Efficiency of the WWTP in a Small Town of South Africa to Eradicate *E. COLI*

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Abstract— *E. coli* is a common Gram-negative facultative anaerobic bacterium. Its principal habitat has been identified in the intestinal tracts of mammals and birds as well as non-host environment (water/sediments). It is widely used as an indicator bacterium and its detection in water indicates possible pollution with waterborne pathogens. The organism's quantification after post treatment (chlorination) serves to evaluate the performance of a WWTP for microbial reduction. South African General Authorisation and Special standards stipulate that treated sewage effluents must have a limit of 1000 and 0 (zero) *E. coli* (per 100mL) respectively. This study aims at determining the efficiency of the WWTP in a small town of South Africa in eradicating the presence of *E. coli* through its contact tank disinfection (chlorination) process. Samples were collected for detection of *E. coli* using Colilert 18 method, from wastewater before chlorination and final effluent after chlorination. Physicochemical analyses were also conducted from the final effluent discharged to the river (Mooi River). The plant applies an average of 10 KG per hour of chlorine to eradicate *E. coli*. Since the inception of the study, up to date the plant is at an average of 48 *E. coli* count detected (8% compliance to zero *E. coli*) at the final effluent. Suspended solids which enhance the presence of these organisms were within the plant WUL at all time. An average of 3.7 mg/L of turbidity was detected. In comparison with the plant WUL, other physicochemical determinants such as pH, conductivity, nitrate, ammonia, ortho-phosphate and COD were at 100%, 100%, 7%, 97%, 100% and 100% respectively. Nitrate is also one determinant affecting the plant optimal performance. Although the average detected organisms showed to be lower, however the plant efficiency of eradicating the organisms is not efficiently meeting the regulated required limits of the plant. Such investigation is crucial in determining the compliance of the plant to its Water Use License (WUL).

Keywords— *E. coli*, Wastewater Treatment Plant (WWTP), Chlorination, Water Use License (WUL), Physicochemical.

I. Introduction

Wastewater is a complex mixture of both inorganic and organic materials. It is divided into domestic waster (also known as sewage), industrial wastewater, and municipal wastewater which is a mixture of the two [1]. There are two crucial reasons for treatment of wastewater: to prevent pollution, by protecting the environment; and protecting public health by safeguarding water supplies and preventing the spread of waterborne diseases [2]. According to General Authorisation in terms of section 39 of the national Water Act of 1998, Table 1 indicates the compliance limit required before a wastewater can be discharged into the environment. However, certain plants can be regulated differently on their Water Use License depending on the capacity and design of the plant. Effluent discharges from treatment process can be an important source of pathogenic bacteria in surface waters [3, 4], however like any other WWTP in South Africa, the basic function of a WWTP is to speed up the processes of purifying wastewater. *E. coli* is widely used as an indicator bacterium [5] and its detection in water indicates possible pollution with waterborne pathogens if treatment process is insufficient [6, 7, 8, 9]. The quality water is important for the well-being of the environment, society and economy [10]. Being exposed (consuming or in contact) to water contaminated with *E. coli* is deleterious to human health as well as aquatic life [11]. The organism's quantification after chlorination which is widely used to disinfect wastewater prior to discharge, serves to evaluate the performance of a WWTP for microbial reduction [12]. The growing demand for water for industrial, agricultural, environmental, municipal and domestic requirements has extended the requirements for an improvement in water treatment processes [13]. Due to certain factors such as resistance of microbial community [9, 11, 14], malfunction or poor management of wastewater systems [15], effluent containing pathogenic bacteria are discharged into receiving water bodies [16, 17]. Section 24 (a) of the South African constitution [18] state that "Every human has the right to an environment that is not harmful to human health or well-being". The very same constitution [18] on section 24 (b) further state that "Everyone has the right to have the environment protected". This study aims at determining the efficiency of the WWTP at a small town in North West Province of South Africa in eradicating the presence of *E. coli* as per the plant WUL requirements. The physicochemical compliance to WUL was also assessed in this study.

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TABLE I: WASTEWATER LIMIT VALUES APPLICABLE TO DISCHARGE OF WASTEWATER INTO A WATER RESOURCE

SUBSTANCE/PARAMETER	GENERAL LIMIT	SPECIAL LIMIT
Faecal Coliforms (per 100 mL)	1000	0
Chemical Oxygen Demand (mg/L)	75	30
pH	5.5-9.5	5.5-7.5
Ammonia (ionised and un-ionised) as Nitrogen (mg/L)	6	2
Nitrate/Nitrite as Nitrogen (mg/L)	15	1.5
Chlorine as Free Chlorine (mg/L)	0.25	0
Suspended Solids (mg/L)	25	10
Electrical conductivity (mS/m)	70 mS/m above intake to a maximum of 150 mS/m	50 mS/m above background receiving water, to a maximum of 100 mS/m
Ortho-Phosphate as phosphorous (mg/L)	10	1 (median) and 2.5 (maximum)
Fluoride mg/L	1	1

II. METHODOLOGY

A. *Study Area*

A Municipality's WWTP, at a small town in North West Province of South Africa was selected as a study area for collection of samples. The area is roughly 120 km (75 mi) west-southwest of Johannesburg and 45 km (28 mi) east-northeast of Klerksdorp. The town itself and surrounding suburbs have a population of 123,669. It is an industrial, service and agricultural growth point of North West province.

B. *Sample Collection*

All procedures were performed according to the protocols described in the Standard Methods for the Examination of Water and Wastewater [19].

Water samples were obtained from the WWTP at one of municipality's in North West Province, South Africa. Samples were collected aseptically using sterile sampling bottles 1L and 250 mL, for physicochemical and microbiological tests respectively. Samples were collected at the following points:

a. At the influent before contact tank (before disinfection);
b. At the discharge point after contact tank (after disinfection).

III. DETECTION OF E. COLI

Collected samples were analysed for presence of *E. coli* using Colilert® method [20]. The Quanti-trays were incubated at 37 °C for 18-24 hours. The results of the quantifications were reported as *E. coli* count/100 mL.

IV. PHYSICOCHEMICAL TESTING

Temperature, pH and chlorine parameters were measured *on site* using XS instrument Bench Meter for temperature and pH, while HACH colorimeter was used to measure chlorine (HACH instrument, Pocket Colorimeter ™, Loveland, USA). Chlorine was measured onsite. Other Physicochemical tests were done for all the samples at the Municipality's Laboratory using Gallery Discrete Analyser (Thermo Scientific).

V. RESULTS

A. *Detection of E. coli*

Colilert method is based on Defined Substrate Technology®. The product utilizes nutrient indicators that produce color and fluorescence when metabolized by *E. coli*. It can detect *E. coli* at 1 CFU/100 mL within 18-22 hours. In all the 119 samples analysed for *E. coli*, only 9 samples were negative for *E. coli*. As expected the number of *E. coli* present in the samples declined from samples before disinfection to final effluent disinfected samples. The compliance of the plant to its WUL limits of zero *E. coli* was 8% (see Table 2). From the number of *E. coli* which entered the contact tank before disinfection, the plant managed to eradicate 99 % in all the month studied (see Table 3).

The study also measured the number of *E. coli* entering the contact tank before disinfection in relation to the number of this organisms surviving disinfection. The analyses were done for a period of four month (January – April 2019). In all the months studied, the plant was not able to obtain 100% reduction of *E. coli*, instead a reduction of around 99% was achieved.

TABLE II: COMPLIANCE OF E. COLI TO THE WWTP'S WUL

Date	*E. coli*			
	Total Samples Tested	No. of zero *E. coli* samples	Avg	% Compl to WUL Limit
Jan 2019-Apr 2019	119	9	48	8%

Avg = Average
Compl = Compliance
WUL = Water Use License

TABLE III: AMOUNT OF E. COLI ERADICATED THROUGH CHLORINATION TREATMENT PROCESS

Date	*E. coli* count/100mL before chlorination	*E. coli* counts/100mL after chlorination	Eradicated *E. coli* %
Jan-19	330095	47	99.99
Feb-19	726795	10	99.99
Mar-19	378106	96	99.97
Apr-19	20934	37	99.82

B. *Physicochemical Quality of the Final Effluent*

Water samples were tested for a wide range of physicochemical parameters. The findings were compared against the plant WUL limits. Table 4 indicates the limits from the plant WUL.

TABLE IV: RECOMMENDED LIMITS FOR DISCHARGE INTO THE ENVIRONMENT

SUBSTANCE/PARAMETER	WUL LIMITS
Faecal Coliforms (per 100 mL)	0
Chemical Oxygen Demand (COD) (mg/L)	≤75 after applying chloride correction
pH	5.5-9.5
Ammonia (as N) (mg/L)	10
Nitrate (as N) (mg/L)	3
Suspended Solids (mg/L)	≤25
Electrical conductivity (mS/m)	≤75 mS/m above intake water
Ortho-Phosphate as phosphorous (mg/L)	<3
Fluoride mg/L	1

As shown in Table 5, eight parameters were analysed and compared with the plant WUL limits stipulated in Table 4. pH (6.74 – 7.9), suspended solids (0.6 – 17 mg/L), electrical conductivity (72.27 – 117.7 mS/m) and ortho phosphate (0-1.93 mg/L) were always within the required limits and achieved compliance of 100%, while ammonia (0 – 10.59 mg/L) and Chemical Oxygen Demand (COD) (3 – 90 mg/L) compliances were 97% and 98% respectively. Since the free residual chlorine (0.16 – 2.65 mg/L) is not regulated on the municipal WUL, it was then measured in line with General Authorization (G.A) limits of 0.25 mg/L. Of the 120 samples analysed for free residual chlorine, 12% of them complied with G.A limits. Nitrate was the parameter with lowest compliance, detected between 0.1-11.4 mg/L, with a compliance of 9% to the plant WUL limits.

Turbidity and temperature were the other studied physicochemical parameters not regulated in South African wastewater final effluent. Temperature measured was between 19 and 26^{0}C. Detected turbidity was between 1 and 4 NTU, with an average of 3.7 NTU.

TABLE V: PHYSICOCHEMICAL PARAMETERS VALUES OF WATER

Parameters	**Avg**	**No. of failures**	**No. of samples analysed**	**% compl**
Cl_2 mg/L	0.83	106	120	12%
pH	7.465	0		100%
S.S mg/L	7.64	0		100%
E.C mS/m	88.37	0		100%
Nitrate mg/L	5.756	109		9%
NH3 (mg/L)	2.688	3		97%
Ortho P (mg/L)	0.428	0		100%
COD mg/L	26.2	2		98%

VI. DISCUSSION

One of the ways to evaluate water quality is to measure water quality variables and assess values for benchmarks, such as guidelines. The wastewater treatment plant at the study area is regulated by South African Department of Water and Sanitation through its WUL which stipulates limits mentioned in Table 4. The License was obtained in 2016 and amended in 2017 due to set limits that were not in line with the plant design. Previously the system was operating under G.A limits. The plant maintained its Green Drop status for several years since its inception in 2008 except in 2009 [22, 23, 24, 25]. Its compliance limits for *E. coli* therefore moved from 1000 *E. coli* count/100mL (G.A) to 0 *E. coli* count/100 mL (WUL).

<u>*E. coli*</u>

Water quality is a newsworthy issue in the health of public due to concerns arising from the none-quality discharge of inadequately treated sewage into water bodies, which can be of health concern to human and the environment [26, 27]. Microbiological water quality standards are majorly based on faecal indicators; though they signify a minor part of the total bacterial in aquatic environment and *E. coli* is a frequently used indicator organism to monitor the microbial quality of water [28]. Even though the plant managed to eradicate *E. coli* completely in 9 times out of the 119 tests, however, from the counts exposed to disinfection, the plant is able to eradicate more than 99%. It has been known for many years that the number of bacteria present in the effluent of an activated-sludge plant is reduced 90 to 99% as compared with the influent [29, 30]. Analysing the effectiveness of *E. coli* reduction, Bonde, 1990 observed that the number of *E. coli* decreased by 95% [31], whereas Szumilas study reported that, modern sewage treatment plants are able to reduce more than 99.99% of coliform bacteria [32]. Study by Budzinska and colleagues also showed elimination of *E. coli* in treated wastewater within the range from 99.40 to 99.92% [33]. Similar findings of above 99% *E. coli* reduction was also observed in this study. When the presence of this organism is not completely eradicated, it therefore indicates possible pollution with pathogenic waterborne organisms [7, 8, 9]. According to a study by Samie, only 2 out of the 14 studied 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) [34]. Zero *E. coli* detection was also observed in this study in few occasions.

The average count discharged into the environment is less than 100 (48 *E. coli* counts/100 mL) which therefore meets the compliance to the limits of 1 000 cfu/ 100 mL set for agricultural purposes (DWAF, 1996). Of the 14 plants studied by Samie, 9 of them complied with the agricultural purpose limit [34].

<u>*Physicochemical Parameters*</u>

Apart from chlorine, turbidity and temperature, out of the 8 physicochemical parameters studied, Ammonia, COD and Nitrate were the only parameters that did not comply to set WUL limits. Osuolale and Okoh study outcomes showed that six (6) out of the twelve (12) parameters tested complied with the South African (SA) effluent GA discharge standard limits as outlined in DWAF [21].

The nitrate level ranged between 0.1 mg/L to 11.4 mg/L compared to 8.03 mg/L to 18.70 mg/L detected in Osuolale and Okoh study. Elevated levels of nitrates can result in eutrophication, giving rise to increase algae growth and eventually leading to reduced dissolved oxygen levels in the water [37]. Osode [38] and Odjadjare et al. [39] also reported compliance of some of the WWTPs in the Eastern Cape Province with respect to nitrate, while in this study, only 11 out the 120 samples analysed complied with the plant WUL limit.

The disposal of untreated high strength ammonium wastewater in water bodies is a significant environmental problem because of the harmful effect of the free ammonia (FA) on the aquatic life and environment [40, 41]. Study by Agoro and colleagues indicated effluents discharges of ammonia between 0.06 and 112 mg/L [42] compared to 0 – 10.59 mg/L in the current study. Chemical Oxygen Demand (COD) is a measure of the oxygen equivalent of organic materials in wastewater and a widely used indicator of wastewater quality [43, 44]. Compliance for COD in the current study (98%) was higher compared to Osuolale and Okoh study in the Eastern Cape Province of South Africa with compliance of 77% to its regulatory standard [35]. As compared to the China's discharge standard limit for wastewater of 60 and 120 mg/L for Grade 1 and 2 respectively [45], while in Germany, the COD discharge limits range from 75 mg/L to 150 mg/L for different scales WWTPs [46]. The current plant WUL limits is stated in table 4. All COD values were higher than the maximum accepted values (125 mg O_2/L) of the Romanian Law in Popa and colleagues study [47].

Due to the lack of regulatory standards limit at the study plant's WUL, chlorine was compared against South African GA limits. According to South African Regulation Standards (G.A limits) as indicated in Table 2, a WWTP is allowed to discharge residual chlorine of less 0.24 mg/L. The studied plant discharge limit is not within the required limit, therefore literature state that many of these chemical disinfectants if overdosed or used inappropriately can react with organic and inorganic precursors and bring the formation of disinfection by-products (DBPs) with adverse health effects to aquatic life [48], therefore affecting the limited water resources in the country [. About 67% of the WWTP-A samples had low free chlorine concentration below the recommended set limit while WWPT-B samples had acceptable levels of free chlorine concentration in a study by Osuolale and Okoh [21].

Turbidity of the final effluent can serve as a measure of treatment efficiency [69-71]. Due to the lack of regulatory standard, the turbidity levels were compared against South Arabian limit for irrigation as well as aesthetic limit from South African Standard for Drinking Water of 5 NTU as there are no set limits for these parameter in SA. In this study, the turbidity detected was less compared to the above limits.

VII. CONCLUSION

The peculiar challenges facing the water and sanitation sector in South Africa are still paramount. In South Africa water is most critical resource and its quality is a prerequisite for all forms of life. Treated wastewater is used to alleviate challenge of water shortages.

Effluent discharges from treatment processes can be an important source of pathogenic bacteria in surface waters however like any other WWTP in South Africa, the basic function of the studied plant WWTP is to speed up the processes of purifying wastewater. Although the treatment plants succeeded in removing majority of *E. coli* from the influents which however were not mostly in line with its WUL limit, effluent discharges are only occasionally devoid of the organisms, thus constituting a potential threat of incidences of infectious diseases.

The high non-compliance with regard to nitrate level suggests that inorganic matters are present in high amounts in the effluent discharge. The continuous discharge of this poor quality effluent will contribute to the eutrophication of the surface water body and subsequently lead to the death of aquatic organisms.

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