Assessment of Factors Which Contribute to Non-Revenue Water in Kenya and their Mitigation: Case of Meru Water Supply

Samwel Aluoch Otieno Alima, Eng. Prof. Patts M. A. Odira, Eng. Prof. Ezekiel Nyanchaga Nyangeri.

Abstract - The water resources availability in Kenya has been decreasing with time due to environmental degradation, increased water demand due to population explosion, irrigated agriculture in the rural areas and industrial development in the cities and major towns. This has overstretched the available water sources to the extent that water supplies are not able to meet the present water demand resulting into water rationing as a way of managing the supply. In addition, there had been lack of clear institutional framework and low funding resulting into low coverage while the population growth is ever increasing. While records available indicated that the total water produced in the country by the regulated utilities was about 420million cubic metres annually, high percentage of it was lost as Non- Revenue Water. The purpose of this study was to assess factors which cause Non-Revenue Water in Kenya based on a case study of Meru Water Supply Scheme. In addition, the study aimed at evaluating the water balance by establishing the levels of all components of Revenue Water and Non-Revenue Water in the scheme. The study also assessed the relationship between pressure and leakages and lastly analysed the economic level of leakage for Meru water supply scheme and strategies to mitigate against Non-Revenue Water. The specific objectives of the study were to assess the factors that cause Non-Revenue Water, evaluate the water balance for Meru water scheme, assess the relationship between pressure and leakages and analyse the economic level of leakage and the strategies to control Non-Revenue Water.A mix of research design was adopted for the study including descriptive, cross sectional and exploratory methods.The research findings show that the level of Non-Revenue Water in Meru Water Scheme depends on the organizational practices like operation and maintenance techniques, methodology of repair works, connection and disconnection practices, lack of as built drawings, illegal connections and organizational culture. It found that high operating pressures result into high leakage volumes whenever leaks occur while the speed and quality of repairs, pressure management, asset management and active leakage control are important factors to reduce Non – Revenue Water.

Key words: Control measures, economic level of leakage, Leakage, Non - Revenue Water, Pressure, Water Balance;

1 Introduction

Deterioration of water sources in the world from global warming and population explosion has increasingly led to water scarcity. In Kenya, water resources availability has been decreasing due to increased water demand from irrigated agriculture in rural areas and industrial development in the cities and major towns. The country has been experiencing high levels of Non - Revenue Water and insufficient tariff to cover operations and maintenance costs (MEWNR, 2014). Non-Revenue Water refers to those components of the water system input which are not billed and do not earn revenue (Farley *et al*, 2008). Reduction of non-revenue water is one of the cheapest ways to alleviate water scarcity. It will improve coverage and at same time avail more funds

for operation, maintenance and renewal of the water supply system.

The average non-revenue water in Kenya has remained high over time and was, by 2016, estimated at 42%. This means the country was losing about Ksh 10 billion annually through losses caused by Non- Revenue Water (MEWNR, 2014). Figure 1.1 shows the trend of NRW from 2007/2008 financial year to 2013/2014 financial year according to the impact reports issued by the Water Services Regulatory Board, every year (WASREB 9).

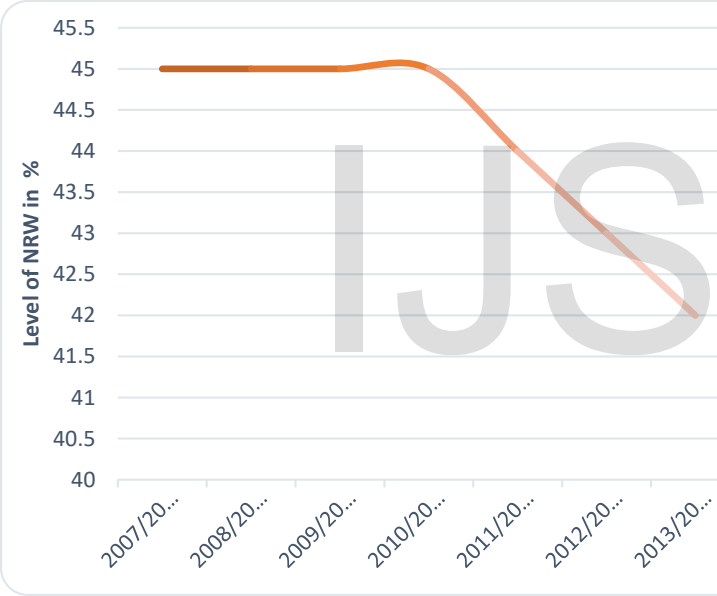

Figure 1*:* Trend of NRW in Kenya Utilities from 2007 to 2014WASREB 2014

Despite all the efforts made by the Government and the relevant institutions, the average Non- Revenue Water (NRW) in Kenya is still very high compared to other countries (WASREB, 2014). Consistent annual efforts to reduce the NRW levels bore minimum results yielding only around 2% annually (WASREB, 2014). In its endeavor to reduce NRW further and avail more water to the consumers the Government of Kenya undertook to reduce NRW ratio by 10% by 2020 in the whole nation (MWI, 2010).

This was in recognition that developing new sources is expensive and takes time, and the quickest way to avail more water to the residents is by reducing NRW. Even though there has been improved funding and good governance in the current dispensation, the level of Non-Revenue Water still remains at around 42%, meaning almost half of the total water produced in Kenya do not earn revenue and therefore do not contribute to the operation, maintenance and renewal of the water supply systems. In Meru Water and Sewerage Services (MEWASS), Non-Revenue Water was 70% in 2001 which meant that only 30% of the production was available to the customers (MWRMD, 2003).

Causes of Non - Revenue Water

Non-Revenue Water refers to those components of water supply system input which are not billed and do not earn revenue. It consists of unbilled authorised consumption, commercial losses, which is sometimes referred to as apparent losses and physical losses often referred to as real losses (Farley *et al*, 2008). The causes of commercial losses (Farley *et al*, 2008) are meter reading errors, slow running meters, use of flat rates, illegal connections, tampering with meters, non - functional meters, loss of records, data entry errors, delays in meter reading and administration errors.

Water theft is another factor causing water losses in a utility (Kingdom *et al*, 2006). Inaccurate master and consumer meters lead to substantial loss of water (MWRMD, 2003) because they take time to be noticed and given the fact that response time in Kenya is very poor.

Water Balance

Non-Revenue Water is determined through water balance by establishing all components of Revenue Water and Non-Revenue Water. The water balance therefore is a water audit to determine how much water is lost in the system, where it is lost, why it is lost and how it can be curbed. It is the first call in the NRW reduction process. In this study, the relationship between pressure and leakages and the economic level of leakage and strategies to mitigate against Non-Revenue Water were evaluated. A number of studies on Non-Revenue Water have been undertaken. Farley *et al.,* (2008) found the causes of commercial losses to be meter reading errors, slow running meters, use of flat rates, illegal connections, tampering with meters, non functional meters, loss of records, data entry errors, delays in meter reading and administration errors.

Water theft also causes water losses in a utility (Kingdom *et al*, 2006). Inaccurate master and consumer meters lead to substantial loss of water because they take time to be noticed (MWRMD, 2003). Physical losses consist of leakages from the system and overflows from the storage tanks (Kingdom et al; 2006). Water balance or water audit reveals the magnitude of the water lost and cost of Non-Revenue Water through a standard international water balance structure developed by the International Water Association (IWA) (Farley *et al*, 2008).

IWA methodology of determining the water balance traces water right from source through the system to consumption point (Charalambous *etal*, 2014).The standard IWA water balance and the result of analysis for Meru Water Scheme is shown in table 1.

Table 1: Water Balance for Meru Water Scheme

				Annual Volume m^3/year	Rate %
Total Production				2,418,360	
System Input Volume				2,355,730	100
Authorized Consumption				1,954,968	83.0
	Billed Consumption	Billed Metered Consumption	Revenue Water **83%**	1,954,968	83.0
		Billed Unmetered Consumption		0	0
	Unbilled authorized Consumption	Unbilled metered Consumption	Non-Revenue **17%**	0	0.0

		Unbilled unmetered Consumption		0	0.0
	Real Losses	Leakage on Water Mains		110,462	4.7
		Overflow from tanks		45,000	1.9
		Leakage on Service pipes		150,538	7.7
	Apparent Losses	Unauthorized Consumption		55,545	2.4
		Metering inaccuracies		39,217	1.7
					101.3

Pressure Management

The rate of leakage in a water supply system is a function of the pressure in the system (Charalambous *et al*, 2014). Pressure and leakage relationships in a network setting are complex and significantly different from the real pipe flow characteristics (WB Module 4, 2006). Empirical relationship between pressure and leakages is given by the equation:

$Q_1/Q_0 = (P_1/P_0)^{N_1}$ or $Q_1 = Q_0 \times (P_1/P_0)^{N_1}$ (1)

Where Q_1 Final leakage at Pressure P_1

Q_0 Initial leakage at Pressure P_o

P_1 Final Pressure at Leakage Q_1

P_0 Initial Pressure at Leakage Q_0

N_1 Leakage exponent

Economic Level of Leakage

The economic level of leakage is the level at which any further reduction would incur costs in excess of the benefits derived from the savings (Pilcher *et al*, 2008). It is therefore the point at which the cost of saving $1m^3$ of water from being lost is more than the cost of production of the same $1m^3$ of water (Islam & Babel, 2013). It involves a comparison of the cost of water being lost and the cost of undertaking NRW reduction measures. The economic level of leakage is shown in figure 2.

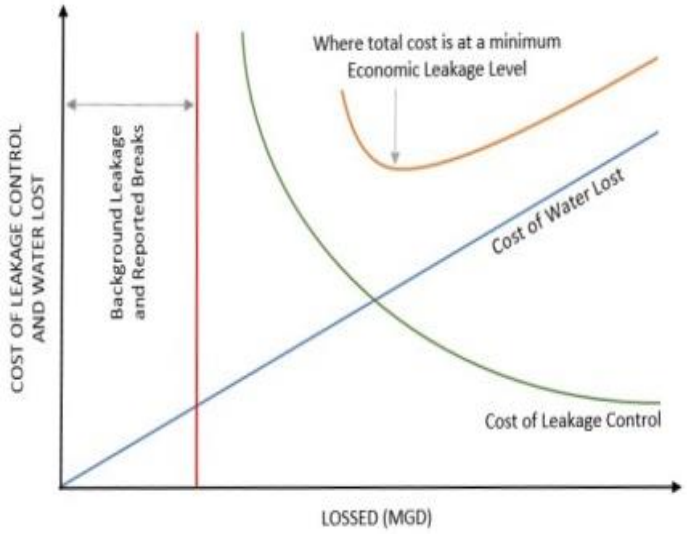

Figure 2: Economic Level of Leakage

Strategies to control Non-Revenue Water are developed from specific techniques, procedures and action plans. These include Non-Revenue water control factors and support framework for NRW reduction. Non-Revenue water control factors include active leakage control, asset management, speed and quality of repairs and pressure management. Non-Revenue water control factorsto reduce real losses from water distribution and service systems (Charalambous *et al*, 2014, Pilcher *et al*, 2008). The four factors must be balanced so as to achieve leakages levels that are economically, environmentally and socially acceptable (Thornton & Lambert, 2008). The Support framework for NRW reduction is shown in table 2.

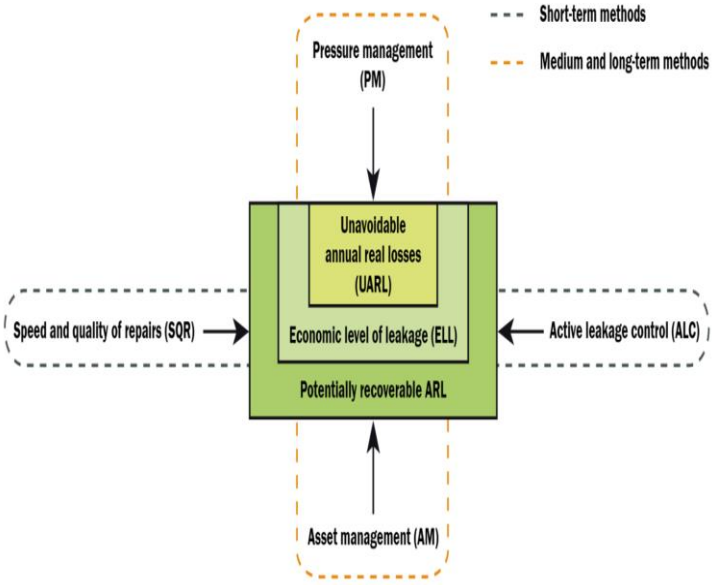

Figure 3: Leakage Control Strategies, *Source: IWA*

2 Study Area and Methodology

This study focused on Meru Water and Sewerage Services (MEWASS) situated in Meru town within Meru County about 300km north of Nairobi City. The main components of the water supply system include Kathita river intake facilities, Gatabora stream intake and Gatabora springs. The total installed capacity of the system is 8,960m^3/day The study determined causes of NRW, water balance, relationship between pressure and leakage, economic level of leakage and strategies to control NRW inorder to learn lessons that can be applied to the water sector in Kenya.The causes of NRWin MEWASS were determined through an exploratory study to determine the contributing factors. It was also done partly through a cross sectional survey through self-administered questionnaire.

Water balance was determined through exploratory study of the existing data and information. It also involved a cross sectional survey through field measurements by actual reading of master meters, zonal meters and consumer meters. The relationship between pressure and leakage was assessed through analysis of existing data at Meru Water Supply Scheme involving several zones or DMA within the supply area. The economic level of leakage was determined by evaluating the secondary data of the various cost centres at MEWASS. The cost of water lost and cost of reducing Non-Revenue Water was determined through the analysis of the identified operational costs.The strategies to control NRW were determined through exploratory and cross sectional studies and analysis of historical data, observations and discussion with stakeholders including consumers. The sample size was selected from the population of staff of Meru Water and Sewerage Services and the consumers.

3 Results

Causes of Non- Revenue Water

The research findings reveal that causes or factors which contribute to Non-Revenue Water in Meru Water Supply Scheme and which can be generalized for the entire country are related to operation and maintenance techniques, methodology of repair works, connection and disconnection practices, meter reading errors, lack of as built drawings, organizational culture, age of pipelines, standard of manufacture of pipe materials

and fittings and system operating pressure. These findings agree with those of Farley *et al.*(2008) who indicated that Non-Revenue Water is caused by non functional meters or faulty meters, water theft, lack of active leakage control and repair work and lack of capacity to undertake leak detection and repair among other countermeasures.

Water Balance

The findings on the evaluation of the water balance indicate that the Revenue Water Volume was 83% of which billed metered consumptions was 83% and billed unmetered consumption was 0%. The Non-Revenue Water Volume was 17% consisting of leakage on water mains, overflow from tanks and leakages from the service pipes and metering inaccuracies and apparent losses.The process of water balance helps utilities to determine the magnitude of water lost, where it is lost, why it is lost and strategies to prevent the loss. The International Water Association (IWA) has developed a standard international water balance structure (Farley et al; 2008). The methodology traces water right from source through the system to consumption point (Charalambous et al; 2014). The IWA methodology was used to evaluate the water balance in Meru Water Supply Scheme.

Through evaluation of the water balance, it was found that it was possible to achieve Non – Revenue Water of 10% or less by eliminating commercial losses which stood at 4.1% and managing the supply and demand to reduce overflow from tanks which was found to be 1.9%. Leakage on service pipelines was at 7.7% and on water mains at 4.7%, which can be reduced through renewal of the pipe network and through leak detection and repair work. The economic level of leakage could easily be achieved at the level of 10% to 14%. The overall water balance analysis was undertaken from each zone and the results for Zone 1 were summarized as shown in Figure3.

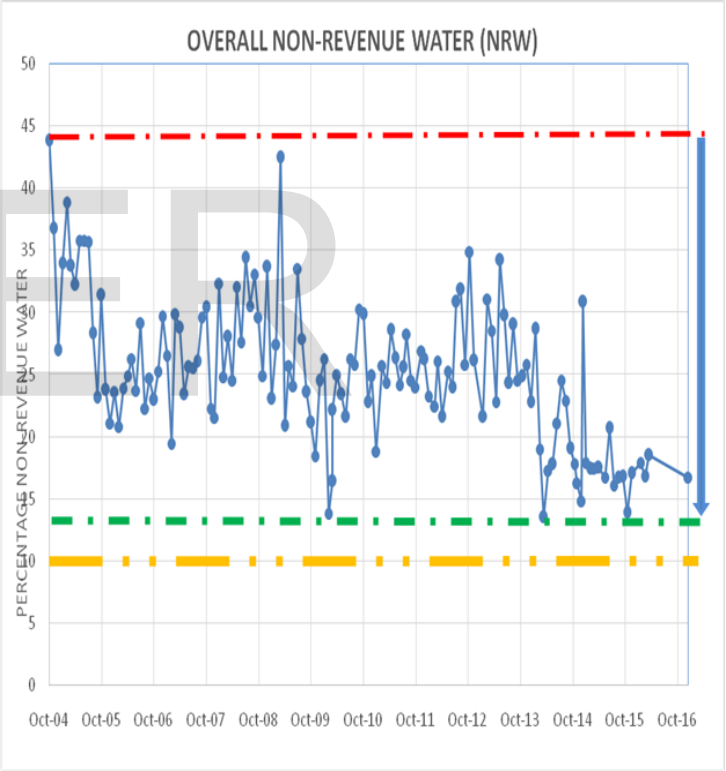

Figure 4: Analysis of overall water balance

Relationship between Pressure and Leakage

The study assessed the relationship between pressure in the system and leakage volume. It could be deduced from the analysis that:

- There exists relationship between pressure and leakage volume of the form:

$$P = K.(Q)^{x} \quad (2)$$

- Power relationship observed ranges from: $\mathbf{P} = (44.22 - 2.183)\ \mathbf{Q}^{(0.461 - 0.516)}$ (3)
- The constant K increases with increase in orifice area
- The power factor is approximately 0.5 for all values of orifice area,thereby specific to characteristics of orifice
- Expected N_1 is approximately = 0.5 (expected range 0.0 – 1.0).
- There exists a power relationship between pressure and leakage volume as follows: $(Q_1/Q_0) = 1.083(P_1/P_0)^{(0.19)}$ (4)
- From the experimental data obtained, N_1 is 0.19.
- Although N_1 falls within the expected range, the value can be improved with more data over a wider range of pressure conditions.

A graph of leakage volume against pressure is shown in figure 5 indicating that a pressure – leakage power relationship exists in the form: $\mathbf{P} = K.(\mathbf{Q})^{x}$ where K and x are constants.

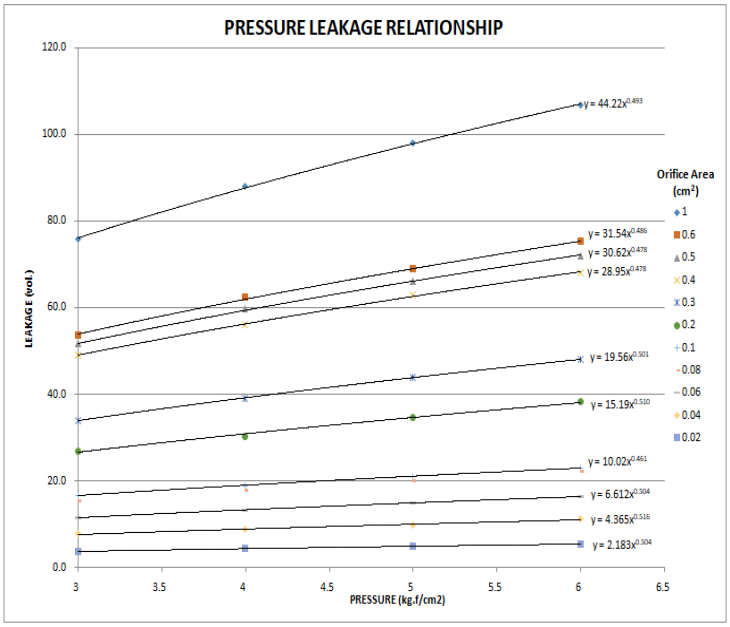

Figure5: Graphical presentation of Pressure – Leakage

Economic Level of Leakage

Analysis of the economic level of leakage was undertaken by comparing the cost of water lost and the cost of NRW management. The analysis revealed that the cost of water lost was Ksh 115 per m^3 while the cost of NRW management was Ksh 385 per m^3. This is an indication that the company is spending more money in NRW management than the cost of water lost. Therefore, subsidy may be required to support the scheme in the management of Non-Revenue Water initially. It is expected that the cost of major items like setting out DMAs, cost of leak detection equipment will come down once all the required fittings at DMAs and equipment for leak detection measures are procured and installed.

The factors affecting the economic level of leakage include; the condition of water distribution system, NRW levels, water demand, water price, the economy of the county, water cost and operating practices (Kanakoudis and Gonelas, 2015). It is for this reason that the cost of Non – Revenue Water Management is very high. The cost of setting DMAs and installation of leak detection equipment is very high. With time it is expected that the cost of Non – Revenue Water Management will comprise only the maintenance cost of the system. Therefore, in the long term, the cost of Non – Revenue Water Management and the cost of water lost may achieve some balance.

Strategies to Reduce Non – Revenue Water

Analysis of the strategies to control Non-Revenue Water revealed that the speed and quality of repairs, pressure management, asset management and active leakage control are important influencing factors. These findings are consistent with the recommendations of IWA Task Force on Water Loss to reduce real losses from water distribution and service systems (Charalambus *et al*, 2014, Pilcher *et al*, 2008). It was also realized that the four factors must be balanced so as to achieve leakage levels that are economically, environmentally and socially acceptable as recommended by Thornton and Lambert (2008) and Lambert, (2000). It is also important that the water supply network is divided into zones or District Meter Areas for ease of implementation of the four factors (Charalambous *et al*, 2014).

4 Conclusions

The research findings reveal that high Non-Revenue Water in Meru Water Supply Scheme depends on the organizational practices like operation and maintenance techniques, methodology of repair works, connection and disconnection practices, , illegal connections and organizational culture. Through evaluation of water balance, it was found that the level of Non- Revenue Water in Meru Water Supply Scheme was approximately 17% as at March 2016. The study found that there is an empirical relationship between pressure and leakage. High operating pressures result into high leakage volumes whenever leaks occur. The analysis of economic level of leakage reveals that the cost of reducing Non – Revenue Water depends on the intensity of the exercise. The speed and quality of repairs, pressure management, asset management and active leakage control are important factors to reduce Non – Revenue Water.

REFERENCES

1. Alan, S.W. (2010). *Non-Revenue Water: Financial Model for Optimal Management in Developing Countries.* RTI Press.
2. Charalambous *et al* (2014). Leak detection and Water loss management. *Water Utility Journal*, 2014.

3.Farley, T. and Liemberger, W., (2006). *Developing a Non-Revenue Reduction Strategy -. Part 1: Investigating and Assessing Water Losses.* OX182PS, *Asian Water*: Oxford shire, UK.

4.Farley, T. and Liemberger, W., (2007). *Developing a Non-Revenue Reduction Strategy. Part 2: Planning and Implementing the Strategy*. OX182PS, Asian Water:Oxford shire, UK.

5.Farley, T. *et al.* (2008). *The Manager's Non-Revenue Water Handbook*: *A guide to understanding water losses.*

6.Islam, M. and Babel, M., (2013). Economic Analysis of Leakage in the Bangkok Water Distribution System. *Journal for Water Resource Planning and Management, 139 (6),* 209-216.

7.Johnson *et al.* (2008). Twort's Water Supply, 6th Edition.

8.Lambert, A. (2000). *System Approach to Leakage Control and Water Distribution Management.* Brno, Czech Republic.

9.McKenzie, L. and Liemberger, W., (2005, September). *Accuracy Limitations of the ILI: Is it an appropriate Indicator for Developing Countries*. Proceedings from the International Water Association Specialist Conference: Leakage 2005. (pp. 82 – 89, 12 - 14 September 2005). Halifax: Nova Scotia, Canada.

10. Ministry of Water Development (1982).*Meru Water Supply, Draft Preliminary Design Report*. Wanjohi Consulting engineers.

11. Ministry of Water Resources (1999). *Sessional Paper No.1 of 1999 on National Policy on Water Resources Management and Development.*

12. Ministry of Environment and Natural Resources (2002). *The Meru Water Supply Project (Japan Grant Aid*). Interim Report of Soft Component Scheme:Nippon Koei Co. Ltd in Association with Nihon Suido Consultants Co Ltd.

13. Ministry of Water Resources Management and Development (2003). *First UFW Survey Report on Meru Water Supply Project under Japanese Grant Aid*. Nippon Koei Ltd in Association with Nihon Suido Consultants Ltd.

14. Ministry of Water and Irrigation (2005, October). *Practice Manual for Water Supply Services in Kenya.* Kenya – Belgium Study and Consultancy Fund October, 2005.

15. Ministry of Water and Irrigation (2009). *The National Water Services Strategy (NWSS) 2007 – 2015.*

16. Ministry of Water and Irrigation (2010). *The Technical Cooperation Project for the Project for Non-Revenue Water in Kenya.* Inception Report, Japan International Cooperation Agency.

17. Ministry of Environment, Water and Natural Resources (2013). *Water and Sanitation Sector Strategic Investment Plan, 2013.*

18. Ministry of Environment, Water and Natural Resources (2014*). Annual Water Sector Review, 2013 – 2014.*

19. Ministry of Environment, Water and Natural Resources (2014[a]). *Standards for Non-Revenue Water Management in Kenya*. Handbook, August 2014.

20. Ministry of Environment, Water and Natural Resources (2014[b]). *Standards for Non-Revenue Water Management in Kenya.* Manual, August 2014.

21. Ministry of Environment, Water and Natural Resources (2014[c]). *Standards for Non-Revenue Water Management in Kenya*. Case Studies, August 2014

22. Ministry of Environment, Water and Natural Resources (2014[d]). *Standards for Non-Revenue Water Management in Kenya.* Guidelines, August 2014.

23. Mugenda, O. M. & Mugenda, A.G., (2003). *Research methods: Quantitative and Qualitative approaches.* Nairobi. Acts Press

24. Pilcher, R. *et al*. (2008). *A Guide to the Water Loss Reduction Strategy and Application Part 1*. The Basic Water Loss Book: Ankara Turkey.

25. Republic of Kenya (2013). The National Water Master Plan, 2013. Ministry of Water

26. Republic of Kenya (2010). Constitution of Kenya, 2010. Nairobi: Government Press

27. Sekaran, U. (2010). *Research Methods for business:A skill Building Approach* (4th Edition). New Delhi: Wiley India.

28. Thornton, J. (2008). *Managing Leakage by Managing Pressure: A Practical Approach.* International Water Association, Task Force on Water Loss.

29. Thornton, J. and Lambert, A. (2008). *Progress in Practical Prediction of Pressure, Leakage, Burst frequency and Pressure.* Consumption Relationships.

30. Water Services Regulatory Board (2014). *A performance Review of Kenya's Water Services Sector 2012 – 2013*. Impact, 7.

31. World Bank Institute (2006, January). *Promoting Knowledge and Learning for a better World.*Non-Revenue Water Reduction, Module 3.The Water Balance Version 1.1, 18th January 2006.

32. World Bank Institute (2006, January). *Promoting Knowledge and Learning for a better World.*Non-Revenue Water Reduction, Module 4. Understanding physical losses key relationshipsVersion 1.1, 18th January 2006.

33. World Bank Institute (2006, January). *Promoting Knowledge and Learning for a better World.*Non-Revenue Water Reduction, Module 9. Implementing NRW Reduction ProgramsVersion 1.1, 18th January 2006.

34. Zyl, R. and Cassa, M. (2014). *Predicting the Leakage and exponents of elastically deforming cracks in pipes.* 12th International Conference on Computing and Control for the Water Industry (CCW12013) Procedia Engineering.