

**PERFORMANCE OF THE PILOT-SCALE MULCH TOWER SYSTEM IN
TREATMENT OF GREYWATER FROM A LOW-COST HOUSING
DEVELOPMENT IN THE BUFFALO CITY, SOUTH AFRICA**

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ABSTRACT

The pilot-scale mulch-tower systems with resorption beds (the MT-RBs) for greywater treatment became operational in six low-cost houses in Buffalo City Municipality, South Africa in February 2009. Treated greywater was used for groundwater recharge. Residents of the houses were in charge of the day-to-day operational maintenance of the MT-RBs. The municipal officials were responsible for project oversight and major repairs. The authors performed the chemical and microbiological analyses; and provided technical advice. Treatment performance and biomass composition of the MT-RBs were monitored between February and May 2009, and in August 2010. In 2009, 33 % of the MT-RBs were in good overall physical condition. Clogging of and bursting of pipes did occur on several occasions. The average concentrations of faecal coliforms, the total bacteria, the total fungi and the total actinomycetes in the mulch dry matter were (in 10⁶ CFUs/gram dry matter): 0.05 to 2.71, 5.0 to 72, 0.24 to 570 and 0.075 to 350, respectively. Mulch layers in MT-RBs contained cockroaches (*Periplanetta americana*, *Blatella germanica*), spiders (*Smeringopus pallidus*, *Laterodectus geometricus*), mothflies (*Psychodidae* sp.), sap beetles (*Nitidulidae* sp.), and slugs (*Deroceras laeve*, *Lehmanna* sp.). No pest infestations of the houses or evolution of odours were observed. There was limited removal of COD, NO₃⁻, PO₄³⁻, SO₄²⁻ or faecal coliforms from greywater. Complete breakdown of all MT-RBs was observed in August 2010. Reasons for treatment breakdown and possible remedial strategies are discussed.

Keywords: greywater treatment, mulch tower, municipal compliance, South Africa

1. INTRODUCTION

United Nations Millennium Development Goal (UNMDG) 7A is aimed at ensuring environmental sustainability, while the UNMDG 7B is designed to halve the number of people without sustainable

access to safe drinking water and basic sanitation by 2015 (UNMDG [1]). Significant improvements in this context have been recorded since 1994 and the onset of democratic government in South Africa. Between 2002 and 2010, the percentage of the population in South Africa which had access to the piped and tap water on-site (at the dwelling) or off-site (from a public tap within 200 m of the dwelling; or from a neighbours tap or borehole) increased from 84.5 to 89.3 % of the population (Statistics South Africa [2]). This has led to a significant improvement of the hygienic situation in the country as the average risk of contraction of diarrhoeal diseases among children under 5 years of age decreased from 17.8 in 2002 to 11.2 % in 2010 (HST [3]). Migration of population into urban areas led to a substantial increase in the building of informal settlements, but even then 96 to 98 % of the population living in this type of had access to safe (drinking) water by 2010 (Statistics South Africa [4]).

In spite of these achievement problems in water delivery still exist. Pipe bursts are common at the household level (PMG [5]), and the insufficient maintenance often limits the usability of communal drinking water taps (Haarhoff et al. [6]). Water-treatment works are often not operated properly which leads to production of drinking water with high levels of microbial contamination (Momba et al. [7]). At the same time, water supply interruptions at the household level were experienced by up to 47.6 % of households in South Africa in 2010 (Statistics South Africa [4]). The number of deaths from intestinal infectious diseases has increased from 14276 in 2000 to 39568 in 2006 (Statistics South Africa [8]). Even though a slight decline followed to 37398 in 2007 (Statistics South Africa [8]), overall there is an increasing trend in this parameter in the past decade. Partial unreliability of the supply of drinking water is one several reasons for this observation, but others are also important.

The first one is the number of the HIV-positive citizens which increased in South Africa from an estimated 4.21 million in 2001 to the estimated 5.38 million in 2011 (Statistics South Africa [9]). If patients become HIV-positive they are more prone to contracting waterborne diseases, such as from *Campylobacter jejuni* (Obi and Bessong [10]). Therefore, among other reasons, they require a permanent access to a safe supply of drinking water to prevent occurrence of opportunistic infections (Laurent [11]). Other reasons, which also make the general population more prone to intestinal diseases, include contamination of the food supply (Gadewar and Fasano [12]) and inadequate sanitation provision (Ashbolt, [13]). The latter reason is explored more in detail in the following paragraph.

By 2009, only 69 % of the South African population gained access to basic sanitation (Statistics South Africa [4]). In the Eastern Cape Province, proportion of the population with no access to sanitation facilities or who were still using the sub-standard bucket toilets dropped from 36.4 to 16.8 % between 2002 and 2010 (Statistics South Africa [2]). However, even if the sanitation infrastructure is in place, or is to be installed, maintenance operations are often not carried out or are irregular (SALGA [14]), which can have a detrimental effect on the health of the population. Part of a well-run sanitation infrastructure is availability of facilities for safe disposal of greywater, i.e. domestic wastewater without any input from toilets (Carden et al. [15]). Greywater of mixed origin is produced under such circumstances, carrying high concentrations of indicator microorganisms and opportunistic pathogens (Carden et al. [15]; Tandlich et al. [16]). It contains easily degradable organic matter that can result in microbial re-growth (Merz et al. [17]). Exposure to greywater by the general population in these circumstances could lead to outbreaks of diarrhoeal diseases.

Microbial re-growth and biodegradation of greywater components decrease the concentration of dissolved oxygen in greywater, resulting in the evolution of odours (Finley et al. [18]) and promotion of mosquito breeding (Arjun et al. [19]). Mosquitoes are vectors for the spread of malaria and other diseases. Greywater has also been shown to contain heavy metals and up to 900 xenobiotics (Eriksson et al. [20]). If sanitation infrastructure is lacking, as happens in informal settlements in South Africa,

then greywater is disposed off in soakaways on the ground (Carden et al. [15]). Similar situation can be encountered when the maintenance of sanitation infrastructure is poor and blockages are common. This leads to surface runoff or greywater infiltration into the soil profile, i.e. potentially leading to contamination of surface water and groundwater resources. Therefore safe management strategies for greywater disposal must be developed.

In 2005, the greywater treatment pilot project was initiated at Scenery Park (Buffalo City Municipality, the Eastern Cape Province, South Africa) as part of a bigger drive to develop concepts for ecological sanitation and low-cost housing. The original design and process principle for a three-step greywater treatment system was developed by Peter Ridderstolpe from WRS Uppsala Inc. (Ridderstolpe [21]). A laboratory-scale mulch tower system (MT) was tested for treatment of greywater of mixed origin between 2006 and 2007 (Zuma et al. [22]). Removal efficiencies of 24 to 28 % were observed for the chemical oxygen demand (COD), NO_3^- and S^2 ; and 52 % of the total suspended solids (TSS; Zuma et al. [22]). The main problems included highly variable phosphate removal and the lack of removal of indicator microorganisms. This could be related to the concentrations and composition of the active biofilm, thus requiring biomass composition characterisation which has not taken place until the current study.

In 2008, pilot-scale MT-RBs were built in six low-cost houses at Scenery Park. On-site, verbal instructions and demonstration about the operation and maintenance of the MTs were provided to the houses' occupants by the municipal officials and the authors. After this the house occupants were in charge of day-to-day maintenance, while municipal officials were responsible for project oversight, through biweekly site visits, and major repairs of the MT-RBs. The authors performed the chemical, microbiological and entomological analyses; and provided technical assistance upon need. Performance of the MT-RBs could only be properly assessed once the low-cost houses have been connected to the municipal water supply, which happened on 1st February 2009. The treatment performance and biomass composition of the MT-RB were therefore monitored from February until May 2009, and again in August 2010, and results are reported here.

2. MATERIALS AND METHODS

2.1 Chemicals and consumables

The following chemicals and consumables were purchased from Merck (Pty.) Ltd. (Johannesburg/Cape Town, South Africa): KH_2PO_4 , Na_2HPO_4 , KNO_3 , NaCl , phenol, HCl (32 % aqueous solution), COD reagents, Na_2SO_4 (95-98 % aqueous solution), glycerol, $\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$, the phosphate kit (catalogue no. 1.14848.0001), m-FC agar, nutrient agar, potato-dextrose agar and components of the actinomycetes plate count agar (APHA [23]) and the one-quarter-strength Ringer solution, except for cycloheximide and bacteriological agar. The following chemicals were purchased from Sigma-Aldrich (Johannesburg, South Africa): cycloheximide, bacteriological agar, 500 mL autoclave-able polyethylene bottles and 250 mL wide-mouth plastic jars for invertebrate sample collection. Ethanol and HNO_3 were purchased from Chemstores (Rhodes University, Grahamstown, South Africa). The following consumables were purchased from EC Labs (Port Elizabeth, South Africa): nylon membrane filters for membrane filtration in bacterial enumerations (pore size 0.45 μm) and the ninety-millimetre sterile Petri dishes. The glass fibre filters (pore size 11 μm) for the determination of TSS were purchased from Microseep (Port Elizabeth, South Africa).

2.2 The MT-RB system

Schematic representation of the MT-RB is shown in Fig. 1. The mulch tower (MT) contained the mulch and the coarse gravel layers. Treatment of greywater was based on the straining, sorption and biodegradation of organic matter in the MT and biofiltration in the geotextile (upper) wing of the resorption bed (RB). Composition of greywater should lead to selection pressure on the structure of biomass inside an MT-RB. Therefore it is likely that the microbial biomass will be able to remove surfactants and other organic compounds by biodegradation and bioaccumulation. At the same time, the biomass can serve as a sorption matrix for any metals present in greywater.

Treated greywater percolated down the soil profile for groundwater recharge. Drainage of the treated greywater into the soil profile should allow immobilisation of any residual phosphorus from the treated greywater. The physical condition of each of the six MT-RBs was assessed according to a pre-defined check list. Treatment performance of the MT was tested by obtaining samples of the untreated greywater (the influent) and the treated greywater (the effluent). Biomass composition of the mulch layers was analysed by enumeration of faecal coliforms (FC), the total bacteria (TB), the total fungi (TF) and the total actinomycetes (TA); as well as qualitative analyses of macroinvertebrates.

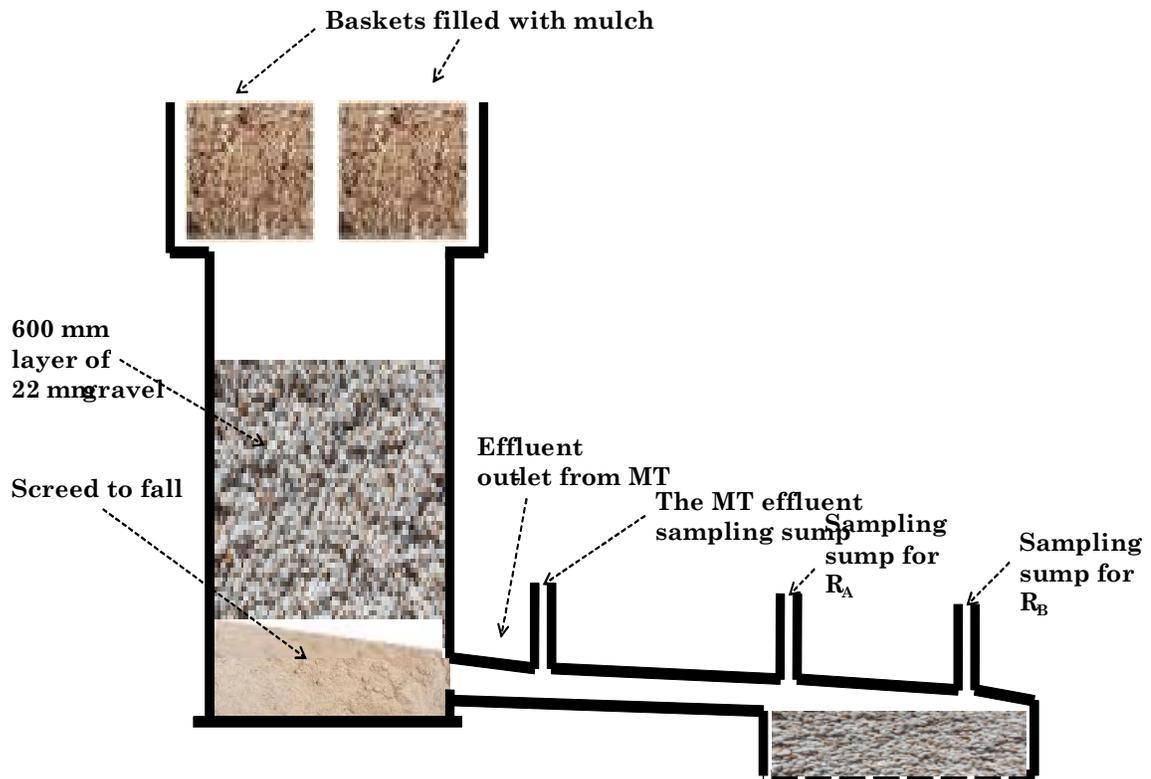


Fig. 1 Schematic representation of the pilot-scale MT-RB system at the Scenery Park low-cost housing development.

2.3 Physical condition of the MT-RBs

Each of the six houses and the MT-RB was coded with a number ranging from 9 to 14. The MT-RBs in houses 9 and 10 comprised one MT per house and a shared RB. All of the other MT-RBs consisted of one MT and one RB per house. Physical condition was checked by assessing the external appearance

of the unit (including damage); the presence of flies in and around the units, olfactometric detection of unpleasant odours; internal condition of the systems; whether the mulch in the MT was compacted or not (possible blockages); presence of food particles and pooling of water on the surface of the mulch (indicating lack of day-to-day maintenance by residents).

Degree of blockage in the MT was assessed by measuring its hydraulic retention time (HRT) by pouring 10 litres of fresh greywater onto the surface of the MT; and then measuring the time taken for the water to emerge in the MT sampling sump (see Fig. 1). This operation was performed together with treatment testing (see section 2.4 for details). Performance testing in RBs was limited to measurements of water levels in the upper geotextile compartment (R_A), and the lower gravel bed compartment (R_B), as RBs were closed off or damaged. Water levels were measured by inserting a wooden stick into the relevant sampling sumps and measuring the depth of the water column.

2.4 Biomass composition and greywater treatment of the MT-RBs

Only houses 12 and 14 had MT-RBs in acceptable physical conditions between February and May 2009. Therefore they were considered to provide optimum performance data about the treatment of greywater by the MT part of the system. These two systems were sampled for biomass composition and assessed for treatment performance. First, nitril gloves (Lasec, Port Elizabeth, South Africa) were put on by the sampling author and these were chemically sterilised with 70 % ethanol. Then representative species of invertebrates in the mulch layer were hand-picked or caught with sterile tweezers. The specimens were immediately placed in 100 % ethanol and stored at 4 °C during transport to the laboratory and until analyses. Qualitative identification of the specimens was done using specialist guides (Scholtz and Holm [24]; Bolton [25]; Dippenaar-Schoeman and Jocque [26]; Herbert and Kilburn [27]).

Next the mulch layers in both baskets were turned over and mixed to achieve homogenisation of the biomass composition. The surface of sterile tupperwares was wiped off with 70 % ethanol. Tupperwares were opened and dipped into the mulch layers in both baskets at houses 12 and 14, and sealed immediately after sampling and their outer surface then chemically sterilised with 70 % ethanol. Mulch layer samples were stored at 4 °C during transport to and until analyses in the laboratory. In the laboratory, 75 ml of the one-quarter-strength Ringer solution was added to the mulch layer samples. Microbial cells were detached from the particles by vortexing on the MP-19 Deluxe Vortex Mixer (Chiltern Scientific, Pretoria, South Africa) for 2 minutes. The particle-associated microbial biomass was then enumerated by spread-plating, after decimal dilutions in physiological saline, as described below.

TB were plated onto nutrient agar and enumerated after incubation at 37 °C for 24 hours. TF were plated onto the potato-dextrose agar and enumerated after incubation at 28 °C for 7 days. TA were enumerated in the extract using the plate-count method (APHA [23]) and enumerated after incubation at 28 °C for 6-7 days. Enumeration of FC was conducted by spread-plating after decimal dilutions or by membrane filtration of 150 ml of the respective greywater samples (Wutor et al. [28]). Results were expressed as the cell concentration per 1 g of the mulch dry matter (CFUs/gdm). The mulch dry matter was determined by drying the mulch samples to constant weight at 60 °C in a UFE 700 oven (Mettler, Schwabach, Germany).

Greywater used for the treatment performance testing was collected as a mixture of bathroom and laundry greywater. After collection, it was stored in sealed twenty-litre plastic drums at 15 °C and used within 24 hours of collection. On-site and after the biomass characterisation sampling was completed, greywater was mixed vigorously by hand-shaking in the plastic drums by vigorous hand-shaking for about 20 seconds. A sample of untreated greywater, i.e. the MT influent (MT_{in}) was obtained by

pouring greywater to the brim of a clean and sterile 500 ml polyethylene bottle. The sampling sump for the MT effluent was emptied using a sampling device that consisted of a small collection bottle attached to a steel dipping rod.

Immediately before sampling, the sampling device were chemically sterilised with 70 % ethanol. Ten litres of greywater was measured out in a calibrated plastic drum and poured onto the two baskets with mulch at a rate of 20 L/min. Great care was taken to distribute the greywater evenly across the surface area of both baskets. As soon as the first trickle of treated greywater emerged in the sampling sump, the sampling device was lowered into the sump and sample collection started. The treated effluent (MT_{out}) was collected in a clean and sterile 500 ml polyethylene bottle. Chemical sterilisation of the outer surface of the sampling bottles was performed as with the tupperwares (see above). All sampling bottles were filled to the brim to exclude any air and were transported at 4 °C to the laboratory. The sampling procedure provided a composite effluent samples which are representative of the entire volume of the treated greywater. Blank samples were collected on-site with sterile deionised water.

In the laboratory, samples of the MT_{in} and MT_{out} were analysed for FC in all samples from 2009, and analyses for TB, TF and TA were performed in the April and May 2009 samples. These enumerations were done in the same way as with the mulch layer biomass characterisation, but the concentrations were expressed in CFUs/100 mL and particle detachment was not performed. All microbiological analyses were completed within 72 hours of sample collection. Turbidity of MT_{in} and MT_{out} was measured using Orbeco Hellige Model 966 Portable Turbidimeter (Lasec, Port Elizabeth, South Africa). The pH values were measured using Cyberscan 5000 pH meter (Eutech Instruments, Singapore).

Electrical conductivity (EC) was measured in the laboratory using AMEL 160 conductivity meter (AMEL Electrochemistry, Italy). The concentration of SO_4^{2-} was measured using the U. S. EPA method 375.4 (U. S. EPA [29]), while the concentration of NO_3^- was measured using the phenol-reagent method (Velghe and Claeys [30]). The COD concentrations were measured using the respective reagents and according to the Standard Methods (APHA [23]) and using the TR300 thermoreactor (Merck, Pty. Ltd., Johannesburg, South Africa) for digestions. Concentrations of PO_4^{3-} were measured using the respective Merck test kit according to the manufacturer's instructions. All spectrophotometric and turbidimetric measurements were done using a Shimadzu UV-1601 spectrophotometer (Shimadzu, Johannesburg, South Africa). The TSS concentrations and percentages of removal for individual parameters were done according to Zuma et al. [22].

3. RESULTS AND DISCUSSION

3.1 Physical condition of the MT-RB

Results from the on-site visits are shown in Table 1. As it can be seen, 50 to 100 % of the MT-RB systems were in good external conditions from February 2009 until May 2009. Damage was observed in all MT-RBs in August 2010, i.e. after regular oversight by the authors ceased in May 2009. This was the result of the project arrangements. Damage observed in August 2010 could have been caused by deterioration of construction materials due to climatic conditions, actions or lack of maintenance by the residents. Upon interview of the residents, it was found that the municipal officials did not inspect the MT-RBs after May 2009, even though this was agreed in the project. The lack of follow-up by

municipal official probably resulted in breakdown of communication and lack of the required maintenance and repairs.

Between February and May 2009, 50 to 85 % of the MT-RBs were free of fly infestation. Flies were visually detected in MT-RBs at houses 9 and 13 in February 2009. In April 2009, this was the case at houses 9, 11 and 13. In spite of this occurring, no house infestation by either flies or other invertebrates (see below) took place, as established through interviews with the residents and visual observations. No flies were detected inside any MT-RB during the site visit in August 2010. A high percentage of the MT-RBs remained aerobic from February until May 2009, as 67 to 100 % of the systems produced no unpleasant odours. Exceptions were encountered when severe odour evolution was observed at house 9 and 11 in April 2009. At house 9, the entire MT was completely flooded, indicating a severe blockage in the MT-RB. All mulch was replaced and stones cleared, but ponding below the gravel layer indicated blockage between the MT and the RB. Municipal officials were contacted about the problem and the authors provided advice on remedial action that needed to be taken by the municipality.

From February until May 2009, 50 % of the MT-RB systems were always in good internal condition. In February 2009, a trench for foundation of a urine-diversion toilet was dug into the RB at house 11; piping was broken between the MT and RB on house 13. A small crack was observed in the sampling sump from the MT at house 14, but this did not influence the sample collection process. Worm casts were detected on the mulch surface and clogging of the gravel layer was detected at house 9 (see previous paragraph for details). The mulch in the MT at house 10 had a visibly dry surface from February until May 2009, suggesting little use and low volumes of greywater produced by the residents.

The mulch layer was slightly compacted at houses 12 and 14 in April 2009. In May 2009, the mulch layer in houses 10, 12, 13 and 14 contained a thin crust or film on top that could potentially prevent drainage of the system. The mulch layer was mixed by the authors, leading to removal of the crust and decrease in compaction of the mulch layers. Pooling on the surface of the mulch layer was detected in 33 to 67 % of the MT-RBs, and 50 to 85 % of the mulch layers contained medium to high concentration of food particles upon visual examination.

Table 1 Summary of physical condition of the MT-RB systems at the Scenery Park low-cost housing development

Parameters	17th February 2009	2nd April 2009	20th May 2009	10th August 2010
External condition	50 % in good condition	100 % in good condition	85 % in good condition	All MT-RB dysfunctional
Presence of flies	67 % fly-free	50 % fly-free	85 % fly-free	All MT-RB dysfunctional
Presence on unpleasant odours	100 % odour-free	67 % odour-free	85 % odour-free	All MT-RB dysfunctional
Internal condition of	50 % in good condition	50 % in good condition	50 % in good condition	All MT-RB dysfunctional

MT				
Pooling of water on surface of the mulch	33 %	67 %	67 %	All MT-RB dysfunctional
Quantity of food on surface of the mulch	50 % medium to high concentration	85 % medium to high concentration	67 % medium to high concentration	All MT-RB dysfunctional
Water depth at R_A (mm)	0-150	0-200	0-160	All MT-RB dysfunctional
Water depth at R_B (mm)	120-480	0-470	0-380	All MT-RB dysfunctional
Volume of water poured through MT (L)	10	10	10	All MT-RB dysfunctional
Hydraulic retention time of MT (s)	45-210	31-118	44-139	All MT-RB dysfunctional

This indicates lack of day-to-day maintenance by the houses' residents and a possible lack of oversight by municipal officials. Pooling of water on the mulch surface was quite significant at house 14 in May 2009. The mixing of the mulch layer led to draining of the pooled greywater. The sampling of biomass and treatment performance was only performed after this draining was completed.

Water depth in the R_A sump ranged from 0 to 200 mm, while the water depth in R_B ranged from 0 to 480 mm. In February 2009, the sampling sump R_A was completely flooded at house 11 due to the digging of the foundation for a urine-diversion toilet (see above). At the same time, the sampling sump R_B was completely dry indicating that water was not flowing into/through the resorption bed. In April 2009, only house 11 had 200 mm depth of water in R_A. All other R_A sumps were dry. The R_B depth was also at a maximum value of 470 mm. A similar situation was observed in May 2009 with a depth of 160 mm in R_A at house 11 and all other R_A sumps found dry. The R_B depth was also at a maximum value of 380 mm. The R_B sumps at house 12 and 14 were completely dry. This leads to the conclusion that the R_B at house 11 was not draining into the soil profile possibly due to a pipe blockage. Municipal officials were contacted, but the problem was either not fixed, or it reappeared as all the MT-RBs were dysfunctional in August 2010.

The HRT values ranged from 31 to 210 seconds which is comparable to the HRT in the laboratory-scale version which was estimated between 60 and 180 seconds (Zuma et al. [22]). No HRT value could be measured at house 11, due to the above-mentioned damage. In May 2009, the MT at house 9 was completely removed, possibly due to the poor condition it was in previously. Therefore no evaluation of the presence of flies or odours, internal condition of the MT, quantity of food presence or

the intensity of pooling present could be performed on this MT-RB system. All systems were dysfunctional during the site visit in August 2010.

3.2 Biomass composition and performance of grey water treatment

The following macroinvertebrates were identified in the mulch layers of both house 12 and 14 on all three site visits in 2009: cockroaches (*Periplanetta americana*, *Blatella germanica*), spiders (*Smeringopus pallidus*, *Laterodectus geometricus*) and sap beetles (*Nitidulidae sp.*). On two sampling occasions, mothflies (*Psychodidae sp.*) were detected in the mulch layer samples, while ants (*Hypoponera sp.*) were only detected on one sampling occasion. Slugs (*Deroceras laeve*, *Lehmannia sp.*) were also detected on one sampling occasion. These invertebrates are herbivores or scavengers which use the MT as a diurnal refuge, as a food source or as a breeding substrate (Scholtz and Holm [24]; Bolton [25]; Dippenaar-Schoeman and Jocque [26]; Herbert and Kilburn [27]). No infestation of the houses was reported by the residents throughout the study, i.e. the MT system can be used for ecological pest-control in low-cost housing developments. Further validation will, however, have to be conducted on this topic.

Results of the treatment performance testing are shown in Table 2 and in the text below. The values shown are averages of the values measured on a given sampling visit in house 12 and 14.

Table 2 Average concentrations of selected chemical and microbiological parameters during the treatment performance testing in 2009

Parameter	MT _{in}			MT _{out}		
	17-02	02-04	20-05	17-02	02-04	20-05
SO ₄ ²⁻ (mg/L)	140	90	120	88	46	130
pH	7.52	6.48	9.07	6.29	6.68	6.59
EC (mS/m)	170	79	65	140	84	52
Turbidity (NTU)	110	72	26	53	43	28
COD (mg/L)	1050	340	820	560	1640	1350
TSS (mg/L)	180	50	73	65	18	110
PO ₄ ³⁻ (mg/L)	21	2.0	3.4	14	4.5	10.2
NO ₃ ⁻ (mg/L)	0.9	4.3	7.0	21	2.4	2.6
FC × 10 ⁶ (CFUs/100 mL)	0	1.3	0	2.3	0.57-146	4.5
TB × 10 ⁶ (CFUs/100 mL)	NA ^a	30	0.76	NA ^a	6.3-43	3.4-220
TF × 10 ⁶ (CFUs/100 mL)	NA ^a	7.7	69	NA ^a	300-2500	29-220

TA × 10⁶ (CFUs/100 mL)	NA ^a	0.03-4.90	10	NA ^a	0.01-0.70	0.36-6.20
FC_{mulch} × 10⁶ (CFUs/gdm)	NA ^a	NA ^a	NA ^a	0.05- 2.71	0.37	0.21
TB_{mulch} × 10⁶ (CFUs/gdm)	NA ^a	NA ^a	NA ^a	72	5.0	6.0
TF_{mulch} × 10⁶ (CFUs/gdm)	NA ^a	NA ^a	NA ^a	550-570	0.24	12
TA_{mulch} × 10⁶ (CFUs/gdm)	NA ^a	NA ^a	NA ^a	0.05-350	0.075	0.47

^a Not applicable

The MT_{in} concentrations of SO₄²⁻ ranged from 90 to 140 mg/L, while the MT_{out} concentrations ranged from 46 to 130 mg/L. Removal of SO₄²⁻ from greywater of mixed origin was obtained for the samples in February and April 2009, when the percentage removals ranged from 37 to 49 %. In May 2009, a release of SO₄²⁻ was observed with the average value equal to 10 mg/L. No odours were detected in any of the MT-RBs and therefore it is unlikely that the systems turned anaerobic. The treatment efficiency for SO₄²⁻ was comparable to the results obtained in the laboratory-scale system (Zuma et al. [22]). All MT-RBs were completely dysfunctional during the site visit in 2010, and only standing water with no mulch was present inside the MT at houses 11 and 12.

The average concentration of SO₄²⁻ in this water sample was equal to 32 mg/L. Values of monitored parameters will be referred to as concentrations in August 2010. The sulphate concentrations in the treated greywater were below 200 mg/L. Therefore no detrimental effects on human health are expected if the SO₄²⁻ ions released in the treated greywater reach the reach groundwater through the soil profile and this is then used as a source of drinking water (DWAF [31]). The pH values of the MT_{in} ranged from 6.48 to 9.07, while the MT_{out} values ranged from 6.29 to 6.69. If the MT is well-maintained, it has the ability to buffer extremely alkaline pH of the greywater to approximately neutral values. This is desirable quality of the MT, because it helps prevent soil degradation during groundwater recharge. The MT buffering capacity was comparable to the performance of the laboratory-scale MT system (Zuma et al. [22]). During the site visit in August 2010, the pH values ranged from 5.58 to 6.50.

The EC values in the influent of the MT ranged from 65 to 170 mS/m, while the effluent values ranged from 52 to 140 mS/m. Between 18 to 20 % of ions was removed from greywater in February and May 2009. The effluent EC values after the MT treatment are below 150 mS/m, and so no adverse health effects will be observed if the MT effluent will be used for groundwater recharge as with SO₄²⁻ (DWAF [31]). The average EC value in August 2010 was equal to 17.7 mS/m. This value would still allow for groundwater recharge with treated effluent, but lack of mulch in the MT-RB could make the treated effluent unusable due to the values of other parameters.

The MT_{in} turbidity values ranged from 26 to 110 NTU. At the same time, the MT_{out} ranged from 28 to 52 NTU. Removal of colloidal matter, i.e. decrease in turbidity values, was observed in February and April 2009, when effluent values were 52-54 % lower than the influent ones. The effluent turbidity values were above 10 NTU, therefore the contact with treated greywater would pose a risk to human

health (DWAF [31]). Thus the MT effluent should not be used for groundwater recharge unless the soil properties on-site are evaluated; and turbidity of the treated greywater can be decreased.

The MT_{in} concentrations of COD ranged from 340 to 1050 mg/L, while the MT_{out} concentrations ranged from 560 to 1640 mg/L. Removal of COD components from greywater of mixed origin was obtained only in February 2009, when the respective percentage of removal was equal to 47 %. In April and May 2009, the COD releases from the MT were observed with percentage equal to 382 and 65 %, respectively. The COD concentrations in August 2010 ranged from 930 to 10400 mg/L, and the treatment efficiency is below the estimated cumulative removals from 24 to 28 % achieved at the laboratory scale (Zuma et al. [22]).

TSS in the influent were between 50 to 180 mg/L, while between 18 to 110 mg/L of TSS was measured in the effluent. Removal of TSS from greywater of mixed origin were obtained only in February and April 2009, when the respective percentage of removal were equal to 63 and 64 %, respectively. This comparable to the estimated cumulative removal of 52 % observed at the laboratory scale (Zuma et al. [22]). The average TSS concentration in August 2010 was equal to 520 mg/L.

The MT_{in} concentrations of PO_4^{3-} ranged from 2.0 to 21 mg/L, while the MT_{out} concentrations ranged from 4.5 to 14 mg/L. Removal of 33 % PO_4^{3-} from greywater of mixed origin was obtained only in February 2009. Releases of 125 and 340 % were observed in April and May 2009, respectively. The release of phosphorus from the MT was also observed in the laboratory scale system (Zuma et al. [22]). The average concentration of PO_4^{3-} in August 2010 was equal to 1.6 mg/L. Release of PO_4^{3-} coincides with the release of COD components, but not increases in TSS. This indicates that phosphorus release might have originated from the release of dead biomass.

The MT_{in} concentrations of NO_3^- ranged from 0.9 to 7.0 mg/L, while the MT_{out} concentrations ranged from 2.4 to 21 mg/L. Removal of NO_3^- from greywater of mixed origin was obtained in April and May 2009 with removal rates of 47 and 63 %, respectively. This is higher than the estimated cumulative removal of 26 % obtained by NO_3^- at laboratory scale (Zuma et al. [22]). The NO_3^- concentrations in August 2010 ranged from 5 to 100 mg/L. The concentrations of FC, TB, TF and TA in the mulch layers were (in 10^6 CFUs/gdm): 0.05 to 2.71, 5.0 to 72, 0.24 to 570 and 0.075 to 350, respectively. This could be the result of the presence of easily biodegradable organic matter from food particles and the mulch. Excrements of the invertebrates might have also contributed the observe trends in microbial data. The FC concentrations indicate severe risk to human health if used for groundwater recharge (DWAF [31]). Releases of all microbial components from the MT were observed in almost all sampling occasions. The average FC concentration in August 2010 was equal to 3.90×10^4 CFUs/gdm.

The above mentioned data indicate that most of the MT-RBs were not well maintained. Removals of COD, SO_4^{2-} , NO_3^- , TSS and PO_4^{3-} were detected on some sampling occasions. This indicates potential for the use of MT in decentralised treatment of greywater in South Africa. Elimination of odours and prevention of invertebrate infestation of the resident houses at Scenery Park suggest that MT could be used as an ecologically and aesthetically-acceptable pest-control tool at household level in low-cost housing developments. Removal variability indicates that the MT-RB systems did not reach steady-state in greywater treatment between February and May 2009. Examination of the physical condition of the MT-RBs showed that the residents did not perform day-to-day maintenance.

3.3 Reasons for treatment failure

During the study it became apparent that the MT-RBs did not perform optimally. Experimental data, interviews with the household residents, as well as interactions between the authors and the municipal officials, indicate that there are several reasons for the inadequate performance of the MT-RBs. These include insufficient involvement by the municipal officials and also a lack of buy-in from the residents. At the same time, there were also positive results such as the prevention of household infestation by pests. Therefore the MT-RBs do have a potential to become more widespread sanitation tool in grey water management in South Africa. However, the reasons for the failure at the Scenery Park development must be understood in detail before that can happen. As a first step in this process, legislation and policy analyses were conducted to establish the bureaucratic and systematic drawbacks which might exist. This was done after the experimental part of the project finished by accessing government documents through the website of the Parliamentary Monitoring Group (see www.pmg.org.za for details). The results and possible solutions are outlined below.

Section 152 of the Constitution of South Africa states that objectives of local government are as follows (Constitution of the Republic of South Africa [32]): “provide democratic and accountable government for local communities; ensure the provision of services to communities in a sustainable manner; promote a safe and healthy environment; promote social and economic development; encourage the involvement of communities and community organisations in matters of local government”. Part B in Schedule 4 of the Constitution states that local government, i.e. the Buffalo City Municipality, is responsible for “water and sanitation services limited to potable water supply systems and domestic waste-water and sewage disposal matters related thereto Systems” (Constitution of the Republic of South Africa [32]). These functions were probably not properly carried out by the Buffalo City Municipality in the context of the Scenery Park project.

Parliamentary briefs and other relevant documents indicate that the main barriers to successful delivery of sanitation to the South African population are as follows (DWAF [33]): financial limitations and viability of supplying a heterogeneous pool of consumers in certain municipalities; prohibitive cost of waterborne sanitation in densely populated urban areas; low level of cost recovery due to financial maladministration; and funding gaps for bulk water infrastructure development. This is frequently compounded by lack of technical capacity for water services provision, lack of communication and awareness by municipal officials and communities in question; as well as low targeting of services into the poor areas are informal settlements (PCWAF [34]). If similar problems were encountered in the Buffalo City Municipality, then this would explain lack of regular maintenance of the MT-RBs and virtually no site visits at Scenery Park by municipal officials. The same reason might be used to explain the missing sense of the day-today maintenance and ownership that the residents probably felt towards the MT-RBs. At the same time, this would also led to the lack of effective communication between the municipal officials and the authors when problems had been reported to the Buffalo City Municipality by the authors after site visits.

The regional office of the Department of Water and Environmental Affairs showed that there was a severe shortage of engineering staff, geohydrologists and general technical skills in the Eastern Cape province in 2009 (PCWEA [35]). Another government entity, namely the National Planning Commission of South Africa, recently published a report where the skills shortage in all sectors of the economy is listed as one of the major threats to the sustainable development of the country (PCWEA [36]). Strategy for water service delivery and related skills-education/development programmes have long been prioritised by the South African Local Government Association (SALGA) and the Department of Water Affairs and Forestry (DWAF; SALGA-DWAF [37]). As early as 2005, SALGA and DWAF compiled databases on the service delivery levels in the water sector across South Africa (PCWAF [38]).

SALGA initiated the following activities to improve water service delivery among its members (Moraka [39]): a consultative process was established to find common needs; and efforts were put into the establishment of the municipal water services networks. At the same time, there has been managed development and sharing of good practices; the municipalities have been actively involved in policy and strategy development on water and sanitation (Moraka [39]). Networking has taken place and mutual assistance has been provided among municipalities to each other on the water and sanitation delivery; and common benchmarking criteria for comparison have been developed (Moraka [39]). At the national level of government, the Department of Water Affairs used its Municipal Infrastructure Grant (MIG) to establish the bilateral forum with local government; and one of the specific focus areas has been capacity building support and skills enhancement (PCWEA [35]).

Therefore it seems that the framework and tools should have been at the Buffalo City Municipality's disposal to play an active and constructive role in the Scenery Park project. A lack of their involvement indicates that additional tools strategies might have to be developed. To improve awareness of hygiene and health, DWAF deployed Community Development Officers into target communities in the past; and distributed educational materials among the population (Yako [40]). Liaising between the national and local authorities is crucial in this context; and deployment of the community engagement officers by the national government into Buffalo City Municipality might be required in the future. Visits by these officers, along with relevant municipal officials in housing development such as Scenery Park, are likely to improve the buy-in to any greywater treatment system by the residents.

Strengthening of local expertise and other capacity is needed, as demonstrated by case studies in Vhembe Local Municipality in Mpumalanga (Yako [40]). High-level skills are often provided to the Municipalities by the Water Board in charge of an area, i.e. Amatola Water in the case of Buffalo City Municipality (PCWEA [41]). Closer collaboration between the community, the local municipality, academia and the Amatola Water might also help improve the success of any future MT-RB installation in the municipalities such as Buffalo City. Besides providing the local municipalities with novel tools to improve sanitation infrastructure delivery, legislation changes are also required.

Based on the experiences of the non-profit organisations that work on water and sanitation issues in South Africa, chapter 3 of the National Water Act needs to be re-formulated (Mvula Trust [42]). This is given by the fact that this chapter of the NWA deals with the Protection of Water Resources and it is not clear how to address the water resources pollution if the cause of the pollution is a government authority such as Municipality (Mvula Trust [42]). In the context of this project, no oversight and active engagement by the Buffalo City Municipality at Scenery Park likely led to the contamination of groundwater resource on-site. Current formulation of the Chapter 3 of the National Water Act does not allow for sanctions against the municipality, thus decreasing the probability of active involvement. This could be solved through the cooperation at the national level of government in development of legislative guidelines and awareness campaign to target local municipalities, as well as sanction in the case of non-compliance.

The Department of Water and Environmental Affairs and the Department of Cooperative Governance and Traditional Affairs should take the lead in this regard (Mvula Trust [42]). All solution proposed in this section should be conducted in conjunction with academia, to allow for the latest scientific knowledge to be implemented, and non-profit organisations which have been working in the area must become part of any remedial action as they have generally the best understanding of the nature of the issues relating the community in question.

4. CONCLUSIONS

Information obtained from the interviews with the household inhabitants established that the visits by municipal officials were rare at Scenery Park. During the original design of the project, it was agreed that municipal official will be performing on-site visits at Scenery Park at least twice a month. It was also agreed that municipal officials will be present on-site during the sampling visits by the authors. This happened only in February 2009, despite prior agreement and confirmation by municipal officials before each 2009 sampling trip. Solution to this problem might be found using cooperation between the national and local government, community members, academia and non-profit organisations. Biweekly or monthly treatment efficiency monitoring should be implemented for the selected chemical and microbial parameters.

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REFERENCES

- [1] United Nations Millennium Development Goals. Available at: <http://www.undp.org/mdg/> (website accessed 27th September 2010).
- [2] Statistics South Africa. General household survey 2010 (Revised version). Statistical release P0318, Statistics South Africa, Pretoria, South Africa, pp. 156, 2011.
- [3] Health Systems Trust. Diarrhoea incidence in under 5 year old children in South Africa. Available at: <http://www.hst.org.za/recently-updated-indicators> (website accessed on 4th October 2011).
- [4] Statistics South Africa. *GHS Series Volume III: Water and sanitation 2002–2010 (In-depth analysis of the General Household Survey data)*. Statistics South Africa (Report No. 03-18-02 2002–2010), Pretoria, South Africa, pp. 77, 2011.
- [5] Parliamentary Monitoring Group. (PMG, 2009). Cholera responses. Available at: <http://www.pmg.org.za/report/20090204-department-health-department-water-affairs-forestry-responses-cholera> (website accessed on 11th February 2010).
- [6] Haarhoff, J., Rietveld, L. C. and Jagals, P. (2009). Rapid technical assessment and troubleshooting of rural water supply systems. *Proceedings of the 10th Annual Water Distribution Systems Analysis Conference, WDSA2008*, August 17-20, 2008, Kruger National Park, South Africa.
- [7] Momba, M. N. B., Tyafa, Z., Brouckaert, B. M., Obi, C. L. (2006). Safe drinking water still a dream in rural areas of South Africa. Case Study: The Eastern Cape Province, *Water SA*, Volume 32, Part 5, pp. 715-720.

- [8] Statistics South Africa. *South African Statistics*. Statistics South Africa, Pretoria, South Africa, pp. 194, 2010.
- [9] Statistics South Africa. Mid-year population estimates 2011. Statistical release P0302, Statistics South Africa, Pretoria, South Africa, pp. 18, 2011.
- [10] Obi, C. L. and Bessong, P. O. (2002). Diarrhoeagenic Bacterial Pathogens in HIV-positive Patients with Diarrhoea in Rural Communities of Limpopo Province, South Africa. *Journal of Health Population and Nutrition* 2002, Volume 20, Part (3), pp. 230-234.
- [11] Laurent, P. Household drinking water systems and their impact on people with weakened immunity, *Medicins Sans Frontier*, MSF-Holland, Public Health Department pp. 72, 2005.
- [12] Gadewar, S. and Fasano, A. Current concepts in the evaluation, diagnosis and management of acute infectious diarrhea. *Current Opinion in Pharmacology*, Volume 5, Part 6 SPEC. ISS.), pp. 559-565, 2005.
- [13] Ashbolt, N. J. Microbial contamination of drinking water and diseases outcomes in developing regions. *Toxicology*, Volume 198, Part (1-3), pp. 229-238, 2004.
- [14] South African Local Government Association (SALGA). Strategic sanitation review on operations, maintenance and sustainability of ventilated improved pit toilets including aspects of sustainability related to the eradication of buckets within the Free State Province, *South African Local Government Association*, Pretoria, South Africa, pp. 62, 2009.
- [15] Carden, K., Armitage, N., Winter, K., Sichone, O. and Rivett, U., *Understanding the use and disposal of greywater in the South Africa*. Water Research Commission (Report No. WRC Report No 1524/1/07), Pretoria, South Africa, pp. 230, 2007.
- [16] Tandlich, R., Zuma, B.M., Dyongman, S.A. and Slaughter, A., Characterization of greywater from selected sites in South Africa for potential reuse in irrigation. (IASTED Ed.), paper number 604-042, pp. 248, *Proceedings from the IASTED International Conference on Water Resource Management AfricaWRM 2008*, Gaborone, Botswana, Acta Press, 2008.
- [17] Merz, C., Scheumann, R., El Hamouri, B. and Kraume, M., Membrane bioreactor technology for the treatment of greywater from a sports and leisure club, *Desalination* 2007, Volume 215, Part 1-3, pp. 37-43.
- [18] Finley, S., Barrington, S. and Lyew, D., Reuse of domestic greywater for the irrigation of food crops, *Water, Air, and Soil Pollution* 2009, Volume 199, Part 1-4, pp. 235-45.
- [19] Arjun, N., Foxon, K., Rodda, N., Smith, M. and Buckley, C., Characterisation of wastewater produced by developing communities. *Proceedings from the 2006 WISA Biennial Conference and Exhibition*, Durban, South Africa, WISA, 2006.
- [20] Eriksson, E., Auffarth, K., Henze, M. and Ledin, A., Characteristics of greywater, *Urban Water* 2002, Volume 4, Part 1, pp. 85-104.
- [21] Ridderstolpe, P. (2007). Mulch filter and resorption trench for onsite greywater management. *EcoSanRes*. Technical Report. Stockholm, Sweden.

- [22] Zuma, B., Tandlich, R., Whittington-Jones, K. and Burgess, J.E., Mulch tower treatment system Part I: Overall performance in greywater treatment, *Desalination* 2009, Volume 242, Part 1-3, pp. 38-56.
- [23] APHA, AWWA and WEF, *Standard methods for the examination of water and wastewater* (20th Edition), APHA, Washington DC, pp. 1496, 1998.
- [24] Scholtz, C. and Holm, E., *The insects of Southern Africa*. Butterworths, Durban, South Africa, pp. 502, 1985.
- [25] Bolton, B., *Identification guide to the ant Genera of the world*, Harvard University Press, Cambridge, Massachusetts, pp. 222, 1994.
- [26] Dippenaar-Schoeman, A. and Jocque, R., *African Spiders: an identification manual. Plant Protection Research Institute Handbook no. 9*, Agricultural Research Institute, Pretoria, South Africa, pp. 392, 1997.
- [27] Herbert, D.G. and Kilburn, R.N., *Field guide to the land snails and slugs of Eastern South Africa*, Natal Museum, Pietermaritzburg, South Africa, pp. 336, 2004.
- [28] Wutor, V.C. Togo, C.A. and Pletschke, B.I., Suitability of total coliform β -galactosidase activity and CFU counts in monitoring faecal contamination of environmental water samples. *Water SA* 2009, Vol. 35, Part 1, pp. 85-88.
- [29] United States Environmental Protection Agency (U. S. EPA; 1978). Sulfate (Turbidimetric). Method number 375.4. Available at: http://www.cornerstonelab.com/EPA-Methods/100-400/375_4.PDF (website accessed on 3rd February 2009).
- [30] Velghe, N. and Claeys, A., Rapid spectrophotometric determination of nitrate with phenol, *Analyst* 1983, Volume 108, Part 1289, pp. 1018-1022.
- [31] Department of Water Affairs and Forestry (DWAF; 1996). South African Water Quality Guidelines, Vol. 1 (Domestic Water Use), Pretoria, South Africa.
- [32] Constitution of the Republic of South Africa. Act No. 108 of 1996. *Government Gazette*, Pretoria, South Africa, pp. 107, 1996.
- [33] Department of Water Affairs and Forestry (DWAF, 2006). Presentation from the Department of Water Affairs and Forestry on Water Services Targets to the Portfolio Committee in Parliament of South Africa. *Meeting held on 16th August 2006*, Parliament of South Africa, Cape Town, South Africa.
- [34] Portfolio Committee on Water Affairs and Forestry (PCWAF, 2006). Water Services Targets: Department presentation. *Minutes of the meeting was held on 16th August 2006*, Parliament of South Africa, Cape Town, South Africa.
- [35] Portfolio Committee on Water and Environmental Affairs (PCWEA). Meeting minutes. *Meeting was held on 8th September 2009*, Parliament of South Africa, Cape Town, South Africa, 2009.

- [36] Portfolio Committee on Water and Environmental Affairs (PCWEA, 2011b). National Planning Commission Diagnostic Report & response by Department of Water & Environmental Affairs. *Meeting was held on 12th January 2011*, Parliament of South Africa, Cape Town, South Africa.
- [37] South African Local Government Association and Department of Water Affairs and Forestry (SALGA-DWAF). Joint presentation to the Portfolio Committee on Water Affairs and Forestry in discussion on Implementation of Strategic Framework for Water Services: Department briefing. *Meeting was held on 18th February 2004*, Parliament of South Africa, Cape Town, South Africa, 2004.
- [38] Portfolio Committee on Water Affairs and Forestry (PCWAF). SA Local Government Association & Various Water User Associations on Department Annual Report: hearings. *Minutes of the meeting was held on 14th October 2005*, Parliament of South Africa, Cape Town, South Africa, 2005.
- [39] Moraka, W. Role of SALGA in service delivery to meet the 2008 and 2010 targets. Presentation to the Portfolio Committee on Water Affairs and Forestry. *Meeting was held on 14th October 2005*, Parliament of South Africa, Cape Town, South Africa, 2005.
- [40] Yako, P. Cholera Outbreak Response in Limpopo and Mpumalanga Provinces: Presentation to the Portfolio Committee on Water and Environmental Affairs. *Meeting held on 4th February 2009*, Parliament of South Africa, Cape Town, South Africa, 2009.
- [41] Portfolio Committee on Water and Environmental Affairs (PCWEA). Water Boards' Strategic Plans & Budgets 2011, & Tariff increases. *Minutes of the meeting was held on 24th May 2011*, Parliament of South Africa, Cape Town, South Africa, 2011.
- [42] Mvula trust. Mvula Trust submission to the Public Hearings on the National Water Act. Portfolio Committee on Water Affairs and Forestry. *Public hearings were held on 16th and 22nd October 2008*, Parliament of South Africa, Cape Town, South Africa.
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