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Impact of Quality Management Tools and Techniques – Case of Namibian Municipal Water Distributors

ABSTRACT

Purpose: The aim of this research is to provide an understanding on the impact of QM tools and techniques in water supply infrastructure maintenance and the generation of NRW by Namibian Municipal Water Distributors.

Design/Methodology/Approach: In-depth interviews was selected as the primary data collection method, while secondary data was collected using document review and observations. In-depth interviews as primary method provided rich data and details on the subject matter from the respondents. Document review and observations provided a holistic perspective and understanding of the context within which maintenance projects are handled by Municipal Water Distributors.

Findings: The study found that as the number of QM tools employed to analyze maintenance data increases, the generation of NRW by the municipality decreases. However for the tools to be effective, they should cover applications such as problem identification, data analysis, process analysis, decision making, planning, quality control and statistical process control, this helped Namibian municipalities to produce low volumes of NRW. In contrast, municipalities using QM tools arbitarily lead to high quantities of NRW generation.

Originality/ Value of the Paper:

The World Bank recommends that NRW should be less than 25% of the total water produced, while in many countries NRW is up to 60%. Developed economies have made efforts to reduce NRW but efforts are still at nascent stage in emerging economies. This is the first study providing evidences of QM tools aplication in maintenance process and effect on NRW.

Keywords: Quality Management, Tools, Maintenance, Municipality

Paper Type: Research Paper

INTRODUCTION

Municipalities always find themselves with a challenge to deal with maintenance of water supply infrastructure. Pipe breaks result in physical water losses which contributes to the generation of Non-Revenue Water (NRW). Calculations suggest that more than US$ 14 billion is lost every year by water utilities around the world due to NRW (Kingdom et al., 2006). The World Bank recommends that NRW should be less than 25 percent of the total water produced. In many countries NRW is up to 60 percent (Pearson and Trow, 2005). High levels of NRW are detrimental to the financial viability of water utilities and pose an extra burden on paying customers. Municipalities are therefore constantly sourcing for cost-effective and reliable maintenance methods. Literature advocates that application of Quality Management (QM) tools has proven to be useful. QM tools are generally used to facilitate positive change and improvement (Goetsch and Davis, 1994). According to Quality America, Inc., there are close to 100 QM tools and they come in various forms, such as check lists, charts and graphs, diagrams and other analysis tools (ReVelle, 2003). According to Samson and Terziovski (1999), QM principles, techniques, processes, and best practices have been proven effective in improving maintenance. However, past studies tend to focus mainly on the use of QM tools in production plants, e.g. Ford Motor Company, Phillips Semiconductor, SGL Carbon and Motorola (Gilbert, 1992). This study will investigate the extent to which QM tools are used in the maintenance of Namibian Municipal water distribution infrastructure.

Namibia is a Republic with the smallest amount of rainfall in sub-Saharan Africa. (Olszewski and John, 2010). Water supply is fundamental to the wellbeing of Namibia as a country and it is also indispensable in the promotion of economic development (Pohamba, 2012). The supply of water in Namibia is costly because ground water is difficult to locate and extract, river water has to be dammed and transported long distances from the source to where it is needed.

It is an irrefutable reality that construction of maintenance free water supply infrastructure in Namibian municipalities is not feasible (Wahab, 1997). The reality is that all the elements and components that make up water supply infrastructure deteriorates with time due to inherent defects in design, construction, and the effects of environmental agents and water supplying activities. Hence, without maintenance, water infrastructure can become inefficient and unreliable. The implications of a delay in maintenance are only too obvious as failure of water supply infrastructure often results in the generation of NRW. Non-Revenue Water (NRW) is generally defined as the difference between the system input volume and billed authorized consumption. It consists of unbilled authorized consumption and apparent and real losses. For the purpose of this study the standard water balance of the International Water Association (IWA) to identify and assess the various components of NRW is used (refer Table 1).

Table 1: Standard IWA Water Balance

System Input Volume	Authorised Consumption	Billed Authorised Consumption	Billed Metered Consumption	Revenue Water
			Billed Unmetered Consumption	
		Unbilled Authorised Consumption	Unbilled Metered Consumption	Non-Revenue Water
			Unbilled Unmetered Consumption	
	Water Losses	Apparent Losses	Unauthorised Consumption – Theft	
			Metering Inaccuracies	
		Real Losses	Leakage on Transmission and Distribution Mains	
			Leakage and Overflows at Storage Tanks	

Literature suggests that NRW generation is undesirable because it seriously affects the financial viability of water utilities through lost revenues and increased operational costs (Kingdom et al., 2006). Furthermore, Lancefield et al. (2015) warns that water scarcity is fast becoming one of the most crucial challenges of our time. They state that the economic growth of emerging markets has multiplied the demand for fresh water and the effects of climate change is already limiting the ready supply of water around the globe.

Since maintenance costs form an integral part of the total operating costs, municipalities are constantly sourcing for cost-effective and reliable maintenance methods. Goetsch and Davis (1994) stated that QM tools and techniques can be used to improve processes and to develop products in any business by identifying, analysing and evaluating data that is relevant to the business. QM tools and techniques are generally used to facilitate positive change and improvement. Shalowitz (1995) and El-Kafafi (2008) emphasise the fact that companies such as Motorola and General Electric have used QM tools to great success. According to Samson and Terziovski (1999), QM principles, techniques, processes, and best practices have been proven effective in improving maintenance. At this point it is important to note that, water utilities have lagged far behind the manufacturing industry in maintenance management (Whittington, 1992).

QM tools help municipal water distributors to identify, analyze and assess qualitative and quantitative data that is relevant to the maintenance of their water distribution infrastructure. The challenge however is to identify QM tools which improve maintenance of municipal water distribution infrastructure while also reducing the generation of NRW. It is clear that these domain specific QM tools would significantly possess appealing applicability because each year more than 32 billion m^3 of treated water are lost through leakage from distribution networks (World-Bank, 2006) and construction of maintenance free water supply infrastructure is not feasible.

The aim of this research is to provide an understanding on the effects of QM tools in water supply infrastructure maintenance and the generation of NRW by Namibian Municipal Water Distributors. The main objective of the research is to investigate the impact of of quality management tools and techniques in the maintenance function of Namibian municipal water distributors, in this respect, the objectives of this study are to:

1. Identifiy QM tools used as well as the NRW produced.

2. Investigate themes, similarities, and differences on the use of QM tools and generation of NRW.
3. Investigate the criteria under which Namibian Municipal Water Distributors select and apply QM tools in the maintenance of water distribution infrastructure.
4. Investigate the extent to which the application of QM tools in water infrastructure maintenance affects the generation of NRW.
5. Propose a QM implementation strategy that can be adopted by Namibian Municipal Water distributors for improved maintenance of infrastructure and reduction of NRW.

LITERATURE REVIEW

Maintenance Strategies for Water Distribution Networks

According to Godfrey and Dragan (2006), maintenance of water networks and water supply in general is a complex arrangement of different factors, such as transport and distribution. Within this arrangement, piped networks represent one of the largest infrastructure assets of industrial society. The management of potable water networks encompasses all activities principally concerned with the supply of water from the outlet of the distribution reservoir to the customers' taps; and all related functions, including water resources provision, water treatment, customer relations, business planning, human resources and information services.

Once a distribution system has been properly constructed and placed in service, routine maintenance should be conducted to monitor the system's performance and identify repairs as needed. Maintenance will maintain the water system operating at optimal performance and maximize the full life expectancy of the system (Abdallah, 2013).

Godfrey and Dragan (2006) states that selection of the maintenance strategy for a water distribution system is a difficult problem due to a large number of system components, e.g. pipes, pumps, valves, meters, etc.; dynamic evolution of the failure mode of a deteriorating water pipe, the existence of a certain degree of coupling among the various system components, limited resources available for maintenance activities; and the associated difficulty in quantifying many of the benefits and costs. The problem has often been treated as a complex optimization problem with several possible objectives used in isolation or combined, e.g. maximization of reliability, minimization of downtime and the minimization of total maintenance costs.

Many authors have described different strategies for maintenance management. Wireman (1998), Al-Saggaf (1997), Mobley (2002) and Gelders and Pintelon (1988) described four basic types of maintenance strategies which they believe can be applied by distribution network service providers and these include corrective, preventive, predictive and proactive maintenance. Gelders and Pintelon (1988) added *perfective maintenance* in their description of the maintenance variety.

Quality Management Tools and Techniques

QM is a system consisting of core values, techniques and tools. According to Hellsten and Klefsjö (2000), core values are the basis of the culture of an organization while techniques are ways to work within the organization to reach the values. QM tools support the QM techniques by collecting and displaying information in ways that help the human brain grasp thoughts and ideas (Evans and Lindsay, 1999). De Cerio (2003) claims that QM tools and techniques are a business strategy or a well-structured and highly effective methodology that achieves improvements in products and processes, which in turn enhance operational performance. The correct selection and use of tools and techniques is a vital component of any successful QM implementation plan.

By using the QM tools and techniques one can investigate problems, identify solutions and implement them in work practices. QM tools and techniques are generally used to facilitate positive change and improvement (Goetsch and Davis, 1994). The correct selection and use of QM tools and techniques is a vital component of any successful QM implementation plan.

QM tool and techniques are regarded as a successful system capable of achieving significant gains in business performance. However, Deming (1995) warns that statistical tools are inadequate if managers use them improperly or when they foster managerial practices that inhibit workers from applying information acquired from statistics to improving processes. Deming (1995) further states that data on product quality and process stability are useless if management's actions are limited to laying blame and exhorting improvement. When applied to physical processes, QM tools and techniques cause the processes to yield better results.

QM practices can be classified into two groups which are management and technical system (Evans and Lindsay, 1999) or into “soft” and “hard” parts (Wilkinson and Willmott, 1995).

The technical system, as defined by Evans and Lindsay (1999) consists of a set of tools and techniques (run charts, control charts, Pareto diagrams, brainstorming, stratification, tree diagrams, histograms, scatter diagrams, force-field analysis, flow charts, etc.), while the hard part, according to Willmott (1995), includes production and work process control techniques which ensure the correct functioning of such processes, including, amongst other things, process design, just-in-time philosophy and the quality control tools. The management system or the soft part constitutes the behavioural aspects of management or the human aspects, such as leadership and people management. These two dimensions reflect all the issues which a manager must bear in mind for the successful implementation of quality management.

Link between Municipal Water Distributors, QM, and Maintenance

According to Rose and Casler (2006) all production systems, when viewed at the most abstract level, might be said to be *transformation processes* that transform resources into useful goods and services. The transformation process typically uses common resources such as labour, capital (for machinery and equipment, materials, etc.), and space (land, buildings, etc.) to effect a change. Economists call these resources the *factors of production* and usually refer to them as labour, capital and land (Snaddon, 2009).

When viewed as a process, a production system may be further characterized by channels of movement in the process both the physical flow of materials (work in process and finished goods) and the flow of information along with the inevitable paperwork that carry and accompany the physical flow. The physical flows are subject to the constraints of the capacity of the production system, which also limits the system's ability to meet output expectations. Similarly, the management of information flows, or the planning and control of the system to achieve acceptable outputs, is an important task.

Visser (2008) modelled maintenance as a transformation process encapsulated in an enterprise system such as shown in Figure 1. Visser (2008) states that the way maintenance is performed will influence the availability of production facilities, the rate of production, quality of end product and cost of production, as well as the safety of the operation. These factors in turn will determine the profitability of the enterprise.

Visser's model is in agreement with Thorsteinsson (2007) who developed a broader and richer definition of the maintenance task based on viewing the maintenance system as a production system where the 'products' are maintenance services. The authors agree that maintenance as an economic production system has inputs, processes and outputs. Maintenance focuses on managing the production system so that it operates as expected, without breakdowns. The QM tools and techniques can be classified as inputs in the maintenance process as they have an impact on the effectiveness of the maintenance process. Problem solving methods, statistical process control, FMEA, fool proofing, sampling, and inspection are for process control and process improvement (Juran, 1995). Statistical process control can be used to achieve process stability, provide guidance on how the process may be improved by the reduction of variation, assess the performance of a process, and provide information to assist with management decision-making (Dale et al., 1997). Without statistical control, the process is in chaos, the noise of which will mask the effect of any attempt to bring improvement (Deming, 1995).

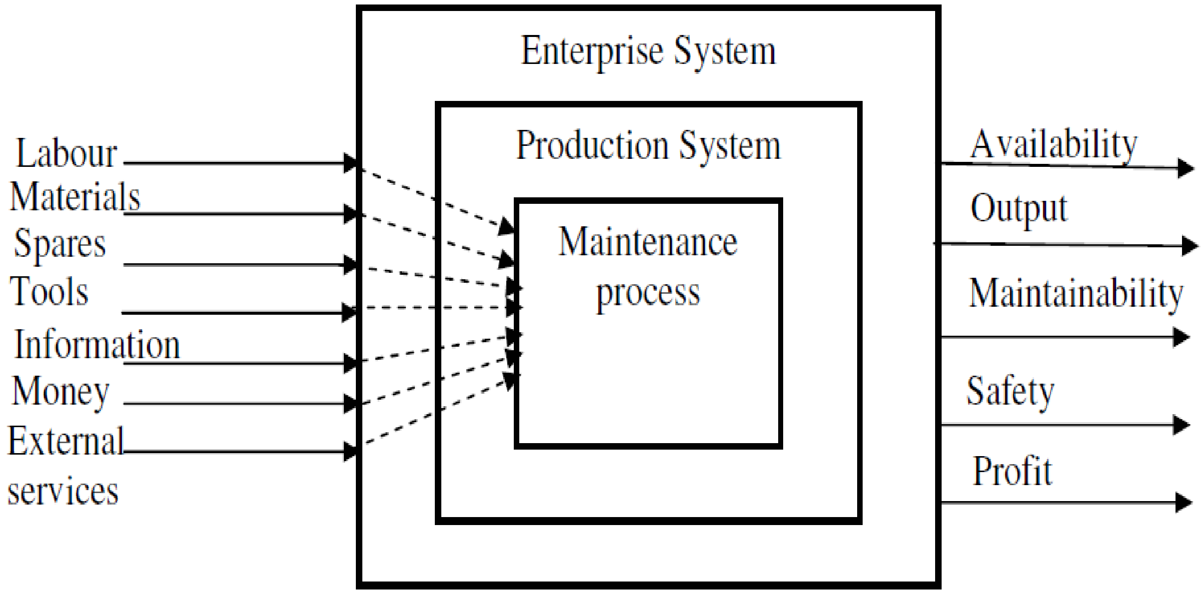

Figure 1: Input-Output model for a production system (Visser, 2008)

Quality improvement in municipal water distributors means elimination of waste such as the generation of NRW, scrap and rework, which increase profitability. In Namibia local authorities are responsible for the provision, operation and maintenance of a wide range of municipal infrastructures and services of which maintenance is part of the production system. Just like any other business entity, municipalities need to check whether they have the right approach of doing business otherwise they might find themselves in the same situation as the Ford motor company for which in 1974, Hartman reported that more than 80 percent of the automobiles they manufactured had to go to a rework facility immediately after the assembly line (Jablonski, 1994).

Based on the above evidence, the study accepts that the link between the application of QM tools and techniques, and maintenance emanates from the fact that maintenance has processes and QM tools and techniques can be inputs to that process. Therefore the link between the application of QM techniques and maintenance can affect the generation of NRW, because without statistical control, the process is in chaos, the noise of which will mask the effect of any attempt to bring improvement (Deming, 1982). From the maintenance perspective, this means QM can help to maximize equipment reliability and hence up-time, thereby extending each individual component's life and reducing the generation of NRW as maintenance is carried out to prevent system failures and to restore the systems functionality when a failure has occurred.

Based on the above evidence, the authors concur with Kingdom et al., (2006), that water utilities have to end the 'Vicious Circle', where they face increased NRW, financial losses, and poor service. Instead they should follow the 'Virtuous Circle' that enables them to decrease NRW, improve efficiency, preserve financial resources, and promote strong customer satisfaction and willingness to invest. This is in line with this research's objectives that are to determine how the interaction between the employment of QM tools and maintenance affect the generation of NRW, in Namibian Municipalities.

RESEARCH METHODOLOGY

Interviewing is one of the many methods used for data collection in a study (Barath et al., 1976),. Kahn (1979) describes an interview as a purposeful discussion between two or more people that can help gather valid and reliable data relevant to research objectives. According to Barath et al. (1976) structured interviews and in-depth interviews are two types of interviews which can be administered in a study. A carefully worded questionnaire is administered with structured interviews while in-depth interviews do not follow a rigid form. In the former, the emphasis is on obtaining answers to carefully phrased questions. Lincoln and Guba (1985) add, with structured interviews, the interviewers can deviate only minimally from the question wording to ensure uniformity of interview administration, while in the latter, the interviewers seek to encourage free and open responses. Patton (2002), adds that in-depth interviews encourage capturing respondents' perceptions in their own words and are a very desirable strategy in qualitative data collection.

The advantages of interviews are that they usually yield rich data, details, and new insights and permit face-to-face contact with respondents (Barath et al., 1976). However, Kahn (1979) argues that interviews are expensive and time-consuming. Kahn (1979) adds that the stage fright of interviewers and respondents have their own risks such as the unintentional manipulation of responses.

Based on the above stated evidences, in-depth interviews was selected as the primary data collection method for the study, while secondary data was collected using document review and observations. In-depth interviews are selected as primary method because it provides rich data and details on the subject matter from the respondents. Document review and observations are expected to provide a holistic perspective (Yin, 1994) and understanding of the context within which maintenance projects are handled by municipal water distributors.

Interview design

A structured interview approach was used in this research. The questions were sent to the interviewees in advance together with the objective of the research to make them aware of the research before the interview. The questionnaire was pre-tested with experienced town council employees responsible for maintenance. The pre-test was done because it helped investigators to refine their data collection plans with respect to both the content of the data and the procedures to be followed. Ghauri et al. (1995) say that a pre-test is the test that checks the understanding of the interviewee regarding the research problem and interview questions, and also provides first-hand insight into what might be called the "cultural endowment of the informants". In addition, Oppenheim (2002) mentioned that the function of pre-test is not the collection of findings but the testing out of questions and procedures. Gill and Johnson (1991) also said that a pre-test can provide good feedback to the researcher for more accurate and clear questions to be used in real case studies and thus allows any potential problems in the interview and questionnaire to be identified and corrected.

After pre-test, the researchers modified some of the questions, which were having the same meaning (repeated questions) or were in the form of combined questions. After the pre-test, the researchers proceeded by setting up interview dates and mailing the questionnaire to the municipal water distributors.

FINDINGS

Three municipal employees were interviewed from each of the eighteen municipalities, distributed through three levels with –

- Level 1: maintenance division management,
- Level 2: maintenance foreman, and
- Level 3: maintenance general workers

The aim of covering these three levels was to enhance the validity and reliability of getting responses with different points of view, and thus triangulating the findings.

The response rates from all the municipalities averaged 67 percent. Mixtures of qualitative and quantitative techniques were used to analyse the data collected through in-depth interviews, documentary analysis, observation and informal conversation. These multiple methods, or “methodological triangulation" (Patton, 2002), are used in order to enhance the internal validity of the data (Yin, 1994; Bromley, 1986). Some of the company documents, including audit reports, policy statements, internal memos and general correspondence, provided a useful reference source to understand the policies and constructing a chronology of key events which have taken, and are taking, place with municipal water distributors.

QM Tools used by Namibian Municipal Water Distributors

It was found that:

a) The average number of tools applied by the municipalities was 7.94 tools.
b) The maximum number of tools used by a single municipality was 22 and the least number of tools employed was 2.

c) The total number of tools used by the municipalities was 143, with a skewness of 1.078. This showed the data is skewed to the right and the mean is greater than the mode.

d) The data has a Kurtosis of -0.1961. Kurtosis is any measure of the "peakedness" of the probability distribution of a real-valued random variable. The values for kurtosis between -2 and +2 are considered acceptable in order to prove normal distribution (George and Mallery, 2010).

The most commonly used tools are tabulated (Table 2) below.

Table 2: Tools and frequency of use

Groups	Frequency of use	% Respondents
Histogram	18	100%
Brainstorming	18	100%
Flow Charts	16	89%
Scatter Diagrams	11	61%
Checklist	9	50%
Critical Path Method	7	39%
Gantt Chart	6	33%
Control Charts	6	33%
Net Present Value	6	33%
Benchmarking	6	33%
Check Sheets	6	33%
Run Charts	6	33%
Process Maps	6	33%
Line Graph	5	28%
Housekeeping	4	22%

The above data only reflects the QM tools used by Namibian municipal water distributors and thus satisfies the first objective of the study. This data will be used in the subsequent sections in order to reach the final objective of the study.

NRW Production

The NRW produced by each municipality was determined by subtracting known water uses from the total water supplied to the distribution system. This information was obtained from interviews and cross-checked using the audited financial statements of each respective municipality.

It was found that the average quantity of NRW produced by the municipalities was 23 percent. The highest percentages of NRW were recorded at Otavi and Keetmashoop with 41 and 35 respectively. The least NRW was recorded at Outjo, Gobabis and Windhoek that have percentages of 3, 11 and 14 respectively.

Table 3 displays the municipalities together with the respective water supplied to the distribution system, water sold and percentage NRW generated during the last fiscal year. It should be noted that no information could be obtained with regard to the percentage of NRW generated by the Outjo municipality in recent years. The last available readings were from 2002, which the Outjo municipality claims to have produced 3 percent.

Table 3: Non-revenue water per Municipality

Town Councils	Bulk Supply (m^3)	Water Sold (m^3)	Non-Revenue Water (m^3)	Percentage (%)
Windhoek	18,842,529.00	16,204,574.94	2,637,954.06	14%
Walvis Bay	5,305,939.00	4,350,869.98	955,069.02	18%
Swakopmund	4,384,736.00	3,640,805.00	743,931.00	17%
Tsumeb	2,793,523.00	2,164,433.00	629,090.00	23%
Otjiwarongo	1,347,300.00	1,142,231.00	205,069.00	15%
Okahandja	1,294,181.00	880,043.08	414,137.92	32%
Grootfontein	162,388.62	116,919.81	45,468.81	28%
Karibib	304,055.19	234,122.50	69,932.69	23%
Keetmanshoop	1,704,882.00	1,106,240.00	598,642.00	35%
Mariental	878,972.00	765,808.00	113,164.00	13%
Gobabis	802,690.00	711,929.00	90,761.00	11%
Karasburg	250,323.00	203,323.00	47,000.00	24%
Omaruru	634,328.00	501,483.00	132,845.00	21%
Outjo	846,595.00	820,825.00	25,770.00	3%
Rundu	2,708,874.00	1,769,962.00	938,912.00	35%
Otavi	276,677.00	164,162.00	112,515.00	41%
Henties Bay	500,274.00	371,451.00	128,823.00	26%
Usakos	372,469.00	230,290.00	142,179.00	38%

Municipalities producing less than 20 percent NRW are generally considered as being well managed and NRW produced more than 20 percent are considered as being poorly managed

(IWA, 2006). Based on this figure, only 33 percent of Namibian municipalities are well managed. The fact that 67 percent of the Namibian municipalities are considered as being poorly managed is a serious concern. This study therefore hopes to help increase well managed municipalities.

The Relationship between the use of QM Tools and Generation of NRW

The QM tools used by the 18 municipalities together with the NRW production, were grouped and classified into four categories: Case A, Case B, Case C and Case D as shown in Figure 2.

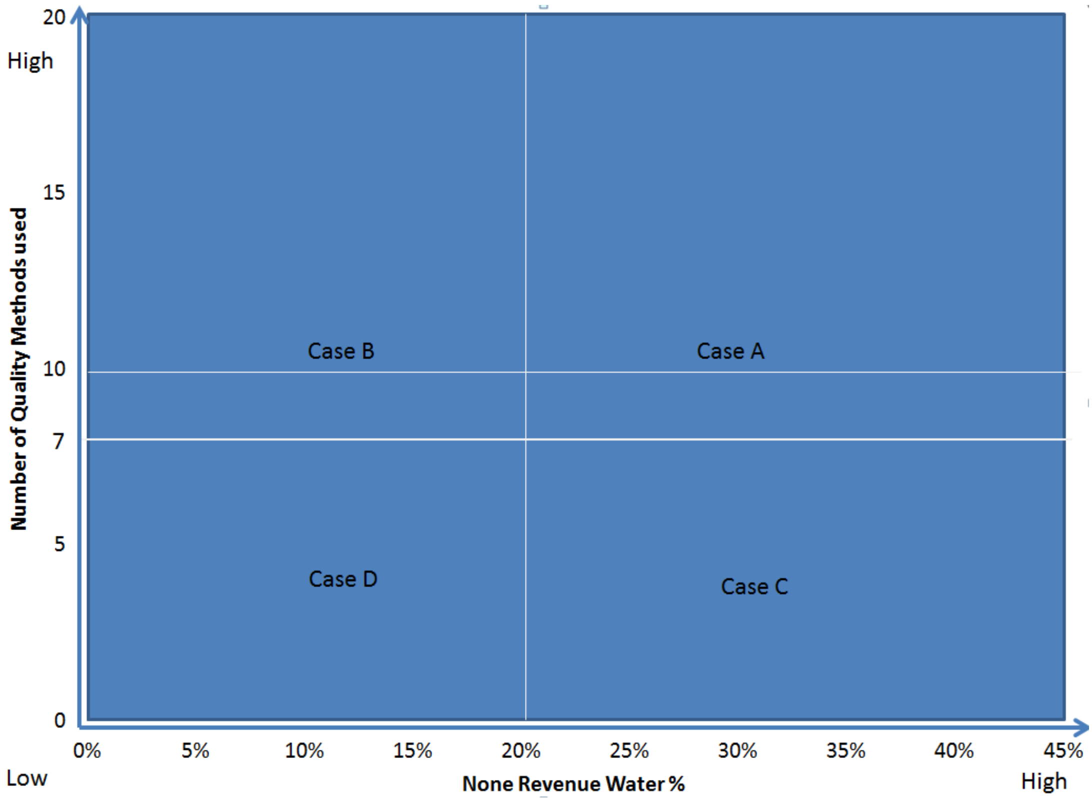

Figure 2: Case organisation chart

The organization of all the cases with their respective categories are summarized and reflected in Table 4 below.

Table 4: Case organisation protocol

	Number of tools used	**Quantity of NRW Generated**
Case A	≥7	> 20%
Case B	≥7	< 20%
Case C	< 7	< 20%

Case D	< 7	> 20%

The quantity of seven tools was selected because literature suggest that there are seven basic tools that solve the vast majority of issues including maintenance work (Montgomery and Douglas, 2005). The basic tools are: Ishikawa diagram, flow charts, scatter diagram, Pareto chart, check sheet, control chart and quality tools. These tools are called basic because they are suitable for people with little formal training in statistics and because can be used to solve the vast majority of issues (Ishikawa, 1989).

Case A Municipalities

The municipality that falls into Case A category is Henties Bay. The municipality constitutes 7 percent of all of Namibia's municipalities. During the interview process, the staff members from this municipality complained that most of their water distribution infrastructure was too old and needed to be replaced. They also mentioned that the coastal weather also aggravated their pipeline condition.

Case B Municipalities

Case B category municipalities are Walvisbay, Swakopmund, Windhoek, Otjiwarongo, Mariental and Gobabis. The Case B, constitutes 33 percent of all Namibia's municipalities. The average percentage of NRW produced by the six municipalities is 13.2 percent. According to the IWA, this data reflects municipalities that are well managed with respect to curbing water losses.

Case C Municipalities

The municipalities which fall into Case C category are Grootfontein, Okahandja, Omaruru, Karibib,Tsumeb Otavi, Rundu, Karasburg, Keetmashoop and Usakos municipalities. The average NRW produced by the ten municipalities is 30.2 percent. Among the ten municipalities, the highest quantity of NRW produced by a single municipality is 41 percent and the lowest is 21 percent. The average percentage NRW produced by these ten municipalities of 30.2 is too high and unacceptable (IWA, 2006).

The ten municipalities use an average of four QM tools and techniques to help organizations to identify, analyze and assess qualitative and quantitative data that is relevant to maintenance. The highest number of tools employed by a single municipality in this category is five, and the least is three.

Case D Municipalities

Only Outjo municipality falls into this category. The maintenance division of the Case D municipality reports to the Health and Safety manager. No information could be obtained with regard to the cubic meters NRW for the recent years. The last available readings were from 2002. With respect to the 2002 records, the municipality claims to have produced 3 percent NRW. Since 2002 is too far into history that these records might be meaningless, with respect to this study.

Selection and Application of QM Tools

Selection of QM tools

To undrerstand the basis of selection for a tool, a questionnaire with a 5-point (1-Strongly disagree, 5-Strongly agree) Likert-type scale was used. The questions were to specify the level of agreement with the following two statements:

a. I am able to use this specific tool without much support – it is user friendly.
b. The results of using this tool are measureable - it is useful.

The regression analysis was then used to determine the relationship between the variables for all the 18 municipalities.

Table 5: Regression results for user friendly and usefulness

Regression Statistics	
Multiple R	0.932079481
R Square	0.868772159
Adjusted R Square	0.854958702
Standard Error	1.948139447
Observations	22

ANOVA

	df	SS	MS	F	Significance F
Regression	2	477.39030	238.6951	62.8931	4.18E-09
Residual	19	72.109698	3.795247		
Total	21	549.5			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	2.4613647	0.6502803	3.7850827	0.001251	1.10031243	3.822417
User friendly	0.0854331	0.0366626	2.3302470	0.030967	0.00869723	0.162169
Usefulness	0.1263153	0.0448502	2.8163810	0.011022	0.03244272	0.220187

Based on the above table: The quantity of QM tools selected is represented by the expression:

Q = 2.46 + 0.085 User Friendliness + 0.126 Usefulness

As can be seen from Table 5 above, the larger Beta value (β) therefore was for usefulness. This shows usefulness makes the strongest contribution in explaining the selection of tools by Namibian municipalities when all the other values in the model are controlled. So, user friendliness does not play a big role in tools selection by municipalities.

The t-statistic was used to validate the outcome results of the model. Table 5 shows t-statistic value for usefulness as 2.81, while for user friendliness as 2.33. The t-statistic therefore validates the finidngs from β value.

Application of QM tools

i. Use of problem identification tools

Case A and B municipalities use flow charts, cause and effect diagrams, check sheets, Pareto charts and run charts for problem identification. Respondents from these municipalities suggest, these tools provide indications when the water distribution system is not operating to its design capability and also show when problem exists.

The main problem identification tool used by the Case B municipalities is root cause analysis, to trace origin of a problem. The interviewees stressed that if you only fix the symptoms, the problems will continue especially when dealing with the issues of dents or buckling of pipes or dirty water drawn into drinking water pipelines due to leaking connecting sockets.

The interviewees stressed that a pipeline system can never be operated in steady state condition all the time, since starting and stopping the pump alone will change the water flow conditions. Sudden change in velocity can produce very high pressures in the piping system which can be several times the normal operating pressure and result in burst pipes and severe damage to the distribution system.

Problem identification is therefore a very important part of maintenance. The maintenance management team uses cause-and-effect or Ishikawa diagram to analyse and find out the root cause for pipeline faults. The team takes into account all potential sources of faults. By eliminating one potential fault at a time, the team will eventually come to the cause of the problem to the water supply system.

The Case B municipality also uses control chart for problem identification in water balance audits. The interviewees stated that the water balance is a key and quick method to assess the NRW. These municipalities use control chart to log data during pressure testing of water distribution. Hydro testing of pipelines is performed to expose defects and to ensure that any remaining defects are insignificant enough to allow operation at design pressures. Buried high water pipelines are tested for strength by pressurizing them to at least 125% of their maximum operating pressure. The control chart makes it easy for the Case B maintenance teams to ascertain the logged operating pressure as well as the test pressure. Control chart helps to determine rate of pressure loss over time as well as to decide whether the losses are excessive or not. Case C and D municipalities said they have not tested their pipelines in the recent dates.

ii. Use of planning tools

Case A and Case B municipalities use planning related QM tools such as Critical Path Analysis (CPA) or Critical Path Method and Gantt chart to help plan all tasks that must be completed as part of maintenance projects. The interviewees from Case A and Case B municipalities stated that the CPA was the basis of both the preparation of a maintenance schedule and of resource planning. The interviewees stated that the CPA helps them to see where remedial action in terms of planning needs to be taken to get the maintenance activities on course. During management of maintenance work, CPA allowed them to monitor achievements of project goals. The CPA is also used to identify the tasks to be delayed if resource needs to be reallocated.

Case C and Case D municipalities do not use the project management related QM tools, mostly because they did not have the expertise to apply the tools. The respondents stated that all work was attended to as a matter of urgency for which no planning was necessary and pipe bursts were given priority.

Respondents from Cases A and B when probed on backlog of maintenance work, mentioned the reasons for such backlogs were mainly due to unforeseen delays in delivery of materials. The reason was further elaborated as being that spare parts availability depends on some external and internal factors such as dealing with employee strikes in neighbouring countries which is difficult to manage. With respect to Cases C and D, work backlogs were said to be mainly due to the inadequacy of maintenance staff performance, lack of effective maintenance management and planning and the lack of resources in the maintenance department e.g. funds, equipment, skills etc.

iii. Use of graphical tools

The most popular graphical tool used by the municipal water distributors was the checklist. The respondents from Cases A and B said, the checklist is a simple but effective fact finding tool. It allows maintenance workers to collect specific information regarding the defects observed on a distribution network and to arrange the data to easily identify issues such as location or time of faults in the distribution network.

The Mariental municipality interviewees stated that, if a defect was observed frequently, the maintenance manager would develop a checklist that measures the number of failure occurrences per month. In this fashion the maintenance teams can isolate the location of the particular defect and focus on correcting the problem. Case C and Case D municipalities also said they use the checklist for monitoring and managing defects within the water distribution network.

Only the Windhoek municipality which falls under Case B, said that they use scatter diagrams. The Windhoek municipality interviewee stated that they mostly use this type of tool to monitor the relationship between pipe pressure and pipe breaks. Increasing the pipeline pressure to a certain amount could result in an increase in the number of pipe breaks. Scatter diagrams are therefore particularly useful tools for detecting the amount of correlation, or the degree of linear relationship, between two variables for the municipal water distributors. The least popular graphical tools are the line graph and the tree diagram, as none of the four case municipalities use these tools.

iv. Use of data analysis tools

The most popular data analysis tool used by the municipal water distributors was the histogram. Histograms were used by all the eighteen municipalities from Case A to D. Interviewees said they used it to display varying data sets. The interviewees from all four case municipalities stated that the histogram makes it possible to identify problems which might not be obvious in the distribution network by visually displaying information.

Only the Windhoek municipality which falls under Case B, said they use Pareto diagrams to monitor maintenance activities. By reading results of a Pareto analysis, the technical staff of this municipality could easily communicate that during the last fiscal year their maintenance teams attended to more scheduled maintenance problems than unscheduled maintenance problems. The vital few problems which were always attended to as part of unscheduled maintenance are pipeline repairs, followed by pump and motor repairs. Pipeline repairs accumulated the greatest number of defects with respect to water distribution infrastructure problems for this municipality. No other municipality uses this tool.

Case A and Case B municipalities said they used control charts to evaluate whether a process is operating within expectations relative to some measured value. They mostly use control charts to monitor pump operational behavior and distribution system efficiencies.

According to the Tsumeb municipality who extract its own water from boreholes, the Water Resources Management Act of 2004, states that ownership of water resources in Namibia below and above the surface of the land belongs to the State. Therefore control charts are a necessary tool to prevent over extraction of water. One of the interviewees from the Case A, said control charts are a method that provides the earliest indication of a degrading equipment condition. Early indications of degrading performance can be investigated to determine the scope of required maintenance and the maintenance scheduled without a need for emergent work. Case C and Case D municipalities do not use control charts.

v. Use of decision making tools

Case A and Case B municipalities use decision making tools. The most popular decision-making tool used by theese municipalities is Net Present Value (NPV) calculation. This tool is said to help in making many maintenance decisions. The Windhoek (Case B) municipality use this tool to decide on whether to carryout preventive maintenance or non-preventive maintenance on their assets. They said the NPV is calculated by comparing repair, energy and replacement costs for preventive and non-preventive maintenance scenarios and bringing the costs to a present value using a discount rate. The preventive maintenance scenario value is subtracted from the non-preventive maintenance value. If the result is positive, performing preventive maintenance makes economic sense. If the value is negative, performing preventive maintenance is not justified economically.

The NPV is also used for making decisions on replacement assets to be purchased for maintenance works. Since the cost of operation can dwarf the original capital cost of the parts, a NPV calculation is an effective tool to evaluate the replacement costs based on cash outflows and inflows.

The other decision-making tool used by the municipalities is the Gantt chart. 50 percent respondents of Case B municipality said they use the Gantt chart as a decision making tool. The interviewees said this tool was useful for showing maintenance activities against time and the tool allows staff members to see at a glance what the various activities are, when each activity begins and ends and how long each activity is scheduled to last.

Case C and case D municipalities do not use any of these tools mostly because they do not know the tools and also do not know where and how to apply them.

vi. Use of process analysis tools

Only 50 percent respondents of Case B municipalities said they use process maps. According to interviewees from Case B, the primary tool for understanding processes is process mapping. Case B municipality members use process maps to show and explain how maintenance work is done especially during meetings and brainstorming activities.

The interviewees stated that the flow charts promote understanding of a process by explaining the steps pictorially. Maintenance staff may have differing ideas about how an operational process works. A flowchart can help them to gain agreement about the sequence of steps and also promote understanding in a way different from written procedures.

The Otjiwarongo municipality interviewee said the flow chart provides a tool for training employees mostly because these days most of the water supply equipment comes with operational and maintenance manuals. The flowcharts are used for training employees to perform maintenance processes according to standardized procedures.

According to the Windhoek municipality interviewee, the flow charts are used for identifying problem areas and opportunities for maintenance process improvement. Once the maintenance manager breaks down the process steps and diagram them, problem areas become more visible. It is easy to spot opportunities for simplifying and refining the process by analysing decision points and redundant steps. Case C and Case D municipalities do not use any process analysis tools.

vii. Use of quality control tools

The quality control tools used by the Case A and Case B municipalities are the checklist, inspections, housekeeping (5Ss), quality control audits and sampling. With respect to inspections, the interviewees stated that as the performance of the pumps and motors deteriorates over time, equipment efficiency decreases, power consumption goes up and operating costs rise. Therefore inspections which include condition monitoring are done by all municipalities. According to the Tsumeb municipality which supplies its own water, pumps are one of the most common rotating machines in a distribution system which require constant monitoring. If a pump fails, this can cause financial losses which can exceed the value of the pump many times over. This is why the availability of pumps is an extremely important factor, therefore inspections which include condition monitoring are of great importance in order to avoid potential pump damage due to unfavourable operating conditions such as dry run, cavitation, overload and incorrect direction of rotation. According to the interviewees, condition monitoring is normally used on rotating equipment and other machinery such as pumps and motors. Periodic inspection using non-destructive testing techniques is normally used for stationary assets such as pipelines, reservoirs and manholes.

Case B municipalities said they use the histogram to monitor the number of faults that happen on the pipeline components. The Windhoek municipality interviewees in particular said histograms provide a quick and easy way of showing a general trend with respect to the accumulating problems on pipeline components over a period of time. The number of maintenance related problems is collected for four consecutive business quarters. On the end of each quarter, maintenance related problems are systematically analysed in order to identify type and amount of maintenance related problems for the quarter in consideration. Also, the undertaken corrective and preventive actions are analysed to verify their effectiveness using the histogram. Furthermore, the number of specific issues repaired during the previous years or quarters can be collected and analysed and the histogram makes it easy to determine whether the problems are increasing or decreasing.

The Impact of the Application of QM Tools on NRW Generation

The extent to which the application of QM tools in water infrastructure maintenance affects the generation of NRW in Namibian municipal water distributors is not documented or known. This knowledge can help municipal water suppliers in managing their distribution networks as well as in the reduction of NRW generation.

The use of QM tools in reducing the NRW generation in Namibian municipalities can be a step in the direction of achieving the water supply and sanitation sector board’s recommendations. This section fulfils objective five that seeks to find out the extent to which the application of QM tools in water infrastructure maintenance affects the generation of NRW.

In order to fulfil this objective, a quantitative analysis utilizing data collected through questionnaire from Namibian municipalities was used. The regression analysis for quantity of water supplied, number of tools used and NRW produced was done. A summary of this data is presented in Table 6 below.

Table 6: Quantity of water supplied, number of tools used and NRW produced

Water System Name	System Input vol.	Authorised consumption	Total water loss	% loss	Number of tools used
Windhoek	18,842,529.00	16,204,574.94	2,637,954.06	14%	22
Walvis Bay	5,693,903.00	4,841,030.00	852,873.00	15%	13
Swakopmund	4,384,736.00	3,640,805.00	743,931.00	17%	13
Tsumeb	2,793,523.00	2,164,433.00	629,090.00	23%	5
Otjiwarongo	1,347,300.00	1,142,231.00	205,069.00	15%	13
Okahandja	1,294,181.00	880,043.08	414,137.92	32%	4
Grootfontein	162,388.62	116,919.81	45,468.81	28%	4
Karibib	304,055.19	234,122.50	69,932.69	23%	4
Keetmanshoop	1,704,882.00	1,106,240.00	598,642.00	35%	3
Mariental	878,972.00	765,808.00	113,164.00	13%	17
Gobabis	802,690.00	711,929.00	90,761.00	11%	18
Karasburg	250,323.00	203,323.00	47,000.00	23%	5
Omaruru	634,328.00	501,483.00	132,845.00	21%	4
Outjo	846,595.00	820,825.00	25,770.00	3%	4
Rundu	2,708,874.00	1,769,962.00	938,912.00	35%	2
Otavi	276,677.00	164,162.00	112,515.00	41%	3
Henties Bay	500,274.00	371,451.00	128,823.00	26%	6
Usakos	372,469.00	230,290.00	142,179.00	38%	3

The multiple regression analysis was done to assess the relationships among the three above stated variables.

Correlation Analysis Results

The correlation coefficient between the number of tools used by a municipality and the NRW generated was found to be -0.665. It is evident therefore that the number of tools employed by a municipality and the generation of NRW have an inverse relationship as reflected by the negative sign of the coefficient. However, since the coefficient is not close to a unit, it means that there is marginal correlation between number of tools used and NRW generation as this value was found to be -0.665. A correlation greater than 0.8 is generally described as strong, whereas a correlation less than 0.5 is generally described as weak (Bradfield, 2011). Table 7 below displays the results of the correlation analysis.

Table 7: Correlation Results

Correlation Statistics	
Multiple R	-0.665374771
R Square	0.442723586
Adjusted R Square	0.368420064
Standard Error	0.082287966
Observations	18

Regression Analysis Results

The regression analysis was used to determine how the independent variables that are number of methods employed and volume or quantity of water supplied to a municipality are related to the dependent variable which is the NRW produced. Table 8 below depicts the regression results.

Table 8: Regression Results

Regression Statistics	
Multiple R	0.665374771
R Square	0.442723586
Adjusted R Square	0.368420064
Standard Error	0.082287966
Observations	18

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	0.080691	0.04034557	5.9583122	0.01246034
Residual	15	0.101569	0.00677130		
Total	17	0.182260			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	1.73E-08	*Upper 95%*
Intercept	0.318825815	0.032456	9.82319605	6.32E-08	0.24964658	0.388005
Methods	-0.01281686	0.004067	-3.15110395	0.0065914	-0.0214863	-0.00414
Input vol	4.93E-09	5.82E-09	0.84789500	0.4098227	-7.47E-09	

Based on Regression analysis:

NRW produced = 0.318825815 - 0.01281686 * Number of methods employed + 4.93426E-09*Q water of supplied to a system

The study was interested in comparing the contribution of each independent variable therefore the standardized coefficients were used. The largest Beta value was number of methods employed with a value of (0.012). This means that this variable makes the strongest contribution to explaining the production of NRW by Namibian municipalities, when all the other values in the model are controlled for. The quantity of water supplied to a system's contribution is lower, (4.93E-9) meaning that it does not play as big of a role as number of methods employed.

The t-statistic was used to validate the outcome results of the model. The number of methods employed has a higher t-statistic value of (3.15) than that of quantity of water supplied to a system (t-statistic - 0.847). The t-statistic confirms the finidng from Beta value. Since, larger t-statistic represents better explanatory power of independent variable (Jaulin, 2010).

This section fulfills objective five which seeks to find out the extent to which the application of QM tools in water infrastructure maintenance affects the generation of NRW.

The fact that the impact of quality management tools and techniques in the maintenance function of Namibian municipal water distributors can be summarised by this model:

NRW produced = 0.318825815 - 0.01281686 * Number of methods employed + 4.93426E-09*Q water of supplied to a system

- means Namibian municipalities can use the model to interpolate and extrapolate the number of tools needed to limit the NRW produced for their water demands.
- The model is however limited due to the fact that it does not specify the exact tools to be used or added.

CONCLUSIONS AND RECOMMENDATIONS

Based on the findings of the research, it is concluded that the application of QM tools in the maintenance function of Namibian water distribution infrastructure helps in reducing the generation of NRW and statistical literacy is synonymous with the use of QM tools.

The study found that there is a marginal negative correlation between the use of QM tools and the generation of NRW. The negative correlation confirms that the application of QM tools has a positive impact on the reduction of the generation of NRW. This is interpreted to mean that as the number of QM tools employed to analyze maintenance data by a municipality increases, the generation of NRW by municipality decreases. However for the tools to be effective, they should cover various applications such as problem identification, data analysis, process analysis, decision making, planning, quality control and statistical process control, as demonstrated by Namibian municipalities which produce low volumes of NRW. Arbitrary selection and use of QM tools with limited applications does not yield desired results as demonstrated by the high quantities of NRW generated by the poorly managed municipalities. It can also be concluded that the Namibian municipalities select and use QM tools because they perceive them to be useful.

Furthermore, statistical literacy is identified as playing a significant role in the selection and application of QM tools as observed from the municipalities which produce low volumes of NRW. These municipalities recruite Maintenance managers who have an engineering background and knowledge in QM tools and techniques, while municipalities which produce high quantities of NRW recruite Maintenance managers having no engineering background and little knowledge in QM tools and techniques. The research also concludes that, the application of QM tools in Namibian municipalities is still under exploited considering that there are over 100 QM tools available for use, while the 18 Namibian municipalities use an average of 8 QM tools.

Contribution to Knowledge

This study is the first study in Namibia that focuses on the effects of quality management tools and techniques in the maintenance function of Namibian municipal water distributors.

Theoretically, the significance and importance of this research is clear for the fact that the results generated were consistent with the other studies from different contexts. For example, Amjad's (2012) study concluded that the use of QM tools and techniques has positive effects on business performance. Gadenne and Sharma (2009) used a questionnaire to investigate the key soft and hard QM tools and techniques used by Australian SMEs. They found that performance was affected by soft as well as hard QM tools.

This study has reinforced the fact that the use of QM tools improves the maintenance processes. This research also confirms the fact that QM tools and techniques are a driver in the reduction of NRW generation in the Namibian municipalities. The municipalities which use a few tools and techniques produce high quantities of NRW, while those that use a large number of tools and techniques produce less quantities of NRW.

Recommendations for Further Research

The major direction for further research is using the theoretical framework of this study with other organisations. Further studies can replicate this work with similar organisations in different countries in order to conduct a comparative analysis to facilitate the development of greater understanding of the issues that have been investigated. The similarities and differences of contexts would provide further explanation of the working of municipal water distributors across different countries.

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