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Full Length Research Paper

Focus on 14 sewage treatment plants in the Mpumalanga Province, South Africa in order to gauge the efficiency of wastewater treatment

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In order to identify the treatment methods used in different sewage treatment plants (STPs) in the Mpumalanga Province and to determine the efficiency of wastewater treatment by these plants, municipal STPs were surveyed, and raw and treated wastewater samples collected. A total of 14 STPs were visited and the collected samples were analysed for physicochemical and microbiological parameters using standard methods. The treatment methods identified included ponds, activated sludge and trickling filters. The reduction of turbidity by the plants varied between 6.2 and 99.6% while conductivity, pH and temperature varied slightly between the influent and the effluent wastewater. Thirteen (92.8%) of the plants used chlorine for disinfection of the final effluent, however only 2 (14.2%) of the plants managed to produce effluent with 0 (zero) faecal coliforms per 100 mℓ. Common pathogenic bacteria isolated from the final effluent included *Salmonella*, *Shigella*, *Escherichia coli, Vibrio* spp. and *Enterococcus* spp. The final effluent was used for irrigation and recycling purposes in 4 plants, all the other treatment plants discharged the effluent into the river or to the environment. The present study indicated that there is a move toward the renovation of wastewater treatment by the municipalities in the Mpumalanga Province with the adoption of biological treatment. All the STPs reduced the turbidity of wastewater as well as the different microbial indicators counts; however, several pathogenic bacterial organisms could still be detected in the final effluent. Further studies are needed to confirm the role of the treatment procedures on nutrient reduction and elimination of other viral and parasitic pathogens by the sewage treatment plants.

Key words: Public health, diarrhoea, environment, microbial indicators, bacteria, sanitation, sewage treatment plants, water contamination, wastewater.

INTRODUCTION

Wastewater is defined as water that carries wastes from homes, businesses, and industries, for which disposal is more economical than use at the time and point of its occurrence. Wastewater components show different degrees of environmental nuisance and contamination hazard due to their chemical and microbiological characteristics (Bohdziewicz and Sroca, 2006).

Outbreaks of cholera, salmonellosis, cryptosporidiosis and giardiasis have been linked to the contamination of drinking water by sewage (Ljungstrom and Castor, 1992; Gaffga et al., 2007). Consequently the treatment of waste water is of utmost public health importance.

Wastewater from homes, commercial buildings and hospitals is collected via a sewer system and flows to municipal sewage treatment plants (STPs) for the stabilization and neutralization of chemicals and inactivation of micro-organisms. In addition to domestic sewage, effluents from industrial facilities are sometimes also discharged into municipal STPs for further treatment before

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being released into the environment. Different methods are used for the treatment of wastewater and sludge in an STP. These include: sedimentation, mesophilic or thermophilic anaerobic digestion, com-posting, storage or by a combination of these methods (Sahlstrom et al., 1994). These treatments may cause inactivation of pathogenic microorganisms. The treatment processes might also impact on physicochemical parameters of the final effluent such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), electrical conductivity, total hardness, alkalinity, dissolved oxygen, some metals and non-metal ions (Rawat et al., 1998; Adami et al., 2007). At the end of the treatment processes, sludge and final effluent are released to the environment. Although recommendations have been made by regulatory bodies in South Africa (DWAF, 1996), reports of pollution of water sources by STPs have been described in the country, suggesting non-compliance with regulations (Fatoki et al., 2003; Swart and Pool, 2007).

Epidemics of cholera have been described in Mozambique and South Africa, particularly the provinces of Mpumalanga and Gauteng (Dalsgaard et al., 2001). Al-though all the cases in Gauteng were identified in migrant labourers from Mozambique, many of the cholera cases in Mpumalanga were acquired locally through contamination of local water sources. Several cases of cholera have also been identified in KwaZulu-Natal Province. The response from the Government to each of the epidemics has been very prompt (DWAF, 2001). However, no study has been carried out in order to verify the potential sources of water contamination as well as the efficiency of sewage treatment plants in Mpumalanga Province, where outbreaks had been reported.

Effluents from the STPs can be reused for agricultural and industrial purposes, for land application or recycled and used as drinking water (Weinberg et al., 2004). If not properly disinfected, these sewage effluents when discharged into the river constitute an important health risk for the population using this water for other purposes such as washing of clothes, bathing or even drinking. Sewage sludge from STPs is generally used as fertilizers by the population or by agricultural companies. Different groups of micro-organisms have been described in sludge including viruses (Pike, 1986; Belguith et al., 2007), bacteria such as *Salmonella*, *Campylobacter*, *Listeria*, *Ecsherichia coli* (Sahlstrom et al., 1994) and parasites such as *Cryptosporidium*, *Giardia* and *Entamoeba histolytica* (Robertson et al., 2006; El Kettani and Azzouzi, 2006). Studies in other countries such as Sweden, China, Poland and Australia have described different methods and efficiency of Sewage Treatment Plants in reducing pathogens in wastewater (Horan et al., 2004; Chen et al., 2004; Herselman et al., 2006). However, a paucity of data or literature exists on the efficiency of sewage treatment in developing countries such as South Africa as well as the treatment procedures used.

Regular monitoring of microbiological content of sewage and final effluent from STPs will illuminate knowledge of the microbial population in human communities and contribute to the understanding of epidemiological patterns of diarrhoeal diseases a well as other infectious diseases transmitted through water. This monitoring will also help in improving the methods of sewage treatment, important in protecting the environment and humans from pathogenic organisms. In the present study, the efficiency of STPs in Mpumalanga Province was assessed by undertaking microbiological and physico-chemical investtigations of wastewater and treated wastewater. Information gathered will be tangential to enhancing the public health profile of communities.

MATERIALS AND METHODS

Study sites and sample collection

Mpumalanga meaning 'w*here the sun rises'* previously known as Eastern Transvaal is one of the 9 Provinces of South Africa and was so renamed on the 24th of August, 1995. Mpumalanga Province is situated in the north-eastern part of South Africa and is bordered by Mozambique and Swaziland in the east and Gauteng in the west. It is one of the smaller provinces with about 79 490 km^2 in surface area, which is 6.5% of the country's earth surface. Mpumalanga has a population of about 2.8 million people. Extreme levels of poverty are evident and the province has the second lowest literacy rate in the country, while the population growth rate is higher than the national average. Mpumalanga attracts sizeable migrant labour flows from across its borders, including refugees from neighbouring Mozambique and is a tourist Province.

Fourteen STPs located in two district municipalities (Nkangala and Ehlanzeni) in Mpumalanga Province were visited between August and October 2006 and have been included in the study. Information on the use of final treated wastewater was obtained from the plant operators. Table 1 indicates the general information on the different STPs visited and the chlorine dosage. Samples were collected from each plant in 1ℓ Nalgene containers, 2 samples from the intake point at the head of the works just after screening, and 2 samples of the final effluent. The samples were kept in cooler bags with ice and transported to the Microbiology Laboratory, University of Venda for analysis.

Determination of physicochemical parameters

Physicochemical properties were measured on site and included: turbidity, conductivity, temperature and pH. The JENWAY pH Meter 3150 was used for the measurement of the pH; The CRISON CM35 Conductivity Meter was used for the measurement of conductivity and a HACH Model 2100P portable turbidimeter was used to measure the turbidity of the samples. All the measurements were done in triplicate and the geometric means were considered. The concentration of free chlorine residual in the treated effluents was determined using a multi-parameter ion-specific meter, HI 93711 (HANNA instruments, Hungary).

Microbiological analysis

The samples were transported on ice to the microbiology laboratory, University of Venda and were analyzed within 24 h after collection. Standard microbiological methods were used to determine the heterotrophic plate counts, the total coliform and the

Table 1. General information on the sewage treatment plants surveyed in Mpumalanga Province during the study period.

Name	Main treatment processes	Free residual chlorine (mg/ℓ)	Use of final effluent
Malelane	Ponds	No chlorination	Irrigation
Matsulu	Activated sludge	0.12	Land application
Kanyamazane	Ponds and trickling filters(2)	0.55	Back to the river (Crocodile River)
Sabie	Activated sludge	0.08	Back to the river (Sabie River)
White River	Activated sludge	1.72	Land application
Nelspruit	Anaerobic digestion, trickling filters(4), activated sludge, maturation ponds	0.71	Back to the river (Crocodile River)
Machadodorp	Activated sludge and ponds	0.16	Ground filtration and disposal
Waterval Boven	Trickling filter (1), activated sludge	0.15	Back to the river
Belfast	Activated sludge and ponds	0.01	Back to the Belfast Dam
Dullstroom	Activated sludge and ponds	0.26	Land application
Hendrina	Trickling filters, activated sludge and ponds	0.18	Back to the river
Middleburg	Activated sludge, ponds	0.16	Irrigation and part to the river
Witbank	Trickling filters (anaerobic digesters (2) not working)	0.23	Back to the river
Lydenburg	Trickling filters (3 and one in construction), ponds (anaerobic digesters not working)	0.15	Used in the cooling system of a mine, for irrigation and the rest back to the river

faecal coliform counts. Different species of micro-organisms were isolated by cultural methods and biochemical assays were used for the identification of individual species as described previously (Obi et al., 2004). The spread-plate method was used for all counts and plate count agar, m-ENDO agar and m-FC agar were used for heterotrophic count, total coliform count and faecal coliform counts, respectively. Each test was done in triplicate and the geometric means were recorded. Appropriate Schemes for the isolation of *E. coli*, *Salmonella* spp., *Shigella* spp., *Campylobacter* spp., *Vibrio* spp., *Enterococus* spp. and *Aeromonas* spp. were employed. A sample of the water was inoculated on specific media (EMB for *E. coli*, SS agar for *Salmonella* and *Shigella*, Skirrow's media for *Campylobacter,* TCBS for *Vibrio*, *Enterococcus*-selective agar for Enterococci). These organisms were further identified by biochemical tests such as gram staining, indoxyl acetate hydrolysis, oxidase, catalase, urea hydrolysis, motility, hydrogen sulphide production and gelatine hydrolysis. The API 20E and the Dryspot *Campylobacter* Test (Oxoid, England) were used for confirmation.

RESULTS

Treatment methods

Of the 14 plants surveyed, 13 were administered by local municipalities and one was managed by a private company (Bio-waters). The size of the STPs visited varied greatly and ranged between 0.1 and 16 Mℓ/d serving populations of 5 000 to more than 100 000 people. In the 2 district municipalities under study, it was demonstrated that waste and wastewater treatment facilities were limited in number and there were areas that were not served by any wastewater treatment service. However, efforts were being made by the different local municipalities to extend the capacity of the plants by up-grading some units in the existing plants or building new treatment units. This was the case in Middleburg where the anaerobic digesters were being replaced by new trickling filters. Upgrades were done a few months earlier on other plants such as Matsulu and Kanyamazane. Processes used in the plants visited include the activated sludge process used in 10 (71%) of the plants, trickling filters used in 6 (43%) of the plants and the ponds system used in combination with other methods in 3 (21%) plants; however, it was used alone in one plant (Malelane) (Table 1). Mesophilic anaerobic digesters were found in 4 (29%) of the plants although this system was functioning properly only in one plant (Nelspruit) and was being replaced in Lydenburg by new trickling filters. A combination of the activated sludge process and trickling filters was used in 3 (21%) of the sewage treatment plants. Disinfection system was present in 13 (93%) and chlorine gas was used for the disinfection of the final effluent. However, chlorine was available in only 9 (64%) of the plants and it was reported that the frequency of recharge or replacement of the disinfection agent was not regular in most plants. The dosage of chlorine in different plants was done based on experience and not on real situations such as the knowledge of water flow.

The wastewater treatment works employed different treatment methods in different sequences. Generally, the raw wastewater was first screened to remove grit and bigger particles, then the water was held in sedimentation tanks (primary settling tanks) with varying retention times, from 5 to 20 days, depending on the plant. Afterwards the

Table 2. Physical properties of wastewater and final treated wastewater from sewage treatment plants in Mpumalanga Province.

Plants	Turbidity		Conductivity		pH		Temperature	
	Raw	Final	Raw	Final	Raw	Final	Raw	Final
Malelane	649	147	875	960	7.19	7.52	23.2	23.4
Matsulu	20.8	1.49	777	631	7.45	7.64	27.4	27.5
Kanyamazane	68.9	26.8	546	568	7.61	7.64	27.2	25.6
Sabie	26.8	26.8	622	361	7.76	7.42	19	18.7
White River	139	11.6	668	494	6.71	6.64	19.2	18.7
Nelspruit	131	18.7	804	709	7.71	7.72	22.4	21.7
Machadodorp	28.9	27.1	797	584	8.51	7.45	21.4	21.2
Waterval Boven	49.3	0.17	452	162.1	7.56	7.35	23	23.7
Belfast	463	12.3	911	928	7.06	7.50	16.7	19.5
Dullstroom	262	6.44	410	504	7.53	7.45	17.5	18.4
Hendrina	308	2.23	738	478	7.54	6.84	24.2	22.2
Middleburg	174	8.73	1071	942	7.53	7.50	24.3	24.8
Witbank	99	24.2	1190	1170	6.89	7.43	26.2	25
Lydenburg	349	8.94	1430	600	8.14	7.52	24.2	25.2
Maximum	649	147	1430	1170	8.51	7.72	27.4	27.5
Minimum	20.8	0.17	410	9.42	6.71	6.64	16.7	18.4
Average	197.76	23.03	806.5	582.75	7.51	7.40	22.56	22.54

water was treated by either activated sludge or trickling filters depending on the availability of the facilities. After treatment in the activated sludge or trickling filters, the water was treated in the secondary sedimentation tanks with a retention time varying from 2 to 20 d depending on the number and size of the tanks. Disinfection was then conducted and the treated wastewater was discharged to its final destination. The use of the final treated wastewater varied amongst the plants and was used for irrigation purposes in three plants (21%), in the cooling system of the mine in one (7%) plant and the other 10 (71%) plants discharged the treated wastewater to the environment (rivers, dams or land).

The concentration of residual chlorine in the final effluent varied markedly among the plants and ranged from 0.01 mg/l in Belfast to 1.72 mg/ml in Nelspruit during the study period. In this study, free residual chlorine range for domestic water (0.3 to 0.6 mg/ℓ) (DWAF, 1996) was considered as standard, since the South African guidelines do not specify any standard for final effluents in sewage treatment plants. Chlorine was overdosed in 2 (14%) plants: White River (1.72 mg/mℓ) and Nelspruit (0.71 mg/mℓ). However, the dosage of chlorine was not effective in 10 (71%) plants. Only one plant (Kanyamazane) had a chlorine residual value in the acceptable range.

Physicochemical characteristics of wastewater and treated wastewater

The turbidity of the influent varied between 20.8 and 649 NTU. Only one (7%) STP from the 14 visited was able to produce final treated water with acceptable turbidity values (<1 NTU). However, all the plants were able to reduce the turbidity after treatment to a lower value than in the influent wastewater. The turbidity of the final effluent ranged between 0.17 and 28 NTU. The temperature of the influent wastewater ranged between 16.7 and 27^{o}C and between 18.4and 27.5^{o}C for the final effluent. The electrical conductivity ranged from 410 to 1 430 µS/ m for the raw wastewater and from 162.1 to 1 170 µS/m for the final effluent. The pH in all the plants ranged between 6.71 and 8.51 pH units for the raw wastewater and from 6.64 pH units in the final effluent. Generally, the pH was stable throughout the treatment process when considering a single plant. Table 2 summarizes the findings on the physicochemical characteristics of wastewater and treated wastewater from the different plants.

Performance of the sewage treatment plants on the removal of bacterial indicators

The determination of bacterial indicators counts in the raw and treated effluent was conducted with the aim of assessing the capacity of the plant to decrease the number of presumptive coliforms as the wastewater flows through the treatment processes. Table 3 shows the different bacterial indicators counts in the sewage treatment plants in Mpumalanga Province. The counts in the influent sewage were very high. However there was generally a significant reduction in the number of CFU after the treatment process. The heterotrophic plate counts varied from 1.6 x 10^{6} cfu/mℓ to 1.94 x 10^{11} cfu/mℓ in the

Table 3. Bacterial indicator counts of wastewater (raw) and treated wastewater (final) from sewage treatment plants in Mpumalanga Province.

Plants	HPC (cfu/mℓ)		TC (cfu/100 mℓ)		FC (cfu/100 mℓ)	
	Raw	Final	Raw	Final	Raw	Final
Malelane	3.2×10^{10}	4.8×10^{5}	2.52×10^{6}	5.4×10^{5}	1.8×10^{5}	1.8×10^{4}
Matsulu	2.6×10^{9}	7.2×10^{4}	1.4×10^{6}	8.0×10^{1}	7.2×10^{3}	6×10^{2}
Kanyamazane	4.0×10^{10}	1.8×10^{5}	1.2×10^{6}	3.6×10^{4}	1.0×10^{5}	1.8×10^{2}
Sabie	3.2×10^{10}	2.8×10^{5}	2.4×10^{5}	5.4×10^{2}	1.6×10^{4}	1.8×10^{2}
White River	1.6×10^{7}	1.0×10^{2}	7.2×10^{4}	0. 0	2.8×10^{3}	0.0
Nelspruit	2.5×10^{8}	3.6×10^{4}	1.8×10^{5}	0.0	4.3×10^{2}	0.0
Machadodorp	2.9×10^{7}	1.3×10^{3}	3.24×10^{6}	6.48×10^{4}	9.7×10^{4}	7.2×10^{3}
Waterval Boven	2.16×10^{8}	1.8×10^{3}	2.3×10^{6}	20	1.87×10^{5}	11
Belfast	3.16×10^{8}	3.2×10^{3}	7.2×10^{5}	120	2.0×10^{5}	50
Dullstroom	2.9×10^{9}	1.68×10^{2}	5.4×10^{6}	6	5.8×10^{4}	7
Hendrina	9.7×10^{8}	3.6×10^{2}	6.48×10^{6}	34	1.62×10^{3}	3
Middleburg	2.6×10^{8}	2.4×10^{2}	2.26×10^{6}	43	1.29×10^{3}	15
Witbank	2.8×10^{10}	6.48×10^{5}	2.52×10^{6}	2.8×10^{4}	2.16×10^{4}	3.6×10^{5}
Lydenburg	1.94×10^{11}	1.29×10^{5}	6.48×10^{6}	1.6×10^{3}	1.2×10^{5}	4.8×10^{2}
Maximum	1.94×10^{11}	6.48×10^{6}	6.48×10^{6}	5.4×10^{5}	2×10^{5}	3.6×10^{5}
Minimum	1.6×10^{7}	10^{2}	7.2×10^{4}	6	430	3
Average	1.3×10^{9}	1.31×10^{5}	2.1×10^{5}	4.8×10^{4}	7.1×10^{4}	2.8×10^{4}

raw wastewater and from 10^{2} cfu/mℓ to 6.48×10^{5} cfu/mℓ in the final effluent. The total coliform counts varied between 7.2×10^{4} cfu/100 mℓ to 6.48×10^{6} cfu/100 mℓ in the raw wastewater and from 6 cfu/100 mℓ to 5.4×10^{5} cfu/100 mℓ in the final effluent.

The faecal coliform counts varied from 4.3×10^{2} cfu/100 mℓ to 2×10^{5} cfu/100 mℓ in the influent and from 3 cfu/100mℓ to 3.6×10^{5} cfu/100 mℓ in the final treated wastewater. Only two plants complied with the South African General and Special standards which stipulate that treated sewage effluents must have a standard of nil faecal coliforms (Act 96 of 18 May 1984 No. 9225, Regulation 991). However, nine plants (64%) had faecal coliform counts within the limits set for agricultural purposes (Irrigation) which is ≤ 1 000 cfu /100 mℓ (DWAF, 1996) and three plants had faecal coliform counts higher than the recommended values.

The percentage reduction of bacterial indicators in the plants visited varied between 12% in Malelane and 71% in Dullstroom for the heterotrophic plate counts, from 11% in Malelane to 88% in Dullstroom and 100% in White River and Nelspruit for the total coliform counts. The reduction of fecal coliform counts varied between 19% in Malelane and 84% in Hendrina and 100% in White River and Nelspruit. In one of the plants (Witbank) the faecal coliform in the final treated effluent was higher than that of the raw sewage indicating possible contamination with biofilms at the end of the works.

Identification of bacterial isolates

Different schemes for the isolation and identification of specific bacterial species indicated the presence of a large variety of potentially pathogenic bacteria in the influent and the final effluent. Table 4 represents the differrent bacterial organisms that were isolated and identified from the different plants. The most common pathogenic bacteria isolated included *Salmonella*, *Shigella*, *E. coli, Vibrio* spp., *Campylobacter* spp. and fecal Enterococci. *Vibrio* spp. were the most encountered followed by *Campylobacter, Enterococcus* and *Salmonella*. *Shigella* spp. were the least encountered in nearly all the plants with colony counts generally less than 10^{6} cfu/mℓ. The indication of a high prevalence of *Vibrio* spp. may constitute a risk factor for cholera outbreak in the region. To have an idea of the general performance of the plants on the elimination of most common pathogenic organisms, the percentage of elimination of the organisms were calculated based on the total number of the isolates of a specific bacterial species in the influent samples and the total number of isolates in the effluent samples and are represented in Figure 1. Organisms that were more resistant to elimination included *Campylobacter* spp., *Salmonella* spp. *Enterococcus* spp. and *Vibrio* spp.

DISCUSSION

In developed countries, municipal sewage systems are

Table 4. Microbial isolates from raw (influent) and treated wastewater (effluent) from sewage treatment plants in Mpumalanga Province.

Location of the plant	Influent	Effluent
Malelane	*Salmonella arizona, Salmonella* spp., *Shigella* spp., *Escherichia coli, Vibrio cholerae, Vibrio parahaemolytica, Campylobacter jejuni, Campylobacter fetus, Enterococcus* spp., *Aeromonas* spp., *Proteus mirabilis, Serratia spp Providentia* spp., *Chrysomonas luteda, Pseudomonas* spp.	*Campylobacter* spp., *Vibrio spp* , *Aeromonas* spp., *Chrysomonas luteda, Enterococcus* spp., *Shigella* spp., *Proteus mirabilis, Pseudomonas* spp., *Escherichia coli*
Matsulu	Salmonella spp., *Shigella* spp., *Escherichia coli, Vibrio* spp., *Vibrio parahaemolytica, Campylobacter jejuni, Campylobacter coli, Enterococcus* spp., *Aeromonas* hydrophyla., *Klebsiella pneumonia, Proteus mirabilis, Serratia* spp., *Chromobacter* spp.,	*Vibrio* spp., *Campylobacter* spp., *Salmonella* spp., *Proteus mirabilis, Shigella* spp., *Chromobacter spp*
Kanyamazane	*Vibrio* spp., *Shigella* spp., *Escherichia coli, Vibrio cholerae,* Salmonella spp., *Campylobacter* spp., *Enterococcus* spp., *Aeromonas* spp., *Proteus mirabilis, Serratia, Plesiomonas shigelloides, Providentia stuartii, Providentia* spp., *Chrysomonas luteda, Klebsiella* spp,	*Chryseomonas luteda*, *Enterococcus* spp., *Proteus mirabilis, Serratia* spp., *Plesiomonas shigelloides, Providentia stuartii, Providentia* spp., *Klebsiella* spp,
Sabie	*Aeromonas* spp., *Chromobacteria spp*, *Chromobacter* spp., *Cedecia* spp., *Citrobacter frundii, Salmonella* spp., *Providencia rottegerii, Klebsiella Arizona, Klebsiella pneumonia, Escherichia coli, Vibrio* spp., *Enterococcus* spp., *Proteus mirabilis, Serratia plymuthia, Plesiomonas shigelloides, Providentia stuartii, Providentia* spp.	Providencia stuartii, *Citrobacter frundii, Salmonella* spp., *Providencia rottegerii, Seratia* spp., *Proteus mirabilis, Serratia plymuthia, Plesiomonas shigelloides*
White River	*Klebsiela pneumonia, Shigella* spp., *Escherichia coli, Vibrio cholerae, Vibrio parahaemolytica, Campylobacter coli, Campylobacter fetus, Enterococcus* spp., *Aeromonas* spp., *Proteus mirabilis, Serratia spp*	Campylobacter spp., Aeromonas spp., *Proteus* spp., *Enterobacter cloacae*
Nelspruit	*Chromobacter* spp., *Cedecia* spp., *Citrobacter frundii, Salmonella* spp., *Providencia rottegerii, Klebsiella Arizona, Klebsiella pneumonia, Escherichia coli, Vibrio cholerae, Vibrio parahaemolytica, Campylobacter jejuni, Campylobacter coli, Enterococcus* spp., *Proteus mirabilis, Serratia plymuthia, Providentia* spp., Pseudomonas spp	*Citrobacter frundii, Providencia rottegerii, Enterococcus spp., Serratia plymuthia, Pseudomonas spp*
Machadodorp	*Klebsiella ozaenae, Shigella* spp., *Escherichia coli, Vibrio cholerae, Vibrio parahaemolytica, Campylobacter jejuni, Campylobacter coli, Campylobacter fetus, Enterococcus* spp., *Aeromonas* spp., *Proteus mirabilis, Serratia*	*Klebsiella ozaenae, Shigella spp., Escherichia coli, Vibrio spp , Campylobacter jejuni, Cedecia rapogeri, Proteus spp*
Waterval Boven	Citrobacter frundii, *Escherichia coli, Vibrio parahaemolytica, Campylobacter jejuni, Campylobacter coli, Cedecia* spp., *Enterococcus* spp., *Aeromonas* spp., *Proteus mirabilis, Serratia plymuthia, Plesiomonas shigelloides, Providentia* spp. *Citrobacter frundii, Salmonella* spp., *Providencia rottegerii, Klebsiella Arizona, Klebsiella pneumonia,*	*Citrobacter frundii, Escherichia coli, Campylobacter coli, Cedecia* spp., *Citrobacter frundii, Salmonella* spp., *Providencia rottegerii, Klebsiella spp.*
Belfast	Aeromonas, Salmonella spp., *Shigella* spp., *Escherichia coli, Vibrio parahaemolytica, Vibrio* spp., *Campylobacter* spp., *Enterococcus* spp., *Aeromonas* spp., *Proteus mirabilis, Serratia* spp., *Plesiomonas shigelloides, Providentia* spp.	*Providentia rottegeri, Enterococcus* spp., *Seratia* spp., *Campylobacter* spp., *Shigella* spp., *Plesiomonas* spp., *Vibrio* spp., *Salmonella spp.*

Table 4. cont.

Dullstroom	*Escherichia coli, Vibrio parahaemolytica, Campylobacter jejuni, Campylobacter* spp., *Enterococcus* spp., *Aeromonas* spp., *Proteus mirabilis, Serratia plymuthia, Plesiomonas shigelloides, Providentia stuartii, Providentia* spp., *Chrysomonas luteda, Klebsiella* spp, *Pseudomonas* spp., *Chromobacter* spp., *Cedecia* spp., *Citrobacter frundii, Salmonella spp*	*Aeromonas spp, Providentia stuartii, Providentia* spp., *Chrysomonas luteda, Klebsiella* spp, *Pseudomonas* spp., *Citrobacter* spp., *Chromobacter* spp., *Cedecia* spp., *Campylobacter spp*
Hendrina	*Escherichia coli, Campylobacter jejuni, Campylobacter coli, Aeromonas* spp., *Proteus mirabilis, Serratia plymuthia, Plesiomonas shigelloides, Providentia stuartii, Providentia* spp., *Chrysomonas luteda,*	*Escherichia coli, Aeromonas* spp., *Proteus mirabilis, Serratia plymuthia, Plesiomonas shigelloides, Providentia* spp., *Chrysomonas luteda,*
Middleburg	*Plesiomonas, Shigella spp., Escherichia coli, Vibrio* spp., *Vibrio parahaemolytica, Campylobacter coli, Campylobacter fetus, Enterococcus spp., Salmonella* spp., *Aeromonas spp., Proteus mirabilis, Serratia spp*	*Aeromonas spp, Escherichia coli, Enterococcus* spp., *Proteus mirabilis, Serratia* spp., *Salmonella spp.*
Witbank	*Shigella spp., Escherichia coli, Salmonella* spp., *Vibrio parahaemolytica, Campylobacter jejuni, Campylobacter coli, Campylobacter fetus, Enterococcus spp., Aeromonas spp., Proteus mirabilis, Serratia*	*Salmonella* spp., *Seratia plymuthia, Klebsiela ozaenae, Enterococcus* spp., *Campylobacter* spp., *Vibrio* spp., *Shigella spp.*
Lydenburg	*Salmonella* spp., *Pseudomonas cepaciae, Shigella spp., Escherichia coli, Vibrio cholerae, Campylobacter* spp., *Enterococcus spp., Aeromonas spp., Proteus mirabilis, Serratia plymuthia, Plesiomonas shigelloides, Providentia spp., Chrysomonas luteda, Klebsiella* spp., *Pseudomonas spp., Chromobacter spp., Cedecia spp., Citrobacter frundii, Enterococcus spp.*	*Ewingella Americana, Aeromonas* spp., *Chrysomonas luteda, Klebsiella* spp, *Pseudomonas* spp., *Chromobacter* spp., *Cedecia* spp., *Citrobacter frundii.*

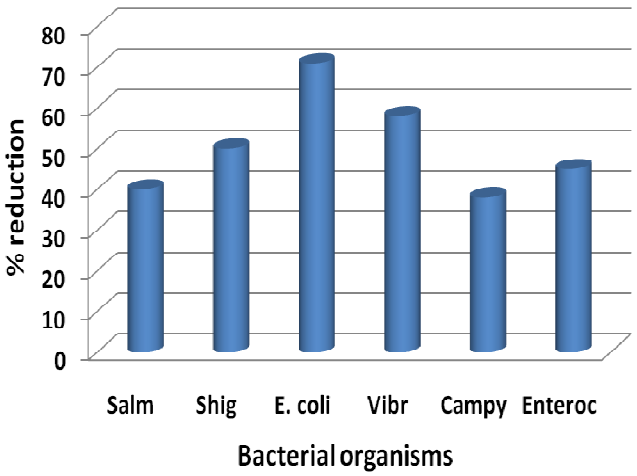

Figure 1. Reduction/inactivation of most commonly isolated potential pathogenic bacteria from STP wastewaters in Mpumalanga. The percentage of reduction represents the ratio of the difference between the number of all isolates from the influent samples from all the plants (Ni) and the number of all the isolates of the same species in the effluent (Ne) from all the plants by the number of all the isolates in the influent: % reduction = 100 x (Ni-Ne)/Ni. Salm, *Salmonell*a spp; Shig, *Shigella* spp; Vibr, *Vibrio* spp; Campy, *Campylobacter* spp; Enteroc, *Enterococcus* spp.

well organized and cover most parts of the regions. However, in most developing countries, the sewage network is rudimentary or absent (World Bank, 1995; Kim et al., 2007). This generally leads to the chronic contamination of rivers, streams and other water sources by pathogenic micro-organisms (Guévart et al., 2006; Gharbi-Khelifi et al., 2007). In South Africa, Sewage articulations exist in nearly all urban areas. However, rural areas as well as townships are generally devoid of such facilities and during the last decade, efforts have been made to improve the sanitation system in such areas to avoid outbreaks such as those described in the provinces of Kwa-Zulu-Natal and in Mpumalanga (Pillay et al., 1997). The objectives of the present study were to document the treatment methods used by the STP in Mpumalanga Province and to assess the capacity of these plants to produce final effluents that are compatible with defined standards and to determine the microbial profile of wastewater and treated wastewater.

For sewage treatment plants to meet national and international standards, there is a need to improve treatment processes and to adopt stringent policies in terms of monitoring and control of the quality of the final effluent. This includes the use of effective methods for the detoxification and disinfection of the sewage effluent.

Depending on the origin of the sewage, different treatment processes should be in place. In a region that cannot afford sewage treatment plants, a lagooning system is the minimal requirement for treatment of wastewater (WHO, 1989). In this study the lagooning system was used alone in Malelane which showed the lowest faecal coliform removal of 10% and gave bacterial indicators higher than indicated by the standards (DWAF, 1996). The water from this plant was used for the irrigation of sugar cane plantations. Although the presence of high level of nutrient might be useful for the irrigated plants the presence of pathogenic bacteria may be detrimental for those who might consume the product without prior proper cleaning. The combination of lagooning system with trickling filter has been described in Zimbabwe and referred to as a hybrid system with high potential of pathogen and nitrite removal (Broome et al., 2003). A similar system was found in Kanyamazane and gave faecal coliform removal of 56% with electrical conductivity value in the acceptable range (< 700 µS/m). The performance of such systems could be improved by the addition of humus tanks (Broome et al., 2003).

Other STP systems include ionizing radiation (Rawat et al., 1998), integrated membrane filtration, mesophilic or thermophilic anaerobic digestion (Gibbs et al., 1997; Al-Bastaki, 2004). The activated sludge process has been described and is used in many STPs around the world (Chen et al, 2004). During our study, biological digestion and activated sludge systems were observed to be the most frequently used in the treatment of wastewater in Mpumalanga Province. In some plants, both systems were used with the main role of inactivating pathogenic micro-organisms and reducing phosphorus from wastewater before its release to the environment.

A large variety of micro-organisms, culturable and non-culturable, have been described in sewage treatment systems from viruses to protozoan and helminths (Wagner and Loy, 2002). Amongst these organisms, some have been described to be pathogenic to man and have been responsible for water-borne epidemics in different part of the world including South Africa. The final effluent from all the plants was supposedly disinfected. However, count (heterotrophic, total and faecal coliform counts) remained high after treatment. Epidemics of cholera in South Africa and other countries in Africa (Pillay et al., 1997) have suggested the possibility of contamination of water sources by sewage effluent probably due to the circulation of non- treated sewage and their mixing with the rivers and streams. In this study, *Vibrio* spp. were the most encountered pathogenic bacteria from the raw wastewater and the treated sewage effluent. This is an indication of the predisposition of the community to cholera. Cholera outbreaks have been described particularly in the Transkei and KwaZulu-Natal Province (Tshibangu, 1987; Bateman, 2000). The frequency of isolation of *Vibrio* spp. in Mpumalanga Province further confirms the endemic circulation of the pathogen in the province and the risk for future outbreaks. Although Vibrios were the most isolated in the influent and the effluent, the pathogenic bacterial profiles of the inflow and the outflow were different. Enterococci were the most common after *Vibrio* in the inflow; however, the number of isolates decreased considerably after treatment. The same phenolmenon was observed with *Campylobacter* spp. and *Salmonella* species which were more resistant to elimination by the treatment processes. Similar results have been described by Horan et al. (2004) who found no decline in the numbers of *Campylobacter* isolates after 22 days of digestion during the first stage in mesophilic anaerobic digesters. Overall, there were differences in survival for the different bacterial organisms as described by Wéry et al. (2008) who found that C*ampylobacter jejuni* was the most resistant to wastewater treatment among the four bacterial groups studied including 2 enteric pathogens, *Salmonella* spp. and *C. jejuni*, and two bacteria commonly used as indicators, *E. coli* and *Clostridium perfringens*. This might be due to the difference in methods used. Activated sludge by alternating anaerobic and aerobic conditions might have more impact on sensitive micro-organisms such as *Campylobacter*. In the present study, the rate of removal of *Campylobacter* spp. could be estimated at 50%. In a study in France, a reduction of all bacteria was observed during wastewater treatment and during the thermophilic phase of composting with substantial diffe-rences among different bacterial groups studied with reference to *Salmonella* spp. and *C. jejuni* that survived better during activated sludge treatment than *E. coli* and were frequently present in agriculture- and sewage-impacted stretches of streams (Vereen et al., 2007).

Other parameters that might affect the treatment of STP wastewater include the temperature, pH, conductivity, dissolved oxygen and elements such as nitrogen and phosphate. Recent studies in Portugal have indicated that temperature, dissolved oxygen (DO) and pH were the variables that mainly influenced the bacterial communities (Moura et al., 2007). In the present study, temperature, conductivity and pH were monitored. However, dissolved oxygen could not be measured at the time of the study. The treatment processes had limited impact on the physical properties of the wastewater particularly the pH, temperature and conductivity which generally remained nearly unchanged between the influent and the final effluent. Rawat et al. (1998) also found similar results in STPs using ionizing radiation in India. However, the turbidity was improved in all the plants visited. The final effluent of an STP might be used for different purposes such as the recycling for drinking. Of the 14 plants surveyed only 1 plant recycled its water. The final effluent was of acceptable microbiological and physical quality with turbidity less than 5 NTU. This water was pumped to a mine industry for use in the cooling system, to an agricultural company for irrigation and part was pumped back to the water treatment plant to be treated

as drinking water.

The present study has indicated that there is a move toward the renovation of wastewater treatment in the Mpumalanga Province with the adoption of biological treatment by the use of trickling filters in combination with ponds or activated sludge system in most plants. However, the number of sewage treatment plants still remains low compared to the population they are supposed to serve in the region. All the STPs managed to reduce the turbidity of wastewater as well as the different microbial indicators counts; however, several pathogenic bacterial organisms could still be detected in the final effluent in some of the plants. The temperature and conductivity were in the range recommended by the EU for STP effluents. Further studies are needed to confirm the role of the treatment procedures in the elimination of other factors such as biochemical oxygen demand, nitrogen and phosphorus by the sewage treatment plants. Regular monitoring of the different treatment plant process units is recommended to detect any malfunction timeously and ensure prompt repairs. The determination of antibiotic resistance and genetic profiles of the isolates will shed more light on the role of sewage effluent in the transmission of water-related diseases in the community.

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