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Evaluation of Waterloss Impacts on Water Distribution and Accessibility in Akure, Nigeria

Safe drinking water is a necessity for life. Providing quality drinking water is a critical service that generates revenues for water utilities to sustain their operations. Population growth put an additional strain on the limited resources. The annual volume of water lost is an important indicator of water distribution efficiency, both in individual years, and as a trend over a period of years. Application of deterministic simulation model on public water supply variables reveals the volume of non-revenue water (NRW) and its cost effects have further created a complex system for the availability, distribution and affordability of the utility. Gradual annual increase in public water supply (AWS) from 9.0 $*10^6 m^3$ *to* 14.4 $* 10^6 m^3$ *had negative effect on annual water accessed (AWA) with* $R^2 = 0.096$*; and highly significant with annual water loss (AWL) with* $R^2 = 0.99$*. This development indicates that water loss mainly through leakages and bursts is a function of public water supply. Hence, estimated volume and cost annual revenue water (NRW) in Akure is* 6 million m^3 *and* 15.6 million *USD respectively. Critical analysis shows that the lost annual revenue could be used to provide education and health services for a period of 6-month in the region.*

Keywords: *water, NRW, simulation, distribution, resources, public, cost*

1. Introduction

The accessibility and even distribution of potable water is a serious global issue. Safe drinking water is limited, the population growth, industrial and social advancement have further complicated the already scarce utility through overstressing the provision of potable water and infrastructural mechanisms for water distribution such as reticulation pipeline networking system, reservoir construction, fitting of flowmeter e.t.c. Ensuring safe, adequate and affordable water supply is becoming an ever more pressing issue for government, water professionals and researcher across the globe. More than 75% of the drinking water infrastructure in Edo North has been in service for decades without replacing with integrated and efficient system this leads to significant source of water loss through leaks, cracks, expiration and damage (Idogho et al., 2013).

Gathering, converting and distribution of safe drinking water is a serious challenge in Nigeria and some other developing nations, these constraints occurred as water loss due to leakages in conveyance pipeline, wastages, theft, improper billing and metering systems (May, 1994). The annual volume of water lost is an important indicator of water distribution efficiency, both in individual years, and as a trend over a period of years. High and increasing water losses are an indicator of ineffective planning and construction, and of low operational maintenance activities (Lambert, 1999). Water loss from a utility's distribution system is a serious constrain which is always associated with loss of revenue and production efforts. Water losses in the distribution system require more water to be treated, which requires additional energy and chemical usage, resulting in wasted resources and total loss of revenues (Mckenzie, 2001). Determining how much water is being lost and where losses are occurring in a distribution system can be a difficult task. Without consistent and accurate measurement, water losses cannot be reliably and consistently managed (Benser and Camper, 2011).

The confusion over inconsistent terms and calculations has led to the development of better tools and methods to track water losses from distribution systems. This scenario has an increasing effect on socio-economic development of entire region of Akure and its environs. Having considered the huge budgetary allocation for publication water supply and distribution, it is important to device technically-based approaches of reducing water loss through physical or real and apparent water losses and also improves water quality at the end-point or delivery stage. Water loss reduction (WLR) often represents an efficient alternative to exploiting new resources, which frequently involves cost-intensive measures, such as new dams, deep wells, seawater desalination or even transferring water from one river basin to another. Therefore, water loss reduction and pressure management contribute to sustainable and integrated water resources management (IWRM). However, this research study is focused on the estimation and analysis of the effects of water losses on public water supply and distribution (PWSD) in relation to social-economic development and integration in Akure, Nigeria.

2. Materials and methods

2.1. Study area

Akure is made up of 18 districts and located in the South-western Zone of Nigeria. Akure lies between longitudes 4″30″ and 6″ East of the Greenwich Meridian, 5″ 45″ and 8″ 15″ North of the Equator. This means that the city lies entirely in the tropics. It is bounded North by Ilara Mokin; in the East by Obanle; in the West by Ondo and Oda in the South. Population: 763,000 comprising Male (56%) and Female (46%). The map of the city is shown in Fig. 1.

Figure 1. Map of Akure (Source: Google, 2013)

2.2 . Water loss modelling

Many drinking water utilities around the world do not give instantaneous respond to leaks problems until the situation becomes complicated. Leaks can effectively be corrected using sensitive optimization modelling approaches which involves monitoring of real-time leaks problem, computerization of adequate pressure system, provision for eddy losses to prevent pipe burst (Fanner, 2009). However, soil conditions for example can have a great effect on the real losses as well as to the ability for them to be identified and located at the ground surface. Apparent and physical losses are computed as follows:

$$WL\epsilon = NRW\tau - KWS\beta \qquad (1)$$

Where $\boldsymbol{NWR\iota}$ is total Non- Revenue Water; $\boldsymbol{WL\rho}$ is real Water Loss; and $\boldsymbol{WL\epsilon}$ is apparent Water Loss (Idogho et al., 2013).

2.2.1 Unavoidable Real Losses (URL)

Output of various studies conducted shown that it is impossible to eliminate real losses from a water distribution system. Therefore Unavoidable Real Losses is therefore computed as follows:

$$URL = 18 \times L_m + N_c + 25 + L_p \times P \tag{2}$$

Where: L_m = main length in Km;
N_c = number of service connections;
L_p = total length in Km; and
P = average pumping pressure.

Leak volume is the function of time (t) and flowrate (R); this development is therefore evaluated as:

$$L_v = t(W + L + P) * R \tag{3}$$

The expression in equation (3) is modified to produce sensitive leak volume value as:

$$L_v = t\mu(W + L + P) * R \tag{4}$$

Where;
Lv = Leak volume (m^3);
t = Time (sec);
μ = Flow constant (0,88)
W = Awareness;
L = Location; and
P = Repairs.

2.3. Water supply and demand formation

Water resources involve simulating systems made up of many component parts that are interrelated. The hydrological system is driven by stochastic variables (i.e., precipitation, evaporation, demand) and involves uncertain processes, parameters, and events. The challenge when evaluating water supply and resource systems is to find an approach that can incorporate all the knowledge available to planners and management into a quantitative framework that can be used to simulate and predict the outcome of alternative approaches and policies (Butler, 2009). While developing a system, the starting point can also be some specific consumption that does not necessarily include leakage. In that case the leakage percentage has to be added in the following way:

$$Q_{ph} = \frac{Q_{av.day}}{f}\left(k_1 k_2 + \frac{1}{100 - l}\right) \tag{4}$$

Factor, f, in the equation is a unit conversion factor while l represents the leakage percentage of the total quantity supplied to the system; Q_{ph} is the quantity of water demand at the peak hour, while, $Q_{av.day}$ is the average quantity of water demanded daily. Therefore, annual average water supply is computed using the relationship on equation (5):

$$AWS = CP_i A_v N_d \tag{5}$$

Where: C = Coefficient of target population;
P_i = Total population;
A_v = Average total water volume;
N_d = Number of water supplied days.

The volume of annual water supply that could finally be assessed by the targeted population is evaluated using the interconnectivity between annual water supply ***(AWS)*** and annual water loss ***(AWL)*** as related in equation (6):

$$AWA = AWS - AWL \tag{6}$$

Where; AWA = Annual water assed (m^3).

2.4. Water Cost Index Computation

It is very important and useful to calibrate the water supply-cost benefit ratio in order to monitor and improve on the service delivery of the utility (Idogho et al., 2013). The Rickard's Real Cost Water Index serves as a benchmark for helping measure hundreds of critical projects on a like-for-like basis (Bond and Richard, 1997). Index values reflect estimated water production costs measured in US dollars per cubic meter for a variety of major global water infrastructure projects ranging from retail water utilities to wholesale water utilities. However, Water Cost index is calculated using Richard's relationship as follows:

$$WCI = \frac{T_p}{T_d} \tag{7}$$

Where: Tp = Total cost of production is calculated as the sum of operating costs, capital costs, and identified subsidies;

Td = Total delivered freshwater volume_(in m^3) is the amount the producer reports as delivered, and excludes water lost either due to system leakage, pilfering, or other forms of loss. This penalizes producers with a large fraction of production volume being lost due to system inefficiency;

WCI = Water Cost Index

2.5. Data analysis

Data on water loss variables were generated using a set of modelled relationships from the measured data. The generated outputs were subjected to statistical and dynamic simulation processes. Excel software and Sigma Plot were used for spread sheet calculations and graphical representations.

Plate 1. Leakage from the burst pipeline

3. Results and discussion

3.1. Calibration of Water supply; loss and accessible variables

Many drinking water utilities around in Akure, Nigeria respond to leaks development only after receiving report of water erupting from a street or a complaint from a customer about a damp basement. Leakage control requires a proactive leakage management program that includes a means to identify hidden leaks, optimize repair functions, manage excessive water pressure levels, and upgrade piping infrastructure before its useful life ends. The result in Table 1 shows the Public water supply system in Akure for a period of 10-year (2003-2012). The volume of annual water loss and accessed was simulated using the public water supply data obtained from the Ondo State Water Corporation. The result in Table 1 indicated that there is an increase in volume of water supply from year 2003 down to 2012. The output of simulation iteration shown that the increase in annual water supply *(AWS)* had negative effect on annual volume of water accessible *(AWA)* with R^2 = 0.096; and strong agreement exist between annual water supply (AWA) and annual water loss with the R^2 = 0.999 as shown in Fig. 2 and 3 respectively. In 2007, equilibrium exists among the public water supply variables; with the annual water supply *(AWS)* of value $10.8 * 10^6 m^3$; annual water loss (AWL) is $5.4 * 10^6 m3$ *and* annual water accessed (AWA) is $5.4 * 10^6 m^3$

respectively. The implication of this development is that half of annual water supply is lost to leaks.

Table 1. Public Water Supply and Loss

N/S	Year	AWS (m^3*10^6)	AWL (m^3*10^6)	AWA (m^3*10^6)
1	2003	9.0	3.2	5.9
2	2004	9.6	3.8	5.8
3	2005	10.0	4.5	5.5
4	2006	10.3	4.8	5.5
5	2007	10.8	5.4	5.4
6	2008	11.0	5.7	5.3
7	2009	11.3	6.1	5.2
8	2010	11.8	6.7	5.1
9	2011	12.1	7.1	4.9
10	2012	14.4	8.6	5.8

Source: (OSWC, 2013; Simulation output)
Note: AWS = Annual water supply (m^3): AWL = Annual water loss (m^3)
AWA = Annual water accessible (m^3)

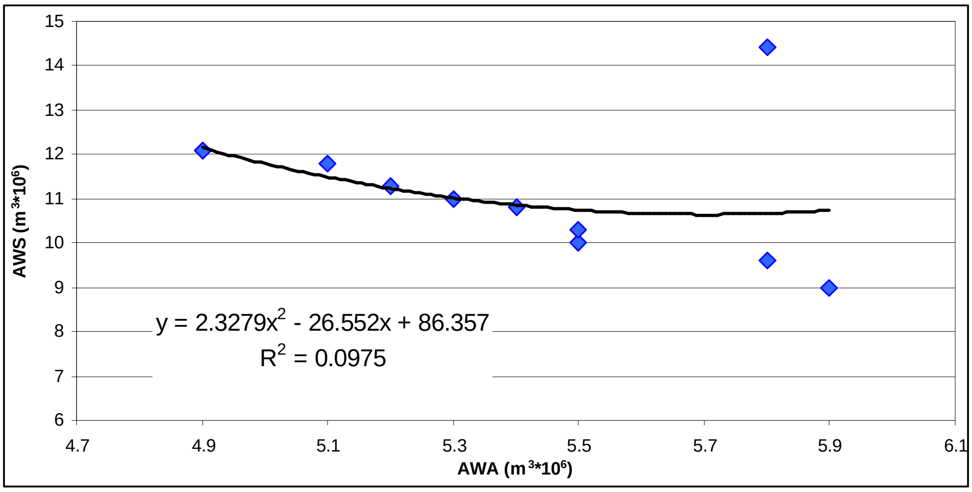

Figure 2.

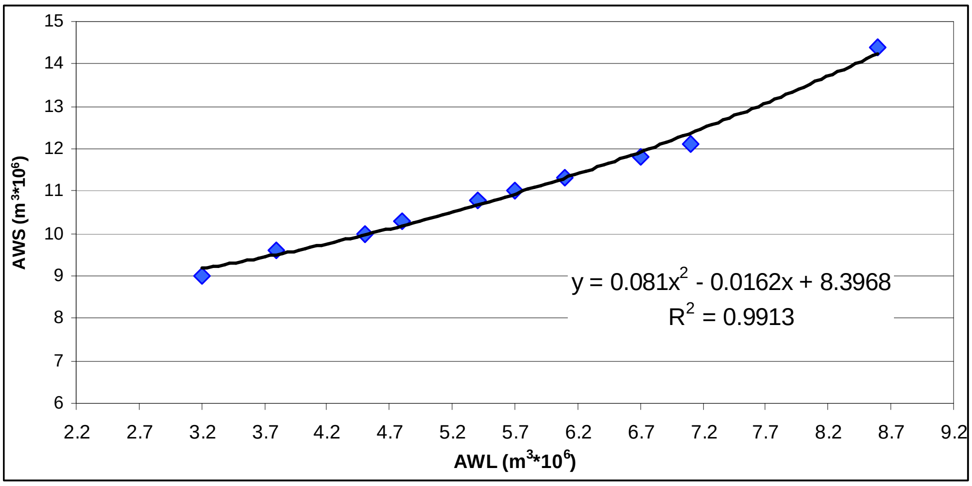

Figure 3.

Most drinking water infrastructure in Akure, Nigeria has been in service for many years and this could be a significant source of water loss through leaks. The pipelines got weak and usually burst if there is any pressure variation. Since pipelines were not properly marked, a lot of them could also be destroyed during road and construction of other infrastructure amenities. This type of water loss is referred to as *Real/Physical loss*. In addition to leaks, water could be "lost" through unauthorized consumption (theft), administrative errors, data handling errors, and metering inaccuracies or failure; and this is referred to as Apparent loss. Based on the output of simulation RUNS, multiple modelling of optimized public water supply accessibility function was formulated as follows:

$$
\begin{aligned}
Y = \mu_0 &+ \alpha 1(AVjan.) + \alpha 2(AVfeb.) + \alpha 3(AVmar.) + \alpha 1(AVapril.) \\
&+ \cdots \ldots \ldots \ldots + \alpha 12(AVdec.) + \alpha 13(Ndjan.) + \alpha 14(Ndfeb.) \\
&+ \cdots \ldots \ldots \alpha 24(Nddec) + \alpha 25(Pijan.) + \alpha 26(Pifeb.) + \cdots \alpha 36(Pidec.) \\
&+ \alpha 37(C) + \alpha 37(LeakP) + \alpha 38\,(BurstP) + \alpha 39(PresureS) \\
&+ \alpha 40(PipelineP).
\end{aligned}
$$

Where;

Y = Public water supply accessibility;
Av = Average volume of water supply (m^3);
Nd = Number of days for water supply;
LeakP = Leakage from the pipe conveying water;
BurstP = Burst of pipeline;
PressureP = Pressure in the pipe;
C = Coefficient of the target population.

3.1.1. Water Cost Benefit Estimates

It is important to establish sound relationship on water production cost, cost of water loss or Non- Revenue Water in order to monitor the degree of utility distribution and its impact on the end-user for possible optimization for better service delivery. Evaluation of water production varies from geographical location to another and also depends on the hydrological formation of the region. The results in Table 2 show the cost of water production; water loss and billed water (i.e water that finally reached the consumers). The true cost of water production in individual geographic areas, which includes operating, capital, and "hidden economic" costs. Highest cost of annual water loss of 30.1 million USD was estimated in 2012 compared 4.8 million USD in 2003. However, there was a progressive increase in the investment of water production from 13.5 million USD in 2003 to 50.4 million USD in 2012. Strong relationship exist between cost of annual supply of water (CAWS) and cost of annual water loss (CAWL) with R^2=0.931.

Table 2. Water Production Cost and Loss Index

N/S	Year	CAWS (Million$)	CAWL (Million $)	CAWA (Million $)	WLI
1	2003	13.5	4.8	8.7	0.35
2	2004	19.2	7.8	11.4	0.40
3	2005	22.0	9.9	12.1	0.45
4	2006	24.7	10.8	13.9	0.43
5	2007	28.1	14.0	14.0	0.50
6	2008	30.8	16.0	14.8	0.51
7	2009	33.9	18.3	14.4	0.53
8	2010	37.8	21.4	16.4	0.56
9	2011	41.1	22.7	18.4	0.55
10	2012	50.4	30.1	19.9	0.59

Source: (OSWC, 2013; Simulation output)

Note: CAWS = Cost of annual water supply ($): CAWL = Cost of annual water loss ($):
CAWA = Cost annual water accessible ($): WLI: Water loss index

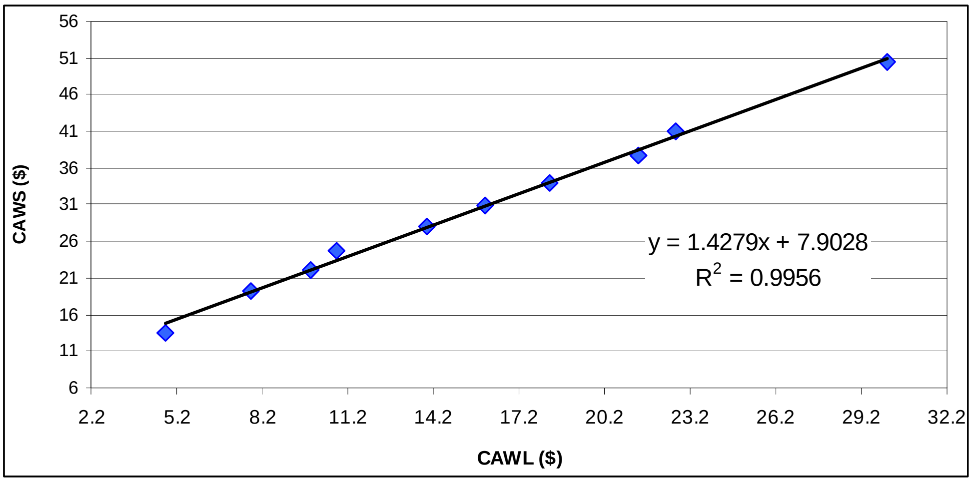

Figure 4.

Akure is estimated to have an annual Non-Revenue Water (NRW) (i.e mostly from real loss) volume of 6 million m^3. This represents approximately 15.6 million USD in revenue that water utilities lose every year.

4. Conclusion

Ensuring safe, sufficient and affordable water supply is becoming an ever more pressing issue for politicians and water professionals. This development has become a serious problem in most of the developing countries. Effective public water supply system is a productive function of many related variables such as non-revenue water (NRW). Annual water loss mainly through physical processes is estimated to revenue loss of 15.6 million USD. This value of fund could be applied for 30% budgetary allocation for Education and Agricultural section for the city. In addition, 60,623 people could be provided with potable water at the rate of 75 litres per person per day annually. Integrated water auditing model (IWAM) is a pivotal step in calibrating an effective water loss management program. Constructive application of the formulated model coupled with the introduction of automated metering device, burst and leak detector will produce a quantified understanding of the integrity of the distribution system and address sound plan to resolve water losses.

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