

Case Study

Physicochemical Appraisal of Effluents Receiving Stream: A Case Study of Mvudi River, South Africa

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Abstract

The impact of discharged treated wastewater effluents on the physicochemical parameters of Mvudi River was appraised over the period of July to September 2012. Physicochemical parameters measured included pH, electrical conductivity, total dissolved solids, chemical oxygen demand, total organic carbon, nitrate, and orthophosphate. The parameters were concurrently monitored in the treated final effluents and the receiving stream. High levels were observed for chemical oxygen demand, nitrate, orthophosphate, total organic carbon, conductivity, total dissolved solid during winter and spring seasons. They were above prescribed limits as stipulated by Department of Water Affairs-South Africa and World Health Organisation for treated waste water effluents. Low pH was observed for discharged effluents which could be attributed to organic acids produced in the anaerobic digestion of the sewage effluents. The study indicated moderate impact of the poorly treated effluents on the physicochemical properties of Mvudi River. High levels of nutrients and high COD, TOC observed could lead to eutrophication and oxygen depletion respectively and thus endanger aquatic organisms. Municipal authorities should ensure the discharged treated effluents to Mvudi River are within the stipulated guidelines. This could be managed through frequent optimization of the treatment processes and procedures employed in the Waste Water Treatment Plant.

Keywords

Chemical Oxygen Demand; Conductivity; Mvudi River; Orthophosphate; Total Organic Carbon; Treated Wastewater Effluents

Introduction

Several studies have shown that disposal of sewage waste from Waste Water Treatment Plant is a major problem around the world which is degrading the water quality since it is more likely to pose environmental stress [1-6]. Effluents discharged into water body can also contain hazardous substances which in turn result in upsetting or degradation of the ecological balance of rivers [7]. From a social perspective, the discharge of effluents into water body can pose negative impacts on human health, primarily from bacteriological and other forms of pathogens that survive in the biological treatment process and inadequate treatment of the effluents [1,2]. Sewage discharges is mainly associated with loading of nutrients such as nitrate and phosphate to the water bodies, hence promoting accelerated growth of toxic algal blooms and leading to a destabilized aquatic ecosystem [8]. The majority of waterborne microorganisms that cause human disease come from sewage waste water. These contain a wide variety of viruses, bacteria, and protozoa that may get washed into drinking water supplies or receiving water bodies [9]. Moreover, Sewage wastewater also carries microbial pathogens that spread many diseases such as diarrhoea, hepatitis, typhoid fever, shigellosis, salmonellosis, campylobacteriosis, giardiasis, cryptosporidiosis and cholera from consumption of water contaminated with pollutants from Waste Water Treatment Plant [10].

Water pollution by effluents from Waste Water Treatment Plant is associated with heavy disease burden [11] and this could significantly influence the current problem of shorter life expectancy more especially in developing countries such as South Africa. The susceptibility of residents of rural communities in South Africa

to disease loaded contaminated water is due to lack of adequate sanitation and water supply infrastructures, economic and technological constraints to adequately treat the available water before use [12,13].

South Africa has a population of 49.4 million people, 52% of whom are estimated to be living in the rural communities [14]. Of this part of the population, 6.0 million still don't not have access to a reliable source of drinking water [15]. This implies that a large part of communities in rural areas depend on untreated surface and groundwater sources for their daily water need [16]. In recent decades, sewage discharge has been reported to be problematic in South Africa since there are inadequate wastewater treatment facilities even though several efforts are being vigorously pursued to control and manage wastewater. The problem is amplified in areas where wastewater treatment systems are simple, ineffective and inefficient. Treatment and assessment of river water and wastewater plays a crucial role in safeguarding public health and the environment [17]. Therefore, whichever level of treatment and method of disposal should strictly comply with national water quality guideline standards and internationally accepted environmental quality criteria, taking into account the recipient environment and

the biological targets which may be affected by such water [18].

The treated sewage effluent from Muledane waste water treatment plant are discharged into water bodies are more likely to pose hazardous effects to aquatic organism since they are laden with elevated concentration of pollutants such as phosphates and nitrates which can potentially accelerate algae bloom and in turn deplete the water dissolved oxygen. This study will provide awareness to the Municipality environmental authorities about the impacts posed to Mvudi River ecosystem due to the effluents discharged into the river. The aim of the study was to assess the impact of discharged treated municipal wastewater effluents on the physicochemical properties of the receiving water and evaluate the correlation of the various parameters.

Materials and Methods

Study site and plant description

The Mvudi River is situated between Longitudes E030° 28' 499" - 030° 28' 640" and Latitudes S23° 00' 028" -S23° 00'100" within Muledane area in Vhembe district, Limpopo Province of South Africa. Figure 1 shows the sampling points along the river.



Figure 1: Map of the study area showing the sampling points: A-upstream, B-effluent discharge point and C-downstream.

The Mvudi River joins the Dzindi River which in turn is a tributary of Luvuvhu River. The sewage treatment plant is situated south of Mvudi River. The sewage treatment plant which has design capacity of 6 mega litres per day receives domestic sewage effluents, some light industrial wastewater, as well as run-off water and treatment is based on the activated sludge system. The treated final effluent is discharged into the Mvudi River.

Description of sampling stations and sample pre-treatment

Four sampling localities were selected and they were named upstream, effluent, discharge point and downstream respectively. The distance between sampling localities was 100m apart. Samples

were collected between July (i.e., winter), August and September (i.e., spring) 2012. Samples were collected in glass containers, pre-cleaned by tap water and finally rinsed by MilliQ (18 Ω cm-1) water. In each selected site samples were collected in triplicate to ensure precision of the results and the sampling containers were filled to the top to avoid further reaction of samples with atmospheric gases and to avoid the presence of air that might chemically or biologically alter the sample [19].

Physicochemical analysis

All laboratory probes and equipments were checked and calibrated according to the manufactures specification. pH, electrical conductivity, Total Dissolved Solids (TDS) of the samples were

determined using a CRISON model mm40 Multimeter probe. The concentrations of orthophosphate as P, nitrate, Total Organic Carbon (TOC) and Chemical Oxygen Demand (COD) were determined in the laboratory by the standard photometric method [18] using the Spectroquant NOVA 100 photometer (Merck Pty Ltd). Samples for COD analysis were digested with a Thermo reactor model TR 620 (Merck Pty Ltd.) and then analyzed by the Spectroquant NOVA 100 photometer (Merck Pty Ltd.). Blank determinations were performed for COD, nitrate, nitrite and orthophosphate and results were adjusted for blank measurement in the presented results. New standards were created for each parameter during every measuring month.

Statistical analysis

The obtained data was subjected to descriptive statistical analysis (95 % confident limit) and Pearson correlation coefficient using

statistical Package for the Social Sciences (SPSS version 17). SPSS Statistics 17.0 is a comprehensive system for analyzing data. In previous studies, statistical analysis using multivariate data from river system have been used to describe environmental classification which in-turn provides better understanding of the chemical processes and difference in environmental variables, nutrient concentrations in the river system [20-22]. In this study, for better understanding of natural and anthropogenic fluxes responsible for characterization of river water quality, we employed Pearson correlation coefficient analysis on the water quality data. Pearson's correlation coefficient assumes that each pair of variables is bivariate normal and it is a measure of linear association.

Results

The results of the physicochemical parameters of samples from the different sampling points are as shown in (Table1).

Variables	Seasons	Effluent	Discharge point	Downstream	Upstream
pH	Winter	5.54±0.49	6.63±0.55	6.01±0.01	7.95±0.06
	Spring ¹	5.61±0.47	6.92±0.05	6.91±0.03	7.04±0.02
	Spring ²	6.65±0.55	6.2±0.07	7.01±0.02	7.08±0.02
	Spring ³	7.06±0.03	7.18±0.02	7.2±0.01	7.00±0.02
	Spring ⁴	6.66±0.0	6.66±0.09	6.61±0.0	6.85±0.2
EC (µS/cm)	Winter	82.7±0.82	44.27±1.79	67.8±0.18	17.19±0.11
	Spring ¹	80.43±0.42	39.4±0.26	50.97±0.95	18.18±0.17
	Spring ²	642.33±11.02	316.33±2.08	730.33±6.66	136.33±2.48
	Spring ³	329±7	148.9±3.91	158.4±1.14	82.8±1.37
	Spring ⁴	311±6	191±11.4	135±0.92	71.6±14
TDS (mg/L)	Winter	53±0.56	28.93±0.06	41.37±0.12	11.04±0.04
	Spring ¹	53.83±5.01	25.17±0.12	42.53±3.95	11.63±0.12
	Spring ²	410.33±6.66	202.33±1.15	467.33±3.79	88.05±1.44
	Spring ³	211±4.71	95.3±2.51	101.2±0.58	51±0.31
	Spring ⁴	199±3.76	97.6±7.35	86.3±0.6	75.2±21
COD (mg/L)	Winter	250.33	55±0.58	83±1	27.67±1.53
	Spring ¹	310.07±0.12	57±1	94.67±2.52	30.27±0.25
	Spring ²	350.33±0.58	100.33±0.58	92±1	28.93±0.57
	Spring ³	400±0.58	205±2.08	195±0.58	16.01±0.01
	Spring ⁴	239±5.29	48±6.56	160±20.2	16±0
TOC (mg/L)	Winter	76.27±2.65	45.1±2.14	58.23±1.76	12.57±0.49
	Spring ¹	150.33±0.58	58.97±0.49	75.13±4.63	13.40±0.01
	Spring ²	330.33±0.58	124.9±3.20	155.3±3.02	28.3±1.39
	Spring ³	105±0.58	55.7±8.70	35.01±0.40	15.3±0.1
	Spring ⁴	140±26.5	105±5.09	127±0.64	8.47±0.4
NO ₃ (mg/L)	Winter	32.87±4.13	19.3±0.26	23.4±2.63	16.27±0.15
	Spring ¹	29.3±0.1	17.3±0.26	20.2±0.1	17.2±0.1
	Spring ²	35.4±0.1	18.23±0.21	20.03±0.06	10.83±0.12
	Spring ³	13.6±0.1	11.41±0.01	11.51±0.01	10.01±0.06
	Spring ⁴	6.9±0.26	1.3±0.1	0.8±0.1	0.63±0.1

PO ₄ ³⁻ (mg/L)	Winter	8.67±0.21	6.37±0.32	5.43±0.31	0.50±0.00
	Spring ¹	10.37±0.21	2.7±0.71	3.61±0.01	0.60±0.01
	Spring ²	20.23±0.15	10.43±0.31	13.63±0.06	3.2±0.1
	Spring ³	6.71±0.01	2.31±0.01	2.1±0.01	0.81±0.01
	Spring ⁴	5.27±0.2	1.83±0.21	1.37±0.2	0.37±0.1

Table 1: Seasonal variation in the concentrations of physico-chemical parameters for the four sampling points in Mvudi River. Values are means of triplicates ± Standard Deviations (SD). Samples collection dates: Winter=26th July, 2012; Spring¹=10th August, 2012; Spring²=31st August, 2012; Spring³=13th September, 2012; Spring⁴=20th September, 2012.

pH

The pH profile varies significantly in the sampling points throughout the study period and ranged from 6.01 to 7.95 during winter and 6.2 to 7.18 during spring. pH of the treated final effluent varies between 5.54 and 7.06 and had the lowest pH recorded. At discharge point, which is also the mixing zone of the treated effluents with river water, the pH varied from 6.2 to 7.2. At downstream point, the pH varied from 7.00 to 7.95 (Table 1).

Electrical Conductivity (EC)

The electrical conductivities of the stream water generally vary throughout the study period and range from 17.17 to 44.27 μS/cm during winter and 18.18 to 730.33 μS/cm during spring. EC of the treated final effluent varies between 80.43 to 642.33 μS/cm. At discharge point, which is also the mixing zone with river water the EC varied from 39.4 to 316 μS/cm. Downstream point EC varied from 67.8 to 730 μS/cm and upstream recorded the lowest EC levels (17 to 136.5 μS/cm). Highest values were observed during early spring in all sampling points (136.5 to 730 μS/cm) (Table 1).

Total Dissolved Solid (TDS)

The Total Dissolved Solid (TDS) profile of the receiving water body samples vary significantly and ranged from 11.04 to 41.37 mg/L during winter season and 25.17 to 467.33 mg/L during spring season (Table 1). The TDS for the discharged effluents varied from 53-410 mg/L, at the discharge point which is also the mixing zone the levels varied from 28 to 202 mg/L, downstream levels varied from 41 to 467 mg/L while at the upstream sampling point the levels varied from 11 to 88 mg/L.

Chemical Oxygen Demand (COD)

The Chemical Oxygen Demand (COD) of the stream water samples varied from 27.67 to 83.0 mg/L during winter and 16.0 to 400 mg/L during spring seasons. Throughout, the study period the treated final effluent samples ranging between 250.33 and 400 mg/L. At discharge point, which is the mixing zone with river water levels varied from 48 to 205 mg/L, at downstream point levels varied from 83 to 195 mg/L while at the upstream point the levels ranged from 16-30 mg/L (Table 1).

Total Organic Carbon (TOC)

The Total Organic Carbon (TOC) of the stream water samples varied 12.57 to 58.23 mg/L during winter and 13.40 to 155.3 mg/L

during spring. The treated final effluent varies between 76.27 to 330.33 mg/L during the seasons. At discharge point, which is also the mixing zone the levels varied from 45 to 124.9 mg/L, at downstream point the levels varied from 35 to 155.3 while at the upstream point the levels ranged from 8.5 to 28.3 mg/L (Table 1).

Nitrates

The nitrate profile of the receiving water body samples varies significantly and ranged from 16.27 to 23.4 mg/L during winter season and 0.60 to 20.03 mg/L during spring season (Table 1). The treated effluent levels varied from 6.9 to 35.4 mg/L. At discharge point, which is also the mixing zone, the levels varied from 1.3 to 19.3 mg/L, at downstream point the levels varied from 0.8 to 23.4 mg/L while at the upstream point the levels ranged from 0.63 to 16.27 mg/L.

Phosphates

The Orthophosphate concentrations (PO₄³⁻) in the stream water varied from 0.50 to 6.37 mg/L during the winter season and 0.28 to 3.98 mg/L during spring season. The treated final effluent mainly had orthophosphate ranges between 5.27 and 20.23 mg/L. At discharge point the levels varied from 1.83 to 10.43 mg/L, at downstream point the levels varied from 1.37 to 13.63 mg/L while at the upstream the levels ranged from 0.37 to 3.2 mg/L (Table 1).

Correlation of physicochemical parameters

The correlations among the physicochemical qualities were calculated and results are presented in table 2. There was no significant correlation observed in pH with NO₃, COD, TOC and PO₄³⁻. pH with EC and TDS registered significant positive correlation (r=0.016, 0.02, P<0.05). pH with NO₃ indicated a negative correlation (r = - 0.453, P < 0.05). Conductivity exhibited positive significant correlation with TDS, TOC and PO₄³⁻ (r = 0.997, 0.768, 0.767 at P<0.01, respectively). Total Dissolved Solid (TDS) showed positive correlation with TOC, PO₄³⁻ (r = 0.759, 0.767 at P<0.01, respectively) and COD (r = 0.416 at P<0.05).

Discussion

These low pH values in the effluent (5.54, table 1) could be attributed to organic acids released through anaerobic decomposition of organic components in the sewage effluents. Chlorination of the treated effluent and formation of dilute hydrochloric and hydrochlorous acids could also drive the pH down [23]. A slight increase in pH is observed at discharge and downstream points

Variables	pH	EC	TDS	COD	NO ₃	TOC	PO ₄
pH	1	0.016	0.02	-0.335	-.453*	-0.332	-0.431
EC	0.016	1	.997**	0.417	0.217	.768**	.767**
TDS	0.02	.997**	1	0.416	0.218	.759**	.767**
COD	-0.335	0.417	0.416	1	0.404	.645**	.568**
TOC	-0.332	.768**	.759**	.645**	0.437	1	.856**
NO ₃	-.453*	0.217	0.218	0.404	1	0.437	.722**
PO ₄	-0.431	.767**	.767**	.568**	.722**	.856**	1

Table 2: Correlation coefficient r for the different physicochemical variables for the four sampling points in Mvudi river. *Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed).

confirming the impact of the effluents mixing with the river water. The pH values at all the sampling points and effluents fall within the World Health Organization recommended range of 7.0 to 8.5 and 6.5 to 8.5 for drinking water and water meant for full contact recreation, respectively [24-26]. The neutral to alkaline pH values obtained in most sampling points has similarities with values reported elsewhere [4,27].

Electrical Conductivity trends (EC)

Higher conductivities were observed downstream and this could be attributed to anthropogenic activities on the downstream river catchment for example erosion and release of sediments due to runoff and rainfall. High values were also observed at the discharge points in winter and spring seasons, this variation could be due to the variation in efficiency of the treatment plant and the changing nature of the influents received by the treatment plant. The South African guideline for conductivity in effluent that could be discharged into the receiving water bodies is 250µS/cm [28] and based on this guideline; the effluent quality does not appear to be compliant with the regulation for electrical conductivity. The South African acceptable limit for conductivity in domestic water supply is 70µS/cm [29]. This limit was exceeded in the receiving water body. The conductivity values observed in this study for the sampled period are mirror the findings of previous studies [4,30]. Higher TDS (28 to 202 mg/L, 41 to 467 mg/L, table 1) were observed downstream and at discharge points in winter and spring seasons suggestive of other point sources of pollution entering the receiving water body. The high levels at the downstream point could be attributed to point sources such as runoff and erosion from the river catchment. Low values were observed in the upstream point. The treated final effluent TDS varied from 53.0 to 410.33 mg/L (Table 1) during the study periods. These TDS values fell within the allowed limits of 0 to 450 mg/L [31]. High TDS values can be detrimental to freshwater organisms by causing osmotic stress and affecting the osmoregulatory capability of the organisms [32].

Chemical oxygen demand trends

The observed significant contribution of COD by the effluent and receiving water body agrees with the previous studies by various researchers [4,27,30]. The COD values were higher than the acceptable limits (i.e., 30 mg/L) set by DWAF water quality

guideline for effluents designed for discharge into the receiving water bodies [28]. Increased levels of COD were observed at the downstream and discharge points in both seasons when compared with upstream. This could be ascribed to the mixing and dilution effect of effluents by stream water. The increased levels of COD in the downstream point compared to the upstream point could be mainly attributed to the discharge of the treated effluents. The COD levels in the effluent are attributed to organic components from the influent received by the treatment plant which normally has a significant component of sewage from domestic effluents [33]. The continuous discharge of effluent with high COD levels will have adverse effects on the receiving water body. This will ultimately lead to negative effects on the quality of the freshwater and subsequently negative impacts on the aquatic ecosystem and river health downstream [27]. This could also impact on the treatment cost and efficiency of the drinking water treatment plants downstream.

Total organic carbon trends

High TOC levels (76 to 330 mg/L, table 1) in the effluent were observed, these levels decreased in the discharge and downstream point due to mixing and dilution effect of the river water. It should be noted that the TOC levels at the upstream point were the lowest indicating the discharged effluent were the main source of the TOC. At the downstream point the levels were observed to decrease by half, this could be attributed to both dilution effect and microbial breakdown and incorporation of the resulting C in their tissues. The TOC levels in effluent, discharge point and downstream is attributable to organic components in the influent received by the treatment plant.

Nitrate trends

Nitrate is the most highly oxidized form of nitrogen and is commonly present in surface and groundwater because it is the product of aerobic oxidation of ammonia. The South African guideline for nitrate in sewage effluent is 1.5 mg/L NO₃-as N [28]. The obtained nitrate concentration values exceeded the recommended limit (6.9 to 35.4 mg/L, table 1). The effluent from the sewage treatment plants could be considered as a source of nitrate into the receiving water body. In the downstream, the nitrate concentration profile was observed to increase gradually, this may be attributed to aerobic decomposition of aquatic flora or contribution from anthropogenic

activities on the downstream river catchment.

Orthophosphate trends

Elevated orthophosphate levels were recorded for the discharged effluent (5.27 to 20.23 mg/L, table 1). The levels decreased at the discharge point which is also the mixing zone, this is attributed to dilution and mixing effect of the river water, a slight increase was then observed at the downstream point which could be “ attributed to anthropogenic activities or release from decaying plant material [4]. However, the level of phosphate in water systems that will reduce the likelihood of algal and other plant growth is 5µg/L [24]. Other investigators have pointed out that eutrophication-related problems in temperate zones of aquatic systems begin to increase at ambient total P concentrations exceeding 0.035 mg/P [23]. Generally, the phosphate-P values were higher during spring season compared to winter season, for the downstream and upstream of the discharge points. This could be attributed to runoff from domestic, municipal, and agricultural waste and seepage from individual sewage treatment systems. Nitrates (NO₃) and phosphorus are essential nutrients to plant life, but when present in excessive quantities, they can stimulate excessive and undesirable plant growth (Eutrophication) such as algal blooms. Eutrophication could unfavorably affect the use of rivers and dams for recreation purposes as the covering of large areas by macrophytes could prevent access to waterways and could cause unattractive and stinking scum which could lead to the growth of blue-green algae and release toxic substances (cyanotoxins) into the water systems. Besides, it is recognised that eutrophication could increase the treatment cost of drinking water through filter clogging in water treatment works [34].

Correlation of physicochemical parameters

The observed pH and NO₃ trend agrees with observations from previous study by [4]. The orthophosphate (PO₄³⁻) exhibited a positive correlation with COD, NO₃ and TOC (r = 0.568, 0.722, 0.856 at P<0.01, respectively, table 2). Positive correlation between physicochemical parameters in the stream water samples could allude to similar sources or causal effect. The positive correlation could also be an indication that the physicochemical parameters are greatly influenced by the sewage treatment activities in the study area. A positive correlation between pH and EC, TDS could be explained by precipitation and formation of metal oxides/hydroxides and subsequent adsorption of chemical species which would cause a decrease in EC and TDS. A positive correlation observed between EC and TDS, TOC, PO₄³⁻, charged species such as PO₄³⁻ contribute to transfer of charges and to TDS, charged organic species that contribute to TOC also contribute to the conductivity of a media, this would explain the positive correlation observed between these parameters and EC.

The impact of discharge of treated municipal waste water plant effluents on the physicochemical parameters of the receiving water body was carried over a period covering winter and spring. Parameters monitored were pH, EC, TDS, COD, TOC, orthophosphates, and nitrates. Peak values of the chemical parameters for all the

sampling points were observed in spring. The upstream point recorded the lowest values for all parameters monitored which represented the background concentrations. A gradual decrease in levels for all parameters was observed at the discharge point which confirmed the importance of the mixing and dilution effect of the receiving stream water. This also indicated the treated effluent was the main contributor of these parameters in the receiving stream water.

A peak in TDS, NO₃ and PO₄³⁻ was observed in the downstream point which indicated possible contribution by anthropogenic activities on the downstream river catchment. A significant number of the measured parameters were observed to exceed the prescribed limits for discharge of treated effluents in surface water bodies. This was observed to be a concern especially on the cumulative effect on the river health and negative impact on the drinking water treatment plant downstream. The mixing and dilution effect of the river water was observed to play a significant role in the gradual decrease in the levels of these physicochemical parameters. It is recommended that the waste water treatment plant monitor operation efficiency of the plant and the discharged effluent quality to prevent any adverse effects on the river health.

Conclusion

Several physicochemical parameters were measured over a period of three months to assess the impact of discharge of wastewater treatment plant effluents on a fresh water resource. Results indicated high concentrations of COD, NO₃, PO₄³⁻, TOC, EC, and TDS at discharge point and downstream of the discharge point. The fresh water resource was observed to be most sensitive to COD with the levels showing increase at discharge point and downstream of discharge point. This was attributed to the high content of organic matter normally present in municipal sewage effluents. The levels were observed to be higher than DWAF set guidelines for discharge of treated effluents. Continued discharge of the effluents could have a negative impact on the dissolved oxygen and consequently affect survival of aquatic organisms. The high level of nutrients observed could also pose a risk of eutrophication. With subsequent on the quality of the water resource. This study recommends assessment of the impact of discharge of the treated effluents on a longer portion of the river downstream of the discharge point to fully assess the assimilative capacity of the water resource

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