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Comparative Analysis of Existing and Optimal Maintenance Policy of Water Borehole Schemes in South Eastern States of Nigeria

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Abstract: A study optimising maintenance cost of water borehole schemes in South Eastern states of Nigeria (Abia, Anambra, Ebonyi, Enugu and Imo States) was carried out. Data was collected from 260 boreholes spread across all local government areas in the states. Optimisation results showed that for boreholes (submersible pumps) pumping once per day, the optimal preventive maintenance frequency and resulting savings in cost are 2 and ₦521,076 for Abia; 2 and ₦783,963 for Anambra; 2 and ₦458,242 for Ebonyi; 2 and ₦740,964 for Enugu; 2 and ₦605,187 Imo. For boreholes pumping twice per day, the optimal preventive maintenance frequency and resulting savings in cost are 5 and ₦1,896,301 for Abia; 4 and ₦3,692,655 for Anambra; 5 and ₦786,913 for Ebonyi; 4 and ₦4,187,161 for Enugu; 4 and ₦2,477,609 for Imo; and for boreholes pumping thrice per day; 8 and ₦2,798,330 for Abia; 7 and ₦8,372,862 for Anambra; 7 and ₦6,485,293 for Ebonyi; 10 and ₦4,014,240 for Enugu; 10 and ₦6,021,503 for Imo; with no downtime as opposed to the wasteful current practice of no preventive maintenance with downtime of up to 12 months or more. As a recommendation for a borehole scheme, there should be a check on the type of submersible pump and generator capacity as the choice made directly affects the total operational cost.

Key words: Analysis, borehole, comparative, optimal, schemes.

Introduction

Two major problems militating against sustainable boreholes water supply are poor funding and high operation and maintenance costs. In addition to this, poor funding hampers the provision of necessary spare parts. This is coupled with high operating and maintenance costs, which results in long downtime and an unsustainable water supply. Hence, preventive maintenance and involvement of communities in maintenance has been emphasised (Agunwamba, 1995, 2000a). Application of coordinated corrective maintenance model to boreholes (submersible pumps), generator set, and pipes results in savings of ₦53,860.00 per scheme for all the present long downtime and high frequency of breakdown associated with boreholes have been made (Agunwamba, 2000b).

Continuance of water supply is required to maintain sustainability. Without planned preventive maintenance there can be no sustainable water supply. The status of 53 private and 17 government-owned borehole water supply schemes in Abia and Imo States was recently

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investigated (Okere, 2010). It was found that over 8% of the boreholes are non-functional due to maintenance problems. Water supply was also seriously interrupted in these communities. Some schemes have remained non-operational for more than two years whereas well maintained privately owned boreholes remain functional mostly for commercial purposes only (Okere, 2010).

An analysis by Malawi's Water Department (UNPP, 1992a) revealed that community self-help in pump maintenance reduced the breakdown rate by 75% while the response time between breakdown and repair rarely exceeded two weeks. Moreover, maintenance costs were reduced to ₦400 from ₦3500 per pump each year. Previously, there was a lack of routine maintenance and of action for up to nine months before they were repaired. Also, an unplanned maintenance scheme increased the frequencies of breakdown. Communities have greater tendencies to feel disenchanted and often revert to old polluted sources when water facilities breakdown (Agunwamba, 1995; UNDP, 1992b). Resorting to contaminated water, therefore, increases the incidence of diseases.

Literature Review

Corrective Maintenance

Corrective maintenance is performed after fault recognition and is intended to put the component or system back in a state in which it can perform a required function. The component is used until it fails. It becomes inevitable as the component must be replaced and the system put back into a functional state. Corrective maintenance has its place in a sound maintenance strategy at least in the planning stage (for example in "what happens if …" – scenarios). This might be the right approach for a component group given that resources are focused on other, possibly more important, assets. Also, for equipment with random occurring instant failures, corrective maintenance might be the only option. As mentioned above, one might consider redesigning the system for these kinds of failures, however, it is quite likely that these failures might be worth "living with" while focussing on other areas with a better goal fulfillment per monetary unit. Water borehole schemes are an example of a multiple component electro-mechanical system with randomly occurring instant failures. The system may fail at the starter panel due to faulty contractors. An improper setting of the relay timers may result in over current and over voltage passage which can burn the pump (Hoko and Hertle, 2006; Howsam et al., 1995). The generator may fail to start due to one fault or the other and the system can be described as failed. A leaking riser pipe will result in reduced pressure in the supply pipeline and the water supply to the overhead tank may be cut off. All these components' failure can occur independently or collectively. Corrective maintenance may be an option to keep the system up and running. Preventive maintenance also presents a good option for sustaining water boreholes schemes by the application of periodic maintenance to some components and condition-based maintenance to others (Zaino, 1987).

Maintenance Policy of Water Boreholes in Nigeria

The UNICEF Country programme highlights both developments and constraints in the water and sanitation sectors. This policy document is supposed to be applied with respect to each country's arrangement. The developments include a decentralisation process for sustainability and maintenance within the United Nations system that provides government, donors, agencies and NGO's a unified approach to sector investment planning (National Action Committee, 1996). Furthermore, the document states that unless these problems are addressed, the future development will continue to be constrained. For Nigeria, the Federal Government of Nigeria in 1976 created 11 River Basin Development Authorities (RBDAS) to harness the country's water resources and optimise Nigeria's agricultural resources for food self-sufficiency. The RBDAS were established to provide water for irrigation, domestic water supply, improvement of recreation facilities and fisheries projects as policy. The Imo state government and subsequently the Abia state government set up water boards. For Imo state, this was later established into a corporation called IWADA (Imo Water Development Authority) to provide potable water to the people through the provision of hand pumps, borehole schemes to communities. The Federal Government of Nigeria in partnership with the European Union has set up the European Union Micro Project Programme (MPP6) for the six states of the Niger Delta Areas (Chima, 1989). The policy is to develop the infrastructure of the rural communities in these states to reduce tension in the areas and uplift the living standards of the people. Amongst others, the major focus included water and sanitation; borehole schemes and hand pumps were provided for the communities. The first phase of this programme lasted for 5 years (2003 – 2008). The MPP9 has also taken off with the same policy guidelines. It is expected that these agencies will service and maintain these schemes and infrastructure (UNDP, 1992c). It must be said that the need for potable water supply particularly for rural areas of our nation cannot be politicised. The overall health and economy of the nation are tied to how much potable water is available in all areas of our social life. All people need potable water and when the government cannot provide it, individuals resort to the borehole system for the supply of potable water.

Recent literature reasearch (Agunwamba, 2000a; Onuoha, 1990; Smith and Tnovinen, 1990) recommended that health impact studies and health indicators are an unpredictable tool for the assessment of water sanitation programmes. As health is a function of many variables, and may not always be related to water, sanitation and hygiene practices, it is sometimes impossible to isolate the effects of individual variables. However, welfare economics requires, among other things, an optimal allocation of commodities among consumers (Atkinson, 2012; Feldman and Roberto [1980] 2006).

Adopted Modelling Approach by Agunwamba (2000c)

There has not been published research of model development of least cost maintenance for water borehole schemes except for Agunwamba (2000c) who pioneered the research by modifying the model developed by Sule and Harmon (2007); Agunwamba (2000c) which was aimed at performing maintenance on individual machines or the entire group of machines. Performing preventive maintenance on individual

Figure 1: Map of Nigeria showing the five South Eastern states (modified after Okonkwo and Eyisi, 2014).

components (submersible pumps, generators and pipes) of a borehole scheme at different intervals and performing corrective maintenance on all simultaneously was performed by Agunwamba (2000c). This is based on a pumping scenario of twice per day of 3 hrs each as shown in Figure 2. For pumping twice per day, $T = 2t_0 + t_1 + t_2$, where T, t_0 , t_1 and t_2 are as defined in the following paragraph.

For a given typical day, t_0 is the water supply period while t_1 and t_2 are the idle times during the day and night periods, respectively. The period between major repairs is T. Hence, the number of breakdown cycles per year is $1/T$. Let K_i be the number of repairs (both corrective and preventive) for component I within a cycle. Therefore, the number of preventive maintenance is $(K_i - 1)$ per cycle. The Total Operation Cost (TOC) of a rural water scheme in a community is expressed as:

$$TOC = R_1C + R_2C + S_o + S_A \tag{1}$$

in which,

R_1C = Running Cost of Production;

R_2C = Running Cost of Preventive maintenance material and travel cost;

S_o = Corrective maintenance material and travel cost and

S_A = Salaries of the repair crew

The production cost is expressed as (Sule and Harmon, 2007 in Agunwamba 2000c);

$$R_1C = a_i + b_it^n \tag{2}$$

where,

a_i = The constant cost parameter representing the pump operator's initial salary and bulbs for lighting the pump house in i^{th} community.

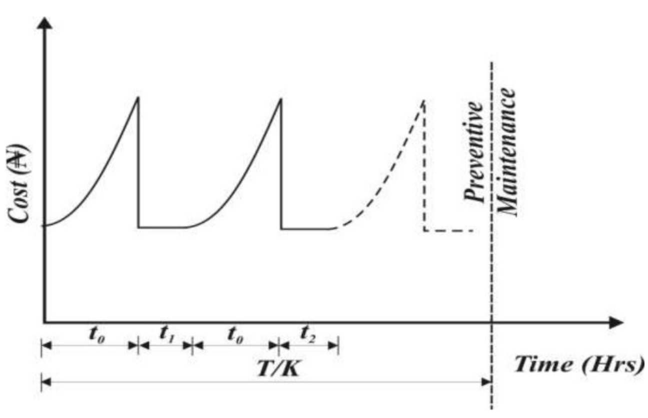

Figure 2: Graphical representation for pumping twice per day. (*Source:* Agunwamba, 2000c).

b_i = Includes salary increment, fuel consumption which increases with time for the i^{th} component,

K_1 = number of repairs and

n = the degree of polynomial describing the best cost function. Hence, the total production cost over a cycle for J component is

$$R_1C = \sum_{i=0}^{j}\left\{\int_0^{2t_0T/k_i} k_i(a_i + b_it^n)dt + \int_0^{t_1T/k_i} k_i(a_i + b_it^n)dt + \int_0^{t_2T/k_i} k_i(a_i + b_it^n)dt\right\} \tag{3}$$

$$TOC = \frac{365N}{T}\left[S_o + \sum_{i=1}^{j}(S_iK_i - S_i + a_iT) + \frac{(aT)^{n+1}}{n+1}.\frac{b_i}{K_i^n}\right] \tag{4}$$

The optimal value of T is given by

$$T = \frac{365}{a}\left[\frac{\sum_{i=1}^{j}B_i}{\sum_{i=1}^{j}\frac{b_i}{K_i^n}.\left(\frac{n}{1+n}\right)}\right]^{\frac{n}{n+1}} \tag{5}$$

$$\text{Where } \sum_{i=1}^{j}B_i = S_o + \sum_{i=1}^{j}(S_iK_i - S_i) \tag{6}$$

The minimum TOC is obtained by substituting the optimal value of T obtained from Eq. 5 into Eq. 1. The mathematical relationship between TOC and K is solved by trial and error to obtain the minimum TOC and corresponding T.

Mathematical Model for Least Cost Water Borehole Schemes Maintenance

This model is loosely based on previous efforts by Agunwamba (2000c) to estimate optimum maintenance costs for rural water borehole schemes in Enugu state. The general approach, carried through to this project, is to identify the cost contributors and assemble them into a structure. The model assumes that a water borehole pumps for 2 hrs, 3 hrs, 4 hrs, 5 hrs, 6 hrs, 8 hrs daily unlike Agunwamba's study which shows

6 hours of pumping. By default, the model creates a generic water borehole as a proxy for public and private water borehole schemes. The reasons for this are partly practical: historical data for many of the water boreholes are limited and the cost data are generally proprietary. Based on the input assumptions, the model populates the various cost contributors for the water borehole schemes based on the normalized data in the database.

Research Methodology

Determination of Total Operation Cost (TOC) of Model

1. The production cost parameter R_1C model solution Equations 7, 8 and 9 for pumping once, twice and thrice, respectively, is substituted into the total operation cost equation 1 to obtain the model equations for each pumping scenario:

(a) Model Equation (Pumping Once)

$$TOC = a_i T(2t_o + t_1 + t_2) + \frac{b_i K_i}{n+i}\left(\frac{T}{K_i}\right)^{n+i} \left[(2t_o)^{n+i} + t_1^{n+i} t_2^{n+i}\right] + R_2 C + S_o + S_A \quad (7)$$

(b) Model Equation (Pumping Twice)

$$TOC = a_i T(2t_o + t_1 + t_2) + \frac{b_i K_i}{n+i}\left(\frac{T}{K_i}\right)^{n+i} \left[(2t_o)^{n+i} + t_1^{n+i} t_2^{n+i}\right] + R_2 C + S_o + S_A \quad (8)$$

(c) Model Equation (Pumping Thrice)

$$TOC = a_i T(3t_o + 2t_o + 2t_1 + t_2) + \frac{b_i K_i}{n+i}\left(\frac{T}{K_i}\right)^{n+i} \left[(3t_o)^{n+i} + (2t_o)^{n+i} + 2t_1^{n+i} t_2^{n+i}\right] + R_2 C + S_o + S_A \quad (9)$$

2. Data from the boreholes for each pumping scenario is arranged and the Total Operations Cost (TOC) computed.
3. The Total Operations Cost TOC is then computed from the TOC model equations for the different scenarios – Eqns 7, 8 and 9. Values of T are varied in the model equations for each borehole and TOC computed each time until the computed TOC from the model is equal to the TOC computed from the field data. The minimum TOC and corresponding T and K values are deduced from each scenario.

Results

Optimum Total Operation Cost (TOC), Period T and Frequency of Maintenance

The Total Operation Cost for each pumping scenario once, twice and thrice for the submersible pump in each state is given in Tables 1, 2 and 3, respectively. The optimal maintenance frequencies and least costs were evaluated based on the estimated model parameters given in Tables 1-3. The calculations were set out in a Microsoft Excel spreadsheet.

The average total operations cost (TOC), Corrective maintenance interval T and frequency of maintenance for boreholes pumping once per day in Abia, Anambra, Ebonyi, Enugu and Imo states are shown in Table 1. These states' location is shown in Figure 1. The average total operations cost (TOC) varies from a minimum of ₦1,229,432 for Ebonyi state to a maximum of ₦6,126,903 for Anambra state. This is due to the different submersible pump and generator capacities in use for the various schemes and their associated operations cost. In Ebonyi State, the installed pump capacities vary from 5Hp to a maximum of 50Hp and the generating set capacities vary from 8kva to 25kva.

Table 1: Optimum Total Operation Cost (TOC), period T and frequency of maintenance (pumping once)

State	*TOC (₦)*	*T (days)*	*Ki*	*Frequency per year*	*No. of cycles per year*	*Frequency of preventive maintenance per cycle*
Abia	4,836,583	160	3	2	2	1
Anambra	6,126,903	200	4	2	2	1
Ebonyi	1,229,432	200	3	2	2	1
Enugu	2,980,448	200	2	2	2	1
Imo	3,716,440	220	2	2	2	1

The low capacity range for pump and generator in use translate to lower fuel consumption and maintenance costs resulting in low total operational cost. In Anambra state, the installed pump capacities vary from 7Hp to 50Hp and generator capacities vary from 10kva to 300kva. The high capacity range for pumps and generators in use translates to higher fuel consumption and maintenance costs resulting in the higher total operational cost.

The corrective maintenance interval T varies from 160 days for Abia state to 220 days for Imo state. This signifies the time limit within which a periodic check on the submersible pump should be carried out to avoid a complete breakdown of the scheme. This period is about the same for all the states.

The average total operations cost (TOC), Corrective maintenance interval T and frequency of maintenance for boreholes pumping twice per day in Abia, Anambra, Ebonyi, Enugu and Imo states are shown in Table 2. The average total operations cost (TOC) varies from a minimum of ₦2,771,206 for Abia state to a maximum of ₦15,074,653 for Enugu state. This is due to the different submersible pump and generator capacities in use and the number of pumping times per day, in this case twice, for the various schemes and its associated operations cost. In Abia state, the installed pump capacities vary from 1.5 Hp to a maximum of 50 Hp and the generating set capacities vary from 5 kva to 200 kva. The low capacity range for pump and generator in use translates to lower fuel consumption and maintenance costs resulting in low total operational cost. In Enugu state, the installed pump capacities vary from 15Hp to 50Hp and generator capacities vary from 50kva to 200kva. This high capacity range for pumps and generators in use and the number of pumping times, in this case twice, translates to higher fuel consumption and maintenance costs resulting in the higher total operational cost. The corrective maintenance interval T varies from 75days for Ebonyi state to 100 days for Anambra state. This signifies the time limit within which a periodic check on the submersible pump should be carried out to avoid a complete breakdown of the scheme.

The average total operations cost (TOC), corrective maintenance interval T and frequency of maintenance for boreholes pumping thrice per day in Abia, Anambra, Ebonyi, Enugu and Imo states are shown in Table 3. The average total operations cost (TOC) varies from a minimum of ₦1,891,400 for Enugu state to a maximum of ₦6,413,543 for the Anambra state. This is due to the different capacities of submersible pumps and generators in use and the number of pumping times per day, in this case thrice, for the various schemes and its associated operations cost. In Enugu state for schemes pumping thrice a day, the installed pump capacities vary from 5.5 Hp to a maximum of 30 Hp and the generating set capacities vary from 25 kva to 100 kva. The low capacity range for pump and generator in use translates to lower fuel consumption and maintenance costs resulting in low total operational cost. In Anambra state, the installed pump capacities vary from 15 Hp to 50 Hp and generator capacities vary from 50 kva

Table 2: Optimum Total Operation Cost (TOC), period T and frequency of maintenance (pumping twice)

State	*TOC (₦)*	*T (days)*	*Ki*	*Frequency per year*	*No. of cycles per year*	*Frequency of preventive maintenance per cycle*
Abia	2,771,206	85	1	4	4	1
Anambra	4,445,319	100	5	4	4	1
Ebonyi	5,946,601	75	4	5	5	1
Enugu	15,074,653	78	1	5	5	1
Imo	2,920,256	90	1	4	4	1

Table 3: Optimum Total Operation Cost (TOC), period T and frequency of maintenance (pumping thrice)

State	*TOC (₦)*	*T (days)*	*Ki*	*Frequency per year*	*No. of cycles per year*	*Frequency of preventive maintenance per cycle*
Abia	2,237,087	46	2	8	8	1
Anambra	6,413,543	50	1	7	7	1
Ebonyi	3,791,123	50	4	7	7	1
Enugu	1,891,400	38	1	10	10	1
Imo	5,865,573	37	5	10	10	1

to 200 kva. This high capacity range for pumps and generators in use and the number of pumping times, in this case thrice, translate to higher fuel consumption and maintenance costs resulting in the higher total operational cost. The corrective maintenance interval T varies from 37 days for Imo state to 50 days for Anambra and Ebonyi states. This signifies the time limit within which a periodic check on the submersible pump should be carried out to avoid a complete breakdown of the scheme.

Comparative Analysis of Optimum Maintenance Policy and Existing Policy

Discussion

Optimisation results obtained by Agunwamba (2000c) in Enugu state showed that the optimal preventive maintenance frequencies of 6 and 6 times, respectively, for water boreholes and generator sets gave savings in total operation cost of ₦85,629 with no downtime. The difference in the results obtained by Agunwamba (2000c) and the results of this study is because Agunwamba (2000c) conducted his study on 14 boreholes in Nsukka zone while about 53 public boreholes were considered in this research. Also, the research of Agunwamba (2000c) produced a TOC without downtime, whereas, the reverse is the case in this research. The costs of consumables (diesel, engine oil, etc.) have greatly increased over time.

Conclusion

Some water borehole schemes mentioned above have been non-operational for more than two years. Unplanned maintenance contributes to prolonged downtime which has several technical and socio-economic implications. Since abandoned, the facility rusts away and in most cases is vandalised because the communities cannot adequately maintain and run it effectively. Besides, unplanned maintenance is more expensive than planned maintenance. For instance, Table 4 shows, with planned maintenance, the optimal total operation cost for Enugu State is ₦2,980,448 against the current cost of ₦3,721,412 a decrease of ₦740,964, Abia State is ₦4,836,583 against the current cost of ₦4,667,507 a decrease of ₦521,076, Imo State is ₦3,716,440 against the current cost of ₦5,397,865 a decrease of ₦605,187, Anambra State is ₦6,126,903 against the current cost of ₦8,137,974 a decrease of ₦783,963, Ebonyi State is ₦1,229,432 against the current cost of ₦1,687,674 a decrease of ₦458,242 per scheme when pumping is done once daily.

With planned maintenance, the optimal total operation cost for Enugu State is ₦15,074,653 against the current cost of ₦19,261,814 a decrease of ₦4,187,161, Abia State is ₦2,771,206 against the current cost of ₦4,667,507 a decrease of ₦1,896,301, Imo State is ₦2,920,256 against the current cost of ₦5,397,865 a decrease of ₦2,477,609, Anambra State is ₦4,445,319

Table 4: Comparisons of average optimal TOC and average existing TOC for all pumping scenarios

State	*Average optimal TOC (₦)*			*Average existing TOC (₦)*		
	Once	*Twice*	*Thrice*	*Once*	*Twice*	*Thrice*
Enugu	2,980,448	15,074,653	1,891,400	3,721,412	19,261,814	5,905,640
Abia	4,836,583	2,771,206	2,237,087	5,357,659	4,667,507	5,035,417
Imo	3,716,440	2,920,256	5,865,573	4,321,627	5,397,865	11,887,076
Anambra	6,126,903	4,445,319	6,413,543	6,910,866	8,137,974	14,786,405
Ebonyi	1,229,432	5,946,601	3,791,123	1,687,674	6,733,514	10,276,416

Table 5: Net savings in total operation cost

State	*Net savings in TOC (₦) (pumping once)*	*Net savings in TOC (₦) (pumping twice)*	*Net savings in TOC (₦) (pumping thrice)*
Enugu	740,964	4,187,161	4,014,240
Abia	521,076	1,896,301	2,798,330
Imo	605,187	2,477,609	6,021,503
Anambra	783,963	3,692,655	8,372,862
Ebonyi	458,242	786,913	6,485,293

against the current cost of ₦8,137,974 a decrease of ₦3,692,655, Ebonyi State is ₦5,946,601 against the current cost of ₦6,733,514 a decrease of ₦786,913 per scheme when pumping is done twice daily.

Finally with planned maintenance, the optimal total operation cost for Enugu State is ₦1,891,400 against the current cost of ₦5,905,640 a decrease of ₦4,014,240, Abia State is ₦2,237,087 against the current cost of ₦5,035,417 a decrease of ₦2,798,330, Imo State is ₦5,865,573 against the current cost of ₦11,887,076 a decrease of ₦6,021,503, Anambra State is ₦6,413,543 against the current cost of ₦14,786,405 a decrease of ₦8,372,862, Ebonyi State is ₦3,791,123 against the current cost of ₦10,276,416 a decrease of ₦6,485,293 per scheme when pumping is done thrice daily.

This cost reduction implies an improved management strategy with the application of the model which will go a long way to enhance the sustainability of water boreholes. The model presented is useful for the evaluation of existing maintenance schemes and the optimal design of new ones and would also prove useful to project developers, owners and operators in the evaluation of water borehole projects, especially in southeastern states in Nigeria.

As a recommendation for a borehole scheme, there should be a check on the type of submersible pump and generator capacity as the choice made directly affects the total operational cost.

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