Determining a Relatively Efficient Borehole Maintenance Cost Model for Community and Industrial Borehole in Anambra State, Nigeria

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Abstract: **This study examined the relative efficiency of two borehole maintenance cost model. The models considered in this study were the Agunwamba's borehole maintenance cost model and a proposed modified Agunwamba borehole maintenance cost model. Also, the linear and quadratic regression model were used to generated some of the parameters for the borehole maintenance model. The study used secondary source of data collection from records on borehole maintenance from two community commercial boreholes and two industrial boreholes in Anambra State. The findings of the study revealed that industrial borehole 2 has a strong adequacy of the model across the various categories of boreholes considered for both the linear and the quadratic regression model. The proposed method was found to recorded the least mean cost and the least standard error using the linear model with a value of ₦2,100,870.84 and ₦1,810,964.40 respectively while the Agunwamba's method found a mean cost of ₦20,654,123.76 and standard error of ₦38,988,729.88. Also, the proposed method recorded the least mean cost and standard error using the quadratic model with a cost value of ₦6,018,935.13 and ₦6,977,089.98 respectively while the Agunwamba's method found a mean cost of ₦20,756,556.66 and standard error of ₦39, 239,725.78. Hence, the proposed method was found to perform better than Agunwamba's method.**

Keywords: **Commercial Borehole, Liner model, Maintenance Cost, Quadratic Model.**

I. INTRODUCTION

One major challenge facing the world at large is how to sustain water supply through borehole, especially in the rural areas and as a result, many researchers have been conducted on this pending issue. Poor feasibility studies and maintenance structure are among the serious factors hindering sustainable water supply (Agunwamba, 2000). Failure modes of boreholes were studied by Ajayi and Abegunrin (1990). Results collected on drilling and borehole performance on the 256 boreholes studied in the crystalline rocks of South-western Nigeria show that the major cause of failure of boreholes is the tapping of aquiclude. Other factors include seasonal variation in water level, improper casing, pump failure and blocked pipes (Okere, 2010).

Sustenance means continuance of water supply, but without planned preventive maintenance, this noble dream will be a mirage. In recent study (Okere, 2010) of the status of 53 private and government owned boreholes in Abia and Imo States it was found that over 8% of the boreholes are not functional due to poor maintenance strategies, especially government owned boreholes while privately owned boreholes that are maintained remain functional for commercial purposes (Okere, 2010). In Nigeria, government and community borehole maintenance is almost non-existence because it is not given a priority it deserves. Government's attitude towards borehole maintenance is quite discouraging because budgetary allocation for the purpose is not made as it is viewed as a waste conduit. Government in Nigeria prefers to spend budgetary allocation on new borehole schemes than maintain existing ones.

In Nigeria, policies in operation and maintenance of boreholes are shrewd under lack of awareness and knowledge aided by timid misconception and therefore, rarely implemented. Planned maintenance schedule if ever it exists, is never followed, but rather dependency is on crises management, i.e. responding to events as they arise. Borehole development in Nigeria is an all comers field and usually done in an uncoordinated and unregulated manner and once a borehole is completed and functional, little or no attention is given to below-ground system, until a problem occur (Howsam, 1994). This can be attributed to the misconception that boreholes correctly designed, constructed and operated require no maintenance. This has made planned maintenance of boreholes in this country a mirage. Also, monitoring which should be associated with maintenance is not accorded a good priority and this may be due to lack of finance, of organizational and logistic resources, of expertise, of coordination between departments involved. However, for sustainability of water supply through borehole, there is need for an efficient optimized maintenance cost model. Hence, the aim of this work is to develop a relatively efficient borehole maintenance cost model in Anambra State, Nigeria.

II. LITERATURE REVIEW

Speaking on the importance of maintenance, Al-Najjar and Pehrsson (2005) revealed from their study that maintenance is directly linked to competitiveness and profitability and thus to the future of the company.

In addition, Al-Nijjar (2007) reveals that the competitiveness and performance of manufacturing companies depend on the availability, reliability and productivity of their production equipment. Also, the economic factors related to maintenance such as maintenance direct cost, production losses and maintenance investments have a major influence on a big share of a company's income. According to Robertson and Jones (2004) maintenance budgets range from 2% to 90% of the total plant operating budget, with the average being 20.8% (Jardine and Tsang, 2006). According to Xianxun (2007), to maintain safety and reliability throughout the service life, including any extended life, aging in the infrastructure must be effectively managed. Aging management deals with problems such as when and where an inspection should be undertaken, what specific maintenance actions and when these actions should be taken.

Maintenance is not just a technical problem but also an economic problem. Business economics are important, as maintenance cannot be managed as a purely technical or technological function only (Pintelon and Van Puyvelde, 2006). Therefore, there is a need for maintenance decision support systems and models in order to take cost-effective decision based on prognostic information. Despite many technological and management advances that has taken place within maintenance, there are still some major issues, identified in literature that remain unresolved throughout the last decades.

The first is the limited scope that is taken with regards to maintenance objectives, as in most of the models of cost optimization approach is taken (Van Horenbeck *et al*., 2010). Moreover, no justification on the used maintenance objectives is given in the form of answering the question: "are these the real business specific maintenance objectives". Many models to determine optimal maintenance policies appear in literature. However, more application oriented research is necessary according to Dekker (1995), as currently the gap between academic models and application in a business context is still the biggest problem encountered within maintenance management and optimization. Generally, case studies are not well represented within the available literature on maintenance management and optimization (Nicolai and Dekker, 2007). There is a clear need to shift from theoretical research to applied research (i.e. develop models applicable to real life case studies) within maintenance optimization (Scarf, 1997; Garg and Deshmukh, 2006).

Directly linked to the few maintenance case studies, that appear in literature is the lack of good maintenance data. As Dekker (1996) states, that data availability is often seen as the biggest obstacle to overcome to close the gap between maintenance optimization models and real life case studies. The necessary data can be listed under three headings, namely failure data, operating data and cost data (Van Horenbeck *et al*., 2010). However, most maintenance information systems mainly contain accounting information, which is not valuable for maintenance optimization, rather than maintenance event and cost data. Most often, it is relatively easy to register or quantify direct maintenance costs (e.g. component cost), but indirect maintenance costs (e.g. due to accelerated wear) are much more difficult to determine. There is a clear need for the existence of a maintenance database that will provide reliable information for maintenance analysis (Celdeira Duarte *et al*., 2013). The introduction of the concept of e-maintenance has according to many authors (Muller *et al*., 2008) improved the potential to solve the maintenance data problem.

III. METHODS AND MATERIAL

3.1 Data Collection

Secondary source of data collection was adopted for this study. The required data were obtained from maintenance cost records of two community commercial boreholes (Umuanuka Community Borehole, Nnewi and Nkpologuwu Community Borehole) and two industrial boreholes (NwanyioCha Commercial Borehole Nnewi and Intafact Beverages Limited Borehole, Onitsha) in Anambra State. The choice of the boreholes was based on availability of reliable data on Borehole maintenance from 2011-2016.

3.2 Required Parameters for Model Formulation

The parameters required for proposed model formulation are essentially those that has to do with

Total Operations Cost (TOC): This includes production cost, preventive maintenance materials and travel costs, corrective maintenance materials and travel costs, the salaries of the operators and repair crew are also included.

The production cost is associated with borehole pumping, which is directly linked with fuel consumption during pumping and salaries of the operators and repair crew.

The maintenance cost for both preventive and corrective are costs associated with component replacement and repair, downtime, frequencies or replacement and breakdown.

These data are arranged in such a way that they became amenable to mathematical manipulation from which parameters of interest in the model formulation are deduced.

3.3 Evaluation of Boreholes Conditions According to LGA's

The questionnaire data is arranged according to state and local government areas where the boreholes are located. The total number of boreholes is broken down into those that are functional and those that are non-functional.

3.4 Model Assumption

- The pump price of diesel (AGO) was taken as N180 per litre for the analysis.
- The frequency of generator maintenance was assumed to be carried out twice per annum.

- 3 – 30 litres of engine oil was used for the servicing of the generators which is a function of the generator rating.
- A litre of engine oil was assumed to be N500
- the cost of the replacement of burnt bulbs was taken as N200 while the life span of the bulb was assumed as 6 months
- Salary are as obtained from the field.
- The chart annexed to this document clearly specified the consumption rate of the generating sets.

3.5 Formulation of the Models

We define the model parameters as such;

C: Purchasing price (capital cost) of new items to be replaced.

R_n: Running (maintenance) cost of items at the beginning of the nth year.

r: Annual interest rate

d: Depreciation (present) value per unit of money during a year.

Given that r is the annual interest rate on the running cost per year. Let P be the present value of money (principal) for the nth year, then the running (maintenance) cost at the nth year is given by

3.51 Formulation of the Model by Agunwamba (2000)

We consider the following assumptions and model parameters of Agunwamba (2000) on cost maintenance for water borehole schemes as follows.

Assume a scenario of pumping t_0 hours (where $t_0 = 3$) twice per day such that the period T between major repairs is given by

$$\mathrm{T} = 2\mathrm{t}_0 + \mathrm{t}_1 + \mathrm{t}_2 \tag{1}$$

Where t_1, t_2 are the idle times between pumping (day and night).

Let

$\frac{1}{T}$: be the number of breakdown cycles per year

k_i: be the number of repairs (corrective and preventive) for component i within a cycle.

$k_i - 1$: be the number of preventive maintenance per cycle.

We define the total operation cost TOC of the water scheme as

$$\mathrm{TOC} = \mathrm{R_1C} + \mathrm{R_2C} + \mathrm{S_0} + \mathrm{S}_A \tag{2}$$

Where

R_1C: is the running cost of production,

R_2C: is the running cost of preventive maintenance material and travel cost.

S_0: is the corrective maintenance material and travel cost

S_A: Salaries of the repair crews

Using Sule and Harmon (1979) expression, we write

$$\mathrm{R_1C} = \mathrm{k_i(a_i + b_i t_n)} \tag{3}$$

As the running cost of production for the ith component (where a_i, b_i, K_i and n retains their usual definitions). Hence, the total production cost over a cycle for the J-component is given by Agunwamba as

$$\mathrm{R_1C} = \sum_{i=1}^{J}\left(\int_0^{2t_0T/k_i} k_i(a_i+b_it^n)dt + \int_0^{t_1T/k_i} k_i(a_i+b_it^n)dt + \int_0^{t_2T/k_i} k_i(a_i+b_it^n)dt\right) \tag{4}$$

For simplicity, we wish to simplify equation (4) further, by letting

$$\text{Let } \mu_j = \begin{cases} \dfrac{2\mathrm{t_0T}}{\mathrm{k_i}}; & j = 0 \\ \cdot & \\ \dfrac{\mathrm{t_jT}}{\mathrm{k_i}}\ ; & j = 1,2 \end{cases}$$

Then equation (4) becomes

$$\mathrm{R_1C} = \sum_{i=1}^{J}\sum_{j=0}^{2} k_i \int_0^{u_j} (a_i + b_i t^n)dt \tag{5}$$

Now observe that

$$\int_0^{u_j} (a_i + b_i t^n)\, dt = a_i u_j + \frac{b_i u_j^{n+1}}{n+1} \tag{6}$$

Substituting equation (6) into equation (5) we have

$$\mathrm{R_1C} = \sum_{i=1}^{J}\sum_{j=0}^{2} k_i\left(a_i u_j + \frac{b_i u_j^{n+1}}{n+1}\right) \tag{7}$$

If $k_i - 1$ is the number of preventive maintenance per cycle, S_i is the cost of preventive maintenance per cycle. Then the maintenance cost for the ith component is $S_i(k_i - 1$, hence for the J-components we shall have

$$R_2C = \sum_{i=0}^{J} S_i(k_i - 1) \tag{8}$$

and

$$S_A = \sum_{i=0}^{J} a_i T \tag{9}$$

Thus, altogether substituting equation (7), (8) and (9) into equation (2), we shall have that the total operating cost (TOC) for the period T is

$$\sum_{i=1}^{J}\sum_{j=0}^{2} k_i\left(a_i u_j + \frac{b_i u_j^{n+1}}{n+1}\right) + \sum_{i=0}^{J} S_i(k_i - 1) + \sum_{i=0}^{J} a_i T + S_0 \tag{10}$$

Hence the total operation cost for one year is

$$TOC = \frac{365}{T}\left[S_0 + \sum_{i=0}^{J}\left(a_i T + k_i S_i - S_i + \sum_{j=0}^{2}\left(k_i a_i u_j + \frac{k_i b_i u_j^{n+1}}{n+1}\right)\right)\right] \tag{11}$$

3.52 Generalized Agunwamba's Model (2000)

We generalize the above model of Agunwamba based on the assumption of the pumping scenario. Here we assume a pumping scenario of m – times per day $m \in N$

Let t_j be the time that elapse (idle time) between the (j-1)th and the jth time of pumping $(j = 1,2 \dots, m)$ where every other assumption remains the same.

Based on this additional assumption on the pumping scenario, we shall have

$$T = m_i t_0 + \sum_{i=1}^{m} t_j \tag{12}$$

Then the total operation cost TOC due to equation (12) becomes

$$TOC = \frac{365}{T}\left[S_0 + \sum_{i=0}^{J}\left(S_i(k_i - 1) + a_i T + mt_0\, a_i T + \frac{(mt_0)^{n+1} b_i T^{n+1}}{(n+1)k_j^n} + \sum_{j=1}^{m}\left(t_j a_i T + \frac{t^{n+1} b_i T^{n+1}}{(n+1)k_j^n}\right)\right)\right] \tag{13}$$

differentiating (13) with respect to T, we have

$$\frac{dTOC}{dT} = \frac{365}{T^2}\left[S_0 + \sum_{i=0}^{J}\left(S_i(k_i - 1) + a_i - T + mt_0\, a_i T + \frac{(mt_0)^{n+1} b_i T^{n+1}}{(n+1)k_j^n} + \sum_{j=1}^{m}\left(t_j a_i + \frac{t_0^{n+1} b_i T^{n+1}}{(n+1)k_j^n}\right)\right)\right]$$

By optimality condition we have

$$\sum_{j=1}^{m}\left(a_i T(1 + mt_0) + \frac{(mt_0)^{n+1} b_i T^{n+1}}{k_j^n} + \sum_{j=1}^{m}\left(t_j a_i T + \frac{t_j^{n+1} b_i T^{n+1}}{k_j^n}\right)\right) =$$

$$\left[S_0 + \sum_{i=0}^{J}\left(S_i(k_i - 1) + a_i T(1 + mt_0) + \frac{(mt_0)^{n+1} b_i T^{n+1}}{(n+1)k_j^n} + \sum_{j=1}^{m}\left(t_j a_i T + \frac{t_j^{n+1} b_i T^{n+1}}{(n+1)k_j^n}\right)\right)\right]$$

$$\Rightarrow \sum_{i=1}^{J}\left(\frac{n(mt_0)^{n+1}b_i T^{n+1}}{(n+1)k_j^n} + \frac{nb_i T^{n+1}}{(n+1)k_j^n}\sum_{j=1}^{m} t_j^{n+1}\right) = S_0 + \sum_{i=0}^{J} S_i(k_i - 1)$$

$$\Rightarrow T^{n+1}\left(\frac{n}{n=1}\right)\left(\sum_{i=1}^{J}\frac{b_i}{k_i^n}\left((mt_0)^{n+1} + \sum_{j=1}^{m} t_j^{n+1}\right)\right) = S_i + \sum_{i=i}^{J} S_i(k_i - 1)$$

$$\Rightarrow T = \left[\frac{S_0 + \sum_{i=i}^{J} S_i(k_i - 1)}{\left(\frac{n}{n=1}\right)\sum_{i=1}^{J}\frac{b_i}{k_i^n}\left((mt_0)^{n+1} + \sum_{j=1}^{m} t_j^{n+1}\right)}\right]^{\frac{1}{n+1}} \quad (14)$$

Observe that in equation (14), if we take $m = 2$, that is pumping twice per day as in the case of Agunwaba, then we easily obtain equation (1) as a special case of general model in (14).

3.53 The proposed Least Cost Water Borehole Scheme Maintenance Cost Model

This model assumes that water borehole pumps for 2 hrs, 3 hrs, 4hrs 5hrs, 6hrs, 7hrs, 8hrs daily unlike Agunwamba's that assume 6hrs daily.

Now, to further modify the Agunwamba's model in this direction of assumption of the least cost approach, we proceed as follows:

Let t_0 be the time for the first (initial) pumping duration in the m-times pumping scenario such that for any given dth day we define the p_d th pumping time hrs to be

$$t_{d\rho d} = t_0 + (\rho_d - 1)r_d; \ \rho_d = 1, 2, \cdots, m; \ d \geq 1, r_d \geq 0 \quad (15)$$

where r_d is a nonnegative integer that denote the fixed time (in hours) difference between successive pumping per dth day. Hence

$$T = \sum_{\rho_d = 1}^{m} t_{d\rho_d} + \sum_{j=1}^{m} t_j \quad (16)$$

Before we proceed further, let consider some of the consequences of the above modification on some of the models that have been studied so far.

Using equation (15) and equation (16) observe that;

(1). If $r_d = 0$, then we have $t_{d\rho d} = t_0$, so that (16) reduces to

$$T = mt_0 + \sum_{j=1}^{m} t_j$$

Which is the case of m-times pumping scenario which we have considered and solved above and if we take $m = 2$, we obtain the pumping scenario assumed by Agunwamba as earlier mentioned above.

$$\textbf{(2). If } r_d = 1, \text{then we have } t_{dp_d} = t_0 + (p_d - 1)\ ;\ p_d = 1, 2, \cdots, m$$

Then the pumping duration increases arithmetically per pumping.

Hence, equation (16) reduces to

$$T = \sum_{p_d=1}^{m} t_{dp_d} + \sum_{j=1}^{m} t_j = \frac{m}{2}[2t_0 + (m-1)] + \sum_{j=1}^{m} t_j$$

In particular, since $r_d = 1$, it is interesting to see that if we take t_0 = 2hrs and m = 7 then using $t_{dp_d} = t_0 + (p_d - 1)$, we can easily see that

$$t_{dp_d} = 2 + (p_d - 1)\ ;\ p_d = 1,2,\cdots,7.$$

Which implies that: t_{11} = 2hrs, t_{12} = 3hrs, t_{13} = 4hrs, t_{14} = 5hrs, t_{15} = 6hrs, t_{16} = 7hrs and t_{17} = 8hrs which are the time specifications for the **least cost approach**.

This is an improvement to the least cost method, since the author did not consider the general m-times pumping scenario per day.

(**3**). **If** $r_d > 1$, then we have $t_{dp_d} = t_0 + (p_d - 1)r_d\ ;\ p_d = 1,2,\cdots,m$

Then the pumping duration increases arithmetically per pumping.

Hence, equation (4) reduces to

$$T = \sum_{p_d=1}^{m} t_{dp_d} + \sum_{j=1}^{m} t_j = \frac{m}{2}[2t_0 + (m-1)r_d] + \sum_{j=1}^{m} t_j$$

Consequently (3) is entirely a new situation which has not been considered so far by above mentioned authors.

For a more general model solution that incorporate the above consequence, we formulate solution due to the assumption that lead to equation (15) and (16).

Now, the total operating cost due to (15) and (16) is given by

$$TOC = \frac{365}{T}\left[S_0 + \sum_{i=1}^{J}\left(\begin{array}{l} S_i(k_i - 1) + a_i T + \left(\dfrac{m[2t_0+(m-1)r_d]}{2}\right)a_i T + \\ \dfrac{(m[2t_0+(m-1)r_d])^{n+1} b_i T^{n+1}}{(n+1)k_j^n} + \sum_{j=1}^{m}\left(t_j a_i T + \dfrac{t_j^{n+1} b_i T^{n+1}}{(n+1)k_j^n}\right)\end{array}\right)\right] d \geq 1$$

$p = 1,2,\cdots,n$

So that

$$\frac{dTOC}{dT} = \frac{365}{T^2}\left[S_0 + \sum_{i=1}^{J}\left(\begin{array}{l} S_i(k_i - 1) + a_i T + \left(\dfrac{m[2t_0+(m-1)r_d]}{2}\right)a_i T + \\ \dfrac{(m[2t_0+(m-1)r_d])^{n+1} b_i T^{n+1}}{(n+1)k_j^n} + \sum_{j=1}^{m}\left(t_j a_i T + \dfrac{t_j^{n+1} b_i T^{n+1}}{(n+1)k_j^n}\right)\end{array}\right)\right] +$$

$$\frac{365}{T}\left[\sum_{i=1}^{J} a_i T\left(1 + \left(\frac{m[2t_0+(m-1)r_d]}{2}\right)\right) + \frac{(m[2t_0+(m-1)r_d])^{n+1} b_i T^{n+1}}{k_i^n} + \sum_{j=1}^{m}\left(t_j a_i + \frac{t_j^{n+1} b_i T^{n+1}}{(n+1)k_i^n}\right)\right]$$

By optimality condition, we have that

$$\sum_{i=1}^{J}\left[a_i T\left(1+\left(\frac{m[2t_0+(m-1)r_d]}{2}\right)\right)+\frac{(m[2t_0+(m-1)r_d])^{n+1}b_i T^{n+1}}{k_i^n}+\sum_{j=1}^{J}\left(t_j a_i+\frac{t_j^{n+1}b_i T^{n+1}}{(n+1)k_i^n}\right)\right]=$$

$$S_0+\sum_{i=1}^{J}\left[\begin{array}{l} S_i(k_i-1)+a_i T\left(1+\left(\frac{m[2t_0+(m-1)r_d]}{2}\right)\right)+\frac{(m[2t_0+(m-1)r_d])^{n+1}b_i T^{n+1}}{(n+1)k_i^n} \\ +\sum_{j=1}^{m}\left(t_j a_i T+\frac{t_j^{n+1}b_i T^{n+1}}{(n+1)k_i^n}\right)\end{array}\right]=$$

Thus, after some algebraic simplification we obtain

$$\sum_{i=1}^{J}\left[\left(\frac{n\left(\frac{m[2t_0+(m-1)r_d]}{2}\right)^{n+1}b_i T^{n+1}}{(n+1)k_i^n}+\frac{nb_i T^{n+1}}{(n+1)k_i^n}\sum_{j=1}^{m}t_j^{n+1}\right)\right]=S_0+\sum_{i=1}^{J}S_i(k_i-1)$$

$$\Rightarrow T^{n+1}\left(\frac{n}{n+1}\right)\sum_{i=1}^{J}\frac{b_i}{k_i^n}\left(\left(\frac{m[2t_0+(m-1)r_d]}{2}\right)^{n+1}+\sum_{j=1}^{m}t_j^{n+1}\right)=S_0+\sum_{i=1}^{J}S_i(k_i-1)$$

$$\Rightarrow T=\left[\frac{S_0+\sum_{i=1}^{J}S_i(k_i-1)}{\left(\frac{n}{n+1}\right)\sum_{i=1}^{J}\frac{b_i}{k_i^n}\left(\left(\frac{m[2t_0+(m-1)r_d]}{2}\right)^{n+1}+\sum_{j=1}^{m}t_j^{n+1}\right)}\right]^{\frac{1}{n+1}};$$

$$d\geq 1,\ r_d\geq 0,\ \rho_d=1,2,\cdots,m \qquad (17)$$

Equation (17) is the optimal time solution for the generalize formulation due to (15) and (16). Hence the optimal solution to above consequences follows from (17) by substituting appropriately for the parameters.

3.6 Relative Efficiency of the Models

The relative efficiency involves the measure of the ratio of the precision of the performance of the two models (inverse of variance or standard deviation of the cost value) (Nikulin, 2001). This implies that the efficiency of the first test to the second would be the variance/standard deviation of the second divided by the variance of the first. Hence, the method with the least variance/standard deviation of the test value is considered less efficient.

Expressed mathematically as:

$$e(MC_1,MC_2)=\frac{Var(MC_2)}{Var(MC_1)} \qquad (18)$$

where MC_1 and MC_2 are the maintenance cost from the two models.

3.3 Data Presentation

The data obtained for the study were summarized below.

Table 1: Maintenance Cost of Boreholes for NwanyioCha Commercial Borehole Nnewi (Industrial 1)

Year	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Number of Pumping per day	> 3	> 3	> 3	> 3	> 3	> 3
Duration of pumping	2920	2300	3200	3010	3871	3799
Staff salary	360000.00	360000.00	384000.00	384000.00	420000.00	420000.00
Fuelling of Generator (₦)	1198750.00	1198.75	1806.75	1806.75	2518.50	2518.50
Maintenance of generator (₦)	174000.00	198500.00	221000.00	215000.00	241000.00	261500.00
Maintenance of Borehole (₦)	18000.00	210000.00	189000.00	230000.00	232000.00	250000.00
Production Cost (₦)	1750750.00	769698.75	795806.75	830806.75	895518.50	934018.50
Number of Repairs	25.00	12.00	18.00	13.00	24.00	25.00

Table 2: Maintenance Cost of Boreholes for Intafact Beverages Limited Onitsha (Industrial 2)

Year	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Number of Pumping per day	> 3	> 3	> 3	> 3	> 3	> 3
Duration of pumping	4172.00	3320.00	4203.00	3320.00	3988.00	4198.00
Staff salary	8960000.00	8960000.00	9920000.00	12984000.00	129840000.00	140420000.00
Fuelling of Generator (₦)	2398750.00	239811.75	320006.75	2398750.11	242318.50	242320.70
Maintenance of generator (₦)	214000.00	200500.00	229000.00	223000.00	289000.00	298500.00
Maintenance of Borehole (₦)	218000.00	230000.00	298000.00	290000.00	298000.00	295000.00
Production Cost (₦)	11790750.00	9630311.75	10767006.75	15895750.11	130669318.50	141255820.70
Number of Repairs	4172.00	3320.00	4203.00	3320.00	3988.00	4198.00

Table 3: Maintenance Cost Boreholes for Umuanuka Community Borehole Nnewi (Community 1)

Year	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Number of Pumping per day	> 3	> 3	> 3	> 3	> 3	> 3
Duration of pumping	1440.00	1250.00	1450.00	1632.00	1450.00	1519.00
Staff salary	250000.00	120000.00	189000.00	168000.00	288000.00	512000.00
Fuelling of Generator (₦)	950000.00	823000.00	980000.00	1095000.00	856000.00	987000.00
Maintenance of generator (₦)	143200.00	152000.00	218000.00	136000.00	189000.00	145500.00
Maintenance of Borehole (₦)	160000.00	160000.00	130000.00	165000.00	100000.00	160000.00
Production Cost (₦)	1503200.00	1255000.00	1517000.00	1564000.00	1433000.00	1804500.00
Number of Repairs	30.00	12.00	12.00	17.00	8.00	14.00

Table 4: Maintenance Cost Boreholes for Nkpologuwu Community Borehole (Community 2)

Year	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Number of Pumping per day	> 3	> 3	> 3	> 3	> 3	> 3
Duration of pumping	1260.00	1300.00	1250.00	1432.00	1490.00	1230.00
Staff salary	150000.00	150000.00	166000.00	166000.00	166000.00	166000.00
Fuelling of Generator (₦)	250000.00	229000.00	250000.00	255000.00	226000.00	245000.00
Maintenance of generator (₦)	123200.00	190000.00	178000.00	136000.00	143000.00	132500.00
Maintenance of Borehole (₦)	260000.00	200000.00	230000.00	260000.00	190000.00	223000.00
Production Cost (₦)	783200.00	769000.00	824000.00	817000.00	725000.00	766500.00
Number of Repairs	23.00	18.00	33.00	27.00	12.00	32.00

IV. DATA ANALYSIS AND DISCUSSION

4.1 Data Analysis

Table 5: Maintenance Cost Parameters using the Linear and Quadratic Model

	Borehole Categories							
	Industrial 1 Linear	Industrial 1 Quadratic	Industrial 2 Linear	Industrial 2 Quadratic	Community Borehole 1 Linear	Community Borehole 1 Quadratic	Community Borehole 2 Linear	Community Borehole 2 Quadratic
Intercept (c)	4.13	-93.0	-13.8	4.88	2.97	-29	4.49	-25.4
Slope (n)	0.043	55.9	5.59	0.283	0.431	1.9	-0.084	1.71
Ai	50	50	50	50	50	50	50	50
logai	1.6989	1.6989	1.6989	1.6989	1.6989	1.6989	1.6989	1.6989
c-logai	2.3010	-94.6989	-15.4989	3.1811	1.2711	-30.6989	2.7911	-27.0989
bi =antilog{c-logai}	200	0.0	0.0	1517.40	18.6681	0.0	618.1587	0.0
T	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
R-sq	0.100	0.152	0.712	0.948	0.490	0.603	0.117	0.729

The result obtained using the linear regression model showed that Industrial 2 had the highest R-square value of 0.712 while Industrial 1 recorded the least with R-square value of 0.100. The result using the quadratic regression model found that Industrial 2 has the highest R-square value of 0.0.948 while Industrial 1 has the least with R-square value of 0.152. Hence, findings revealed that Industrial 2 has a better adequacy of the model for both the linear and the quadratic model while Industrial 2 has the least adequacy of the model.

Table 6: Table showing the estimated maintenance cost of Borehole for Agunwamba TOC and the Proposed Method using the Linear Model

Models	Agunwamba Method	Proposed Method
Industrial 1 Linear Model	913608.1755	998262.7359
Industrial 2 Linear Model	79136625.79	4806709.236
Community 1 Linear Model	1256514.076	1389523.186
Community 2 Linear Model	1309747.011	1208988.195
Mean	20654123.76	2100870.838
Standard Deviation	38988729.88	1810964.402

The result of the linear model presented in table 6 found the mean maintenance cost using Agunwamba method as ₦20,654,123.76 and a standard deviation of ₦38,988,729.88 while the proposed methods gave mean maintenance cost of ₦2,100,870.84 and a standard deviation of ₦1,810,964.40. This result indicate that the proposed method gave the least cost and the least error. Hence, the proposed method performed better than Agunwamba method.

Table 7: Table showing the estimated maintenance cost of Borehole for Agunwamba TOC and the Proposed Method using the Quadratic Model

Models	Agunwamba Method	Proposed Method
Industrial 1 Quadratic Model	885837.1324	15777938.51
Industrial 2 Quadratic Model	79605590.04	6309865.287
Community 1 Quadratic Model	1249144.065	1322590.051
Community 2 Quadratic Model	1245655.416	665346.6836
Mean	20746556.66	6018935.132
Standard Deviation	39239725.78	6977089.977

The result of the linear model presented in Table 7 found the mean maintenance cost using Agunwamba method as ₦20,756,556.66 and a standard deviation of ₦39, 239,725.78 while the proposed methods gave mean maintenance cost of ₦6,018,935.13 and a standard deviation of ₦6,977,089.98. This result indicate that the proposed method gave the least cost and the least error. Hence, the proposed method performed better than Agunwamba method.

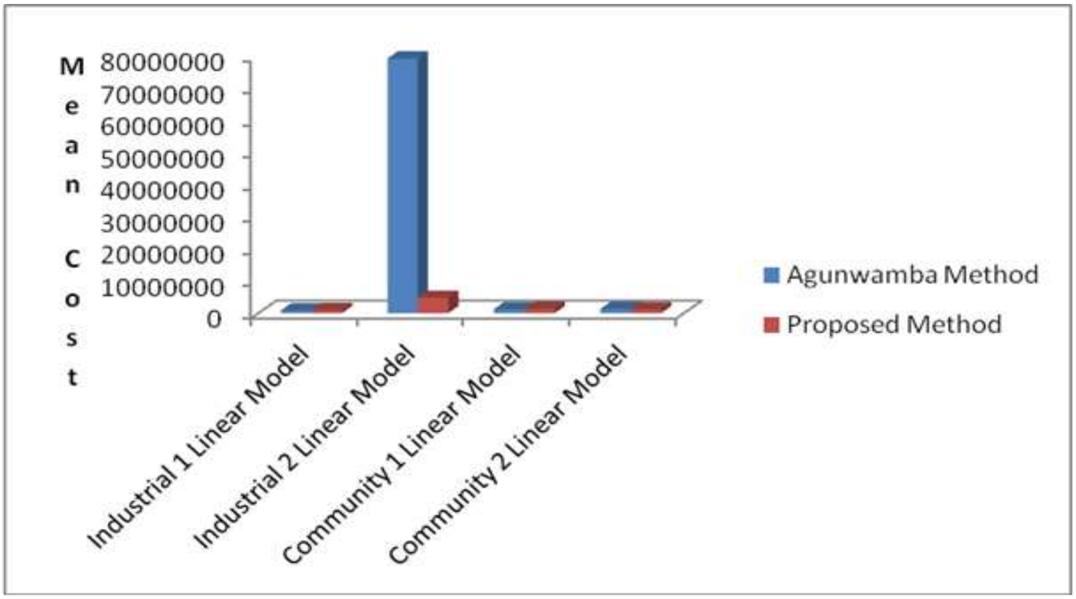

Figure 1: Bar Chart showing the estimated maintenance cost of Borehole for Agunwamba TOC and the Proposed Method using the Linear Model

The result found in figure 1 showed that the proposed method has the least mean cost and the least error across the various categories of boreholes for the linear model.

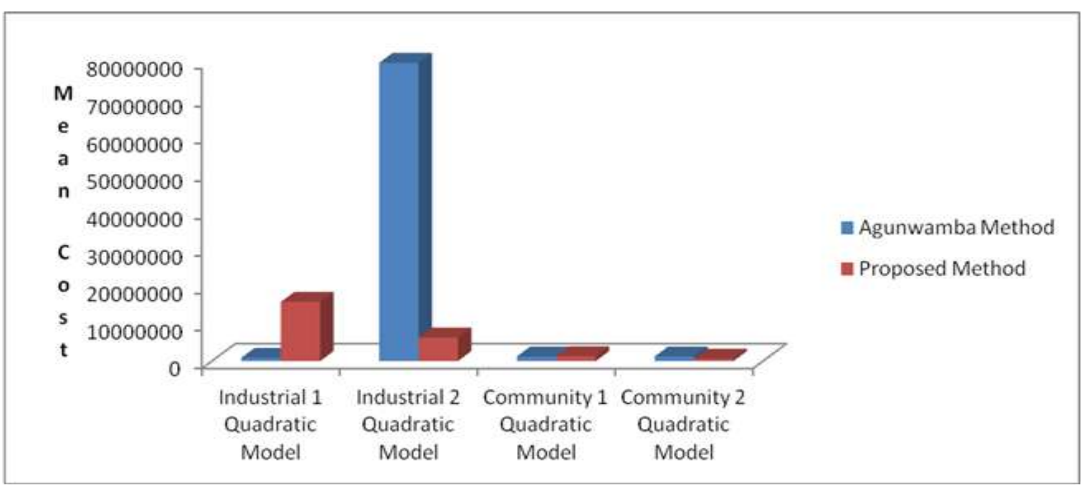

Figure 2: Bar Chart showing the estimated maintenance cost of Borehole for Agunwamba TOC and the Proposed Method using the Quadratic Model

The result found in figure 2 showed that the proposed method has the least mean cost and the least error across the various categories of boreholes for the quadratic model.

V. CONCLUSION

This study examined the relative efficiency of two borehole maintenance cost model. The models considered in this study are the Agunwamba's borehole maintenance cost model and a proposed modified Agunwamba borehole maintenance cost model. The findings of the study using the linear and the quadratic regression model revealed that the industrial 2 has a strong adequacy of the model across the various categories of boreholes. The proposed method was found to recorded the least mean cost and standard error using the linear model with a value of ₦2,100,870.84 and ₦1,810,964.40 respectively while the Agunwamba's method found a mean cost of ₦20,654,123.76 and standard error of ₦38,988,729.88. Also, the proposed method recorded the least mean cost and standard error using the quadratic model with a value of ₦6,018,935.13 and ₦6,977,089.98 respectively while the Agunwamba's method found a mean cost of ₦20,756,556.66 and standard error of ₦39, 239,725.78. Hence, the study concludes that the proposed method performed better than Agunwamba's method.

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