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TEMPORAL AND SPATIAL PHYSICOCHEMICAL WATER QUALITY IN BLANTYRE URBAN STREAMS

S.M. Kuyeli[1], W.R.L Masamba*[2], E. Fabiano[3], S.M. Sajidu[3], E.M.T. Henry[4]
[1]Blantyre City Assembly Pollution Control Office, Private Bag 67, Blantyre, Malawi.
[2]Harry Oppenheimer Okavango Research Centre, University of Botswana. P/Bag 285, Maun, Botswana.
[3]Chemistry Department, Chancellor College, P.O. Box 280, Zomba, Malawi. and
[4]Deceased.

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ABSTRACT

Water samples collected from the five major streams in Blantyre city, *viz.*, Limbe, Naperi, Mudi, Nasolo and Chirimba, were analysed for phosphates ($PO_4{}^{3-}$), nitrates ($NO_3{}^{-}$), sulphates ($SO_4{}^{2-}$), biochemical oxygen demand (BOD), suspended solids (SS), pH, oil and grease, and electroconductivity (EC). The samples were collected in both dry and rainy seasons of 2006 and analysed using standard methods. Results showed that the impairment of water quality in a stream depended on the type of industry in its vicinity and state of sewerlines which conduit the wastewater from the source to the designated Blantyre City Assembly wastewater treatment plants. pH, EC, $SO_4{}^{2-}$, oil and grease were within the acceptable limits set by Malawi Bureau of Standards and World Health Organization for drinking surface water. However the concentrations of $PO_4{}^{3-}$, $NO_3{}^{-}$ and BOD were above the maximum allowable limits set by the regulatory bodies. The results suggested that effluents from industries in the city had high potential of polluting the water bodies and could result into gross impairment of water quality in the receiving streams. It is therefore recommended that Blantyre City Assembly and other environmental regulatory bodies such as Environmental Affairs Department and Water Resources Board should be more aggressive and effective in environmental monitoring, assessment and enforcement of environmental laws and regulations so as to preserve the water resource from further degradation.

Key words and phrases: Physicochemical water quality; Blantyre

1. INTRODUCTION

Eutrophication of rivers and lakes and pollution of surface waters with toxic chemicals such as heavy metals are of major environmental concern globally. Informal discharge of industrial effluents, vehicular emissions, agricultural and urban activities are amongst the main sources of chemicals and nutrients to the aquatic ecosystems. High concentrations of biologically available nutrients lead to diverse problems such as eutrophication of natural water due to excess nitrates and phosphates (Bolger and Stevens, 1999).

Water services in many urban areas are provided by a centralized system. However, these centralized systems in a majority of urban areas in developing countries are unable to cope with the rapid increase in population, fast growth of industries, ageing and deterioration of infrastructure, over-extraction and also inability to recover the actual cost of managing the systems. The failure has led to a great deal of pressure on the limited available water resources; consequently, some residents, particularly the urban poor, have no access to basic safe water and may even use river water for domestic purposes (Phiri et al., 2005). The generally poor quality water results in the users suffering from debilitating effects of water-borne diseases like cholera, diarrhea, bilharzias, gastroenteritis and those that may not be easily related to water contamination due to chronic intake of toxic chemicals (Water-borne diseases, undated).

Blantyre city in Malawi has the largest urban settlement with an approximate population of 700,000 people and it covers an area of some 228 square km (Blantyre City Assembly Urban Structure plan,1999). The city has eight designated industrial areas namely Makata, Ginnery corner, Maselema, Limbe, Chirimba, South Lunzu, Maone and Chitawira (Figure 1). Of these, Makata, Ginnery corner, Maselemea, Limbe, Chirimba and Maone are actively hosting industries whilst South Lunzu is yet to be developed. The existing industrial sites are further categorized into heavy and light industrial sites. Makata and Limbe, for example are the sole heavy industrial sites hosting more than thirty companies whilst Chirimba industrial area, though designated a heavy industrial area, is the least developed in terms of number of industries in the area. Apart from Makata, Ginnery corner industrial site is another active site followed by Limbe and Maselema and the least is Chirimba and Maone industrial sites. Chitawira and Maselema are classic examples of light industrial areas (Blantyre City Assembly, 1999). All the industrial areas are located along the banks of the main rivers or streams of Blantyre city. Makata industrial area lies between Mudi and Nasolo

*Corresponding author: W.R.L Masamba, Harry Oppenheimer Okavango Research Centre, University of Botswana. P/Bag 285, Maun, Botswana, Tel.: +267 6861 833; Email: wmasamba@orc.ub.bw

streams whilst Ginnery corner industrial area is along Mudi River. Maselema industrial area exists along the Naperi river and Chirimba stream hosts Chirimba industrial area. There are several rules for treatment of wastes in the industries (Local Government Act, 1982; Blantyre City Assembly, 1999) but disposal of untreated wastewater into drains and subsequently into the citys major streams is very common, thus posing a potential health and environmental risk to the people living in the city of Blantyre and downstream. Other sources of water pollution in the city such as runoffs from domestic and agricultural activities and also vehicular emissions (Lakudzala et al., 1999; Masamba and Chimbalanga, 2001, Sajidu et al, 2007) have been identified. Previous studies have indicated substantial heavy metal pollution in the citys water bodies including streams (Lakudzala et al., 1999; Sajidu et al, 2007; Kaonga et al, 2008).

After the previous studies, some major changes in industrial activities have occurred in the city of Blantyre including decrease in volumes of wastewater generated by David Whitehead company which used to be major contributor of wastewater effluent in Makata industrial area; change of ownership and wastewater management of Cold Storage Company; closure of the Shire Bus Line; doubling of wastewater generation from both Calsberg and Chibuku Products due to increase in production and installation of some industrial pretreatment plants such as at Chibuku, Plascon and Dulux. Additionally, the previous studies did not undertake water quality analyses on some of the citys streams such as Chirimba and Naperi. Therefore this study was undertaken to investigate the current physicochemical characteristics of water in all the citys major streams in order to assess the impact of industrial activities within the streams vicinities.

2. STUDY SITES

Figure 1 shows locations of the sampling points. Water samples were collected from selected points along the Mudi, Nasolo, Naperi, Chirimba and Limbe streams. These were points of the streams before industrial area, within and after industrial activities.

3. MATERIALS AND METHODS

Sampling was done in the months of October to November, 2005 for dry season and February, 2006 for rainy season using the method of grab sampling. Samples were collected using one-liter plastic bottles that had been cleaned by detergents, soaked in 10% nitric acid and rinsed several times with distilled water. Three one-liter samples were collected at each point. pH values were recorded at Soche wastewater treatment plant within two hours after sample collection using a Kent Eil 7020 pH meter. Nitrates were measured by salicylate colorimetric (Yang et al., 1998) method using a JENWAY 6405 UV/Vis spectrophotometer. Phosphates were determined by vanadomolybdophosphoric acid calorimetric method with a JENWAY 6405 UV/Vis spectrophotometer (APHA, 1985) after preliminary perchloric acid digestion of the samples. Sulphates were measured using a JENWAY 6405 UV/Vis spectrophotometer as barium sulphate (turbidimetric method) as described in APHA (1985). Biochemical oxygen demand was determined by the Winkler method of oxygen measurement in the samples before and after incubating for 5 days at 20^oC whereas suspended solids were determined by filtering the samples through pre-weighed glass fibre filters as described in ALPHA (1985). Oil and grease (OG) were measured by acidifying the homogenized samples followed by separation using petroleum spirit Solvent extraction in the OG determination was done using Soxhelet extracting unit (APHA, 1985).

4. RESULTS AND DISCUSSION

Table 1 and 2 show the parameters obtained in the stream water in the dry and rainy seasons sampled at points before, within and after industrial sections of the streams.

4.1. *Water pH*

The pH values ranged from 6.5 to 8.6 in the dry season and 6.9 to 8.1 in the rainy season and they were all within the optimum pH requirement of 6.5 to 9.50 (WHO, 2004). However, reduced pH values of the water samples, after passing industrial areas, were observed in Nasolo stream ($pH = 8.4$ before and $pH = 6.5$ after in dry season). This could be due to discharge of acidic wastewater from industries such as metal solutions and organic acids as observed by an earlier study (Sajidu et al, 2007). No significant pH difference was observed in the rainy season for the Nasolo stream and the rest of the streams.

4.2. *Water electroconductivity*

Electroconductivity (EC) values in all the streams ranged from 4.0 to 20.0 $mScm^{-1}$ in dry season and 2.8 to 6.2 $mScm^{-1}$ in rainy season. EC is an estimate of total dissolved salts in water and water with EC values between 2.5 and 10.0 $mScm^{-1}$ is not recommended for human consumption and normally not suitable for irrigation except for very salt tolerant crops with special techniques of management. Water with EC values of over 10.0 $mScm^{-1}$ is neither suitable for human consumption nor for irrigation. All the streams had EC values above 2.5 $mScm^{-1}$. In most cases the values increased after passing through industrial areas. Due to dilution factors, EC values in rainy season were lower than those of dry season in all the streams.

4.3. *Levels of Biochemical oxygen demand in water*

The levels of biochemical oxygen demand (BOD) in all the streams in the dry season far exceeded Malawi Bureau of Standard limit of 20mg/L (MBS, 2005) except at Limbe upstream point ($13.010.90mg/L$) and Naperi stream where farthest upstream and downstream points registered $16.502.10mg/L$ and $16.602.0mg/L$ respectively. Mudi stream was observed to be the worst where the BOD levels ranged from $180.03.1mg/L$ to $300.5010.4mg/L$. In the rainy season the levels of BOD were relatively lower than the dry season results although 50% of the sampling points values were above the limit of 20 mg/L. The extreme values were observed in Limbe stream within industrial area and downstream points ($51.02.73mg/L$ and $54.032.83mg/L$ respectively), and Chirimba upstream ($70.50.71mg/L$). The least polluted was Naperi where all the BOD values were found to be below the MBS limit. During the rainy season, the BOD levels for Limbe, Mudi and Nasolo streams increased after the industrial sites which was not the case

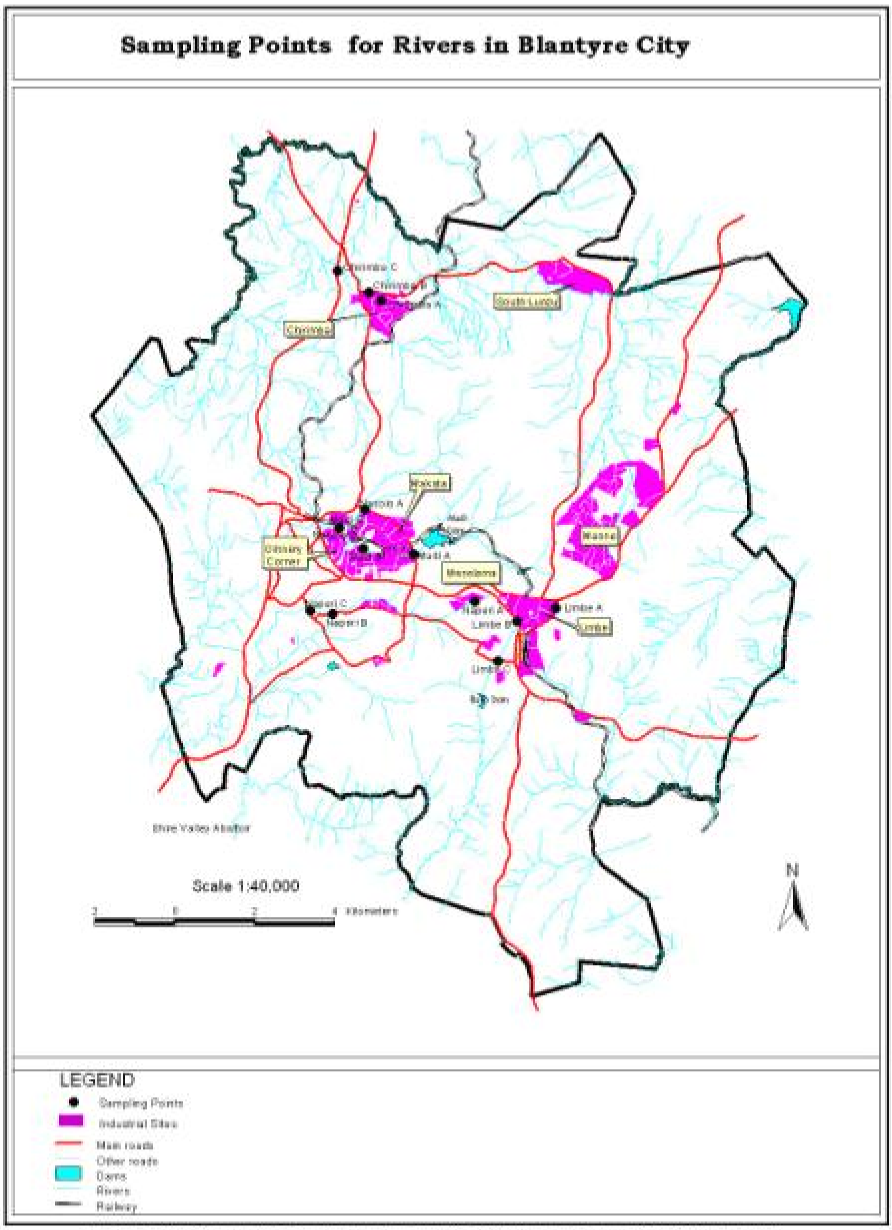

FIG. 1.— Map of Blantyre City showing Sampling points and the main industrial sites

in the rainy season. The high values of BOD observed in the streams could arise from manhole overflows, which were quite common during the study period. The sewerlines conduit both domestic and industrial effluents of high BOD which, if obstructed end up in the streams. This reason compounded with the fact that some industries dump solid waste along the river banks, the levels of aggregate organic pollution was high in all the streams. Although the BOD levels were lower in the wet season due to dilution effect, the observed levels in the streams were a big threat to aquatic life such as fish and aesthetic value of the water.

4.4. *Levels of suspended solids in water*

High levels of suspended solids (SS) in dry season were obtained in the water samples of Mudi stream (within industrial area, $SS = 65.63 \pm 3.05 mg/L$) and Nasolo stream (after industrial area, $SS = 42.11 \pm 0.53 mg/L$) and in rainy season for water samples in Limbe stream (before industrial area, $SS = 42.99 \pm 0.11 mg/L$) and Chirimba stream (before, during and after industrial area $SS = 46.00 \pm 0.95, 283.78 \pm 6.54$ and $40.00 \pm 2.21 mg/L$ respectively). There were no observable trends in SS concentrations from upstream, through the industrial area to downstream in all the streams. Although the national standards authority (MBS, 2005) only has limit for dissolved solids in drinking water, high concentrations of suspended solids can also cause problems to aquatic life by blocking light from reaching submerged vegetation; increasing surface water temperature since the solids absorb heat from sunlight; reducing water clarity and clogging of fish gills (Murphy, undated).

4.5. *Concentrations of oil and grease in water*

Oil and grease (OG) concentrations ranged from 0.02 to 2.46 mg/L in the dry season and 0.17 to 5.30 mg/L

TABLE 1
Levels of pH, electroconductivity (EC), biochemical oxygen demand (BOD_5) and suspended solids (SS)

Section of river	**Dry season**				**Rainy season**			
	pH	EC ($mScm^{-1}$)	BOD_5 (mg/L)	SS (mg/L)	pH	EC ($mScm^{-1}$)	BOD_5 (mg/L)	SS (mg/L)
Limbe								
A	8.6	9.0	13.01 ± 0.90	2.01 ± 0.08	7.7	3.0	11.08 ± 1.24	42.99?0.11
B	8.3	12.0	22.12 ± 0.10	25.30 ± 1.02	7.2	4.6	51.00 ± 12.73	7.00 ± 0.98
C	7.9	12.0	36.00 ± 1.00	6.00 ± 0.00	7.2	4.6	54.03 ± 2.83	3.02 ± 0.66
Naperi								
A	7.9	6.0	16.50 ± 2.10	37.09 ± 0.98	7.4	2.9	16.50 ± 0.71	5.00 ± 0.00
B	7.8	4.0	30.09 ± 0.80	38.02 ± 1.22	7.5	2.8	4.51 ± 0.51	27.00 ± 0.00
C	8.0	4.0	16.60 ± 2.00	12.68 ± 0.98	7.3	2.8	14.03 ± 1.41	3.98 ± 0.02
Mudi								
A	8.1	8.0	230.04 ± 4.20	19.07 ± 1.05	7.6	3.1	41.90 ± 3.26	16.05 ± 0.54
B	7.8	4.0	180.00 ± 3.10	65.63 ± 3.05	7.4	4.1	39.00 ± 4.20	40.01 ± 4.32
C	7.3	5.5	270.44 ± 5.10	32.05 ± 1.05	7.1	3.6	36.00 ± 0.00	6.00 ± 0.76
Nasolo								
A	8.4	17.0	96.00 ± 1.20	18.00 ± 0.63	8.0	6.2	35.00 ± 1.41	26.00 ± 0.00
C	6.5	20.0	122.00 ± 5.40	42.11 ± 0.53	7.7	3.6	28.01 ± 2.83	8.01 ± 0.38
Chirimba								
A	7.5	9.0	42.20 ± 0.30	13.00 ± 0.56	7.1	3.5	70.50 ± 0.71	46.00 ± 0.095
B	7.2	20.0	30.00 ± 2.00	39.78 ± 1.35	6.9	4.0	12.60 ± 0.42	283.78 ± 6.54
C	7.7	17.0	38.00 ± 1.10	19.06 ± 0.98	8.1	5.0	18.51 ± 0.70	40.00 ± 2.21

A is a point before, B is a point within and C is point after industrial activities on the rivers.
Nasolo stream was only sampled before and after the industrial area. $n = 3$.

in rainy season. In all the streams, OG concentrations increased after the streams had passed through industrial sites indicating the possibility of informal discharges of oily effluents from the industrial sites into the streams. Oil and grease limits are normally set by professional judgment and currently Malawi has no national standard for oil and grease for drinking water and other uses. All the more, high levels of oil and grease reduce dissolved oxygen in the water and alter the usability and aesthetic values of the water (Khan et al, 2006).

4.6. *Nitrates levels in water*

High concentration of nitrates were obtained in all the streams except Mudi River. In the dry season the nitrate values in the streams were as high as $139.94 \pm 0.50 mg/L$ for Limbe downstream, $138.87 \pm 9.11 mg/L$ for Naperi downstream, $111.25 \pm 14.39 mg/L$ for Nasolo upstream and $243.07 \pm 6.73 mg/L$ for Chirimba upstream. The levels observed were much higher than the World Health Organization limit (50 mg/l) for surface potable water. In the rainy season, generally the levels of nitrates were found to be lower than those in the dry season probably due to dilution effect although in most cases the levels were still higher than Malawi Standard of 10 mg/L. The highest levels observed in streams included Mudi upstream ($16.91 \pm 0.00 mg/L$), Nasolo upstream ($37.57 \pm 0.00 mg/L$), Naperi downstream ($49.64 \pm 8.89 mg/L$), Limbe upstream ($33.31 \pm 1.74 mg/L$) and Chirimba downstream ($37.57 \pm 0.00 mg/L$). The blocked sewerlines serving the industrial areas in addition to small-scale subsistence farming along the river banks could have significantly contributed to the high nitrate levels obtained. An earlier study in 2005 by Sajidu et al (2007) obtained lower concentrations of nitrates in Nasolo and Limbe streams compared to the results of this study demonstrating either an increase in discharge of nitrogen containing compounds into the streams with time or that the two studies are only capturing time point events.

4.7. *Phosphate levels in water*

Phosphate levels in Limbe, Mudi, Nasolo and Chirimba streams were significantly above the guideline limit of 0.5 mg/L (WHO, 1963) with increasing trends from upstream through the industrial sites to the down stream in the dry season. The concentrations for Limbe stream ranged from 0.83 to 4.26 mg/L, Mudi stream 2.82 mg/L upstream to 6.92 mg/L downstream, Nasolo stream 5.0mg/L upstream and 8.61 mg/L downstream and Chirimba stream from 5.77 mg/L upstream to 19.2 mg/L downstream. In the rainy season, phosphates were only detected in Mudi and Chirimba streams. The concentrations in Mudi ranged from 1.14 mg/L to 4.0 mg/L, both points being upstream whilst levels in Chirimba stream ranged from 0.29 mg/L upstream to 5.43 mg/L downstream. Significant increases were observed in both

TABLE 2
CONCENTRATIONS OF OIL AND GREASE (OG), PHOSPHATES ($PO_4{}^{3-}$), NITRATES ($NO_3{}^{-}$) AND SULPHATES ($SO_4{}^{2-}$)

Section of river	**Dry season**				**Rainy season**			
	OG (mg/L)	$PO_4{}^{3-}$ (mg/L)	$NO_3{}^{-}$ (mg/L)	$SO_4{}^{2-}$ (mg/L)	OG (mg/L)	$PO_4{}^{3-}$ (mg/L)	$NO_3{}^{-}$ (mg/L)	$SO_4{}^{2-}$ (mg/L)
Limbe								
A	0.07 ± 0.01	0.83 ± 0.39	16.23 ± 0.31	7.12 ± 0.72	1.67 ± 0.84	ND	33.31 ± 1.74	16.23 ± 2.46
B		4.26 ± 1.16	139.94 ± 0.50	21.19 ± 1.79		ND	7.88 ± 0.92	23.04 ± 0.00
C	0.56 ± 0.01	3.61 ± 0.39	25.40 ± 3.57	14.58 ± 0.68	5.30 ± 1.34	ND	32.95 ± 0.00	22.75 ± 1.02
Naperi								
A	0.02 ± 0.00	ND	2.15 ± 0.55	21.88 ± 0.72	0.17 ± 0.04	ND	28.47 ± 4.50	5.36 ± 0.82
B		ND	12.12 ± 1.20	34.72 ± 0.96		ND	13.51 ± 3.17	7.46 ± 1.84
C	ND	ND	67.97 ± 4.97	33.13 ± 0.00	ND	ND	49.64 ± 8.89	6.01 ± 1.54
Mudi								
A	0.57 ± 0.01	ND	1.56 ± 0.01	83.83 ± 2.11	0.73 ± 0.02	4.00 ± 0.81	16.91 ± 0.00	10.00 ± 0.20
B		2.82 ± 0.89	0.59 ± 0.27	17.45 ± 0.60		1.14 ± 0.81	2.60 ± 0.00	11.23?0.10
C	1.03 ± 0.01	4.62 ± 2.18	5.08 ± 0.40	11.70 ± 1.50	2.29 ± 0.54	1.71 ± 0.81	2.75 ± 0.41	5.80 ± 0.00
Nasolo								
A	0.07 ± 0.00	5.00 ± 0.00	111.25 ± 14.39	15.54 ± 0.43	0.73 ± 0.03	ND	37.57 ± 0.00	28.99 ± 1.64
B	2.46 ± 0.01	8.61 ± 1.18	8.37 ± 0.45	18.98 ± 1.22	0.67 ± 0.01	ND	8.09 ± 0.00	13.04 ± 3.89
Chirimba								
A	0.16 ± 0.00	5.77 ± 1.63	243.07 ± 6.73	8.47 ± 0.32	0.29 ± 0.40	9.68 ± 0.00	19.56 ± 1.44	
B	1.38 ± 0.04	10.26 ± 0.89	6.64 ± 1.55	103.61 ± 6.32	2.61 ± 0.85	1.43 ± 1.21	9.33 ± 1.34	36.16 ± 2.56
C		19.20 ± 0.54	10.84 ± 2.35	116.77 ± 3.09		5.43 ± 0.40	37.57 ± 0.00	37.10 ± 0.00

A is a point before, B is a point within and C is point after industrial activities on the rivers. Nasolo stream was only sampled before and after the industrial area. $n = 3$, ND=not detected.

streams after passing through industrial areas. The high phosphate levels may be due to blocked sewers in the case of Mudi and Nasolo which happen to be the streams that sandwich the heavy industrial area in the city among which are industries like chemicals, brewery, abattoir, and printing which exhibit high levels of industrial phosphates because they use phosphate detergents and diluted phosphoric acid used for cleaning production lines (Kuyeli, personal communication). On the other hand, the observed exacerbated levels in Chirimba stream can be attributed to the discharge of effluent from an edible oil refinery situated along its banks. The sewerlines in Chirimba industrial area were non functional as such effluent from industries were discharged direct into the stream. The high levels could also be due to farming activities taking place along the streams whereby farmers apply phosphates fertilizers in their fields.

4.8. *Sulphate levels in water*

The mean concentrations of sulphates at all sampling points in the streams were lower than the safe limit for drinking water (250 mg/L) (WHO, 2004). However, relatively high levels were obtained in water samples of Chirimba stream within the industrial area ($103.61 \pm 6.32 mg/L$) and downstream ($116.77 \pm 3.09 mg/L$) due to raw effluent emanating from industries since the sewer line is non functional.

5. CONCLUSION

This study has shown that the streams in Blantyre city are polluted especially in terms of BOD, and nutrients. The BOD pollution of the streams is high throughout the year despite the dilution effect experienced in the rainy season. The levels are above the acceptable limit on drinking water as required by the Malawi Bureau of Standards. BOD, oil and grease, and phosphate levels increased after the streams had passed through industrial areas whereas as no trends were noted for nitrates, sulphates, pH and suspended solids. There is therefore a need to properly manage wastes in the city and control as well as monitor industrial and human activities in order to ensure that such activities have minimal negative effects on the citys streams.

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