Development and Implementation of an Open-Source Based Internet Accessible Water Quality Management System for Improving the Quality of Water Services in South Africa

Philip de Souza[1], Allestair Wensley[2], Leonardo Manus[3], Eddie Delport[4], Frank Stevens[5], Grant Mackintosh[1] and Mzi Ramba[1]

[1]Emanti Management, PO Box 1264, Stellenbosch, South Africa, 7599 (E-mail: info@emanti.co.za)
[2]Department: Water Affairs and Forestry, Private Bag X313, Pretoria, South Africa, 0001 (E-mail: allestairw@dwaf.gov.za)
[3]Department: Water Affairs and Forestry, Private Bag X313, Pretoria, South Africa, 0001 (E-mail: manuslev@dwaf.gov.za)
[4]Institute of Municipal Engineering of Southern Africa, PO Box 2190 Westville, South Africa, 3630 (E-mail: eddiedel@sun.ac.za)
[5]Institute of Municipal Engineering of Southern Africa, PO Box 2190 Westville, South Africa, 3630 (E-mail: frankst@dmws.durban.gov.za)

Abstract

South Africa, like many developing countries, faces significant challenges in the sustainable provision of adequate and safe water services. South Africa's Water Services Act of 1997 stipulates the standard of service provisioning, and specifies the responsibility of the Water Services Authority (WSA) (municipality) including operation and maintenance of infrastructure, monitoring and management of drinking water quality, etc. In order to ensure an effective and sustainable water service, the above mentioned aspects must be addressed by WSAs. Many municipalities, however, continued to have inadequate water treatment and associated water quality management practises in place; both as effects the provision of safe drinking water and the controlled discharge to environment of treated effluent. As the water services sector leader and national regulator, the national Department: Water Affairs and Forestry (DWAF) is proactively deploying a range of supportive initiatives in order to support municipalities to remedy the situation. The Institution of Municipal Engineering of Southern Africa (IMESA) is a voluntary professional association, assisting the municipal engineering sector through various sector initiatives. This paper reports on the significant progress made in a joint DWAF/IMESA initiative to support municipalities in the function of effective Water Quality Management through the national deployment of a web-based electronic Water Quality Management System.

1. Background

South Africa, like many developing countries, faces significant challenges in the sustainable provision of adequate and safe water services. South Africa's Water Services Act of 1997 stipulates the standard of service provisioning, and in particular specifies the responsibility of the Water

Services Authority (WSA) (municipality). One of the main goals for Water Services Authorities is to ensure access to safe and reliable water services to all communities (Hodgson and Manus, 2008) including operation and maintenance of infrastructure, monitoring and management of drinking water quality, etc. In order to ensure an effective and sustainable water service, the above mentioned aspects must be addressed by WSAs.

As very few WSAs have satisfactory drinking-water quality monitoring programmes and even fewer utilise the data as intended, and in order to drive improvement, DWAF and other water sector partners have undertaken various initiatives to assist WSAs with operation and management of water services, including development of a National Drinking-Water Quality Management Framework for South Africa (DWAF, 2005). In particular, it was evident that a need existed for a drinking-water quality data capture and information dissemination tool, which will both assist WSAs to meet their responsibilities, and meet DWAFs needs to monitor and regulate the operation of WSAs in a proactive cooperative governance fashion. Consequently DWAF, together with the Institute of Municipal Engineering of Southern Africa (IMESA) have rolled out an internet-based Water Quality Management System (eWQMS) to all 166 WSAs in South Africa (Stevens et al, 2008,). The purpose of the eWQMS initiative was to provide WSAs with a tool which will allow effective drinking-water quality management, and serve as an information conduit which would provide DWAF with credible information for effective regulation (Manus and Hodgson, 2008).

This paper will highlight key elements of Municipal Water Quality Management in South Africa, the open-source nature of the eWQMS, various features and functions of the eWQMS, with focus on how outputs from the system are being used for indicating performance at WSAs and driving progressive improvement.

2. Essential Elements Of Municipal Water Quality Management

Studies have shown that water quality management related weaknesses in South Africa include (Mackintosh *et al*, 2004):

- Inadequate monitoring (i.e. water treatment plant and within networks)
- Lack of well structured maintenance (crisis management basis)
- Lack of management awareness and buy-in
- Lack of capacity to perform water quality management functions
- Lack of budget for water quality management at all levels
- Lack of structured programmes to deal with water quality issues

In order to address the above limitations, the DWAF/IMESA initiative focused on rolling-out the electronic Water Quality Management System (eWQMS) developed an appropriate mode of engagement with WSAs (Mackintosh et al, 2007).

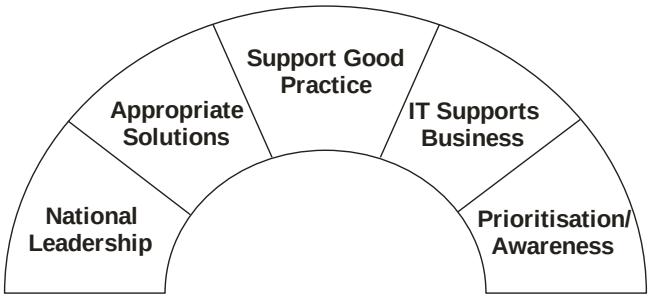


Figure 1: Effective Municipal Engagement Arch

The engagement model that has been utilised can be represented as an arch made of five blocks. Each part of the arch is an aspect that can help or hinder the achievement of sustainable municipal WQM, as follows:

- National leadership (clear and effective leadership, guidance and support from DWAF)
- Municipal appropriate solutions ("bottom-up" inputs via WSAs and not "top-down")
- Support existing good practice (positively engage good practice and develop towards full legislative compliance)
- IT supports business (tool introduced must provide positive value to municipal users)
- Prioritisation of municipal Water Quality Management (what is needed and where is it needed)

In order for municipalities to improve water quality related performance, it is essential that municipalities have the ability to learn and understand, and are able to utilise information to formulate strategies and implement actions to address issues of concern. Experience has shown that if a municipality is to achieve optimum water quality performance, it will need to advance via a stepwise process. A five step Business Capability Model is presented as follows (adapted from Ingham, 2007):

- **Step 1: Unconscious incompetence (unaware)** – the municipality is unaware of what they don't know (i.e. they do not know the requirements for effective water quality management)
- **Step 2: Conscious Incompetence (aware)** – the municipality is aware of what they don't know (i.e. the municipality is ignorant and they are aware of their ignorance). The municipality now knows the basics of water quality management but is unsure of how to practically implement a water quality management programme or respond to issues of concern.
- **Step 3: Conscious Competence (practice)** – the municipality is aware of how to do things properly (i.e. the municipality has the ability to do something but they have to concentrate on doing it properly). The municipality implements a basic water quality management programme and starts to practice identifying and resolving issues of concern.
- **Step 4: Unconscious Competence (habit)** – the municipality is unaware of how they do the things they know how to do (i.e. the municipality does things without even thinking about it). At this stage the municipality (and especially the staff comprising the water quality team) automatically responds to and resolves issues of concern. The municipality is also striving to continuously improve and would like to benchmark its performance vs. other

municipalities.

- **Step 5: Mastery** – this would apply to a municipality that has taken a step further than unconscious competence and has optimized the total water management cycle within its area of jurisdiction. Municipalities at this stage are very proactive, identify issues, formulate strategies to close any gaps and timeously resolve issues.

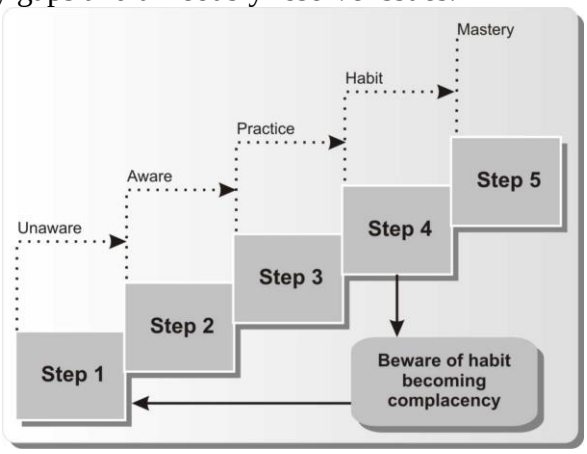


Figure 2: Five step Business Capability Model for achieving optimum water quality performance (adapted from Ingham, 2007)

Although experience has shown that each municipality in South Africa can be considered unique, it is hypothesized that all municipalities will need to follow the above steps to master water quality management. Bearing the above in mind, the paper will focus on how the eWQMS has assisted municipalities (at each of the various stages) to achieve improve water quality performance.

3. Electronic Water Quality Management System (eWQMS)

Considering the Municipal Engagement Model (Figure 1) and the Business Capability Model (Figure 2), it is clear that any information management system implemented to improve the current situation in South Africa should therefore:

- Ensure raised awareness (this should lead to increased budget allocation and improved water quality)
- Build on existing Good Practice (i.e. not be counter-productive, instead add value) (e.g. link to existing systems/Laboratory Information Management Systems)
- Bottom-up approach – i.e. the system must be useful to municipalities (e.g. provision of monthly reports, notification of issues of concern)
- The system must be easy to use, robust, reliable and low cost (preferably Free Open Source Software based to prevent payment of high software licenses by municipalities)
- Enable intervention in areas facing public health threats
- Provide strategic data to municipalities, DWAF, other role players, etc
- Satisfy municipal Governance Requirements
- Support DWAFs regulatory function and other role player requirements
- Undergo iterative enhancements via municipal and sector feedback

The above key aspects have been incorporated into the development of the eWQMS. The eWQMS is a novel Open Source Software based system which is able to guide (i) regulatory compliance by WSAs, (ii) the timeous supportive intervention in water quality failures, (iii) infrastructure improvement, and (iv) capacity development of municipal staff. The eWQMS is accessible via the internet (www.wqms.co.za), and is a very useful means for allowing a range of participating parties (including Water Service Authorities, Provincial and National Government, etc) to guide the tracking, reviewing and improving of water quality. Importantly, the eWQMS has been developed in a "bottom up" approach with WSAs, IMESA, DWAF and the Water Research Commission. Features of the eWQMS include (a) *Management Dashboard* (highlights sample sites satisfying and/or failing drinking-water quality requirements), (b) *Compliance Overview* (summary of legislative compliance), (c) *Data Analysis* (dynamically generate tables and graphs), (d) *Reports* (archive of water quality management reports), (e) *Monthly Summary Reports* (automatically generated reports), (f) *Information* (drinking-water related information and references), (g) *Infrastructure* (capture details of water system infrastructure), (h) *Administration* (configure and manage system set-up) and (i) *Risk Toolbox (*WSAs can perform a self-assessment of the status of DWQM Programmes, water supply system infrastructure, etc).

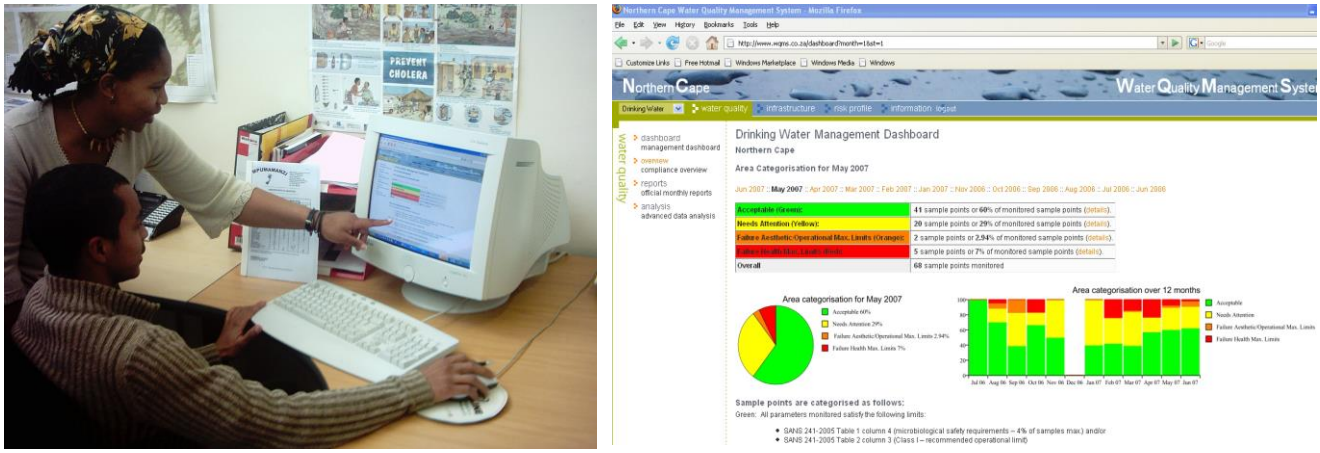


Figure 3: eWQMS users examine the Management Dashboard screen, both highlighting compliance and drawing attention to health threats

A key yardstick as to successful implementation is the extent to which water quality data flows onto eWQMS. The figure overleaf shows the progress achieved and the current participation rate as regards monthly data submission by WSAs (municipalities). In particular, for July 2008, 152 out of 166 WSAs in South Africa (i.e. 92%) submitted data to the eWQMS before the cut-off date for reporting purposes.

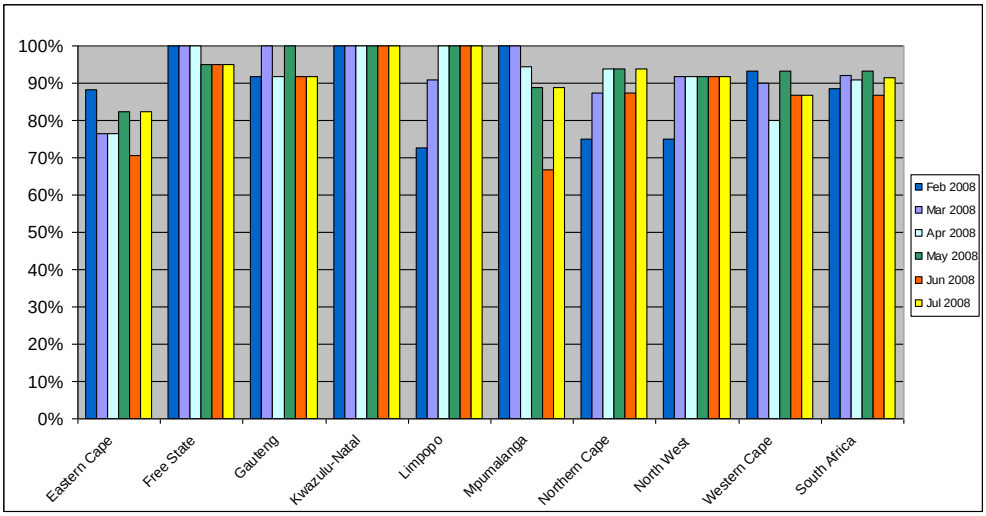


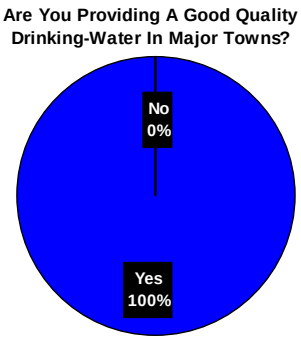
Figure 4: WSAs in South Africa loading drinking-water quality data onto the eWQMS

4. Demonstration Of Derived Benefits From Using The Internet Accessible eWQMS

Considering Figure 2 in Section 2, the following section will demonstrate the various steps of water quality management competence in municipalities, and include examples of how the eWQMS has assisted municipalities.

4.1 Step 1: Unaware

In order to improve water quality management, municipalities must be aware of the requirements for effective water quality management ("they don't know that they don't know"). This lack of awareness/knowledge was clearly evidenced during initial piloting and roll-out of the eWQMS, where by way of example, in 2004 in the Western Cape (a province in South Africa), a study of drinking-water quality management yielded the following key outputs (see figure below).



Drinking Water Quality Summary

Bacteriological :: Physical :: Chemical

	Total Coliforms		Faecal Coliforms	
Area	Samples	Compliance (%)	Samples	Compliance (%)
Western Cape (Masibambane)	***162***	***58***	***162***	***81***
Boland DM	30	47	30	90
Central Karoo DM	24	58	24	67
Eden DM	48	71	48	85
Overberg DM	30	53	30	73
West Coast DM	30	53	30	83

Figure 5: Results obtained from drinking water quality monitoring and management study and associated audit of drinking-water quality

The above figures clearly highlight that although the municipalities stated that they were providing a drinking-water of good quality to consumers, the statement was in strong contrast to the actual results, which showed only 58% compliance with regards to total coliforms (a bacteriological indicator of treatment efficiency) and only 81% compliance with regards to faecal coliforms (a

bacteriological indicator of health risk). South African drinking-water quality standards at the time of the study required 96% compliance with regards to both parameters for a drinking-water to qualify as "good". In addition, and of great concern was that a large proportion of municipalities (31%) were unaware of the drinking-water quality standards that needed to be maintained.

Similar findings were prevalent in other provinces of South Africa. To improve awareness, DWAF has implemented many water quality monitoring and management related initiatives (workshops, training material and sessions, conferences, etc). In conjunction, the eWQMS has supported improved awareness through discussions at forums, training at workshops, use of easy to understand colour coding highlighting issues of concern, indicating progress regarding data submission, the provision of water related information (e.g. guidelines for managing water system infrastructure, water quality parameters, their effects and how to rectify issues) and references (e.g. National Water Act, Water Services Act, National DWQM Framework, etc) (see figure below).

The approaches utilised (the eWQMS and other DWAF based initiatives) has lead to significant improvement in water quality monitoring and management awareness throughout South Africa.

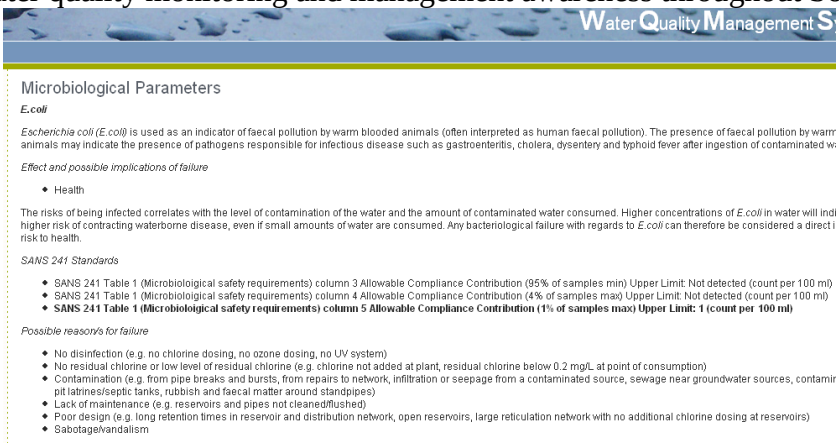


Figure 6: Information page explaining the significance of *E.coli* and its effects, the applicable standards and possible reasons for failure

4.2 Step 2: Aware

Even though WSAs become aware, they probably do not know what exactly is required from them, and thus the eWQMS has been configured to assist with this. Not only does the eWQMS make WSAs aware of the minimum water quality monitoring requirements (e.g. What parameters should be monitored? How many samples should I collect?) (see Figure 7 overleaf), it also immediately tracks the status of data loaded onto the eWQMS vs. applicable water quality standards, with the eWQMS making use of summarised views (graphs and tables) of data which are colour coded to assist with interpretation and identifying issues of concern (for example, GREEN = Acceptable, RED = Poor) (see Figure 8 overleaf). The eWQMS has therefore assisted the water sector to speak a common language ("I see you had two "REDs" last month – what did you do to rectify the issue?").

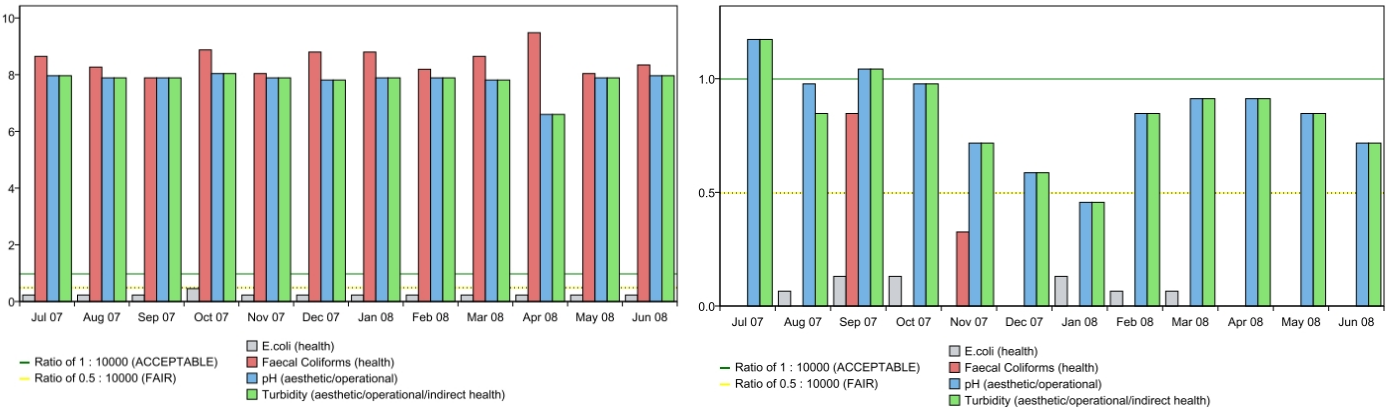


Figure 7: *Comparison of samples collected in two WSAs highlighting good practice (left) versus poor practice (right) (e.g. consistent monthly collection of sufficient samples for minimum required parameters versus the need for more consistent monitoring and improved bacteriological monitoring – i.e. "straight line" versus "waved" bar graph)*

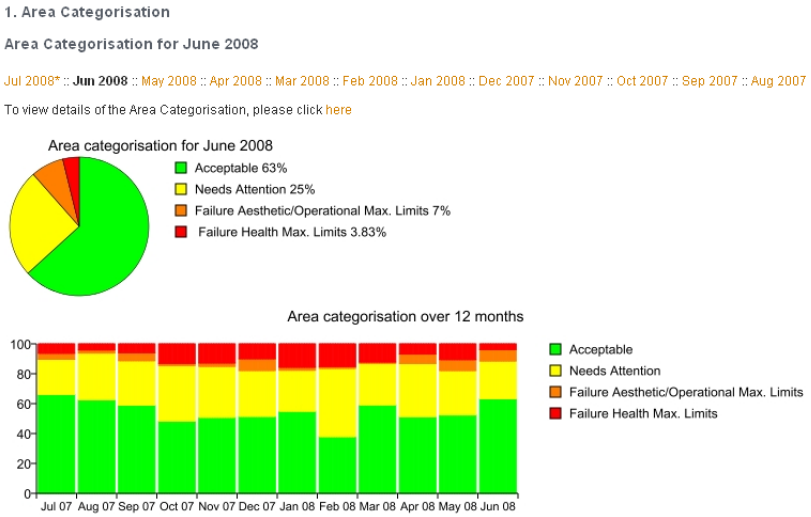


Figure 8: *Management Dashboard for Northern Cape highlighting colour coding* (e.g. RED = health related issue)

In addition, as municipalities are often poorly capacitated, and to assist municipalities with communication, a monthly summary report is automatically generated by the eWQMS. This report is also communicated to other sector stakeholders so that they are aware of issues of concern.

Although these outputs make the WSA aware of the main water quality challenges they face, it does not, however, guarantee that they utilise the information effectively. In order to address the above, the WSA needs to become more comfortable with water quality management and identify the underlying causes of issues. For this to occur, the WSA needs to practice (Step 3).

4.3 Step 3: Practice

Practice includes both effective monitoring and associated management, and utilising the various graphical and tabular outputs from the eWQMS to further investigate and address key issues of concern. At present, many municipalities do not do day-to-day operational monitoring (e.g. daily

checks of pH, turbidity, electrical conductivity, free chlorine residual and adjustment to ensure effective operation), and most municipalities do not use all the eWQMS features, with use largely limited to the automatically generated outputs (e.g. Management Dashboard, Compliance Overview, Reports). The use or lack of use of the more advanced features of the eWQMS (e.g. Analysis) provides an indication of the water quality management status of the municipality, with water quality management champion municipalities utilising a greater range of the available features. Importantly, technical staff utilise these outputs to track issue resolution and to convey to top management where an issue has been successfully addressed and resolved (i.e. they form good habits – Step 4) (see Figure 9 below).

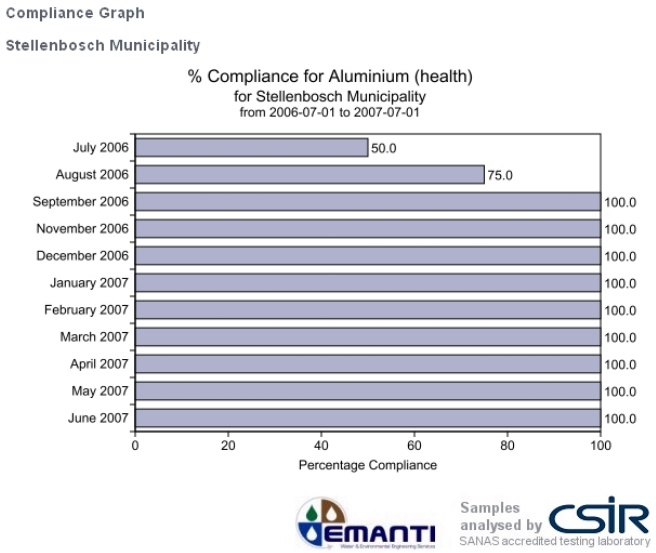


Figure 9: High residual aluminium values identified through monitoring were resolved (through improved pH control) and have continued to be non-problematic

4.4 Step 4: Habit

Through use of the eWQMS good habits can be grown. By way of example, the monthly summary report is automatically generated on the 15th of every month (e.g. July 2008 report was generated on the 15th August 2008). In order for the municipality to obtain an automatic report (which saves them time and effort), they need to load data onto the eWQMS before the end of the 14th. This incentive has been very effective, with some 92% of municipalities loading data before the cut-off date for the July 2008 report. In addition, once municipalities are more familiar with water quality management aspects, they increasingly want to meet stipulated minimum requirements and improve performance (i.e. they begin to become champions). In order to assist, an "audit" of the current municipal water quality management programme is automatically displayed on the eWQMS (see Figure 10). In addition, municipalities develop a need to benchmark their performance versus other municipalities, and therefore the eWQMS has been configured to contain benchmarking elements (see Figure 11 below). This information is used to indicate to Municipal Council the status of the municipality (above/below national average), indicate how funding has been used to improve performance, etc.

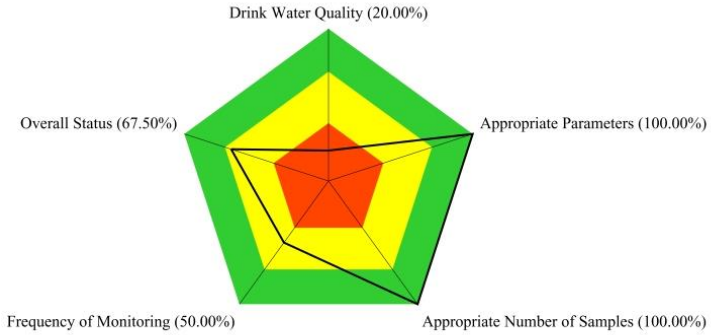


Figure 10: Water quality monitoring programme assessment, highlighting key issues as drinking-water quality and frequency of monitoring (RED/YELLOW on the diagram)

Drinking Water Quality Summary

Microbiological Safety :: Microbiological Operational :: Physical :: Chemical

Configure Parameters			Faecal Coliforms (health)		E.coli (health)	
Area	Population	Min Samples	SampleCount	Compliance %	SampleCount	Compliance %
South Africa	*48606643*	*58328*	*13265*	*98.0 (view)*	*30686*	*96.0 view*
Western Cape	*5083373*	*6100*	*1814*	*98.0 (view)*	*3746*	*95.0 view*
Drakenstein Municipality	*213914*	*257*	*181*	*100.0 view*	*525*	*100.0 view*
Gouda	0	0	4	100.0 view	12	100.0 view
Hermon	0	0	7	100.0 view	23	100.0 view
Paarl	0	0	108	100.0 view	321	100.0 view
Pearl Valley	0	0	4	100.0 view	12	100.0 view
Saron	0	0	10	100.0 view	26	100.0 view
Simondium	0	0	4	100.0 view	12	100.0 view
Wellington	0	0	44	100.0 view	119	100.0 view
Data Period	2006/11/01 to 2007/11/01					

Figure 11: Overview screen indicating (i) performance of municipality vs. provincial and national performance and (ii) recommended minimum number of samples that should be collected

A key concern related to Step 4 (Habit) is municipal complacency, where for example, a single individual is responsible for water quality management functions within the municipality. Where this person is ill or leaves the organisation, a gap immediately exists. This can literally turn a champion municipality into a struggling municipality overnight. Through storage of other water services related information on the eWQMS (e.g. not only water quality data but sample point locations, infrastructure types, laboratory information, etc), a municipality can maintain knowledge within the organisation, thus minimising disruptions as a result of staff migration. This information also assists with mentoring of junior staff.

4.5 Step 5: Mastery

Although the metropolitan municipalities and some of the better resourced local municipalities may argue that they have already "mastered" water quality management, investigations have revealed that this might not be the case. It is therefore argued that within the South African context, the vast majority of WSA are at best at Step 4 (Habit). With increased competence in water quality management is the desire to perform strategic assessments to identify key gaps that need to be addressed to optimize water services. The eWQMS has started to address this need, and currently

contains a number of risk based assessment tools, which can be used by WSAs to conduct self-assessments of infrastructure (e.g. Water Research Commission Supply System Assessment Tool, Water Research Commission Wastewater Ponds Assessment Tool), water quality management programmes, etc. The outputs from these tools should be used to draft Action Plans, so that the WSA can master water quality management within its area. By way of example, a Strategic Assessment of Water Quality Management (Gap Analysis) has been conducted for all WSAs in South Africa in both 2006 and 2007. The Strategic Assessment identifies the requirements for sustainable water quality management and considers the following six aspects: (1) Water Legislation, Policies and Regulations; (2) Water Resources and Water System Infrastructure; (3) Water Quality Monitoring, Laboratories and Logistics; (4) Human Resources; (5) Management; and (6) Finances. In the Northern Cape, no improvement between 2006 and 2007 was noted in four of the above six categories. However, significant improvement was noted in both Category 1 (the understanding of water quality requirements) and Category 3 (performing the water quality monitoring function) (see Table 2 below). By way of example, the improved performance in drinking-water quality monitoring at a particular WSA in the Northern Cape, namely Kamiesberg Municipality is also highlighted (see Figure 12).

Table 2: Improved understanding of water quality requirements in the Northern Cape

	Water Legislation, Policies and Regulations				Drinking Water Quality Monitoring, Laboratories and Logistics			
	Acceptable	Marginal	Poor	No Data	Acceptable	Marginal	Poor	No Data
2006	25%	22%	47%	6%	6%	25%	63%	6%
2007	53%	25%	22%	0%	28%	66%	6%	0%

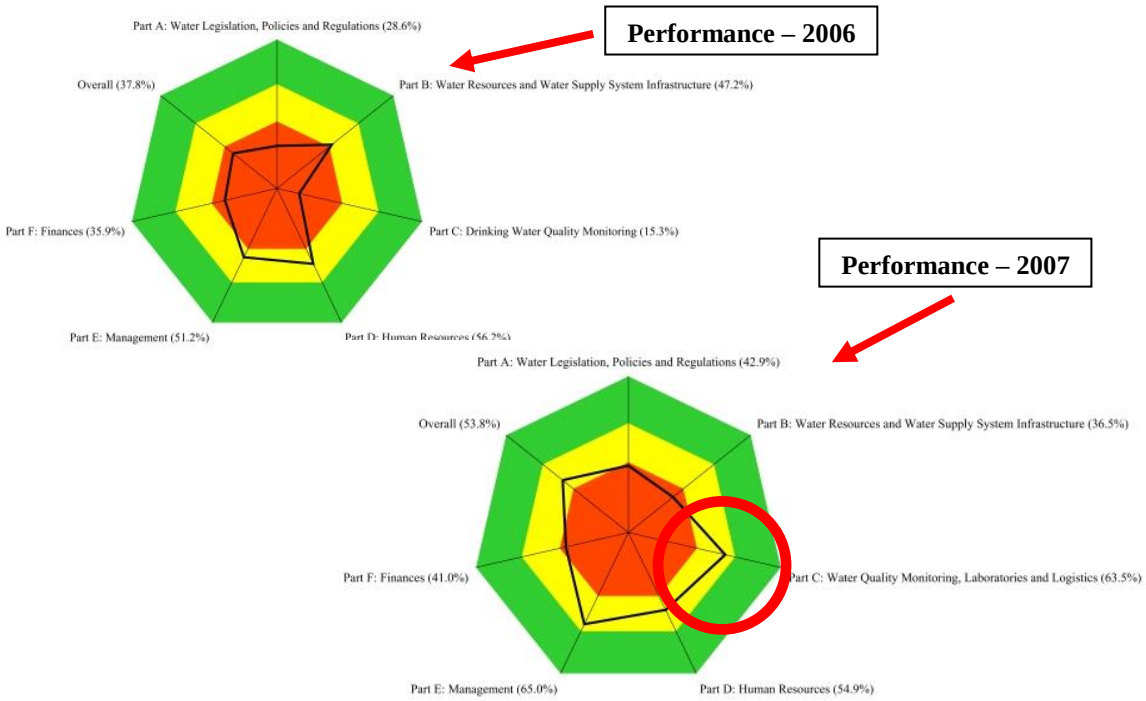


Figure 12: Improved water quality management performance at Kamiesberg Municipality

5. Conclusions

The implementation of the web-based Water Quality based Performance Management System for Local Government in South Africa has:

- Created improved awareness of the requirements for effective water quality monitoring and management
- Driven progressive improvement in water quality
- Provided real-time reporting of water quality by municipalities
- Enabled early intervention in areas facing immediate public health threats
- Provided strategic data and information related to the quality of water services

Of importance to note, however, is that the use of eWQMS alone cannot solve issues, and a number of key factors are also required, including awareness and prioritisation (from Mayor to Technician), on-going communications between role players, operational test equipment and proficiency therewith, water quality data collection and assessment, and ongoing support and interaction.

Through use of the eWQMS, however, municipalities are made more aware of issues of concern which therefore assists with directing limited resources to areas of need. Thus by using the system significant improvements in water quality can be achieved despite little or no additional capacity. By simply having a structured water quality sampling programme and working "smarter" with better information, municipalities become more effective and thus make better use of the capacity it already has. Therefore, by using the eWQMS to its full potential, municipalities in South Africa will be empowered to master water quality management.

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