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Impact of Partially Treated Wastewater on Downstream Water Quality of Notwane River in Botswana

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Authors' contributions

This work was carried out in collaboration between all authors. Author GKG designed the study, performed the statistical analysis and wrote the first draft of the manuscript. Author GM collected the data and also performed data analysis. Author BK managed the literature searches. All authors read and approved the final manuscript.

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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 (BOD_5), Ammonia-nitrogen (Ammonia-N) and Nitrate-nitrogen (Nitrate-N). 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), BOD_5 (11.2-27.0 mg/l), Ammonia-N (2.4-60.5 mg/l), Nitrate-N (20.6-28.6 mg/l). Analysis of variance, Games-Howel multiple comparisons and Pearson correlation were used to separate variable means. The results signal river non-point pollution due to runoff inflow of organics mainly from land use 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-N and Nitrate-N 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.

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Keywords: Wastewater discharge; notwane river; non-point pollution; waste dumping; Botswana Bureau of Standards.

1. 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 m^3 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 [1]. 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 (NH_3-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 [2]. 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. It was 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 [3].

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 are 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 [4], [5]. 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 [6,7,8,9,10]. 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 [11]. Nitrate-nitrogen concentrations above 10 mg/l as N in livestock drinking water causes methemoglobinemia [10], [9,7]. 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. Although numerous benefits of using wastewater for irrigation have been reported [12,13,14,15], excessive application of nutrients may result in negative effects on productivity, crop and soil quality [13,15]. Due to 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.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted in Gaborone (24.62S and 25.97E). Gaborone is the capital city of Botswana, a country situated in Southern Africa as depicted in Fig. 1.

2.2 Sampling and Chemical Analysis

The study was conducted between 15th February 2013 and 15th April 2013 to represent hot summer season, a period with high envisaged microbial activity in the warm water column along a 15 km stream stretch. Substrate transformations are very sensitive to high microbial activity enhanced by the warm water column. Any changes in the peripheral landscape affecting water quality along the river transect can thus be monitored during February – April which coincides with the warm water column. The samples were collected from four sites located as follows: Site 1 (24.62S, 25.97E Gaborone Sewage Ponds Discharge point); Site 2 (24.59S, 26.00E Phakalane, Ruretse bridge); Site 3 (24.57S, 26.02E Oodi bridge); Site 4 (24.54S, 26.05E, Matebeleng). The sites are approximately 5 km apart. In this period, sampling per site was carried out four times on a biweekly basis. Water samples were collected in 500ml sampling plastic bottles cleaned prior to sampling by washing and rinsing with non-ionic detergent and deionized water, respectively. At each sampling site, three water samples were randomly drawn and pooled to get a representative sample. The sample bottles were accordingly labelled by site, stored in an icebox at less than 4^0C and transported to the laboratory for analysis. In the laboratory, analysis of different parameters was conducted using standard methods for the examination of water and wastewater according to the American Public Health Association (APHA) [16]. The parameters examined were temperature, pH, 5-day Biological Oxygen Demand (BOD_5), Ammonia-Nitrogen and Nitrate-Nitrogen. The 5-day BOD is the amount of oxygen required to oxidize biodegradable organic matter over a 5-day period at 20°C [17,18] a parameter used to measure waste strength on streams.

2.3 Statistical Analysis

Data on physico-chemical parameters was 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, BOD_5, Ammonia-Nitrogen and Nitrate-Nitrogen and the relationship among parameters along the stream.

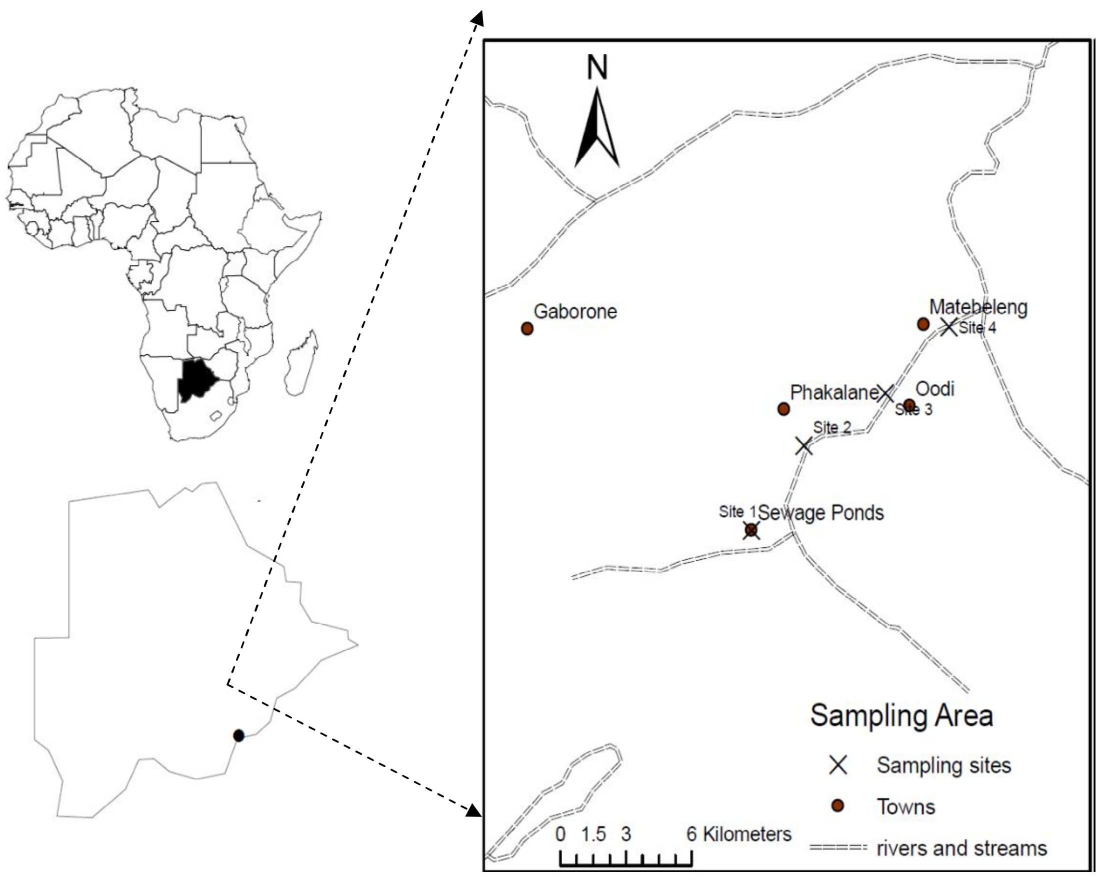

Fig. 1. Location of Botswana and the study area

3. RESULTS

The spatial BOD_5 status of Notwane River transect during the period February – April 2013 is shown in Fig. 2. The BOD_5 level ranged from 11.2 to 27.0 mg/l.

The Ammonia-N concentration in the river reach is shown in Fig. 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.

The Nitrate-N concentration in the river reach is given in Fig. 4. It ranged between 18.0 and 28.6 mg/l between site 3 and site 2 in that order.

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

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

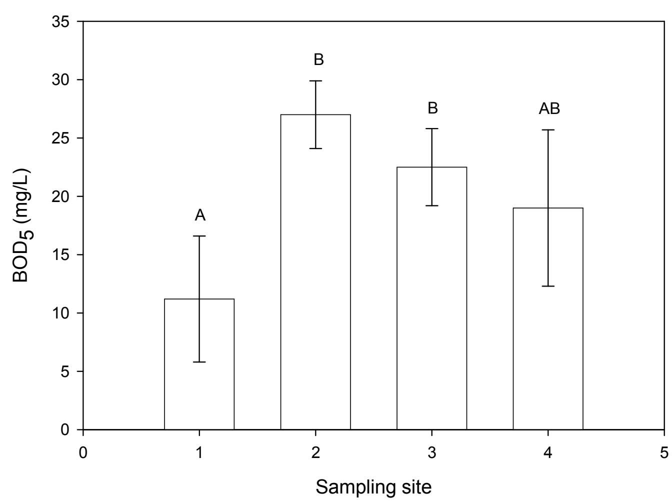

Fig. 2. BOD_5 concentration of Notwane River reach

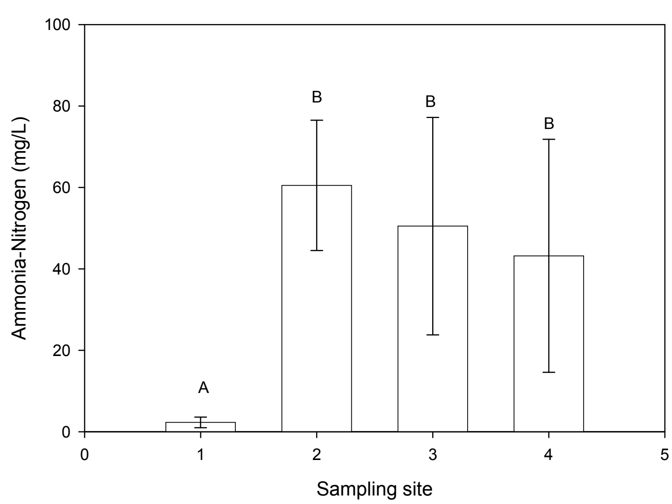

Fig. 3. Ammonia-N concentration of Notwane River reach

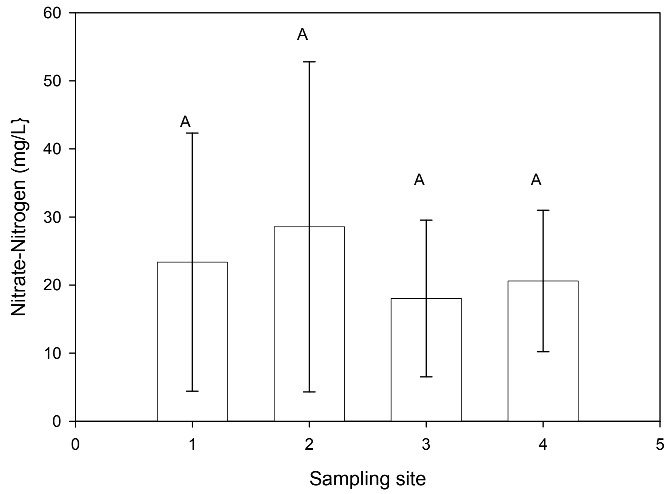

Fig. 4. Nitrate-N concentration of Notwane River reach

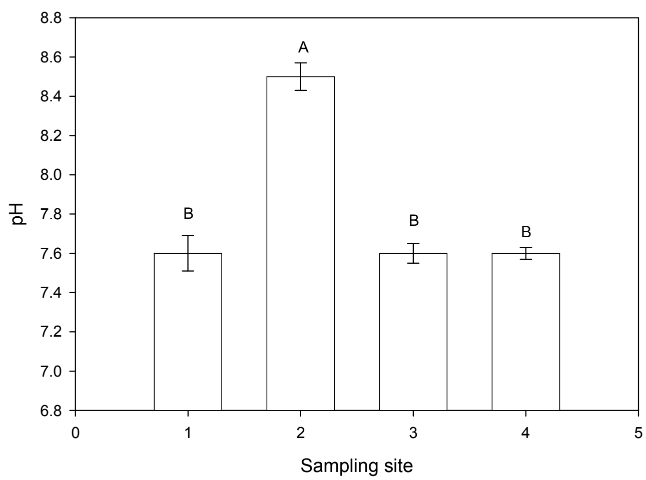

Fig. 5. pH status of Notwane River reach

4. DISCUSSION

The results for BOD_5 in the river reach varied from 11.2 to 27.0 mg/l (Fig. 2). According to the Botswana Bureau of Standards (BOBS), the level of BOD_5 is within acceptable limits (Table 1). The BOD_5 level at the wastewater discharge point has remained nearly the same since the initial evaluation in 2004 [1]. However, there is a spatial trend that suggests potential future non-point pollution from the surrounding watershed. There is a significant difference ($P<0.05$) between the ponds wastewater discharge point (Site 1) and Site 2 (approximately 5 km downstream) as shown in Fig. 2. This suggests post treated wastewater discharge contamination. This trend is supported or verified by a similar trend of an associate contaminant in Ammonia-N that normally hydrolyzes from Organic-N (Fig. 3). This contamination may be due to runoff inflow of organics from land use and other anthropogenic activities such as domestic waste dumping around the sampling point [19,17,4,6]. The subsequent sequential spatial decrease in BOD_5 and Ammonia-N, albeit insignificant for both parameters as shown in Figs. 2 and 3, can partially be attributed to settling along the watercourse, microbial degradation and dilution [5,20].

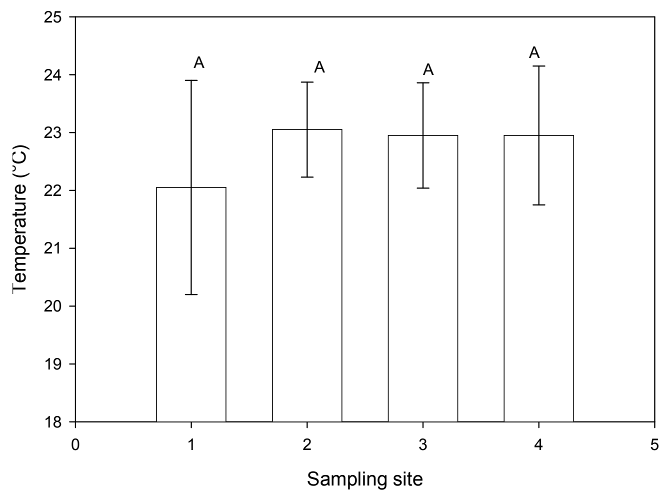

Fig. 6. Temperature status of Notwane River reach

Table 1. Botswana Bureau of Standards (BOBS) upper discharge limits for physico-chemical parameters

Physicochemical parameter	BOBS* Discharge limit
BOD_5 (mg/l)	30
Ammonia-N (mg/l)	10
Nitrate (mg/l)	22
Temperature (^{0}C)	35
pH	6-9

**Maximum allowable level* [21]

The Ammonia-N concentration in the river reach, varied from 2.4 to 60.5 mg/l (Fig. 3). The Ammonia-N level at the ponds 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 could be attributed to injection of pollutant load at Site 2 [19,17,4,6] and subsequent attenuation due to settling, microbial oxidation of ammonia into other nitrogen forms and dilution [5,20]. The Ammonia-N content in a water body is an indication of the sustainability of the water body production system. At an elevated concentration of ammonia and other nutrients, there is a high potential for eutrophication in rivers [18].

The Nitrate-N concentration in the river reach ranged between 18.0 and 28.6 mg/l (Fig. 4). The Nitrate-N was the only contaminant above the discharge limit (Table 1) at the wastewater ponds discharge sampling point. Elevated levels of Nitrate-N at Site 2 relative to other sampling sites, albeit insignificant, suggest ammonium ions oxidation owing to correspondingly elevated levels of Ammonia-N at the same site and subsequent reduction of the same at downstream sites 3 and 4. The reduction in Nitrate-N downstream of Site 2 (Fig. 4) could be due to the transformation of the elevated Nitrate-N into other nitrogen forms that for their breakdown, require organic carbon (BOD) in the absence of dissolved oxygen (DO). Organic carbon needed for the aforementioned transformation process corresponds to BOD reduction downstream of Site 2 (Fig. 2). The pH of the river reaches varied from 7.6 to 8.5 (Fig. 5). The pH value was only significantly different ($P>0.05$) at Site 2. According to [9], a pH value of 8.5 must have accelerated Ammonia-N loss from the water body by ammonia gas volatilization owing to the high concentration of hydroxyl anions as opposed to hydrogen ions that support the existence of inorganic nitrogen as ammonium ions.

The temperature regime of the water body in the river reach ranged from 22 to 23°C (Fig. 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 processes

Table 2. Pearson's correlation coefficients for the different physico-chemical parameters

Variables	BOD	NH^+_4	NO^-_3	Temp	pH
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)*

could partially account for BOD, Ammonia-N, Nitrate-N, pH and temperature trends that are interdependent as explained Table 2.

Fig. 2. Spatial concentration variation of parameters (a) BOD_5 (b) Ammonia-N (c) Nitrate-N and (d) pH. Vertical bars sharing the same letters are not significantly different at α = 0.05.

To establish a correlation among the physico-chemical parameters, Pearson's correlation was obtained as shown in Table 2.

There was an increase in the level of BOD_5 corresponding to increase in the level of Ammonia-N (r^2=0.529) suggesting that the two contaminants emanate, as expected, from the same source and therefore strengthening the non-point pollution source suggested by trends observed and discussed earlier (Figs. 2-5). There was a significant correlation between BOD_5 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 [22,23,9]. Site 2 exhibited a significantly high pH of 8.5 relative to all other sampling sites (Fig. 5) and correspondingly elevated levels of BOD_5 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 BOD_5 at Site 2 and subsequent attenuation of BOD_5 at sampling sites downstream of this site. There was no significant correlation between Ammonia-N and Nitrate-N despite the fact that Nitrate-N is the end product of oxidized Ammonia-N [23]. This lack of a significant correlation between the two nitrogen species is due to the fact that, high levels of Nitrate-N were injected at the ponds discharge point (sampling Site 1) (Fig. 4). Under high dissolved oxygen conditions, a situation common in open water bodies such as ponds, streams and rivers wastes receiving relatively low strength such as treated wastewater, the nitrate state of nitrogen is sustained because the further transformation of Nitrate-N is curtailed by none existence of either anaerobic or anoxic conditions. The relatively low ammonia oxidation contribution to Nitrate-N content at Site 2 led to a weak correlation between the two nitrogen species.

5. 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. This contamination is due to runoff inflow of organics from land use and other anthropogenic activities such as domestic waste dumping.
(2) A high level of Nitrate-N is discharged from the ponds and is sustained throughout the river stretch. This is partly due to inefficiencies of the wastewater treatment plant and also due to the fact that under high dissolved oxygen conditions, the nitrate state of nitrogen is sustained because the further transformation of Nitrate-N is curtailed by none existence of either anaerobic or anoxic conditions.

6. 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 needs 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 the southern hemisphere summer.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Nkegbe E, Emongor V, Koorapetsi I. Assessment of effluent quality at Glen Valley wastewater treatment plant. Journal of Applied Sciences. 2005;5(4):647-650.
2. Emongor VE, Khonga EB, Ramolemana GM, Marumo K, Machacha S, Motsamai T. Suitability of treated secondary sewage effluent for irrigation of horticultural crops in Botswana. Journal of Applied Sciences. 2005;5(3):451-454.
3. Kotlhao K, Ngila C, Emongor VE. Metal determination in secondary treated sewage water for crop irrigation in Gaborone, Botswana. Bots. J. Agric. Appl. Sci. 2006; 2(1):34-44.
4. Agwa OK, Sito E, Ogugbue CJ. A spatial assessment of microbiological and physicochemical quality of a stream receiving raw abattoir waste. Middle-East J. of Sci. Res. 2013;14(7):879-886.
5. Walakira P, Okot-Okumu J. Impact of industrial effluents on water quality of streams in Nakawa-Ntinda, Uganda. J. Appl. Sci. Manage. 2011;15:289-296.
6. Bawa KV, Gaikawad VP. Water quality assessment of Godavari river at Nashik, India: Impact of sewage and industrial wastewater. Universal J. of Environ. Res. and Tech. 2013;3(4):452-457.
7. Singleton, M.J., Esser, B.K., Moran, J.E., Hudson GB, Harter T. Saturated zone denitrification: Potential for natural attenuation of nitrate contamination in shallow groundwater under dairy operations. Environ. Sci. Technol. 2007; 41:759-765.
8. Phiri O, Mumba P, Moyo BHZ, Kadewa W. Assessment of impact of industrial effluents on water quality of receiving rivers in urban areas of Malawi. Int. J. Environ. Sci. Tech. 2005;2:237-244.
9. Metcalf and Eddy Inc. Wastewater engineering treatment, disposal and reuse. 4th ed. In Tchobanoglous G, Burton FL. and Stensel, H.D. (eds), McGraw-Hill, New York; 2003.
10. Kadelac RH, Knight RL. Treatment wetlands. CRC Press LLC. Boca Raton, FL; 1996.
11. Rodvang SJ, Mikalson DM, Ryan MC. Changes in groundwater quality in an irrigated area of southern Alberta. J. Environ. Qual. 2004;33:476-487.
12. Lubello C, Gori R, Nicese FP, Ferrini F. Municipal-treated wastewater reuse for plant nurseries irrigation. Water Research. 2004;38:2939–2947.
13. Kiziloglu FM, Turan M, Sahin U, Kuslu Y, Dursun A. Effects of untreated and treated wastewater irrigation on some chemical properties of cauliflower (*Brassica olerecea* L. var. botrytis) and red cabbage (*Brassica olerecea* L. var. rubra) grown on calcareous soil in Turkey. Agricultural Water Management. 2008;95:716-724.
14. Manas P, Castro E, Heras J, De las. Irrigation with treated wastewater: Effects on soil, lettuce (*Lactuca sativa*) crop and dynamics of microorganisms. Journal of environmental science health A. 2009;44: 1261–1274.
15. Pereira BFF, HE ZL, Silva MS, Herpin U, Nogueira SF, Montes CR, Melfi AJ. Reclaimed wastewater: Impact on soil-plant system under tropical conditions. Journal of Hazardous Materials, Amsterdam. 2011;192(1):54–61.
16. American Public Health Association (APHA). Standard methods for the examination of water and wastewater. 19th ed., APHA, Washington, DC, USA; 1995.
17. Koech HK, Ogendi GM, Kipkemboi J. Status of treated slaughter-house effluent and its effects on the physicochemical characteristics of surface water in Kavuthi stream, Dagoretti-Kenya. Res. J of Environ and Earth Sci. 2012;4:789-796.
18. Rim-Rukeh A, Agbozu LE. Impact of partially treated sewage effluent on water quality of recipient Epie Creek Niger Delta, Nigeria using Malaysian Water Quality Index (WQI). J. Appl. Sci. Environ. Manage. 2013;17:5-12.
19. Igbinosa EO, Okoh AI. Impact of discharge wastewater effluents on the physic-

chemical qualities of a receiving watershed in a typical rural community. Int. J. Environ. Sci. Tech. 2009;6(2):175-182.
20. Ewemoje OE, Ihuoma SO. Physicochemical changes in the quality of surface water due to sewage discharge in Ibadan, South-Western Nigeria. Energy and Environ. Res. 2014;4:55-61.
21. Central Statistics Office (CSO). Botswana water statistics. CSO, Gaborone, Botswana; 2009.
22. Crites R, Tchobanoglous G. Small and decentralized wastewater management system. McGraw-Hill, New York; 1998.
23. Viessman W, Hammer MJ. Water supply and pollution control. 6th ed. Wesley Longman, Inc., Menlo Park. California; 1998.

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