ANALELE UNIVERSITĂȚII
"EFTIMIE MURGU" REȘIȚA
ANUL XX, NR. 3, 2013, ISSN 1453 - 7397

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Calibration of System Input Volume and Non-Revenue Water Index in Edo North, Nigeria

*Water scarcity is a serious problem in developing world. It could be physical scarcity or economic water shortage. The output of physics-based study conducted in Edo North, Nigeria revealed that physical water losses in the water distribution network have compounded the accessibility and affordability of safe drinking water. Water supply and loss variables such as Water Supply **(WS)** Physical Water Loss **(WLρ)** Apparent Water Loss **(WL_E)** Water Loss Reduction Index (**WLRI)** and Available Water **(AW)** were mathematically modeled to produce realistic and efficient water loss management and improve water revenue. The result of the modeling iterations show that the average physical and apparent losses of 4,000m^3 and 2,700m^3 of **(WLρ)** and **(WL_E)** correspond to 13,200m^3, 6,400m^3 and 0.5 of **WS/SIV, AW** and **WLRI** in 2007. Strong indication exists between the **WLRI** for both physical and apparent losses with the coefficient of determination R^2=0.83 and 0.99 respectively. This relationship shows that more water is being lost through real loss with average total of 59.2% and 40.8% of apparent losses. However, a reduction of Total Non-Revenue Water (TNRW) from 50.7% to 10.6% was recorded between 2007 to 2011. This reduction led to a total increase of 4,400m^3 of Revenue Water, decrease in Non-Revenue Water reduction cost from 36% in 2007 to 7% in 2011 and saving of US$17,400 which could be used to provide health facility for malaria treatment for 14,500 people on daily basis. Water efficiency, and particularly drinking water loss, is a serious issue which has significant financial and economic depression; awareness in this respect is totally unrecognized by both individual and governmental sector. Generally, long-term strategies towards the reduction of water losses should continue to be sustained by Edo State government, donor agencies and some private sectors in the area of water supply in order to support the fulfillment of the Millennium Development Goals, control of leakage and water losses.*

Keywords: Physical loss, Apparent loss, Water Reduction, Revenue, Index, Available Water, leakage.

1. Introduction

It has become increasingly clear that leakage from water supply systems represents a major problem in the achievement of the human right to water and attainment of Millennium Development of Goal on water and sanitation by year 2015, particularly in developing nations (Exner, 2008). "Water is Life" is a notion which is accepted without exception. It is one commodity without which life cannot exist on this earth – not only because it is essential for the actual living process but also because it is necessary for supporting man's material activities, which lead to his material development (Hassanali, 2005). Water loss is a serious challenge in advanced and developing countries (Arange, 2006). This occurs either through physical losses (mainly leakage in networks) or theft of water from the system or from water users not being properly billed, or due payments not being collected (TUBI, 2005). This development has caused the government and private investors in the area of water sector technical and managerial setback towards the supply and even distribution of portable water to the teeming population (Bulter, 2009).

"Non-Revenue Water" (NRW) is very high in Nigeria, thus increasing the degree of water stress ratio in both southern and western region of the country (Idogho et al., 2012). The worldwide cost of NRW is conservatively estimated at $15 billion/year. More losses occur in the developing world, where some 45 million m^3/day are lost through leakage enough to serve nearly 200 million people-and close to 30 million m3/day are delivered but not invoiced (Worldbank, 2008). Water loss management as one aspect of water efficiency then has to be seen as a part of integrated water management which could be achieved with the formulation of physics-based models for apparent and physical or real water losses. It is assumed that, in 2002, an average of 26% of the system input for 1760 people worldwide got 'lost'; (67%) caused by real losses and 33% by apparent losses (Thornton et al., 2005). In Edo North in Nigeria, an average of more 45% of the system input is believed to be 'lost' due to apparent and real losses. Improper pipeline network system and poor metering and water calibration mechanism further complicate these losses. Water quality is such an important parameter touching on all aspects of ecosystems and human well-being such as the health of a community, food production, economic activity, ecosystem health and biodiversity (Seago, 2005). Ensuring adequate amounts of high enough water quality is essential if we are to improve the situation of those living at low financial, wealth and educational levels (Waterkeyn 2010). 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). In addition, it has been estimated in Nigeria that commercial losses of water are more in value to two-third of the total annual budgetary allocation for investment in water supply. Findings reveal that the complication persists due to fraudulent activities and corruption-such as illegal connections, fraudulent meter reading, or meter tampering by the public and also Water Corporation Personnel.

Having noticed continuous degree of water loss through physical and apparent loss of water over years in Edo North, which has led to high value of Non-Revenue Water (NRW) in most of our communities in Edo North, this research study is therefore focused on reducing the value of NRW to insignificant level by establishing stochastic and physics based models veritable in running ***physical and apparent variables.*** The output of the iteration is expected to provide a long-time and realistic measure for water loss reduction, increase the people that could access the limited resource and promotes even distribution of the utility to the subscribers and users.

2. Materials and Methods

2.1 The Study Area

Edo state region of North Senatorial District, Nigeria is among the deltas in the world. It constitutes the coastline area of Nigeria. It is bounded in the south by Delta state in the West by Ondo state in the North and North East by Kogi State and in the East by Anambra state. Edo State covers an area of 19,744km^2 and has a total population of 2,159,848 and population density of 109 (based on the 1991 census figure). The state has approximately between latitude 05^o 44'N and 07^o 34'N of the Equator and between latitude 06^o 04^o'E and 06^o 43^o'E. Edo State has annual mean rainfall of above 2,000mm, air temperature of 27^{o}c and relative humidity of above 65%. Fig.1 shows the photograph map of Edo State indicating the study areas. Reconnaissance survey using baseline data extracting mechanism was applied to obtain information in all the sampled areas in Edo-State. A total of 18 Water Corporation Station were visited throughout the state. The conditions of Surface Water Schemes in the State are shown below in Table 1.

Table 1. Condition of Surface Water schemes in Edo State, Nigeria

N/S	Scheme Name	Year Scheme Commenced Operation	Treat-ment	Installed Capacity (m^3/day)	Present Capacity (m^3/day)	Capacity Utili-zation (%)
1	Estako-West	1986	Full	180,000.0	30,000.0	16.6
2	Estako-Central	1980	Full	56,345.0	22,654.0	40.3
3	Estako-East	1999	Partial	44,500.0	21,500.0	48.3

4	Owan East	2000	Partial	227,000.0	136,000.0	60.0
5	Owan West	2003	Full	120,000.0	6,000.0	50.0
6	Akoko-Edo	2007	Full	35, 000.0	22,000.0	62.9

Source: Edo State Water Supply Baseline Survey, 2008

Figure 1. Map of Edo-State showing the regions of study

Data for this research study were primarily sourced from the 18 Water Treatment and Distribution Stations across the State. Water supply and loss variables such as Water Supply (***WS***), Water Loss (***WL***), Water Available (***WA***) and Water Loss Reduction Index (***WLRI***) for each region were scientifically established to formulate veritable stochastic models. Figure 2 shows common source of water loss in developing nation.

Figure 2. Water loss through wastage

3.1.1. Non-Revenue Water

Non-Revenue Water (NRW) could be grouped into Real Losses, which is the physical loss within the system which is primarily, composed of background losses and leakages; and Apparent Losses, which is the loss due to metering inaccuracies, systematic data handling errors, and unauthorized usage and illegal water connections. Computation of NRW values is location specific; however the expression in equation (1) could be used with appropriate correction factor (μ).

$$NWR_{\tau} = WL_{\rho} + WL_{\epsilon} \quad (1)$$

Where ***NWR*$_{I}$** is total Non- Revenue Water; ***WL*$_{\rho}$** is real Water Loss; and ***WL*$_{\epsilon}$** is apparent Water Loss. Physical or real water loss could be derived using the relationship between Water Supply (***WS***) and correction factor (μ) as shown in equation (2).

$$WL_{\rho} = \mu WS \quad (2)$$

Where water loss coefficient value (μ) ranges from 0.1 to 0.5 for computation of water loss in Edo State and its environs. Table 3 shows the summary of structured Water loss values Coefficient in Edo State. High water loss coefficient value (μ) indicates significant increase in water loss through both apparent and physical losses.

Table 3. Average Water Loss Coefficient (μ) in Edo State, Nigeria

S/N	**Regions**	**μ**
1	Estako West	0.4
2	Estako Central	0.3
3	Estako East	0.3

4	Owan East	0.4
5	Owan West	0.2
6	Akoko Edo	0.2

Source: (Idogho et al., 2009).

3.1.2. Computation of Physical Water Loss Using Pressure-Leakage Relationship (PLR)

The Pressure-Leakage Relationship Analysis is widely accepted in accurately estimating the Real Losses. The Power Law Formula in equation (3) is often used to compute Real Losses (Thornton, 2003).

$$Q_2 = Q_1 \times PCF \quad (3)$$

Where:

P_1 = Pressure at point 1
P_2 = Pressure at point 2
Q_1 = Flow at P_1
Q_2 = Flow at P_2
PCF (Pressure Correction Factor) = $(P1/P2)^N$ (Thornton, 2008). The expression in equation (3) was modified as follows:

$$Q_2 = KQ_1PCF \quad (4)$$

Where the modification coefficient ***K*** is applied to adjust flow discharge due pipeline lock-outs closed hydraulic valves. The values of N and K are 1.0 and 0.8 respectively. Equation (4) could mathematically be written as follows:

$$WL\rho = KWS\beta \quad (5)$$

Where β = Pressure coefficient.
Therefore Apparent Water Loss (WLe) is calculated as shown as follows:

$$WL\epsilon = NRW\tau - KWS\beta \quad (6)$$

3.1.2 Water Loss Reduction Index (WLRI): Using Structured WS, AW and WL Approach:

This approach is to determine the degree at which both physical and apparent water loss is checked and controlled. It uses directly the Water Supply/ System Input Volume variables. This relationship is mathematically expressed as follows:

$$\text{WLRI} = \frac{WL\rho + WL\varepsilon}{WS} \quad (7)$$

Government at every level and other stakeholders in water sectors target to reduce the cost of Non-Revenue Water through leakages, theft and some other sources on time basis in order to double the their capacity of service delivery and even distribution of the scarce utility. Application of pipelines monitoring technique (PMT), digital calibration of metering system (CMS) and pressure regulation system (PRS) are regularly being introduced. Due to the application of the above stated measures, Water Loss Reduction Index is modified as follows:

$$SWLRI = a_0 a_n \left(\frac{WLp + WLe}{WS} \right) \quad (8)$$

Where;

SWLRI = Structured Water Loss Reduction Index; $\boldsymbol{a_0}$ and $\boldsymbol{a_n}$ are correcting values. The values of $\boldsymbol{a_0}$ and $\boldsymbol{a_n}$ applied for the purpose of this research study are 0.65 and 0.5 respectively.

3.2. Data Computation and Analysis

Mathematical-based equations were used to computer various data on Water Supply and Loss Variables as shown in table 4,5,6,7, 8, 9 and 10 respectively. Calibration series curves such as linear, power and polynomial were used to produce Non-Revenue Water (ANWR), WLRI, WS and AW curves.

4. Results and Discussion

4.1. System Input Volume and Non-Revenue Water

Water resources are becoming increasingly precious and contested. In Edo State, water resource suffers high degree of water losses from their water distribution networks. Physical losses due to leakage of pipeline and overflow of water from storage tanks and reservoirs accounts for 35% to 45% of the total System Input Volume or water produced. Computation of water loss components associated with apparent water loss such as under-registration on customers' meters, errors in data handling, and water theft. is often very difficult. However, computation of total annual water balance based on precise measurement data and adequate estimations must take relevant water loss components into consideration for efficient reduction of water losses and establishment of realistic countermeasures. This situation is not limited to Edo State only; it is a general phenomenon in Nigeria and most of the developing nations. On the basis of the data collection, processing and analysis an overview of all the components of inflow into the individual supply zones were estimated.

The results of the findings are shown in Table 4-10. Lowest average Water Supply (WS) or System Input Volume of 17.9(10^3m^3) was recorded in Estako-West followed by Estako-Central with 9.7(10^3m^3) and Akoko Edo with WS/SIV value of 2.2 (10^3m^3), these WS/SIV values correspond to the values of Water Loss Reduction Index (WLRI) of 0.65, 0.52 and 0.33 as shown the table1.

Table 4. Water supply and non- revenue water in Edo State, Nigeria (2007)

N/S	Regions	WS/SIV (10^3m^3)	NRW (10^3m^3		AW/BW (10^3m^3)	WLRI
			WLp	WLe		
1	Estako-West	17.9	7.91	4.6	6.3	0.65
2	Estako-Cent	9.7	3.0	2.0	4.6	0.52
3	Estako-East	10.5	3.2	2.1	5.3	0.50
4	Owan-East	15.8	5.0	3.4	7.4	0.53
5	Owan West	14.1	3.7	2.4	8.0	0.43
6	Akoko-Edo	11.1	2.2	1.5	7.4	0.33

Source: Field Study 2012

Table 5. Water supply and non- revenue water in Edo State, Nigeria (2008)

N/S	Regions	WS/SIV (10^3m^3)	NRW (10^3m^3)		AW/BW (10^3m^3)	WLRI
			WLp	WLe		
1	Estako West	19.5	4.2	3.4	11.9	0.4
2	Estako- Cent	11.9	2.0	1.7	8.2	0.3
3	Estako-East	12.3	2.0	1.6	8.7	0.3
4	Owan East	17.9	3.1	2.6	12.2	0.3
5	Owan West	16.2	2.3	1.8	12.1	0.3
6	Akoko-Edo	12.2	1.3	1.1	9.8	0.2

Source: Field Study 2012

Computed data on water supply and loss variables shown that the estimations available provide a realistic value of Non-Revenue Water (NRW). In 2007, an average of 51% of the system input for 49,629 (135 liters/person/day) people in Edo State got 'lost'; (58.5%) caused by real losses and 41.6% by apparent losses as shown in table 9. However, significant reduction of Total Non-Revenue Water (TNRW) and %TNRW of 2.3 (10^3m^3) and 10.6% in 2011 against TNRW; %TNRW value of 6.7(10^3m^3) and 50.7% in 2007 led to improved System Input Volume (SIV)/Water Supply(WS) with 89.2% in 2011.

High degree of NRW has further complicated accessibility of the limited utility in Edo State which in thus increase the traffic of Im^3 of water by 50%. Socio-economic development and Human Development Index have deeply been affected. In order to check the situation by of reducing water loss and improve System Input Volume, Edo-State government at all levels in collaboration with some international donor agencies such as WORLDBANK and UNICEF are formulating technically based countermeasures. Systematic measurements of flows were applied for leakage estimation. Also pipeline network was technically-monitored using mathematical modeling iteration to obtain realistic data on leakage and pipeline network capacity. In addition, introduction of sensitive instrumentation and control instrument such as Automatic Meter Reading (AMR) is being used in the State to obtain accurate data of metered water. Again, some trained operators were engaged to work on leakage management program, periodic leak detection sweeps, leak locating, leak repair and pressure management. Integration of all these countermeasures by the State Government, Donor Agencies and Private Sectors since the year 2007 has yielded significant result in Edo State as shown in the output of the research study.

Table 6. Water supply and non- revenue water Edo State, Nigeria (2009)

N/S	**Regions**	**WS/SIV (10^3m^3)**	**NRW (10^3m^3)**		**AW/BW (10^3m^3)**	**WLRI**
			WLp	**WLe**		
1	Estako West	22.1	3.8	3.4	14.9	0.3
2	Estako Cent	13.3	1.9	1.6	9.8	0.3
3	Estako East	14.1	2.2	2.0	9.9	0.3
4	Owan West	19.3	2.7	2.4	14.2	0.3
5	Owan West	18.1	2.0	1.8	14.3	0.2
6	Akoko-Edo	14.4	1.6	1.5	11.3	0.2

Source: Field study, 2012

Table 7. Water supply and non- revenue water edo State, Nigeria (2009)

N/S	**Regions**	**WS/SIV (10^3m^3)**	**NRW 10^3m^3**		**AW/BW (10^3m^3)**	**WLRI**
			WLp	**WLe**		
1	Estako West	25.3	4.0	2.6	18.7	0.3
2	Estako-Cent	15.9	2.0	1.3	1.3	0.2
3	Estako-East	16.1	2.0	1.3	12.6	0.2
4	Owan - East	24.8	3.1	2.1	19.6	0.2
5	Owan - West	20.7	2.2	1.5	17.0	0.2
6	Akoko Edo	16.4	1.3	0.9	14.2	0.2

Source: Field Study, 2012

Table 8. Water supply and non- revenue water Edo State, Nigeria (2010)

N/S	**Regions**	**WS/SIV (10^3m^3)**	**NRW (10^3m^3)**		**AW/BW (10^3m^3)**	**WLRI**
			WLp	**WLe**		
1	Estako West	28.2	2.5	1.2	24.5	0.13
2	Estako Central	17.5	1.2	0.6	15.7	0.10
3	Estako East	18.8	1.3	0.6	22.2	0.10
4	Owan-East	24.8	1.7	0.9	22.2	0.11
5	Owan West	21.6	1.4	0.7	19.5	0.10
6	Akoko-Edo	18.4	0.8	0.4	17.2	0.07

Source: Field Study, 2012

Table 9. Average dailywater supply and non-revenue components

N	Years	WS/ SIV 10^3m^3	ANRW (10^3m^3)		AW/ BW 10^3m^3	WLRI	TNRW	WLp %	WLe %	TNRW %
			AWLp	ANLe			10^3m^3	WLp %	WLe %	TNRW %
1	2007	13.2	4.0	2.7	6.4	0.5	6.7	59.7	40.3	50.7
2	2008	15.0	2.5	2.0	4.5	0.3	4.5	55.5	44.5	30.0
3	2009	16.9	2.4	2.1	12.4	0.3	4.5	55.5	44.5	30.0
4	2010	19.9	2.4	1.6	15.9	0.2	4.0	60.0	40.0	20.0
5	2011	21.6	1.5	0.7	19.3	0.1	2.3	65.2	34.5	10.6

Source: Field Study, 2012

Where
WS/SIV =Total water supply or SIV which is the System Input Volume (10^3m^3)
NRW = Total Non-Revenue Water (Total Water Loss)
WLp = The Physical/Real Water loss
Wle = The apparent water loss
AW = Available Water
BW = Billed water
WRLI = Water Loss Reduction Index
TNRW = Total Non-Revenue Water

4.1 Calibration of Non-Revenue Water (NRW) and Water Loss Reduction Index

Calibration analysis in Fig.1 shows that the strategies applied by Edo State and some other stakeholders in water sector towards the reduction of water losses are highly significant at 0.05 level of confidence interval. Highest Water Loss Reduction Index ***(WLRI)*** value of 0.5 corresponds to Physical Water Loss ***(WLρ)*** and Apparent Water Loss ***(WL_E)*** values of 4.0 (10^3m^3) and 2.7(10^3m^3) in 2007, while in 2011, ***(WLρ)*** and ***(WL_E)*** values of 1.5 (10^3m^3) and 0.7 (10^3m^3) corresponded to ***(WLRI)*** value of 0.1. The result of the calibration analysis further indicates more water is lost through real loss than apparent loss as revealed in Fig. 1 with the coefficient of determination (R^2)=0.83 and 0.9 respectively. Total average daily System Input Volume saved and efficiently used in Edo State from 2007 and 2011 is estimated to 4.4(10^3m^3) which could be useful for 44,000 people on the calculation of 100litres per person per day.

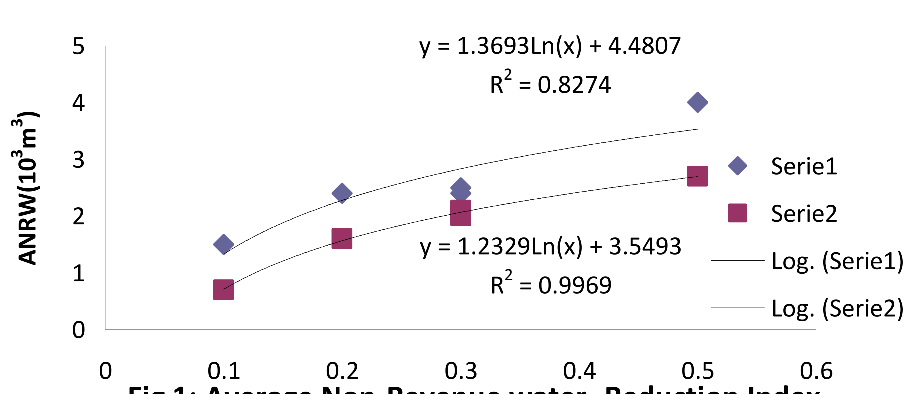

Fig 1: Average Non-Revenue water- Reduction Index Curve

Series 1: ***(WLρ)= Physical loss,*** Series 2: ***(WL_E)*** = ***Apparent loss***

4.3. Water Supplies-Available Water Ratio

The technical conceptual approach to the leakage detection, repair and control in water supply systems is a fundamental contribution to better and increase efficient utilization of available water sources and improvement of Revenue Water (RW), (Fanner, 2007). There is significant increase in Revenue Water (RW) or Available Water resource (AW) from 6.4× (10^3m^3) in 2007 to 19.3× (10^3m^3) in 2011 as indicated in table 9. The calibration analysis in fig.2 shows strong relationship between Water Supply (WS)/ System Input Volume (SIV) and Available Water (AW)/Revenue Water (NR) with R^2 values of 0.78 and 0.8 for logarithmic and power regression approaches. If the water loss reduction approaches applied are sustained in Edo State, it is projected AW/NR will be 97% of WS/SIV by year 2050.

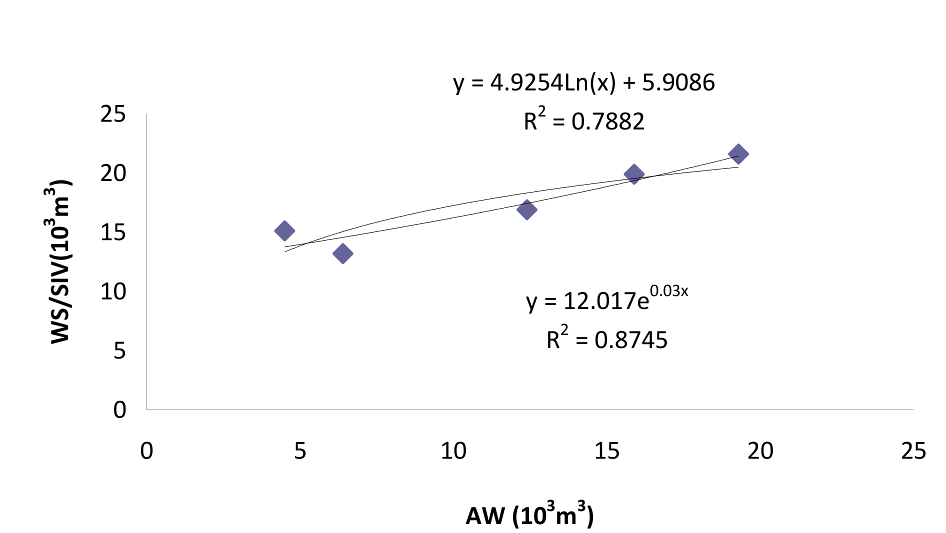

Figure 2. Average Water Supply/ System Input Volume-Avaliable WaterCalibration Curve

4.4. Financial Implication of Non-Revenue Water (NRW)

Edo State lost an average of 50.7% percent of their water through NRW losses, an amount valued at US$ 14.6 million ($40,100 per day) in 2007 and US$ 8.2 million ($22,700 per day) in 2011 as shown in table 10. The losses affected all economic sectors in State and in addition led to poor accessibility of the already scarce utility, unemployment and reduction of Human Development Index. Having considered the financial implication as result of water loss, countermeasures were geared up to reduce water loss and increase Revenue Water in Edo State. The approach has yielded significant result as shown in fig.3. Average amount of financial resources budgeted and spent to control water loss reduced from 36% in 2007 to 7% in 2011, this shows that the State is gradually winning battle against water loss.

Table 10. Average Daily Cost Analysis of System Input (SIV) volume and non-water revenue (NWR) in Edo State Nigeria

N/S	Year	SIV ($) 10^3	ACNWR ($) 10^3	%CNWR
1	2007	79.1	40.1	49.4
2	2008	120.0	36.1	29.4

3	2009	135.1	35.9	26.5
4	2010	202.6	41.1	19.8
5	2011	219.8	22.7	10.1

Source: Field Study, 2012

Where:
ACSIV = Average Cost of System Input Volume ($)
ACNWR = Average Cost of Non –Revenue Water ($)
%CNWR = Percentage of Average Cost of Non-Revenue Water

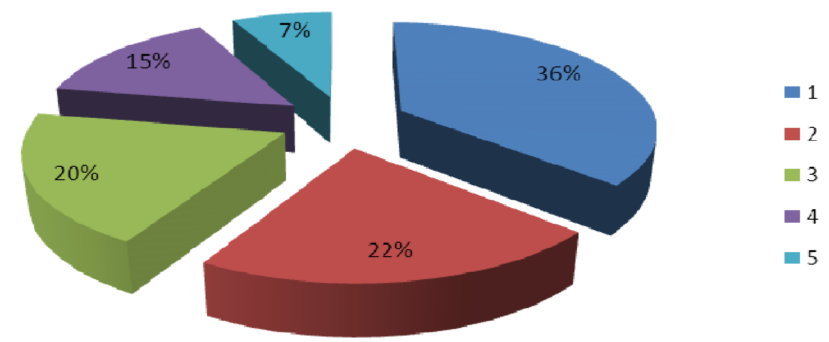

Fig. 3: Percentage Cost of Reducing NRW

Series	Year
1	2007
2	2008
3	2009
4	2010
5	2011

5. Conclusion

Over some years, Edo State has been faced by acute water stress and shortage caused by total neglect of investment in the distribution network and inadequate leakage control system. More than 2.4 million m^3 which represents 50.7% of total System Input Volume were calculated to be leaking annually. The leakage situation of water supply systems indicates a number of factors which consists of inappropriate material for construction of the water supply systems, the increasing age of the water supply systems and the connected deterioration of their technical condition. The large scale rehabilitation of the water supply system would certainly help in the overall leakage reduction and opens way in the same time to continuous leakage fighting on the more detailed scale and to optimization of discharge pressures. The reduction of physical water losses from 50.7% to 10.6% means average daily leaks of 6,700m^3 would be reduced to 2,300m^3 which translates that an average of US$88,000 is saved daily. In addition, about 52,000 more people would be able to access safe drinking water on the basis of 85 liters per person per day. Government and other stakeholders should continue to address the problem of water scarcity due to physical water loss by introducing excellent pressure management system, application pressure monitoring instrument, application of water loss software packages and engagement of technically-based professionals for critical data analysis and rapid implementation of decision. Again, strong political will must match financial strength to invest towards water loss reduction by government at every level. Generally, this research study is focused on the Edo North Senatorial District (about 400,000 people) which is one-fifth of the total population; the output of the study could be extrapolated and used to address the water loss of the other two senatorial districts.

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