

Impact of partially treated wastewater on downstream water quality of Notwane River in Botswana

Abstract: The impact of partially treated wastewater on the water quality of Notwane river stretch in the Gaborone region of Botswana was investigated. Water samples collected at effluent discharge point and three other sampling sites downstream were analyzed for pH, temperature, Biological Oxygen Demand (BOD₅), ammonia nitrogen and nitrate nitrogen. Sampling was conducted bi-weekly between February 2013 and April 2013. The ranges of measured parameters were: pH (7.6-8.5), temperature (22-23°C), BOD₅ (11.2-27.0 mg/l), ammonia nitrogen (2.4-60.5 mg/l), nitrate nitrogen (20.6-28.6 mg/l). Analysis of variance, Games-Howel multiple comparison and Pearson correlation were used to separate variable means. The results signal river non-point pollution due to runoff inflow of organics mainly from agriculture and domestic waste dumping by nearby dwellings. Temperature, BOD₅, and pH range values were all within the Botswana Bureau of Standards (BOBS) limit while the maximum ammonia-nitrogen and nitrate nitrogen were above BOBS limit by 50.5 mg/l and 6.6 mg/l respectively. Regulations on indiscriminate waste dumping and discharge standards adherence should be enforced.

Keywords: Wastewater discharge, Notwane river, non-point pollution, waste dumping, Botswana Bureau of Standards

INTRODUCTION

Notwane River is a natural waterway that, several decades ago conveyed water emanating only from watershed upstream. The river was then dammed upstream at Gaborone dam in 1964. In 1997, the Gaborone Wastewater Treatment Plant was commissioned to process municipal sewage effluent of about $40,000 \text{ m}^3 \text{ day}^{-1}$ produced in and around the city of Gaborone in Botswana. This treated wastewater is discharged into the Notwane river downstream of Gaborone dam.

The effluent treatment process at the Wastewater Treatment Plant was assessed in 2004 (Nkegbe et al., 2005). It was concluded that the efficiency of the activated sludge treatment process was highly efficient in removing Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD_5), Total Suspended Solids (TSS), ammonia nitrogen ($\text{NH}_3\text{-N}$), Total Kjeldahl Nitrogen (TKN) and nitrates (NO_3^-) to meet the discharge guidelines or standards. The suitability of the treated wastewater for irrigation of horticultural crops was also evaluated (Emongor et al., 2005). It was concluded that the treated secondary effluent was suitable for irrigation water purposes. It was consequently imperative, at the time, to determine the water quality along the Notwane river in order to establish the pollution level and sources of pollution. Kotlhao et al. (2006) concluded that the secondary effluent along Notwane river was suitable for irrigation of crops as the river was not heavily polluted due to the low heavy metals including mercury (Hg), lead (Pb) and arsenic (As) which are of concern to human health when they accumulate in the environment.

Since the initial evaluation of water quality of treated secondary effluent along the Notwane river in 2004, the population of the city of Gaborone as well as industrial

and agricultural activities along the river have markedly increased. Therefore, the Notwane river flow regime and water quality is dependent on the quality and quantity of the increased effluent and the subsequent physico-biochemical processes from this effluent discharge point onwards. When discharged in aquatic systems such as Notwane river, municipal treatment works effluents can lead to elevated levels of Biological Oxygen Demand (BOD), and nutrients mainly, nitrogen. This could affect physico-chemical characteristics of receiving water body therefore leading to eutrophication and thus reduction in water as a resource to an array of uses (Agwa and Ogugbue, 2013; Walakira and Okot-Okumu, 2011). When used for irrigation and livestock watering, that is, common uses for Notwane river water, the effects of the contaminants on the soils, groundwater and livestock health could be detrimental (Bawa and Gaikawad, 2013; Singleton, et al. 2007; Phiri, et al. 2005; Metcalf and Eddy, 2003; Kadelac and Knight, 1996). Nitrate nitrogen is negatively charged and highly soluble in water and therefore stays in the water column as it is repelled by negatively charged soil particles thus reaching mostly shallow groundwater and surface water rapidly (Rodvang, et al. 2004). Nitrate nitrogen concentrations above 10mg/l as N in livestock drinking water causes methemoglobinemia (Kadela and Knight, 1996; Metcalf and Eddy, 2003; Singleton, et al. 2007). Toxicity may result in serious illness or death of the animal due to lack of oxygen in body tissues. Nitrite nitrogen, formed in the rumen from ingested nitrate nitrogen, is absorbed into the bloodstream and combines with hemoglobin in the red blood cells to form methemoglobin. Methemoglobin cannot transport oxygen so death may result due to suffocation. Even though numerous benefits of using wastewater for irrigation have been reported (Lubello et al., 2004, Kiziloglu, et al., 2008, Manas et al., 2009, Pereira et

al., 2011), excessive application of nutrients may result in negative effects on productivity, crop and soil quality (Kiziloglu.et al., 2008, Pereira et al., 2011). For these numerous negative effects of wastewater contaminants interaction with various environs, it was found imperative to evaluate the water quality along Notwane River, nine years since the initial study, for agricultural purposes such as horticulture and livestock watering.

MATERIALS AND METHODS

Study area

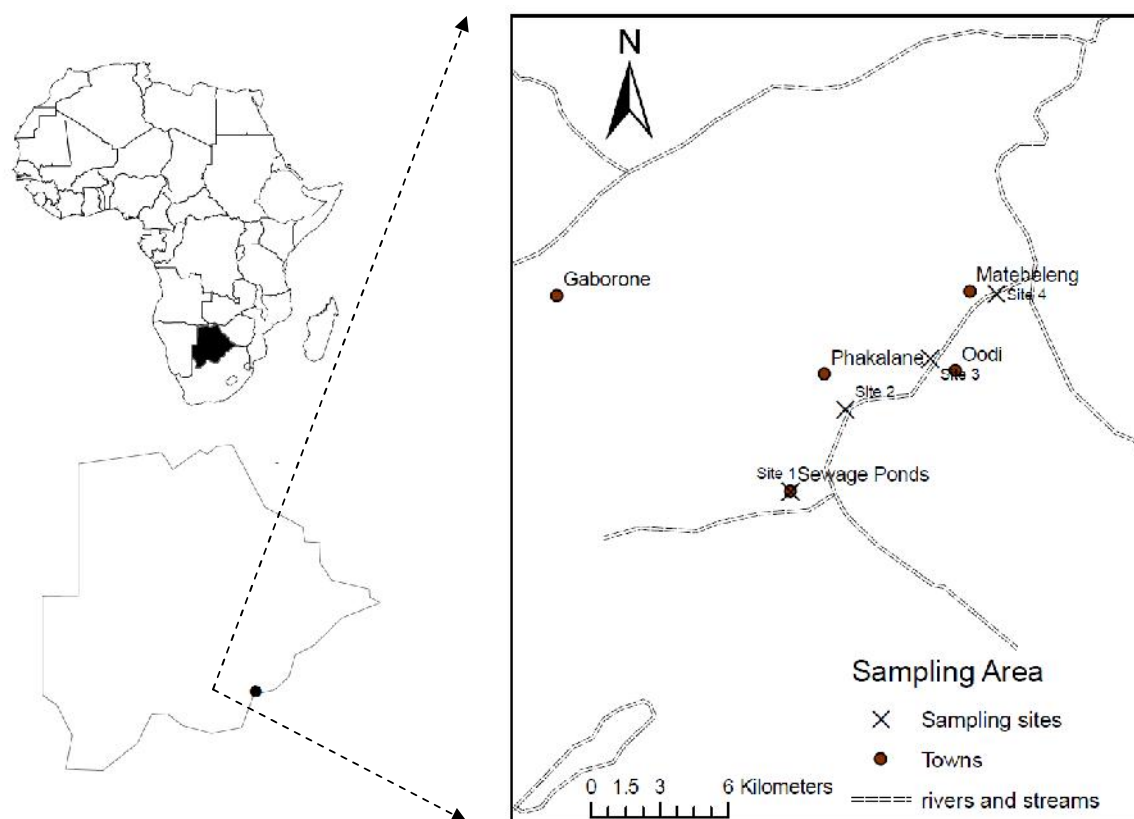


Figure 1. Location of Botswana and the study area.

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85 *Sampling and chemical analysis*

86 The study was conducted between 15th February 2013 and 15th April 2013 to
 87 represent hot summer season, a period with high envisaged microbial activities in
 88 the warm water column along a 15 km stream stretch. The samples were collected
 89 from four sites located as follows: Site 1 (24.62S, 25.97E Gaborone Sewage
 90 Ponds Discharge point); Site 2 (24.59S, 26.00E Phakalane, Rurets bridge); Site 3
 91 (24.57S, 26.02E Oodi bridge); Site 4 (24.54S, 26.05E, Matebeleng). The sites are
 92 approximately 5 km apart. In this period, sampling per site was carried out four
 93 times on a biweekly basis. Water samples were collected with 500ml sampling
 94 plastic bottles cleaned prior to sampling by washing and rinsing with non-ionic
 95 detergent and deionized water respectively. At each sampling site, three water
 96 samples were randomly drawn and pooled to get a representative sample. The
 97 sample bottles were accordingly labelled by sites, stored in an ice box at less than
 98 4⁰C and transported to the laboratory for analysis. In the laboratory, analysis for
 99 different parameters was conducted using standard methods for the examination of
 100 water and wastewater according to American Public Health Association (APHA)
 101 (APHA, 1995). The parameters examined were temperature, pH, 5-day Biological
 102 Oxygen Demand (BOD₅), Ammonia-Nitrogen and Nitrate-Nitrogen. The 5-day
 103 BOD is the amount of oxygen required to oxidize biodegradable organic matter
 104 over a 5-day period at 20 ⁰C (Koech, et al. 2012, Rim-Rukheh, and Agbozu,
 105 2013), a parameter used to measure waste strength on streams.

106 *Statistical analysis*

Physico-chemical parameters data were subjected to analysis using: Statistical Package for the Social Sciences (SPSS)- Predictive Analysis SoftWare (PASW) Statistics 17, Analysis of Variance (ANOVA), Games-Howel multiple comparison and Pearson correlation at alpha level 0.05 (2-tailed) to evaluate changes in levels of temperature, pH, BOD₅, Ammonia-Nitrogen and Nitrate-Nitrogen and the relationship among parameters along the stream.

RESULTS

The spatial BOD₅ status of the Notwane River studied transect during the period February – April 2013 is shown in Figure 2. The BOD₅ level ranged from 11.2 to 27.0 mg/l.

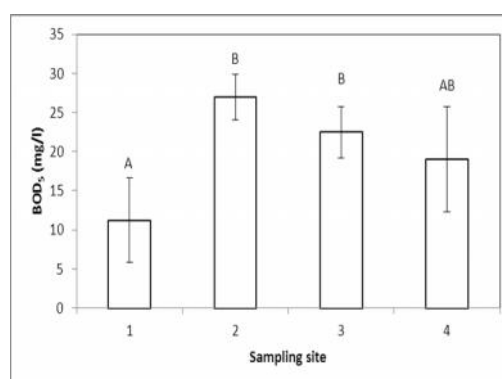
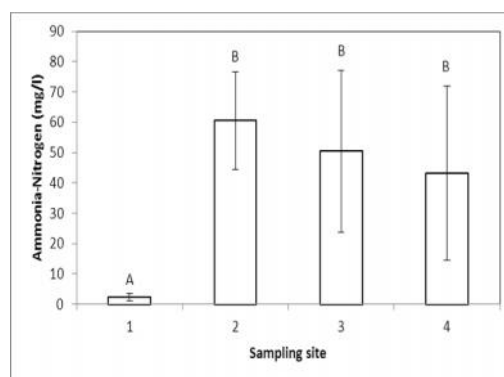


Figure 2. BOD₅ concentration of Notwane River reach

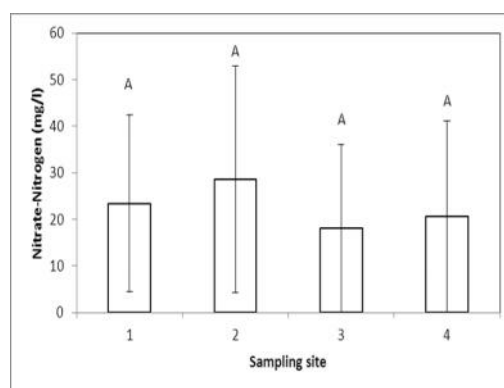
The ammonia-N concentration in the studied river reach is shown in Figure 3. It ranged from 2.4 to 60.5 mg/l between treated wastewater discharge point and the first subsequent sampling point 5 km downstream.



122

123 Figure 3. Ammonia-Nitrogen concentration of Notwane River reach

124 The nitrate nitrogen concentration in the river reach is given in Figure 4. It ranged
 125 between 18.0 and 28.6 mg/l between site 3 and site 2 in that order.



126

127 Figure 4. Nitrate-Nitrogen concentration of Notwane River reach

128 The pH status in the river reach is given in Figure 5. The pH ranged from 7.6 to
 129 8.5.

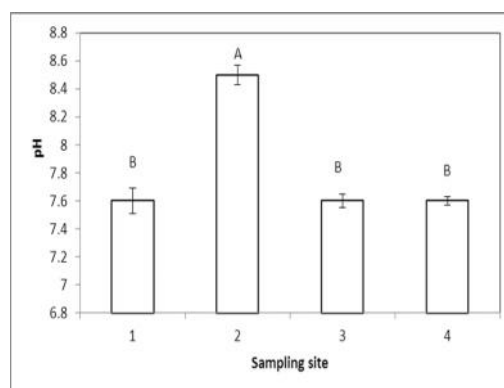


Figure 5. pH status of Notwane River reach

The temperature regime of the water body in the river reach is shown in Figure 6.

At all sites, the temperature regime of the water body column ranged between 22 and 23°C with site 2 recording the highest temperature.

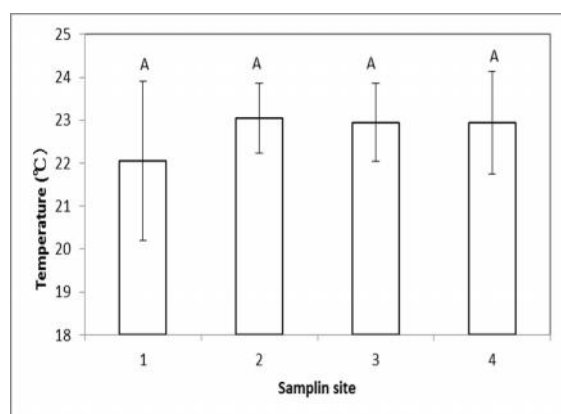


Figure 6. Temperature status of Notwane River reach

DISCUSSION

The results for BOD₅ in the river reach varied from 11.2 to 27.0 mg/l (Figure 2). According to Botswana Bureau of Standards (BOBS), the level of BOD₅ is within acceptable limits (Table 1). The BOD₅ level at the wastewater discharge point has remained nearly the same since the initial evaluation in 2004 (Nkegbe et al., 2005).

However, there is a spatial trend that suggests potential future non-point pollution from surrounding watershed. There is a significant difference ($P < 0.05$) between ponds wastewater discharge point and approximately 5 km downstream as shown in Figure 2 suggesting post treated wastewater discharge contamination. This trend is supported or verified by a similar trend of an associate contaminant in ammonia-N that normally hydrolyses from organic-N (Figure 3). This contamination maybe due to runoff inflow of organics from land use and other anthropogenic activities such as agriculture and domestic waste dumping around the sampling point (Igbinosa and Okoh, 2009; Koech, et al. 2012; Agwa and Ogugbue, 2013; Bawa and Gaikawad, 2013). Subsequent sequential spatial decrease in BOD₅ and Ammonia though not significantly so for both parameters ($P > 0.05$) as observed in Figures 2 and 3 can partially be attributed to settling along the water course, microbial degradation and dilution (Walakira and Okot-Okumu, 2011; Ewemoje and Ihuoma, 2014).

Table 1. Botswana Bureau of Standards (BOBS) upper discharge limits for physicochemical parameters

Physicochemical parameter	BOBS* Discharge limit
BOD ₅ (mg/l)	30
Ammonia-N (mg/l)	10
Nitrate (mg/l)	22
Temperature (°C)	35
pH	6-9

*Maximum allowable level (Central Statistics Office, 2009)

The ammonia-N concentration in the river reach, varied from 2.4 to 60.5 mg/l (Figure 3). The ammonia-N level at the discharge point is within acceptable BOBS upper limit (Table 1) whilst at all the other sampling points downstream in descending order were, 50.5, 40.5 and 33.2 mg/l more than the BOBS upper limit for site 2 (5 km downstream), site 3 (10 km downstream) and site 4 (15 km downstream), respectively. This, just like is the case with BOD₅, can be attributed to injection of pollutant load at site 2 (Igbinosa and Okoh, 2009; Koech, et al. 2012; Agwa and Ogugbue, 2013; Bawa and Gaikawad, 2013) and subsequent attenuation due to settling, microbial oxidation of ammonia into other nitrogen forms and dilution (Walakira and Okot-Okumu, 2011; Ewemoje and Ihumoe, 2014). The ammonia-N content in a water body is an indication of the sustainability of the water body production system. At elevated concentration of ammonia and other nutrients, there is high potential for eutrophication in rivers (Rim-Rukeh and Agbozu, 2013).

The nitrate nitrogen concentration in the river reach ranged between 18.0 and 28.6 mg/l (Figure 4). The nitrate-nitrogen was the only contaminant above discharge limit (Table 1) at the wastewater discharge sampling point. Elevated levels of nitrate-N at site 2 relative to other sampling sites, though not significantly different ($P>0.05$), suggest ammonium ions oxidation owing to correspondingly elevated levels of ammonia nitrogen at the same site and subsequent reduction of the same at downstream sites 3 and 4. The reduction in nitrate nitrogen downstream of site 2 (Figure 4) could be due to transformation of the elevated nitrate nitrogen into other nitrogen forms that for their breakdown, require organic carbon (BOD) in the absence of dissolved oxygen (DO). Organic carbon required in the aforementioned transformation process corresponds to BOD reduction downstream of site 2 (Figure 2). The pH in the river reach varied from 7.6 to 8.5 (Figure 5). The pH value was only significantly different ($P>0.05$) at site 2. According to Metcalf and Eddy

(2003), a pH value of 8.5 must have accelerated ammonia nitrogen loss from the water body by ammonia gas volatilization owing to high concentration of hydroxyl anions as opposed to hydrogen ions that support existence of inorganic nitrogen as ammonium ions.

The temperature regime of the water body in the river reach ranged from 22 to 23°C (Figure 6). The temperature range was too narrow to cause any significant microbial process difference between sampling sites.

Therefore, two pathways, namely, volatilization and microbial mediated oxidation process could partially account for BOD, ammonia nitrogen and nitrate nitrogen, pH and temperature trends that are interdependent as explained above.

Figure 2. Spatial concentration variation of parameters (a) BOD₅ (b) Ammonia-N (c) Nitrate-N and (d) pH. Vertical bars sharing the same letters are not significantly different at $\alpha = 0.05$.

To establish correlation among the physicochemical parameters, Pearson's correlation was obtained as shown in Table 2.

Table 2. Pearson's correlation coefficients for the different physicochemical parameters

Variab les	BOD	NH ₄ ⁺	NO ₃ ⁻	Te mp	p H
BOD	1				
NH ₄ ⁺	0.529*	1			

NO ₃ ⁻	0.202	0.184	1		
Temp	-0.125	0.452	-0.385	1	
pH	0.523*	0.452	0.278	0.184	1

*= Correlation is significant at P<0.05 level (2 tailed)

There was an increase in the level of BOD₅ corresponding to increase in the level of ammonia nitrogen ($r^2=0.529$) suggesting that the two contaminants emanate, as expected, from the same source and therefore strengthening non-point pollution source suggested by trends observed and discussed earlier (Figures 2-5). There was a significant correlation between BOD₅ and pH. The pH is a key factor in the growth of microorganisms responsible for BOD removal in water bodies. Most bacteria cannot tolerate pH above 9.5 and grow optimally on a narrow pH range of 6.5 to 7.5 (Crites and Tchobanoglous, 1998; Viessman and Hammer, 1998; Metcalf and Eddy, 2003). Site 2 exhibited a significantly high pH of 8.5 relative to all other sampling sites (Figure 5) and correspondingly elevated levels of BOD₅ at the same site. The other sampling sites experienced higher but closer pH to the upper limit of the optimum pH range for bacterial growth. Therefore it can be concluded that, this pH regime is responsible for the sustenance of elevated levels of BOD₅ at site 2 and subsequent attenuation of BOD₅ at sampling sites downstream of site 2. There was no significant correlation between ammonia nitrogen and nitrate nitrogen despite the fact that nitrate nitrogen is the end product of oxidized ammonia nitrogen (Viessman and Hammer, 1998). This lack of significant correlation between the two nitrogen species is due to the fact that, high levels of nitrate nitrogen were injected at the ponds discharge point (sampling Site 1) (Figure 4). Under high dissolved oxygen conditions, a situation common in open water bodies such as ponds, streams and rivers

receiving relatively low strength wastes like treated wastewater, nitrate state of nitrogen is sustained because further transformation of nitrate nitrogen is curtailed by none existence of either anaerobic or anoxic conditions. The relatively low ammonia oxidation contribution to nitrate nitrogen content at sampling Site 2 led to weak correlation between the two nitrogen species.

CONCLUSIONS

The following conclusions are made from the study:

(1) Non-point pollution source is responsible for the deterioration of chemical water quality downstream of Notwane river;

(2) A high level of nitrate nitrogen is discharged from the ponds and is sustained throughout the river stretch.

RECOMMENDATIONS

The following recommendations are proposed:

(1) An in-depth study of the precinct of the river section must be pursued and proper delineation of pollution source sites and mitigation measures implemented to curb river contamination and ensuing pollution.

(2) The activated sludge wastewater treatment plant from which the ponds receive water for secondary treatment need to be upgraded and maintained to meet nitrogen discharge standards.

(3) Discharge standards must be enforced to ensure compliance.

(4) There is need to conduct a study to assess winter season trends since the current study was conducted in southern hemisphere summer.

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