Comparative Analysis of Optimum Maintenance cost for Water Boreholes in South-Eastern Nigeria

Abstracts

Aims: This study considered the optimal maintenance cost of water boreholes for a multiple pumping scenario in South-East Nigeria. The objective of the study was to determine the optimal maintenance cost of water boreholes for the Southeastern region of Nigeria.

Place and Duration of Study: The data used in this study is secondary data obtained from selected community and commercial boreholes in the Abia State, Anambra State, Ebonyi State, Enugu State and Imo State.

Methodology: The linear model and the quadratic model were used to determine the cost parameters for the optimization of the maintenance cost of the water boreholes.

Results: The result of the study showed that the maintenance cost obtained for Anambra State is more adequate than the other states since it recorded a higher coefficient of determination value using the linear and quadratic model. Also, it was found the quadratic model was better than the linear model for the estimation of cost parameters used for determining the optimum maintenance cost of water boreholes in South-East Nigeria. The findings showed that the quadratic model recorded the best net savings for Abia, Anambra, and Enugu with the corresponding cost of ₦4,079,246.817, ₦5,198,716.141, and ₦4,767,680.392 respectively. It was found that the linear model recorded the best net savings for Ebonyi, and Imo with the corresponding cost of ₦1,593,013.72 and ₦8,692,452.91 respectively. Hence, the quadratic models was identified as the best model for the estimation of cost parameters and enhance the performance of the optimal total operating cost of the water borehole model in South-East Nigeria.

Conclusion: The study concludes by recommending the quadratic model for the estimation of cost parameters for the optimization of maintenance cost of water boreholes until further studies prove otherwise.

Keywords: Linear model, Maintenance cost, Quadratic model, Water boreholes

1.0 Introduction

Groundwater is high quality and economic source of water for most towns in Nigeria. All over the world, people resort to groundwater when surface water is not available. Until recently, all artificial wells were without pumps. The borehole is a revolutionary innovation brought about by the pressure of increasing population and increasing human control over nature. Shallow wells dug by hand are probably the oldest method of Well construction. The high water demand proved that these shallow wells are inadequate in meeting the ever-increasing demand for water, hence the need to go deeper for sustainable supply to meet everyday water need. This gave the need for borehole drilling which was aided by technological advancement.

In Nigeria, borehole drilling projects were embarked on by the Federal Government, State Governments, Donor Agencies, communities, etc. in the early 1980s. Many of these boreholes failed. About 50% of these boreholes were dry and about 30% were later abandoned. The rate of borehole failure in the country has been on the increase in recent time. Borehole failure has constituted a lot of financial drain in the purse of the Federal Government, and other sponsors (Eduvie, 2006). It is important to note that the alarming failure rate of boreholes is inhibiting the achievement of sustainable water supply.

In the past 10 years, over 5000 boreholes have been drilled and commissioned by Anambra/Imo River Basin Authority. Most of these boreholes which are located in Anambra and Imo States are in a state of disrepair because the Authority failed in providing adequate and timely maintenance. Poor funding, coupled with high operational and maintenance costs are the major factors militating against the sustainability of water supply through boreholes.

The sustainability of water supply through boreholes looks grimmer as the wells get older and maintenance requirements and costs are consistently overlooked. All these are caused by an ideological entrapment of donors and water agencies, that maintenance of rural water supply to a large extend must be carried out by local groups. But this is impossible without the help of the agencies in terms of information, funding and technical expertise. Sponsors of the boreholes project have invested quite huge sums of money but have failed to sustain water supply through boreholes by not investing in maintenance and the result is a failure. Sustainability of water supply through borehole has been a major problem, especially in the rural areas and as a result, this has drawn the attention of most researchers in this area. 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 the continuance of water supply, but without planned preventive maintenance, this noble dream will be a mirage. In the study (Okere, 2010) of the status of 53 private and government-owned boreholes in Abia state and Imo State, 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. The government in Nigeria prefers to spend the budgetary allocation on new borehole schemes than maintain existing ones.

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 the below-ground system until a problem occurs (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. For the sustainability of water supply through the borehole, there must be an optimized maintenance policy under the prevailing stochastic parameters. The government, communities and external supporting agencies have committed huge sums of money through the provision of drilling rigs, geophysical equipment, chemical laboratory test kits, pumps, etc. to ensure the sustainability of the programme. Despite these huge investments, there are still severe problems of borehole failure due to poor maintenance or lack of adequate maintenance policy; hence the present study work seeks to obtain an optimized maintenance policy which will help to improve on the sustainability of water supply through boreholes. This work will also save a lot of money for the sponsors of borehole projects and improve the health of the populace through the provision of sustained potable water supply. Hence, the need for the present study to determine the optimal maintenance cost of water borehole operation in South-East Nigeria.

2. Literature Review

With today's global competition and increasing demands on stakeholders, there is a clear need to improve manufacturing performance. Due to widespread automation, the implementation of advanced manufacturing technologies, and the high capital of manufacturing facilities, the importance of asset and maintenance management in manufacturing is constantly increasing (Tsang, 2002). The economic downturn and the dynamic business environment are driving companies to seek more efficient and effective maintenance. The enormous costs and risks associated with improper maintenance have been observed and documented in the industry.

Al-Najjar and Pehrsson (2005) found from their study that maintenance is directly related to competitiveness and profitability and thus to the future of the company.

According to Al-Nijjar (2007), who supports the study by Mckone and Weiss (1998), the competitiveness and performance of manufacturing companies depend on the availability, reliability and productivity of their production facilities. The economic factors associated with maintenance, such as direct maintenance costs, production losses and maintenance investments, also have a major impact on a large part of a company's income.

According to Robertson and Jones (2004), maintenance budgets are between 2% and 90% of the total operating budget of the facility, with an average of 20.8% (Jardine and Tsang, 2006).

The study by Ezekafor and Agunwamba (2019) examined the relative efficiency of two borehole maintenance cost model. The study compared the performance of the Agunwamba's borehole maintenance cost model and a proposed modified Agunwamba borehole maintenance cost model. Also, the linear and quadratic regression models were used to obtain some of the parameters required for the borehole maintenance cost model. The results of the study indicated that industrial borehole 2 has strong model suitability for the different categories of boreholes considered for both the linear and quadratic regression models. The proposed method was found to have the lowest mean cost and the lowest standard error using the linear model and the quadratic model. Therefore, it was found that the proposed method performed better than the Agunwamba method.

Ibeje et al. (2020) employed a least-cost maintenance model to determine the optimal frequency of maintenance of water boreholes in South Eastern states of Nigeria. The study took into account the costs of the existing maintenance strategy and the optimal maintenance policy for three different pumping scenarios. The result of the study found that the optimal preventive maintenance frequencies for the states of Enugu, Anambra, Imo, and Abia were 4, 4, 5, and 6 times a year for water boreholes that pumped once, 9, 10, 10, and 12 times a year, respectively have been pumping water boreholes twice and 12, 19, 16 and 17 per year for water wells boreholes that are pumped three times. Additional results indicated a cost savings of $42,757.02; $209965.51; $33020.72; $59,776.74 for a one-time pumping of water boreholes; $44,056.46; $145,760.21; $154929.56; $95,402.73 for two pumps and $816.2611; $95,713.3; $548596; $ 399735.14 for three pumping was earned for each condition when the model was compared to the current maintenance policy. However, the study did not specify the type of model that was used to determine the cost parameters.

3. Methods and Material

3.1 Method of Data Collection

The data used in this study was secondary data sourced from the maintenance cost records, service logs of submersible pumps in operating boreholes, manufacturer's estimates of useful life and replacement rates of components, manufacturer's pricelists and purchase receipts from existing projects and parts replacement lists for operating boreholes of selected community and commercial boreholes in the Abia State, Anambra State, Ebony State, Enugu State and Imo State. The choice of the boreholes selected in the present study was based on the availability of reliable data on the cost of borehole maintenance amongst the five states in the South Eastern region of Nigeria from 2011-2016.

3.2 Background Information of the Study Areas

Southeast Nigeria includes the five Igbo states of Abia, Anambra, Ebonyi, Enugu and Imo, all of which form one of the six geopolitical zones in Nigeria. It lies between the latitudes 4^0 40'to 7^0 20' north of the equator and the lengths 6^0 00 'to 8^0 20' east of the Greenwich meridian (Okonkwo and Eyis, 2014). The cultural area covers around 50,000 km^2 of the total area of 923,768 km^2 in Nigeria (Okeke et al. 2006). Southeast Nigeria is bordered by the states of Benue and Kogi to the north, by the state of Rivers to the south, by the state of Cross River to the east and by the state of Delta to the west. It covers a landmass of 22,525 square kilometres (Madu, 2006). Figure 1 shows the map of the south east Nigeria with the location of the five states.

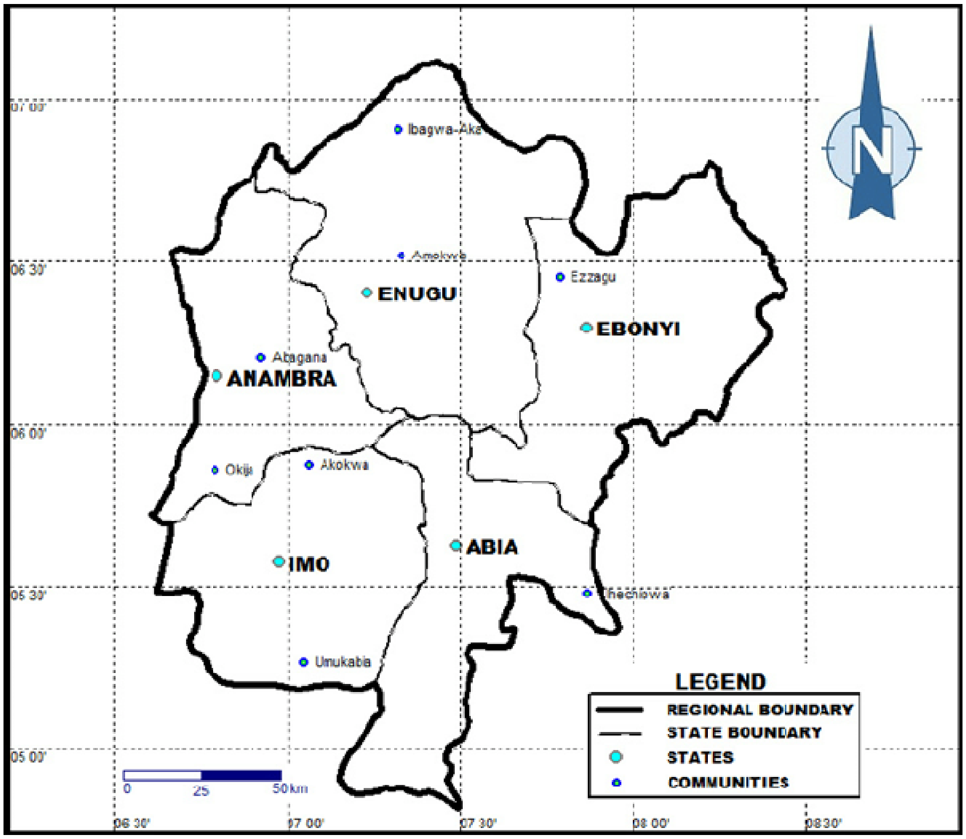

Fig 1: Map of South East Nigeria showing the five States in the region (Okonkwo and Eyis, 2014)

3.3 Method of Data Analysis

This study employed the linear regression model and the quadratic regression model to determine the production parameters of the before the optimization of the maintenance cost of the water boreholes. The models were specified as equation (1) and (2).

$$y = \beta_0 + \beta_1 t + \varepsilon \quad (1)$$

$$y = \beta_0 + \beta_1 t + \beta_2 t^2 + \varepsilon \quad (2)$$

Where y is the dependent variable, t is the time which is generic and represents the dependent variable, β0, …, β2 are the model coefficients to be estimated, and ε represents the random error. In the present study, $y = R_n/a$. Hence, the model parameters are defined as: c is the purchasing price (capital cost) of new items to be replaced, R_n represents the running (maintenance) cost of items at the beginning of the n^{th} year, *r* is the annual interest rate, a_i represents the constant cost parameter representing the pump operator's initial salary and bulbs for lighting the pump house in i^{th} locality and is obtained using equation (1) and (2), b_i comprises of salary increment, fuel consumption which increases with time for the i^{th} component, n is the slope measure of the model while d is the depreciation (present) value per unit of money during a year.

The data was transformed using log transformation to reduce the influence of outliers and to satisfy the assumption of normality required for the regression analysis. Also, the performance of the linear and quadratic model for estimating the cost parameters for the various states considered in the present study is based on the coefficient of determination measure. This implies that the higher the value of the R-square the better the model. To improve the usefulness of the maintenance cost model equation (3), there is need to obtaining an adequate slope (n) and constant (c) of the linear or quadratic model which are required to obtain the total operating cost (TOC) of the water boreholes under study.

The total operating cost (TOC) is the essential cost in the evaluation of the maintenance cost in this study. The total operation cost measures the costs and needs that a business has to make to generate sales, which is the goal of every business. The total operating cost comprises of the 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.

According to Ezekafor and Agunwamba (2019), the model by Agunwamba (2000) for the estimation of model parameters for the cost of maintenance for the water borehole scheme is given as:

$$TOC = \frac{365}{T}\left[S_0 + \sum_{i=1}^{J}\left(a_i T + k_i S_i - S_i + \sum_{j=0}^{2}\left(k_i a_i u_j + \frac{k_i b_i u_j^{n+1}}{n+1}\right)\right)\right] \quad (3)$$

Where k_i is the number of repairs (corrective and preventive) for component I within a cycle,

k_i-1 is the number of preventive maintenance per cycle,

S_0 is the corrective maintenance material and travel cost

S_i represents the salaries of the repair crews,

T is the optimal operating cost and u are model parameters, The optimal time solution for the generalize formulation of equation (3) is given by Ezekafor and Agunwamba (2019) as

$$T=\left[\frac{S_0+\sum_{i=1}^{J}S_i(k_i-1)}{\left(\frac{n}{n+1}\right)\sum_{i=1}^{J}\frac{b_i}{k_i^n}\left(\left(\frac{m[2t_0+(m-1)r_d]}{2}\right)^{n+1}+\sum_{j=1}^{m}t_j^{n+1}\right)}\right]^{\frac{1}{n+1}} \qquad (4)$$

$d\geq 1,\ r_d\geq 0$

Note that r_d is a nonnegative integer that denote the fixed time (in hours) difference between successive pumping per d^{th} day and m is the number times water is being pumped.

The equation (4) will be used to obtain the optimal TOC while equation (5) will be used to obtain the net savings in TOC which is given as:

Net Savings in TOC = Average existing TOC - Average optimal TOC (5)

In equation (5), the average existing TOC represents the total operating cost obtained at the field.

Analysis of the net profit is vital to ascertain a company's financial health. The investors or business owners assess whether a company's management is making enough profit from its sales and whether it includes operating expenses and overheads through the net profit analysis.

4. Data Analysis and Results

In this section, the result of the permuted quadratic model and the linear model will be presented. The linear model was used to examine the performance of the proposed permuted quadratic model.

4.2 Calibration of Production Cost Parameters for the five states in South-eastern Nigeria

The production cost parameters were determined for multiple pumping scenarios using the linear and quadratic regression models for the states considered in the study. The result presented in table 1 shows the production cost parameters for the models considered in this study.

Table 1. Summary result of the production Cost Parameters using the Linear Model in South-East States in Nigeria

	States				
	Abia	Anambra	Ebonyi	Enugu	Imo
c	0.56	0.34	0.34	0.66	0.27
n	0.12	0.49	0.46	0.05	0.62
a_i	50	50	50	50	50
Logai	1.69897	1.69897	1.69897	1.69897	1.698970004
c-logai	-1.13897	-1.35897	-1.35897	-1.03897	-1.42897
b_i **=antilog{c-logai}**	0.072616	0.043755	0.043755	0.09141764	0.037241743
t	1.5	1.5	1.5	1.5	1.5
R-square	0.613	0.984	0.906	0.015	0.957

The result presented in table 1 showed that the linear model for Anambra State recorded the highest R-square value of 0.984 while Enugu state has the least R-square value of 0.015. Also, it was found that Anambra State has the highest regression coefficient or slope with a value of 0.49 while Enugu State has the least slope with a value of 0.05.

Table 2. Summary Result of the production Cost Parameters using the Quadratic Model in South-East States in Nigeria

	States				
	Abia	Anambra	Ebony	Enugu	Imo
c	0.4972	0.67	0.4	-0.8	1.4
n	0.5968	-0.82	0.19	6.35	-3.7
a_i	50	50	50	50	50
Logai	1.69897	1.69897	1.69897	1.69897	1.698970004
c-logai	-1.20177	-1.02897	-1.29897	-2.49897	-0.29897
b_i **=antilog{c-logai}**	0.062839	0.093547	0.050238	0.00316979	0.502377286
t	1.5	1.5	1.5	1.5	1.5
R-square	0.695	0.991	0.906	0.494	0.988

he result obtained in table 2 revealed that Anambra State has the highest R-square value of 0.991 while Enugu state has the least with R-square value of 0.494. Also, it was found that Enugu State has the highest regression coefficient or slope with a value of 6.35 while Anambra State has the least slope with a value of -0.82. It was observed that the coefficient of determination the quadratic model across the states were more adequate and better than that obtained by the linear model. This result implies that the quadratic model has proven to be a better model than the linear model.

Table 3. Result of comparative Analysis of Optimum Maintenance Policy and Existing Policy by States

State	Average Optimal TOC (₦)		Average Existing TOC (₦)
	Linear	Quadratic	
Abia	303,094.95	106,884.49	4,186,131.31
Anambra	128,349.28	79,899.25	5,278,615.4
Ebony	135,534.47	250,540.69	1,728,548.2
Enugu	372,857.94	79,891.72	4,847,572.114
Imo	103,387.88	162,337.36	8,795,840.8

The result obtained in table 3 shows the distribution of the average optimal TOC for the two models used for estimating the cost parameters. Also, the result presented in table 4 revealed that the quadratic model recorded the best savings for Abia, Anambra, and Enugu with the corresponding cost of ₦4,079,246.817, ₦5,198,716.141, and ₦4,767,680.392 respectively. While the linear model was the best savings for Ebonyi, and Imo with the corresponding cost of ₦1,593,013.72 and ₦8,692,452.91 respectively.

Table 4. Summary result of the Net Savings in Total Operation Cost by States

State	Net Savings in TOC (₦)	
	Linear	Quadratic
Abia	3,883,036.35	4,079,246.817
Anambra	5,150,266.11	5,198,716.141
Ebony	1,593,013.72	1,478,007.505
Enugu	4,474,714.16	4,767,680.392
Imo	8,692,452.91	8,633,503.436

5.0 Conclusion

This study considered the optimal maintenance cost of water boreholes for a multiple pumping scenario in South-East Nigeria. The present study is an extension of the work by Ibeje et al. (2020), which considered water borehole maintenance for scenarios such as single, double and triple pumping in the South Eastern region of Nigeria. However, the high water demand in the southeast region has meant that borehole owners have to pump water several times so that the realization of scenarios with not several pumps is not possible. Also, the linear model and the quadratic model were used to estimate the cost parameters used in obtaining the optimal maintenance cost for the various states. This contradicts the results of studies like Ibeje et al. (2020) who did not mention the model employed for estimating the cost parameters in their study.

The findings of the present study showed that the maintenance costs for Anambra state using the linear and quadratic models were adequate than the other states. This is because the state of Anambra measured the highest coefficient of determination. Similarly, the performance of the quadratic model was found to be better than the linear model for estimating the cost parameters used to determine the optimal maintenance cost of water boreholes because the model had the highest coefficient of determination measure across the considered states.

Further findings showed that the quadratic model recorded the best net savings for Abia, Anambra, and Enugu with the corresponding cost of ₦4,079,246.817, ₦5,198,716.141, and ₦4,767,680.392 respectively. It was found that the linear model recorded the best net savings for Ebonyi, and Imo with the corresponding cost of ₦1,593,013.72 and ₦8,692,452.91 respectively. Hence, we conclude that using the quadratic model for the estimation of cost parameters prove to enhance the performance of the optimal total operating cost of the water borehole model in South-East Nigeria for the period considered in the study. This assertion is in line with the findings by Ezekafor and Agunwamba (2019) which concluded that the quadratic model was better than the linear model for the estimation of cost parameters for obtaining the maintenance cost of water boreholes for industrial and community boreholes in Anambra State. Based on the findings of the study we recommend the quadratic model for the estimation of cost parameters for the optimization of maintenance cost of water boreholes until further studies prove otherwise.

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