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Water Management Scheme: Panacea to Development Using Nigeria's University of Ibadan Water Supply Scheme as a Case Study

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***Abstract*—**The supply of potable water at least is a very important index in national development. Water tariffs depend on the treatment cost which carries the highest percentage of the total operation cost in any water supply scheme. In order to keep water tariffs as low as possible, treatment costs have to be minimized. The University of Ibadan, Nigeria, water supply scheme consists of a treatment plant with three distribution stations (Amina way, Kurumi and Lander) and two raw water supply sources (Awba dam and Eleyele dam). An operational study of the scheme was carried out to ascertain the efficiency of the supply of potable water on the campus to justify the need for water supply schemes in tertiary institutions. The study involved regular collection, processing and analysis of periodic operational data. Data collected include supply reading (water production on daily basis) and consumers metered reading for a period of 22 months (October 2013 - July 2015), and also collected, were the operating hours of both plants and human beings. Applying the required mathematical equations, total loss was determined for the distribution system, which was translated into monetary terms. Adequacies of the operational functions were also determined. The study revealed that water supply scheme is justified in tertiary institutions. It was also found that approximately 10.7 million Nigerian naira (₦) is lost to leakages during the 22-month study period; the system's storage capacity is no longer adequate, especially for peak water production. The capacity of the system as a whole is insufficient for the present university population and that the existing water supply system is not being operated in an optimal manner especially due to personnel, power and system ageing constraints.

***Keywords*—**Operational, efficiency, production, supply, water treatment plant, water loss.

I. Introduction

STABLE and quality water supply is sine qua non to a fast growing economic development and industrialization. It also determines to a greater extent, the stability and effectiveness of academic periods, as student riots broke out on a number of occasions when schools were forced to close down due to inadequate water supply. Nigeria water corporations' source, produce and distribute water to final consumers at different points of location. The University of Ibadan water scheme consists of a treatment plant having a capacity of 5,400m^3 for daily production and a distribution network consisting of four main reserves, about 250 pipes and more than 50 valves involving about 110 nodes [1]. Each stage of the water supply is associated with losses either from pumps, pipes or distribution lines that could either be technical or non-technical in nature. Technical losses (TL's) occur as a result of components failure, water loses in pipe lines (burst pipes, joint leakages etc.), faulty metering and control calibration measuring instruments associated with water production equipments etc., and can easily be measured and controlled provided that the water system consists of known production quantities.

Non-technical losses (NTL's), on the other hand, are defined as any consumed water which is not billed because of a measurement equipment failure or the ill-intention and fraudulent manipulation of the system equipment [2]. It may be caused from water theft through unmetered water supply and metering inconsistencies or estimated through supply and conditions which technical losses failed to account for [3]. Water theft serves as the major component causing NTL's in water systems and can be defined as the deliberate attempt of an individual or group of individuals, sometimes with or without the knowledge of the water producing company's staff, to alter actual billing charges or either not to pay consumed charges at all through illegal connections or using faulty meters. Recent research revealed that water losses and its theft (major contributor to non-technical losses) accounts for 30% to 40% of the total annual revenue accrued in Nigeria [4]. The aim of this work is to study and determine operational efficiency losses and then provide possible solutions. This will be achieved by carrying out analytical estimation of NTL's and management efficiency in the water system of University of Ibadan using available records from the university's Department of Works and Maintenance.

II. Literature Review

The optimum economic operation of any water supply scheme has occupied an important position in the water industry. According to UNICEF [5], some 3 in 10 people worldwide, or 2.1 billion, lack access to safe, readily available water at home, it has become necessary for water generating utilities to run their plants with minimum cost while satisfying their customers water demand (Peak and Base supply). In order to achieve this, all the generating units in any water treatment plant must be operated in such a way that optimum economic efficiency can be achieved. According to an anonymous writer [6], the world urban population is expected to increase by 72% by 2050, from 3.6 billion in 2011 to 6.3 billion in 2050. Africa

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and Asia will lead urban population growth, Africa and Asia together will account for 86 per cent of all growth in the world's urban population over the next four decades. In developing countries, the average sanitation coverage (56%) is far less than water coverage (85%). For example, in Africa, even in urban areas, the coverage for sanitation is 46% and water is 84%; with these figures being recorded significantly lower in rural areas. Current models of urban planning and water management have already failed or are likely to fail from the perspective of cost effectiveness, technical performance, social equity, and environmental sustainability.

Nonrevenue water (NRW) is described as the water produced and supplied but fails to reach consumers. The water loss may emanate from leakages from pipes, reservoirs or other hydraulic structures. Excessively high levels of NRW are detrimental to the developmental progress of the society. New technology has allowed great advances in the collection and processing of data essential for the control of water to water supply systems [7]. The reliability and accuracy of measuring devices, remote sensing systems, communication and processing facilities have improved significantly, thus contributing to the improved efficiency of water supply schemes [7].

According to [8], total loss (TL) in production and water systems comprise of three components namely the **technical losses**, inherent in the physical delivery of water to the consumer. It includes pipe bursts, valve drops, and reservoirs leakages; **Administrative loss** that accounts for water used by the distribution utility in the proper operation of the distribution network such as dislodging of a water clarifier; and **non technical losses**, caused primarily by human error, whether intentional or not. Non-technical losses include the water lost due to pilferage, tampering of meters, and erroneous meter reading and/or billing. All estimates of nontechnical losses are based on the accuracy of the calculation of technical losses [9]. According to [10], TL's are part of the water losses in the system, resulting in losses in pipes, installations of facilities, reticulation systems, and valves and fire hydrant losses. Reference [11] states that TL's consist mainly of water shortages in a water supply system such as pipes, valves, flow meters, reservoirs pumps, etc. While [12] suggests some of the losses depend on the technical specification of the equipment in the water supply system. In a system with the appropriate operating conditions, most losses are the result of technical deficiencies. Reduction of these losses is difficult and almost impractical.

Reference [8] says that NTL's are almost non-existent or negligibly small in developed countries, as most of the population can afford to pay tariffs reducing the costs of supply. Many utilities in developing countries have succeeded in significantly reducing or eliminating nontechnical losses in water supply in a sustainable manner, while other continue to show high losses. The level of NTL's varies generally according to the economic condition of the country. In countries where GDP per capital is very low, it is common to find higher levels of NTL's. However, in countries such as Indonesia and Thailand, GDP per capital is low but the reported NTL's level is also remarkably low [7]. High rates of NTL's activities have been reported in developing countries like Bangladesh, India, Pakistan, Lebanon etc., where 20% to 30% of NTL's have been observed [8]. Meanwhile, Nigeria has been reported to have a large proportion of production and distribution losses of about 40% [13], [14].

III. Methodology

Since it obvious that a supply system cannot operate without the constant influx of accurate data from all important points of the system such as water sources, reservoirs, pumping stations and the users of these facilities. The first task in the operational efficiency study was to determine the relative effectiveness of each of the water supply scheme units. Water production data were taken from Water Treatment Plant at Nigeria's University of Ibadan, followed by meter reading of the water supply to the campus from the 11 meters installed at various locations, where consumers are being fed. This was carried out on monthly basis between October 2013 and July 2015. Also, the numbers of operational conditions of the facilities in use on the water supply network were analysed based on available data during the period of investigation to determine the adequacy or otherwise of the treatment plant and the sub-system units.

A. Determination of Distribution Losses

The overall losses in the system were evaluated by comparing the released treated water delivered by the water treatment plant and the total metered received water during the stipulated period of time. The same was done for the raw water supplied and received during the investigation period. Mathematically, let E_S be the overall water delivered from the water treatment plant for the month, E_B be the water received for the month, and E_L be water expended due to distribution losses. Then,

$$EL = ES - EB \tag{1}$$

The results of the loss analysis are shown in Table I.

1. Analysis of Financial Cost of Water Loss

From Table II, it has been shown that the financial losses exceed 10.738 million, seven hundred and thirty eight thousand naira translating 35, 206.73(Thirty five thousand, two hundred and seven) US dollars is the lost in the water supply scheme of the University of Ibadan within the study period of 22 months. This is too much in a country with the average GDP per capital of 2,458 US dollars [16]

B. Clear Well Tank Capacity Required

There many factors responsible for water demand in the University, these include the period of the year, the number of students on campus during the various period of the year. Typical water demand over time in the university is depicted in Fig. 1.

In order that the clear well tank capacity for the water treatment plant meets the population demand to have clear water at all times, the weighting factor method was used to calculate the required tank capacity. The calculation allows for a capacity at a base level that will accommodate 125% of the estimated average demand and add a 20% allowance to that for growth. The weighting method was used for the calculation and the results show in Table II.

TABLE I
WATER LOSSES FOR THE PERIOD IN STUDY

DATE	Used Potable Water	Raw Water Awba Dam	Raw Water Eleyele	Total Raw water	Treated Water	Shortfall Raw water	Shortfall Treated
Oct 2013	60408000	10,334,000	50,277,000	60,611,000	60,423,000	-188,000	-15,000
Nov.	51012000	17,334,000	33,877,000	51,211,000	51,083,000	-128,000	-71,000
Dec.	51030000	20,789,000	29,879,000	50,668,000	50,096,000	-572,000	934,000
Jan 2014	55026000	14,679,000	40,889,000	55,568,000	55,499,000	-69,000	-473,000
Feb.	54216000	0	54,554,000	54,554,000	54,327,000	-227,000	-111,000
Mar.	50256000	0	50,753,000	50,753,000	50,983,000	230,000	-727,000
Apr.	68292000	0	67,789,000	67,789,000	67,983,000	194,000	309,000
May	52416000	30,334,000	20,877,000	51,211,000	52,429,000	1,218,000	-13,000
June	64296000	30,334,000	30,877,000	61,211,000	64,900,000	3,689,000	-604,000
July	57168000	30,334,000	26,877,000	57,211,000	56,910,000	-301,000	258,000
Aug.	58860000	35,334,000	20,877,000	56,211,000	58,907,000	2,696,000	-47,000
Sept.	57402000	25,879,000	31,703,000	57,582,000	57,506,000	-76,000	-104,000
Oct.	58392000	28,006,000	30,330,000	58,336,000	57,555,000	-781,000	837,000
Nov.	66978000	30,786,000	36,891,000	67,677,000	67,086,000	-591,000	-108,000
Dec.	54270000	20,456,000	34,125,000	54,581,000	54,133,000	-448,000	137,000
Jan 2015	56052000	0	56,508,000	56,508,000	56,143,000	-365,000	-91,000
Feb.	56538000	0	56,530,000	56,530,000	56,412,000	-118,000	126,000
Mar.	58410000	0	60,755,000	60,755,000	58,787,000	-1,968,000	-377,000
Apr.	59076000	35,768.00	60,040,000	60,075,768	59,230,000	-845,768	-154,000
May	60282000	30,789,000	30,231,000	61,020,000	60,269,000	-751,000	13,000
June	59310000	33,890,000	25,848,000	59,738,000	59,200,000	-538,000	110,000
July	60966000	40,456,000	20,762,000	61,218,000	60,853,000	-365,000	113,000

(304, 768 x 8.4) + (58,000 x 141) = 2,560,051.20 + 8,178,000 = ₦ 10,738,051.20

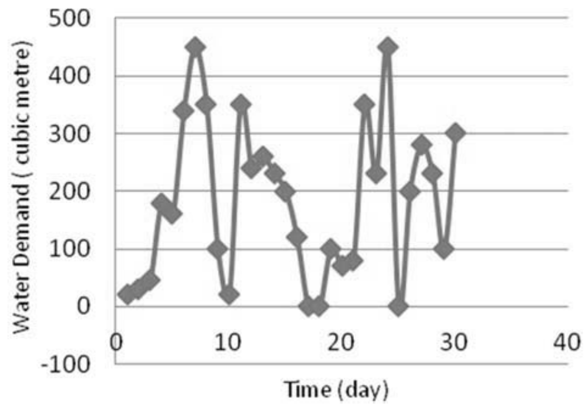

Fig. 1 Typical water demand for the month of September 2015 [15]

From the University records, we have subjectively estimated the demand for water in cubic metres for a projected population of 50,000 people as follows:

TABLE II
ESTIMATED WATER DEMAND (M^3)

Water Demand (m^3)	Chances of occurring (%)	Period of the Session
150< 300	5	when students are on recess
300<450	30	second semester when some students have gone on industrial experience
450<600	50	when students are writing exam
600<750	15	when students are on full academic activities

TABLE III
CLEAR WELL TANK CAPACITY CALCULATION

Water Requirement in m^3 Interval	Midpoint (X)	Probability P(X)	X.P(X)
150< 300	225	0.050	1.125
300<450	375	0.30	112.5
450<600	525	0.50	262.5
600<750	675	0.15	101.25
		Total	**477.375**

Expected value of demand = $E(X) = \sum XP(X) = 477.375$ m^3; Base level = 125% (477.375) = 596.72; Final capacity = 596.72(1.2) = 716.06, say 720 m^3 capacity tank

C. Operational Efficiency of Production Machines

After establishing the required capacity of the clear well, the operational capacities of the machines feeding the clear well tank need to be determined. The dosing pump and the transfer pumps are two production sections, *A* and *B* respectively (in series), with individual and system capacities for the water production mix, as shown in Fig. 2.

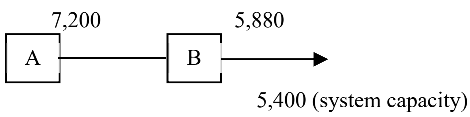

Fig. 2 Water production Mix

The actual present output of the treatment plant is 4,500 cubic metres per day while the treatment capacity is 5,400 cubic metres per day. To justify the usage of these machines, it is therefore, necessary to find (a) the potential use factors and (b) The system efficiency for each of the sections *A* and *B*

1. The Potential Use Factors

$$\text{Potential use factors} = \text{PUF} = \frac{\text{system capacity}}{\text{Individual unit capacity}}$$

Individual unit capacity:

$$\text{For A (Dosing pump)} = \frac{5400}{7200} = 75\%$$

$$\text{For B (Transfer Pump)} = \frac{5400}{5880} = 91.8\%$$

2. The System Efficiency

$$\text{System efficiency} = \text{SE} = \frac{actual\ output}{systemcapcity} = \frac{450}{540} = 83.3\%$$

This calculation tells us that the treatment plant is producing at only 83.3% of system capacity and that even if it were operated at full system capacity; sections *A* and *B* would be used at only 75% and 91.8%, respectively, of their individual capacities.

D. Determining the Required Number of High-Lift Pumps in Operations

Having established that the dosing and transfer pumps production capacity is less than optimum, it is required to determine the sufficiency of the high-lift pump in use to know the number needed to meet the yearly production capacity of 1,971,000 m^3 per year. The water treatment plant operates 8,760 hours per year and the high-lift pump is part of a production lines which are being used only 60% of the time. Assuming the output is about 3% defective, and a pump discharges $0.068 m^3/s$, and allowing for temperature adjustments and maintenance downtime, and accepting that the pumps are about 80% efficient, the number of pumps required for the operation were determined.

We begin with the output requirement and work backward to first determine the required system capacity. Since 3% of the total parts are defective, only 97% are good, thus SE = 0.97.

$$\text{Required system capacity} = \frac{\text{actual output}}{\text{SE}} = 2{,}031{,}958.6\ m^3/\text{yr}$$

Since the firm operates 8,760 hours per year, this can be restated as:

$$\text{Required system capacity} = \frac{2{,}063{,}1958.6\ cubicmetres/yr}{8{,}760\ hr/yr} = 231.96\ m^3/\text{hr}$$

The actual output that can be obtained from each pump depends upon the individual unit capacity, its use factor, and its individual efficiency.

$$\text{Individual unit capacity} = \frac{3{,}600\ \text{sec}/hr}{36\ \text{sec}/cubicmetres} = 100\ m^3/\text{hr-machine}$$

Pump subsystem capacity = (individual unit capacity) (PUF) = (100) (0.60) = 60 m^3/hr –machine

Actual Pump output = (Pump subsystem capacity) x (Pump subsystem efficiency) = 60 $m^3/hr.x$ (0.80) = 48 m^3/hr.- machine

$$\text{Number of pumps required} = \frac{\text{required system capacity}}{\text{actual moldes output per machine}}$$

$$\frac{231.96}{48cubicmetres/hr - machine} = 4.8325\ \text{machines}$$

It must be noted that the problem involved two levels of efficiency, one on the system level (that is, the 97%) and one on a subsystem level (the 80%). From the calculations, we know that in order to overcome the system inefficiency, the water treatment plant must produce 103.1 m^3/hr. But because of the pump use factor (0.60) and pump subsystem efficiency (80%), each machine could actually average only 19.2 m^3/hr; resulting in 5.4 machines requirements. The water treatment plant should probably plan for the installation of six machines. However, with careful scheduling of maintenance activities, it might be able to improve efficiency enough to get by with five machines.

E. The Production Activity

After the determination of the tank capacities and machine adequacies, the next thing to look into is the human capacities in water production at the university. The water treatment plant has a production activity that has a normal time of eight hours, but the activity seems to have been prolonged recently by an increasing number of unavoidable delays. There is therefore a need to determine a new standard for the production activity of the treatment plant. To achieve this, a work-sampling study was conducted of the university's water treatment plant to guide in the determination of adequate and efficient water production activities. The results are shown in Table III.

TABLE III
WORK SAMPLING STUDY OF THE UNIVERSITY OF IBADAN WATER TREATMENT PLANT

Activity	Number of observations	Percent of observations
Working	585	78
Unavoidable delay	90	12
Personal time	75	10
Total	**750**	**100**

The labour laws of Nigeria grants its workers a personal time allowance of 12.5% of total time and this was factored in for the calculation in the new production time standard. Incorporating the unavoidable delay time, a standard time for water production activity was determined and compared with the true unavoidable time and personal time at 95% confidence level.

Time for Water Production

(a) Allowances allowed in the new standard of activities should now consist of: Personal time 12.5%; Unavoidable delay 7.5%; Total 20%.

$$\text{Standard Time for Production} = \frac{NT(100)}{100 - \%\ \text{allowance}} = \frac{8(100)}{100 - 20} = 8 \text{ hours}$$

However, for 95% confidence interval Z= 1.96. Half the interval width h = Zs_p

$$\text{where } S_p = \sqrt{\frac{pq}{n}} = \sqrt{\frac{(0.075)(0.925)}{750}} = 0.0096$$

$$h = 1.96(0.0096) = 0.0189$$

The interval is ± 1.9%. This result; of h = 1.9 % with 95 % confident level analysis revealed that the true unavoidable delay time is between 5.6% to 9.4% of total time of production. Using the same confident level of 95%, the true personal time needed is from 10.13% to 14.89% of the total time.

F. Maintenance Cost Policy

As part of the operational efficiency study of the water treatment plant of the University of Ibadan, the total cost of the present maintenance policy for the machinery was studied. Some historical data were collected and a simulated breakdown of the system machinery over a 16-hr period, as shown in Table IV. The water treatment plant has two maintenance technicians (pump mechanics), assuming charges for their time working or idle at ₦ 11.50/hr each and downtime cost of the machines, from lost production, is estimated at ₦ 120/hr. Simulated service maintenance cost, simulated breakdown maintenance cost, and simulated total maintenance cost for the present work activity were calculated to know if hiring another technician could be justified.

TABLE IV
BREAKDOWN OF THE SYSTEM MACHINERY

Request for repair (arrival time)	Total repair time required (worker hours)
0100	1.0
0730	3.0
0800	0.5
1150	2.0
1220	0.5
Total	7.0 hours

Simulated service maintenance cost

Service cost = (2 technicians) (₦ 11.50/hr) (16 hr) = ₦ 368

The simulated breakdown maintenance cost (note that we assume two technicians are twice as effective as one and reduce the downtime accordingly) is shown in Table V.

TABLE V
BREAKDOWN MAINTENANCE COST

(1) Request arrival time	(2) Repair time required (2 technicians Hr Min	(3) Repair time Begins	(4) Repair time Ends	(5) Machine downtime hr (2 technicians)	(6) Machine downtime hr (3 technicians)
01:00	0.50/ 30	01:00	01:30	0.50	0.33
07:30	1:50/ 90	07:30	09:00	1.50	1.00
08:00	0.25/ 15	09:00	09:15	1.25	0.67
11:50	1.00/ 60	11:50	12:50	1.00	0.67
12:20	0.25/ 15	12:50	13:05	0.75	0.33
	3:50 hr			5.00	3.00

The machine downtime is shown in the accompanying table, in hours, in column 5, as the decimal difference between the request arrival time (1) and the ending repair time (4). Note that for the 08:00 breakdown repair request, the technicians were not available until 09:00, when they finished an earlier job. Therefore;

Breakdown cost = (₦ 120/hr) (5 hr) = ₦ 600
Total cost = service + breakdown
= ₦ 368 + ₦ 600
= ₦ 968/period

G. The Machine Downtime

The machine downtime hours for three technicians would have to be calculated in the same way as was done for two. The calculations are not included, but the final result is shown in column 6.

Service maintenance cost = (3) (₦ 11.50) (16) = ₦ 552
Breakdown maintenance cost = (₦ 120)(3 hr) = ₦ <u>360</u>
Total ₦ 912

From the above analysis, there appears to be an advantage to adding a third technician. For optimum maintenance policy, it is necessary to adjust the crew size to where total maintenance costs were minimal. With three technicians, the expected total cost per period was ₦ 56 per period less than with two technicians over a 16-hour period. Other less-tangible considerations might also be important factors in this situation, but the cost calculation at least establishes the economic preference for three technicians.

IV. CONCLUSION AND RECOMMENDATIONS

A. Conclusion

It has been shown that it has been shown that the financial losses exceed 10.738 million, seven hundred and thirty eight thousand naira translating 35, 206.73(Thirty five thousand, two hundred and seven) US dollars is the lost in the water supply scheme of the University of Ibadan within the study period of 22 months.

The system's storage capacity was found to be inadequate, especially for peak water production. The capacity of the system, as a whole, appears to be no longer sufficient for the present university population and for the uses the water is put to, and that a water supply scheme is not operationally efficient.

The existing water supply system is not being operated in an optimal manner especially due to personnel, power and system ageing constraints resulting in frequent disruption in water supply.

B. Recommendations

Water production activities and the crew size of operatives should be reviewed to meet the challenging demand of the water supply scheme. At least eight more staff should be employed water at production scheme to take care of production, monitoring and distributions. To boost the system efficiency, six new high lift pumps are to be installed and the reservoir capacity increased to 720 m^3

The university should put in place efforts to replace gradually the old asbestos cement pipes used in water supply to cope with the growing population.

REFERENCES

[1] Isuza, C. S (2006): Operational Studies on U.I.'S Water Supply System Using WaterCAD. An Unpublished M.Sc. Project in the Department of Mechanical Engineering, University of Ibadan.
[2] Inigo, M; Biscarri, F; Leon, C; Guerrero, J.L; Biscarri, J and Rocio, M (2011): Detection of Frauds And other Non-Technical Losses in Utility Unpublished Thesis at Electronic Technology Department, University of sevilla, spain.
[3] Tejinder, S (2009) Analysis of NTL and its Economic Consequences in Power System Unpublished Thesis at Electrical and Instrumentation Department, Thapar University Patiala (PUNJAB).
[4] Amuda, M.C (2012) Analysis of Technical Losses in Water Supply System Unpublished Thesis at Civil Engineering Department, Federal University of Technology, Akure.
[5] WHO/UNESCO (2010). Progress on Sanitation and Drinking-water: 2010 Update. Geneva: WHO press. JMP 2010 Update assessed March 6, 2017.
[6] Anonymous (2013): Water as social and Economic good http://www.gwp.org/en/ToolBox?ABOUT?IWRM-plans/IWRM-Principles/Water-is-finite-and vulnerable-resource accessed on 27th, January 2015.
[7] Obradovic, Dusan and Lonsdale, Peter (1998) Public Water Supply: Data, Models and Operational Management E& FN Spon London.
[8] Millard, R; and Emmerson, M (2009) 'Non-Technical Losses-How do other countries tackle the Problem. Proceedings of 22nd Technical Convention.
[9] World Bank Group (2009) 'Reducing Technical and Non-Technical losses in Water Supply Sector'.
[10] Al-Mahroqi, Y; Metwally, I.A; Al-Ainai and Al- Badi (2012) 'Reduction of Power loss in Distribution system' World Academy of science and Technology Vol. 63 pp. 565-591.
[11] Navani, J. P; Sharma, N. K; and Sonai, Sapra (2011) Technical and Non-Technical losses in System And its economic Consequence in Indian Economy. International Journal of Science Engineering Vol. 1 pp. 757-761.
[12] Sopeoloun, N; Temeedu, S; Yusuf, M. A and Alabi, S (2012) 'Decreasing Network Loss in Water Supply. Journal of Technical and Economical Loss Analysis Vol. 4 pp 813- 818.
[13] Omoreige, E and Ogidiolu, E. A (2012): Nigeria Water Solution retrieved on May 2, 2013.
[14] Anuoluwa, M. C (2013) Reducing Water Loss in Nigeria Retrieved on January, 2, 2015.
[15] Field Survey 2015.
[16] Anonymous (2017) https://tradingeconomics.com/nigeria/gdp-per-capita assessed 6/6/2017.