Research Article
Application of Stabilization Pond Effluent Quality Parameters in Assessing Treatment Efficiency, Disposal Safety and Irrigation Suitability

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Abstract: Physico-chemical and microbiological parameters of treated pond effluent and effluent-receiving stream water were assessed for their suitability for irrigation and effluent for discharge safety. The study was done at stabilization ponds in northern Zimbabwe. Monthly effluent and stream water samples were collected between May and October, 2011 from the 5th maturation pond outlet of a 2A-4F-5M stabilization pond system and at a point that was 4 km downstream. Overall pond treatment efficiency estimates were >89% with respect to BOD_5, TSS and faecal coliforms (FCs). Mean treated effluent parameters (22.18 ± 1.64 mg/L BOD_5, 17.00 ± 1.19 mg/L TSS and 37.33 ± 2.99 cfu/100 mL FCs) were significantly lower ($p<0.05$) than safe surface disposal limits. Treated effluent and stream water were both non-saline (mean electrical conductivity: effluent = 779.50 ± 37.79 μS/cm and stream water = 470.33 ± 41.83 μS/cm) with a low sodium hazard (mean SAR: pond effluent = 1.71 ± 0.06 and stream water = 1.08 ± 0.10). Residual Sodium Carbonate (RSC) values were negative indicating safe water. Non-toxic levels of Cl^- and Na^+ were observed in stream water but slight restrictions for irrigation use were observed for the effluent. Effluent was slightly alkaline (pH 8.30 ± 0.13) and safe. Stream water and effluent quality parameters were significantly different ($p<0.05$) except for FCs, CO_3^{2-}, Cd^{2+}, K^+, Pb^{2+} and PO_4^{3-}. Treated effluent was suitable for both surface discharge and for irrigation. Strong relationships were observed between effluent parameters and also between stream water parameters. Treated effluent from Woodbrook waste stabilization ponds can periodically be used for irrigation. This may help to restore stream water quality with a view to public health protection and environmental preservation.

Keywords: Discharge standards, irrigated agriculture, stabilization pond, treated effluent, wastewater reuse

INTRODUCTION

Wastewater reuse for irrigation is an old international practice (Glyona, 1971; Arthur, 1983) which is receiving renewed attention as scarcity of freshwater resources is increasing parallel to increasing population and water demand (Phocaides, 2007; Scheierling et al., 2011). There is greater likelihood of increased wastewater reuse in water-stressed countries in the near future as freshwater resources dwindle by the day. Agricultural wastewater reuse has both agronomic and economic justification (Alobaidy et al., 2010) as it contributes to the livelihoods of many households. Vegetable markets today are flooded with garden produce from wastewater-irrigated agriculture. Despite the widespread of informal reuse of wastewater, its significance and acceptance in Southern Africa is yet to receive adequate attention upon a looming water crisis.

Various criteria of evaluating the suitability of water for irrigation have been repeatedly reviewed (Ayers and Westcot, 1985; Phocaides, 2007). Irrigation water quality may have negative impacts on crops, soil, irrigation systems and agricultural management practices (Scheierling et al., 2011). Salinity, water infiltration rate, specific ion toxicity and miscellaneous factors have been commonly used to evaluate the suitability of water for irrigation (Ayers and Westcot, 1985; Al-Zboon and Al-Ananzeh, 2008). However, soil physical properties, climatic conditions, water use and other associated factors have also been used (Phocaides, 2007).

The objectives of the study were to:

- Determine the pond treatment efficiency of domestic sewage with respect to BOD_5, TSS and FCs,
- Determine the suitability of treated effluent for safe surface discharge using national (Zimbabwean) standards

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- Evaluate the suitability of both treated effluent and stream water for irrigated agriculture using international guidelines (FAO). The local municipality of the small town under study may be losing a valuable resource (treated effluent) for irrigated agriculture by disposing of it into a stream, or may be polluting the effluent-receiving stream, potentially putting downstream water users at health risk.

MATERIALS AND METHODS

Description of the study area: Bindura town is located (17° 30' 18"S and 31° 19' 49"E) about 90 km north east of Harare. The area is characterised by hot dry and wet summers (September-March) and cold dry winters (May-August). The mean daily temperature range is 12 -26°C and the average annual rainfall of 810 mm. About 3 000 m^3 (reduced due to water rationing) of basically raw domestic sewage are transported under gravity every day to Woodbrook Waste Stabilisation Ponds (WWSPs) that are located about 5 km east of the town. The ponds were designed to produce effluent that meets meet (EMA, 2007) surface discharge standards (Table 1). Other design specifications are: average dry weather flow of 5.6 ML/day, daily peak flow factor of 1.8 and an influent BOD of 580 mg/L. WWSPs consist of a single train of 2 parallel anaerobic ponds in series to 4 facultative and 5 maturation ponds (2A-2F-5M).

Sampling and sample analysis: Standard methods of water and effluent sampling were used (APHA (American Public Health Association), 1998). Effluent samples were collected from the 5th maturation pond outlet. Influent samples were collected just before the

anaerobic pond and stream water was sampled at the point of abstraction for irrigation 4 km downstream (EMA, 2007). Samples were put into pre-treated dil. HNO_3 stoppered polyethylene bottles that had earlier been washed with dil. HNO_3, then with distilled water and rinsed with the sample to be collected. For faecal coliform analysis, sterilised sample bottles were used for sampling (EMA, 2007). The bulk samples were sent to the chemistry laboratory for the physico-chemical analysis of selected parameters. Analyses were performed at Bindura University laboratories. Effluent and stream water were sampled monthly for a period of six months (May-October, 2011).

Electrical Conductivity (EC), pH, TDS and temperature were measured on site (100ml sample) using a multi-parameter tester 35 (Eutech Instruments, USA). Analytical methods used were: FAAS (Shimadzu AA-6601F) for metals (Na^+, K^+, Pb^{2+}, Cu^{2+}; Cd^{2+}), membrane filtration for faecal coliforms (FCs) (on membrane lauryl sulphate broth at $44.5 \pm 0.5°C$) and titrimetry for HCO_3^-, CO_3^{2-} (with H_2SO_4 to phenolphthalein and methyl orange end points), Ca^{2+} and Mg^{2+} (EDTA- Eriochrome Black T indicator) and Cl^- (standard $AgNO_3$). The dilution method (BOD_5), gravimetry (TSS) and spectrophotometry (NO_3-N, PO_4-P) (Speckoluv-vis spectrophotometer) were used. All measurements were done in duplicate using analytical grade reagents. Blank determinations were run in between samples and instruments were calibrated (according to manufacturers' recommendations) before use. Standard equations were used for the computation of Sodium Adsorption Ratio (SAR) and Residual Sodium Carbonate (RSC).

Table 1:Physico-chemical and biological characteristics of pond effluent and stream water at WWSPs in Bindura (units are mg/L unless specified)

Parameter	Mean ± SE[1]		Effluent discharge standards[2] [2]National	Irrigation water quality standards[3] FAO/WHO
	Pond effluent	Stream water		
BOD_5	22.18±1.64	10.81±0.60	≤30	-
pH (units)	8.30±0.13	7.50±0.01	6 - 9	6.5 – 8.4
EC (µS/cm)	779.50±37.79	470.33±41.83	≤ 1 000	0.25 -3.0 dS/m)
Temperature (°C)	25.83±0.25	23.50±0.23	≤ 35	-
FC (cfu/100 mL)	37.33±2.99	156.17±57.41	≤ 1 000	< 100
TSS	17.00±1.19	42.52±6.96	≤ 25	< 100
TDS	484.67±14.07	301.00±26.87	≤ 500	< 2 000
NO_3-N	0.63±0.06	2.98±0.16	-	-
PO_4-P	1.21±0.14	1.44±0.15	-	< 2.0
K^+	10.18±0.58	26.142±2.89	-	< 34.7
Ca^{2+}	38.92±1.33	28.80±1.97	-	< 400
Mg^{2+}	15.73±1.51	10.13±0.41	-	< 61
Na^+	49.92±0.93	12.52±1.98	≤ 200	< 460
Pb^{2+}	0.11±0.02	0.34±0.18	≤ 0.05	5.0
Cu^{2+}	0.028±0.012	0.13±0.03	≤ 1.0	0.2
Cd^{2+}	0.001±0.00	0.019±0.01	≤ 0.01	0.01
Cl^-	71.22±1.32	52.70±4.9	≤ 250	< 350
CO_3^{2-}	13.76±1.74	7.55±1.95	-	-
HCO_3^-	131.08±11.37	40.23±6.36	-	< 610
SO_4^{2-}	49.27±3.6	76.02±6.1	≤ 250	-
[4]SAR	1.71±0.01	1.08±0.1	-	< 9
RSC me/L	-0.64±0.11	-1.59±0.06	-	-
Ca^{2+}: Mg^{2+} ratio	1.65±0.09	1.75±0.15	-	-

1: Standard error of mean for 6 months' measurements; 2: EMA: SI 6 of 2007 (CAP 20:27); 3: FAO (Ayers and Westcot, 1985); 4: SAR = ≤8 for; TDS<150 mg/L and≤4 for TDS>150 mg/L; - (dash): Not specified/unavailable

Statistical analysis: Data were subjected to descriptive statistical analysis to generate mean parameter values and standard errors (at 95% confidence limit). Statistical significant differences between effluent and stream water parameters were solicited by an independent sample t-test. A one sample t test was used determine significant differences between treated effluent and stream water quality parameters with FAO irrigation water quality guidelines and between effluent and national (EMA) effluent discharge standards. Regression analysis was performed to establish the strength of relationships between parameters within effluent and within stream water. A Statistical Package for Social Sciences (SPSS version 16) was used.

RESULTS AND DISCUSSION

The treatment performances of the ponds (89.11% for BOD_5, 86.26% for TSS and 99.99% for FCs) were consistent with those reported from a large body of literature (Glyona, 1971; Arthur, 1983; Al-Zboon and Al-Ananzeh, 2008; Gratziou and Chalatsi, 2011). Effluent parameters were significantly lower ($p<0.05$) than national discharge standards (Table 1). Effluent could be discharged into a receiving water body provided that the stream water characteristics meet effluent requirements for discharge. Water rationing that is practised by the town's municipality reduces wastewater generation avoiding overloading of WWSPs.

Effluent quality at the discharge point did not reveal potential severe pollution to the receiving stream. This was also observed in a similar study by Momba *et al.* (2006) although inconsistent with common observations where effluent pollutes the effluent-receiving watercourse (Doughari *et al.*, 2007). Upstream water quality parameters were not determined during the study because the effluent-receiving stream is seasonal and experienced low to no flows. The use of TSS and BOD in determining pond treatment efficiency has been criticised (Arthur, 1983) but seems to be widely used in literature (Glyona, 1971; Gratziou and Chalatsi, 2011).

Zimbabwe uses Food and Agriculture Organisation (FAO) irrigation guidelines. Results indicated that all stream water parameters (except for FCs and Cu) were significantly lower ($p<0.05$) than FAO irrigation guidelines, with slight to moderate restrictions on use with respect to specific ion toxicity (Table 1). An independent samples t-test revealed that effluent and stream water quality parameters were significantly different ($p<0.05$) except for FC, CO_3^{2-}, Cd^{2+}, K^+, Pb^{2+} and PO_4^{3-}. Temperature ($R^2 = 0.643$, $p = 0.055$) and FCs ($R^2 = 0.457$, $p = 0.141$) showed strong influence on effluent BOD_5 while Ca^{2+} ($R^2 = 0.400$, $p = 0.178$), Cu^{2+} ($R^2 = 0.627$, $p = 0.061$) and HCO_3^- ($R^2 = 0.681$, $p = 0.043$) strongly influenced effluent EC. It was observed

that for stream water, FCs ($R^2 = 0.451$, $p = 0.144$) strongly influenced BOD_5. No particular parameters ($R^2>0.5$) and significantly ($p<0.05$) influenced stream water EC.

Effluent and stream water had slight to moderate degree of restriction on use due to the potential water infiltration rate problem. No potential salinity problems were noted for both. Low salinity water (about 0.2 dS/m) leaches soil minerals and salts while excessive salinity reduces the availability of soil-water (Ayers and Westcot, 1985). Negative Residual Sodium Carbonate (RSC) values of effluent and stream water observed (Table 1) show safe irrigation water (<1.25 meq/L). The values suggest no complete precipitation of Ca^{2+} and Mg^{2+} in the soil (Alobaidy *et al.*, 2010) which increases the Na^+ hazard in irrigation water.

Stream water (0.54 me/L Na^+; $52.70\pm2.4.90$ mg/L Cl^-) had no restriction on irrigation use due to Na^+ and Cl^- toxicity for foliar and root absorption (SAR< 3, Na^+ <3 meq/L; 70-355 mg/L Cl^- respectively). However, pond effluent (2.17 me/L Na^+; 70.63 ± 1.70 mg/L Cl^-) (Table l) showed potential Na^+ and Cl^- toxicity hazards with slight to moderate degree of restriction due to root absorption. No restriction on use for irrigation was observed for stream water due to HCO_3^- (0.84me/L) toxicity and unsightly foliar deposits although slight to moderate restrictions were observed for effluent (2.15me/L). Tolerant crops to Na^+ and Cl^- may be selected and proper agricultural management practices encouraged when irrigating with this effluent. It was expected that pond effluent contained significantly higher ($p<0.05$) Na^+ concentration than stream water (Table 1) as most of it originates from household grey water. Results indicated that both effluent and stream water had Na: Ca ratios >3:1, suggesting no potential soil structural breakdown when used for irrigation.

The concentrations of Pb^{2+} and Cu^{2+} in pond effluent were significantly lower ($p<0.05$) than FAO maximum concentrations recommended for irrigation water (Table 1). Cu^{2+} is toxic to a number of plants at concentrations of 0.1 mg/L while Cd^{2+} is toxic to beans, turnips at concentrations also was 0.1mg/L (Ayers and Westcot,1985). TSS posed no potential problems on use of effluent and stream water for irrigation.

Alkaline effluent pH was expected as the reclaimed wastewater contained a high level of HCO_3^- which has an alkalising effect that raises pH. The concentration of HCO_3^- strongly influenced both stream water ($R^2 = 0.603$, $p = 0.069$) and effluent ($R^2 = 0.502$, $p = 0.115$) pH. Alkaline pH values in soil of above pH 8.5 may reduce the availability of some micronutrients such as Fe and P to plants (Phacoides, 2007). Results also indicated that HCO_3^- and SO_4^{2-} had no potential to pose restrictions on effluent and stream water for toxicity and irrigation equipment.

Nutrient levels (NO_3-N, PO_4-P and K) in both pond effluent and stream water posed no potential toxicity

and hazardous problems on use for irrigation. Excessive nitrogen in irrigation water has been linked to over-stimulation of growth and delayed maturity, plugged valves, pipelines and sprinklers due to overgrowth of algae (Ayers and Westcot, 1985) while high levels of phosphorus usually cause eutrophication downstream.

Faecal coliforms in pond effluent indicated safe use while in stream water they placed slight restrictions on irrigation use (Table 1). A possible source of additional faecal coliforms to stream water than treated effluent could be animal dung downstream. Unrestricted wastewater reuse has however been linked to vector-borne, water related and water borne diseases (Arthur, 1983; Ayers and Westcot, 1985; Jemez *et al*., 2010).

CONCLUSION

In this study, the physico-chemical and microbiological parameters of treated pond effluent and effluent-receiving stream water were assessed for their suitability for irrigation and effluent for discharge safety. The treatment performance of the stabilisation ponds were between 85 and 100%. Wastewater generation from the town was limited by water rationing resulting in very low flows to the treatment ponds. Treated effluent from WWSPs could be discharged into a receiving water body provided that the stream water characteristics meet effluent requirements for discharge. Effluent quality at the discharge point did not reveal potential severe pollution to the receiving stream. Treated effluent and stream water had slight to moderate degree of restriction on use due to the potential water infiltration rate problem. No potential salinity problems were noted for both. However, there is need for continuous monitoring of pond effluent so that the integrity of the effluent-receiving stream ecosystem and public health are preserved.

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