420.62
15	0	0	0	1	0.90	1	5.0	5.0	7851.74
16	0.625	0.125	0.125	0.125	0.63	1	5.5	1.5	11332.93
17	0	0	1	0	0.80	1	9.0	1.0	10345.24
18	0.25	0.25	0.25	0.25	0.72	1	5.6	2.4	9745.98
19	0.125	0.625	0.125	0.125	0.67	1	4.3	2.7	10395.65
20	0.125	0.125	0.625	0.125	0.76	1	7.3	1.7	10177.18

From Table 3, a total of 15 mixes were considered. 10 mixes were selected and use for the formulation of the model, while the remaining were used to validate the model as shown in Table 4.

Table 4 also contained the average experimental values for cost/m³ Cells having two run order numbers indicate the replicate mixes and the response in this case is the average response for the replicate mixes.

Table 4: Actual and fractional mix for Osadebe

Run Order	Components in actual ratios				Component proportions				Responses
	Water (X_1)	Cement (X_2)	Quarry dust (X_3)	Laterite X_4	Water (Z_1)	Cement (Z_2)	Quarry dust (Z_3)	Laterite (Z_4)	cost (cum)
3,13	0.54	1	5.4	0.6	0.071618	0.132626	0.716180	0.079576	12628.93
9	0.585	1	4.2	1.8	0.077126	0.131839	0.553724	0.237310	11310.31
4	0.67	1	7.2	0.8	0.069286	0.103413	0.744571	0.082730	10969.65
6	0.72	1	5.2	2.8	0.074074	0.102881	0.534979	0.288066	9484.10

Run Order	Components in actual ratios				Component proportions				Responses
	Water (X_1)	Cement (X_2)	Quarry dust (X_3)	Laterite X_4	Water (Z_1)	Cement (Z_2)	Quarry dust (Z_3)	Laterite (Z_4)	cost (cum)
1,11	0.63	1	3.0	3.0	0.082569	0.131062	0.393185	0.393185	9827.35
14	0.72	1	6.0	2.0	0.074074	0.102881	0.617284	0.205761	10420.62
5	0.77	1	4.0	4.0	0.078813	0.102354	0.409417	0.409417	8747.33
7,17	0.80	1	9.0	1.0	0.067797	0.084746	0.762712	0.084746	10359.14
10	0.85	1	7.0	3.0	0.071730	0.084388	0.590717	0.253165	9074.90
12,15	0.63	1	5.5	1.5	0.073001	0.115875	0.637312	0.173812	7565.81
MIXES FOR MODEL VALIDATION									
2,18	0.72	1	5.6	2.4	0.074074	0.102881	0.576132	0.246914	9960.22
16	0.63	1	5.5	1.5	0.073001	0.115875	0.637312	0.173812	11002.28
19	0.674	1	4.3	2.7	0.077703	0.115287	0.495734	0.311275	10008.25
20	0.76	1	7.3	1.7	0.070632	0.092937	0.678439	0.157993	10191.25
8	0.81	1	5.3	3.7	0.074931	0.092507	0.490287	0.342276	8705.96

RESULT AND DISCUSSION

The test results of the cost/m^3 of the laterite-quarry dust blocks based on densities are presented as part of Table 3. The elements of the Z matrix are presented in Table 5.

Formulation of Model Equation for Cost/M^3

Table 5: Elements of the Z matrix for the Osadebe's model

Z_1	Z_2	Z_3	Z_4	Z_1Z_2	Z_1Z_3	Z_1Z_4	Z_2Z_3	Z_2Z_4	Z_3Z_4
0.071618	0.132626	0.71618	0.079576	0.009498	0.051291	0.005699	0.094984	0.010554	0.05699
0.077126	0.131839	0.553724	0.23731	0.010168	0.042707	0.018303	0.073003	0.031287	0.131405
0.069286	0.103413	0.744571	0.08273	0.007165	0.051589	0.005732	0.076998	0.008555	0.061598
0.074074	0.102881	0.534979	0.288066	0.007621	0.039628	0.021338	0.055039	0.029636	0.154109
0.082569	0.131062	0.393185	0.393185	0.010822	0.032465	0.032465	0.051531	0.051531	0.154594
0.074074	0.102881	0.617284	0.205761	0.007621	0.045725	0.015242	0.063507	0.021169	0.127013
0.078813	0.102354	0.409417	0.409417	0.008067	0.032267	0.032267	0.041905	0.041905	0.167622
0.067797	0.084746	0.762712	0.084746	0.005745	0.051709	0.005745	0.064637	0.007182	0.064637
0.07173	0.084388	0.590717	0.253165	0.006053	0.042372	0.018159	0.04985	0.021364	0.149549
0.07563	0.084034	0.420168	0.420168	0.006355	0.031777	0.031777	0.035308	0.035308	0.176541

Substituting the numerical average replicate values of cost observed at the ten design points of the simplex into Equation (8) and solving simultaneously gives the following values of the coefficients:
$\beta 1$ = 600929.5220, $\beta 2$ = 1860935.8210 $\beta 3$ = - 68181.6244 $\beta 4$ = - 115333.9974 $\beta 12$ = - 11972976.1400, $\beta 13$ = 752974.3327 $\beta 14$ = 796465.0364 $\beta 23$ = - 1441109.9880 $\beta 24$ = - 1139548.0070,
$\beta 34$ = 4638.9496

The resulting regression equation for the Osadebe second degree model is given below:

$$\hat{y} = - 3488008.6746Z1 + 185572.7053Z2 - 7669.0810Z3\ 34884.3830Z4 + 4002431.4096Z1Z2 + 3956123.9856Z1Z3\ 4320728.7499Z1Z4 - 173993.0987\ Z2Z3 - 169847.4049Z2Z4 + 7486.8129Z3Z4 \quad (10)$$

Table 6: Experimental and model predicted values for Cost for the different mixes

Run Order	Actual mix ratios				Experimental result (Naira/m^3)	Model predicted results (Naira/m^3)
	Water	Cement	Quarry dust	laterite		
1	0.63	1	3.0	3.0	9827.35	9827.35
2	0.72	1	5.6	2.4	9784.14	9960.22
3	0.54	1	5.4	0.6	12863.72	12628.93
4	0.67	1	7.2	0.8	10969.65	10969.65
5	0.77	1	4.0	4.0	8747.33	8747.33
6	0.72	1	5.2	2.8	9484.10	9484.10
7	0.80	1	9.0	1.0	10359.14	10359.14
8	0.81	1	5.3	3.7	8881.01	8705.96
9	0.59	1	4.2	1.8	11310.31	11310.31

Run Order	Actual mix ratios				Experimental result (Naira/m³)	Model predicted results (Naira/m³)
	Water	Cement	Quarry dust	laterite		
10	0.85	1	7.0	3.0	9074.90	9074.90
11	0.63	1	3.0	3.0	9899.73	9827.35
12	0.90	1	5.0	5.0	7565.81	7565.81
13	0.54	1	5.4	0.6	12628.93	12628.93
14	0.72	1	6.0	2.0	10420.62	10420.62
15	0.90	1	5.0	5.0	7851.74	7565.81
16	0.63	1	5.5	1.5	11332.93	11002.28
17	0.80	1	9.0	1.0	10345.24	10359.14
18	0.72	1	5.6	2.4	9745.98	9960.22
19	0.67	1	4.3	2.7	10395.65	10008.25
20	0.76	1	7.3	1.7	10177.18	10191.25

Test for Lack-Of-Fit and Adequacy

The analysis of variance table at 95% confidence limit for the observed and predicted values at the check points using Microsoft Excel is shown in Table 7. The calculated *F* value of 1.22 is less than the critical value $F_{0.5}$ (5, 5) = 5.05. Similarly, the *p-value* of 0.416 is greater than 0.05. Also the R^2 value is about 0.985. We therefore conclude that the model equation is adequate for predicting the cost of sand – quarry dust mixes

Table 7: Analysis of Variance for Cost (Osadebe's model)

Run order	Std order	Observed (₦)	Predicted (₦)		*y(observed)* (₦)	*y(predicted)* (₦)
2	11	9784.14	9960.22	Mean	10052.82	9971.3605
18	20	9745.98	9960.22	Variance	662257.17	542796.6663
16	12	11332.98	11002.28	Observations	6	6
19	13	10395.65	10008.25	df	5	5
20	14	10177.18	10191.25	F	1.22008334	
8	15	8881.01	8705.96	P(F<=f) one-tail	0.416266224	
				F Critical one-tail	5.050329058	

Normal Probability Plot

Figure 1 shows normal probability plot. The points in figure lie very close to the reference line with a *p-value* of 0.089 which is greater than 0.05. The data therefore follow a normal distribution, thereby hence justifying the assumption required for use of analysis of variance.

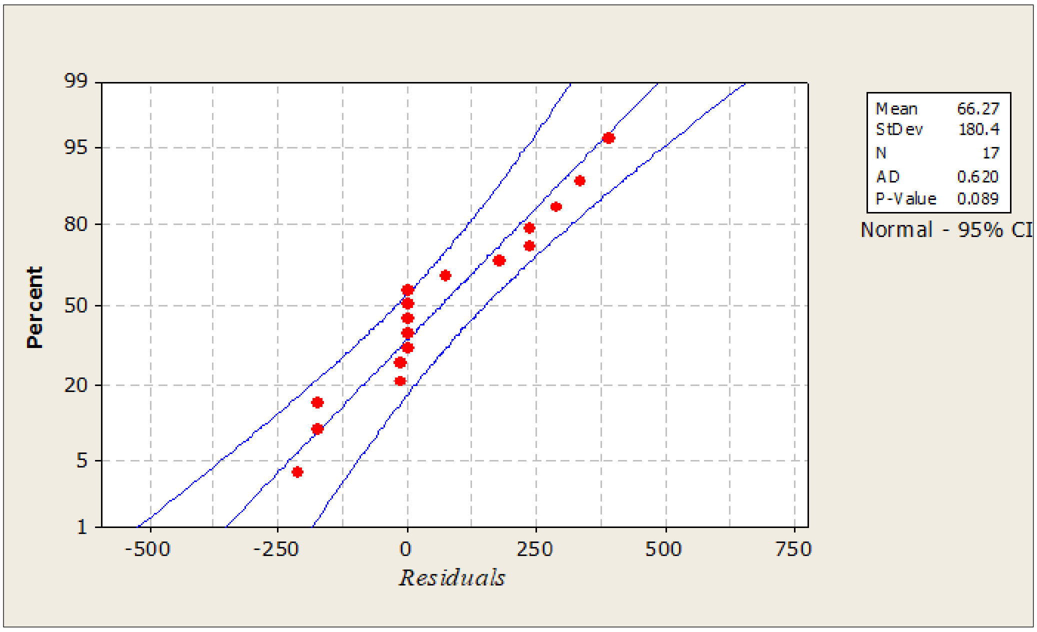

Fig. 1

RECOMMENDATION AND CONCLUSION

The following recommendation and conclusions is made from this study:

1. The use of laterite- quarry dust cement block is highly recommended as they have been proven to be cost effective
2. Abundant deposit of laterite and quarry dust has been used successfully, to produce block. This will invertly reduced the over dependence on conventional river sand which is costly, scares and unavailable in most part of world especially in landlocked areas.
3. A model for predicting the cost of laterite-quarry dust cement block has been developed using Osadebe regression Equation.
4. The adequacy of the model was tested using statistical tools and found to adequate.

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