EVALUATION OF POLLUTION LOADING INTO MSIMBAZI RIVER BY RAPID ASSESSMENT AND DIRECT MEASUREMENT METHODS

J.H.Y. Katima[1], H.O. Mbele, and J. W. Ntalikwa
Department of Chemical and Process Engineering, University of Dar es Salaam,
P.O. Box 35131 Dar es Salaam

This paper assesses the suitability of Rapid Assessment (RA) methodology as a tool for making an environmental pollution inventory in data poor situation. The RA method was applied to estimate Biological Oxygen Demand (BOD), nitrogen and phosphorous loading into the Msimbazi River in Dar es salaam, Tanzania. The Direct Measurement (DM) was done to validate the results obtained from RA. The methodology is based on estimating waste loads from function variables such as production rate, population, etc. and pollution intensities from domestic, industry and agricultural sources. The incorporation of penetration factors for waste loads reduction refines the assessment procedure. The RA results show that domestic source releases 7600, 390 and 3200 tons/year of BOD_5, Phosphorous and Nitrogen respectively. Industrial activities in the area release BOD_5 loading of 2500 tons/year and it was found that Tanzania Breweries Ltd (TBL) and Murza oil Processing Industries were major contributors of BOD_5 waste. Agriculture seemed to have less contribution with insignificant discharge of BOD_5, 3 and 14 tons/year of Phosphorous and Nitrogen, respectively. The results from DM were significantly different from those obtained using RA. For example at the point of discharge the difference observed was 23, 67 and 72%. This suggests that not all pollutants produced by a given anthropogenic activity reaches a water body as part of it undergoes natural decay or is entrapped by soils. These necessited inclusions of Penetration Factors (PFs) which reduced the gap between the two methods to 4, 13 and 8% for BOD_5, phosphorous and nitrogen, respectively.

Keywords: *Environmental pollution, Rapid Assessment, Direct measurement, Penetration factor(s) Pollution intensities*

INTRODUCTION

Nutrients such as nitrates and phosphates are unwanted in water bodies as they cause rapid growth of aquatic plants which in turn may have three significant adverse impacts on the aquatic life, namely they may restrict the penetration of sunlight into a water body and thus affect photosynthesis, they may restrict atmospheric oxygen to dissolve and when they die they may cause depletion of oxygen during their decomposition. Therefore, nutrients flow into a water body should be controlled in order to conserve the well being of aquatic ecosystem. Inevitably, the first step of controlling the nutrients loading is to establish the source and amount of nutrients being generated within the catchment area of the water body in question. This can be done by making direct measurement. However, direct measurement is expensive and time consuming in sampling and analysis and for some parameters expensive equipment may be required. Besides, since the dynamics of anthropogenic activities keep changing with time, continuous measurement is essential which again is costly and time consuming. For example the costs of determining chemical oxygen demand (COD),BOD_5, Ortho P, total P, NO_3^--N, NH_3-N, and Organic N are 12,500, 15,000, 9,000, 9,000, 10,500, 9,500, and 10,000 Tanzanian shillings

1 Corresponding author

(TAS) per sample per trial respectively (Chemical and Process Engineering (CPE) Chemical Laboratory Price List, 1997/98). Apart from costs incurred there is an issue of environmental pollution due to the chemicals used during analysis. For example discharging of mercury during COD determination, although it is expected that mercury-containing solutions should not be discharged directly into sewers without pre-treatment, evidence show that this is not the case. Nevertheless, the DM method is the best method that may give realist pollution loading into a water body.

Use of models is being advocated to overcome some of the deficiencies of direct measurements. The rapid assessment method aims at establishing mathematical models that can be used with reasonable accuracy to estimate the amount of nutrients generated in a particular catchment area. The method is based on the documented, and often extensive experience of the nature and quantities of pollutants generated from each kind of source. RA needs only information like production rate, fertiliser application etc.

The advantages of rapid assessment approach are:

a) Convenience of use, which makes it possible to conduct, integrated source inventories of pollution sources in highly complex situations.

b) The possibility of estimating conveniently the effectiveness of alternative control schemes in terms of their polluting load reduction potential.

LITERARTURE REVIEW

Management and effective control of the environmental pollution must be based on the best available knowledge of the sources that produce it and the quantities that are emitted (World Health Organisation (WHO), 1989). Utilising the available information, risk estimates regarding public health and the environmental in general, can be made and an adequate control strategy devised.

Wherever there are environmental problems, an inventory on the type of pollution and waste source, including their location and emission levels is necessary and important. Very detailed and precise inventories can be very resource intensive and involve sophisticated monitoring and data processing systems. Hence the budgetary and personnel requirements for such programs are often beyond the scope of many agencies in developing countries.

In 1982 WHO published a procedure entitled Rapid Assessment (RA) of sources of Air, Water and Land pollution. The procedure has been found particularly useful in developing countries like Tanzania because it uses limited available information to make reasonable estimation of pollution load.

This study follows the same RA methodology used by WHO publication (WHO, 1982 and 1989) that was further improved by Scheren (1995).The quantities of effluent loads released into the environment from urban areas or any industrial or other activity depend, in the general case, on a number of parameters. Thus, as in the case of effluents, the load E of pollutant j could be expressed as:

Ej=f (Source type, Unit of activity, Source size, Process or design particularities, source age and technology sophistication, Source maintenance and operating practices, type and quality of raw material used, type, design and age of the control systems employed, and ambient conditions).

Most RA procedures can be generalised by the following formula:

$$\text{Waste load} = \text{Function Variable} * \text{Pollution Intensity} \quad (1)$$

Table 1: Function variables and pollution factors for the principle pollution sources

Pollution source	Function variable	Pollution factor
Industries	Production	Waste production per unit product
Domestic	Population number	Waste production per person
Agriculture	Agrochemical/fertiliser use	Runoff and leaching per unit agrochemical/fertiliser used

Table 1: Sampling points

Sampling Point	Description
1	Reference point. It is located at Vingunguti area before the dumpsite
2	At Vingunguti: Dumpsite, Vingunguti slaughterhouse and Vingunguti ward
3 *	At the discharge point of Vingunguti oxidation ponds and Vingunguti Ward
4	Around Sukita in Buguruni ward
5*	At Ubungo River which collects wastes from Ubungo Ward
6*	A stream taking water from Mabibo oxidation ponds which discharges into Ubungo River
7*	A stream taking discharges from Kigogo Ward
8	Discharge from Jangwani and Ilala Ward
9	Discharge from Magomeni Ward
10*	At Sinza River which also collects wastewater from Manzese, Mwananyamala, Tandale and Kinindoni Ward
11	Final discharge point it also include waste from TBL and Upanga Ward

* These sample points were on tributaries and not along Msimbazi River

Where:

Pollution Intensity = Amount of waste produced per unit of a certain function variable. Pollution Intensities are obtained from studies of similar cases.

Examples of function variable are Annual production, Population number, Area of cultivated and non-cultivated land, etc. The Sizes of functional variables need to be gathered through field surveys, etc.

A RA method for an environmental pollution inventory is based on applied inventory methods. Estimating waste loads from functional variables see Table 1 and pollution intensities. The incorporation of penetration factors for rivers, wetlands and treatment plants refines the assessment procedure and provides information on the current and potential abatement of total waste loads.

The pollutant undergoes natural purification, abstraction, etc. and finally it does not wholly reach a water body. This being the case equation 1 will overestimate the pollution load. This calls for incorporation of penetration factors.

Penetration factors: Waste loads calculated before are those generated at different pollution sources which are higher than the loads eventually discharged into lakes or rivers. The difference in loading can be expressed by one or more penetration factor each with a value between 1 and 0.

Soil binding characteristics of nitrates and phosphates

Soils are capable of reducing BOD, suspended solids (SS), ammonium-N and phosphorus in sewage. Result from several studies have shown that immobilisation of P in soil occurs through adsorption, chemical precipitation, bacterial action, plant and algal uptake (Drizo et al., 1999). Of these, adsorption plays the greatest role. The adsorption capacity of soil depends upon chemical and physical properties of the materials. Phosphate

Table 2: Pollution loading as calculated by DM and RA (without PF) method

Sampling Point	BOD5, t/y (DM)	BOD5, t/y (RA)	Diff.	P, t/y (DM)	P, t/y (RA)	Diff.	N, t/y (DM)	N, t/y (RA)	Diff.
1*	11231.62	11195.90	-0.3%	60.98	60.78	-0.3%	3032.48	3022.83	-0.3%
2	9827.67	11841.00	+20.5%	74.66	88.80	+16.3%	2447.99	3247.64	+37.8%
4	11231.62	13467.90	+19.9%	85.66	140.87	+64.5%	2113.37	3673.55	+73.8%
8	12284.58	15730.45	+28.1%	92.36	259.85	+181.3%	1662.73	4639.25	+179.0%
9	15443.48	15979.58	+3.5%	89.98	174.31	+93.7%	1088.66	1436.21	+31.9%
11	16379.74	21065.66	+28.6%	145.9	442.48	+203.3%	1736.35	6144.10	+253.9%

even at low solution concentrations can be specifically adsorbed (covalently bonded) to the surfaces of soil minerals especially those with Al - OH and Fe - OH groups on their surface. Most soils have a large capacity to retain P. Even large additions of P will be mostly retained by soils provided there is adequate contact with the soil (Drizo et al., 1999).

Therefore given much time for water to be in contact with water or rather waste water the nutrients are expected to move from water to soil or vice versa depending on their concentration gradient. The experiment to determine the maximum nutrients (P and N) adsorption capacity has been done and their results were used to determine the penetration factor due to soil binding characteristic.

Incorporation of PF modified Equation (1) to read

$$Waste\ load = Function\ Variable * Pollution-$$
$$-Intensity * PenetrationFactor(s) \qquad (2)$$

Mtitu (2000) found out that the values of pollution loads (BOD, NO^-_3, and PO^{3-}_4) obtained from Rapid Assessment method were higher compared to those obtained from direct measurement when natural-purification effect (referring to as penetration factor) was not considered. The author further managed to include natural-purification effect for BOD, and the data obtained were reasonably comparable. For NO^-_3 the values obtained from both DM and RA methods without considering purification effect are also comparable within reasonable limits. This suggests that there was no apparent natural-purification effect in river for Nitrate. But for PO^{3-}_4 Mtitu (2000) observed a difference of 80% between the values obtained from RA and DM methods, suggesting that not all PO^{3-}_4 released by a particular source reaches the water body.

This research effort has focused on establishing the natural-purification or penetration factors for NO_3^- and PO_4^- particularly the soil binding effects.

MATERIAL AND METHODS

Methods of Quantification of Pollution Loads: Rapid Assessment

Identification of pollution sources was done in the study area by physically visiting the area and holding discussions with residents of the area. The data (i.e. function variables) were obtained from (a) production records of industries discharging wastewater in the Msimbazi River (b) Population census record (1988) and (c) Dar es Salaam Water and Sewage Authority (DAWASA).

The yearly waste loads calculated in the RA technique are general loads from the different pollution sources.

Experimental Procedure

Experiments were designed so as to get the values that can be compared to the RA values. Eleven sampling points were chosen in such a way that the values for each parameter could be obtained for both RA and DM. The choice of the sampling point was made based on target human activities in the catchment that may lead to pollution loading. In other words the sampling points were not equally spaced. Sample point 1 was on the

Table 3: Pollution loading as calculated by DM and RA (with PF) method

Sampling Point	BOD5, t/y (DM)	BOD5, t/y (RA with PF)	Diff.	P, t/y (DM)	P, t/y (RA with PF)	Diff.	N, t/y (DM)	N, t/y (RA with PF)	Diff.
1*	11231.62	11231.62	0	60.98	60.78	0	3032.48	3032.48	0
2	9827.67	11173.69	-13.7%	74.66	75.09	-0.5%	2447.99	2314.50	+5.5%
4	11231.62	11994.75	-6.8%	85.66	90.17	-5.3%	2113.37	1518.11	+28.2%
8	12284.58	13303.81	-8.3%	92.36	103.83	-12.4%	1662.73	1460.41	+12.2%
9	15443.48	13250.52	+14.2%	89.98	85.64	+4.8%	1088.66	1186.67	-9.0%
11	16379.74	16984.00	-3.7%	145.9	126.40	+13.4%	1736.35	1869.79	-7.7%

*This is taken as reference point

upstream of the river whereas sample 11 was on the downstream. Table 1 summarises the characteristics of the sampling points.

The DM method comprises of sampling at selected /various points of the area to be studied and the analysis is done in the laboratory for target pollutants e.g. BOD_5, P, N, pH, etc. Direct measurement is always done to validate the RA method (Zander, 1997, Scherem, 1995, Mtitu, 2000, Katima and Mtitu, 2002). One sample per day per sampling point was taken for analysis.

Experiments were carried out in two phases. Phase one was aimed at getting the values of pollution parameter that would be compared with RA values. The experiments included: Determination of NH_3-N, NO_3-N, NO_2-N and Organic-N (summation of these gave the total nitrogen N); Determination of Ortho-phosphorus and total Phosphorus; Determination of COD which was used to determine BOD_5. Phase two aimed at establishing soil-binding characteristics for nutrients: Phosphorus adsorption and adsorption of NH_4-N, NO_3-N, NO_2-N and Organic-N onto soil. Standard methods (American Public Health Association (1971)) have been used.

RESULTS AND DISCUSSIONS

Rapid Assessment Method

Pollution loads by RA were calculated at each selected point using equation (1). The total pollution load discharged at each point is basically a mass balance at that particular point i.e. it is the summation of the contribution of different sources, see equation (3). The RA values of pollution load were evaluated first without considering penetration factors and then with penetration factors. The pollution loading results from the RA (without PF) are shown in Table 2.

$$\textit{Total load} = \textit{Point pollution} + \textit{Previous point pollution} \quad (3)$$

Direct Measurement

Target pollutants (i.e. BOD_5, N and P) were measured directly and then used to compute the total pollution loading of at each point. Figure 1 shows the variation of BOD_5 along the river on different days. It can be seen that the BOD_5 was not constant. For example it varied from about 20.0 mg/L to about 180 mg/l on sampling point 1. The observed variations may be attributed to weather conditions and the human activities taking

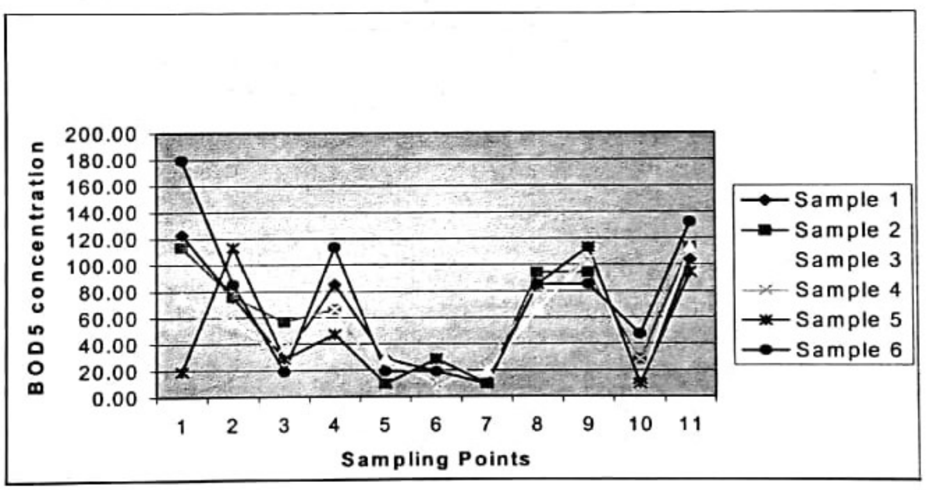

Figure 1: BOD5 concentration measured along Msimbazi River by the DM method

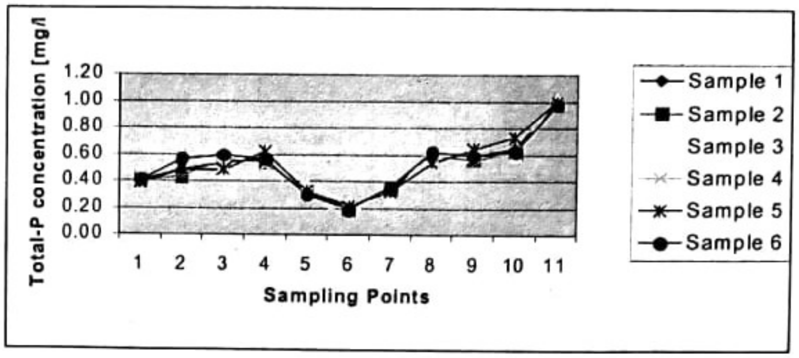

Figure 2: Total-P concentration measured along Msimbazi River by the DM method

place in the catchment on that particular day. For example on rainy days the concentration of BOD_5 in river could either go up or down depending on the intensity of precipitation. Normally, rain flushes the pollutants from the catchment into the river stream which may result in an increase in pollutant concentration. However if the precipitation is significant the dilution effect outweighs the flushing effect and thus the pollutant concentrations goes down (Vighi et al 1991).

From Figure 1 it can be seen that, although the BOD_5 concentration did not show a consistent picture (as it was going up and down as one moves from sampling point 1 to sampling point 11, on average the BOD5 concentration is higher than the recommended discharge concentration i.e. 30 mg/L (WHO, 1989). However, on average, the BOD5 concentration is increasing from sampling point 1 to sampling point 11 (it varies from 67 mg/l on sampling point 1 to about 110 mg/l at sampling point 11). This should be expected, because as one moves from sampling point 1 to 11, apart from the river receiving pollutants from the previous sampling point, it also receives pollutants from the nearby catchment area.

Figure 2 shows the variation of total phosphorous concentration along the river as determined using the DM method. It can be seen that, for all samples, the concentration at sampling point 11 is much higher than observed at the other points. This may be attributed to the contribution from TBL which discharges effluents with relatively high concentrations of total-P which ranges between 0.4 to 1 mg/l. It should be noted that the accepted total-P concentration is 0.3 mg/l (WHO, 1989). On the rainy days the observed level was higher than those observed on dry days. This may be attributed to the reason outlined above.

Figure 3 shows the variation of Total-N concentration along the river. It can be seen that the Total-N concentration decreases as you move downstream. This is expected especially if there no new sources of NO_3^- as more tributaries join the Msimbazi river dilution will take place and hence low Total-N concentration. WHO, [1991] reported that as the river flows increases the NO_3^- along the river decreases.

Total pollution loading of the target pollutants as estimated by the DM method is as shown in Table 2.

Comparing pollution loading by RA (without PF) and DM methods

Table 2 compares the results obtained from DM

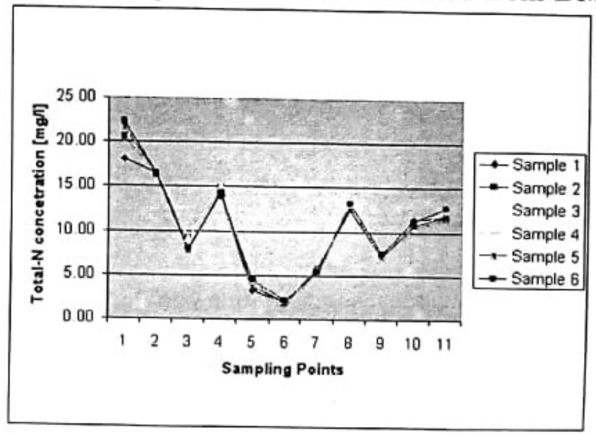

Figure 3: Total-N concentration measured along Msimbazi River by the DM method

and RA (without PF) method. It can be seen that there are discrepancies in almost all sampling points. In this study, RA method, generally it has overestimated the pollution loading. This suggests that not all the pollutants discharged at a particular source reach the river. This brings the concept of penetration factors (PF). This concept recognises the fact that, there are often natural purification processes and soil binding which reduce the amount of the pollution load reaching the water body. Lemmens et al (1998) estimated the values of PF due to natural decay of BOD_5. These values were adopted in this study. However, there are no reported values for soil binding characteristics for P and N. This study established the probable binding characteristics of the soils in the Msimbazi river catchment.

Soil binding characteristic

The time taken for water to travel from the discharging point to the river mouth is assumed long enough for the liquid to be in equilibrium with the soil. Therefore the results obtained after shaking wastewater of known concentrations of P and N with soil have been used to calculate binding characteristic of soil with nutrients. This was simply taken to be equal to the final concentration to initial concentration of the pollutant in water after equilibrating the water containing the target pollutant with the soil. Figures 4 and 5 show PF for phosphorous and nitrogen (total), respectively. For detailed calculations of PF refer to Mbele (2002).

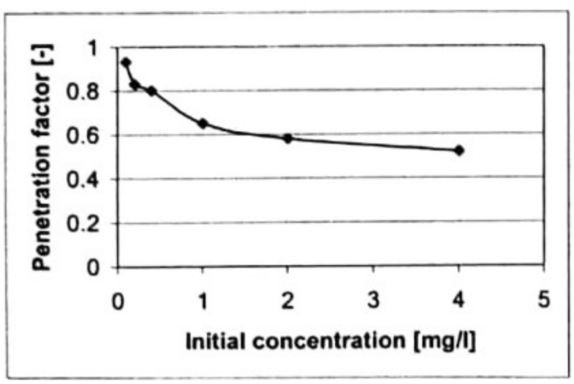

Figure 4: Penetration factors due to P-soil binding characteristic

The results show that the amount of pollutants bound onto soil depends on the concentrations of that particular pollutant in water in a given time. This is attributed to the fact that the diffusion of pollutant through water onto the soil surface follows a normal mass transfer equation as shown in equation (4). That is to say the penetration factor for pollutants due to binding characteristic of the soil depends on the concentration of the particular pollutant in a water body.

$$\frac{\partial N_A}{\partial t} = Kc(C - C^*) \tag{4}$$

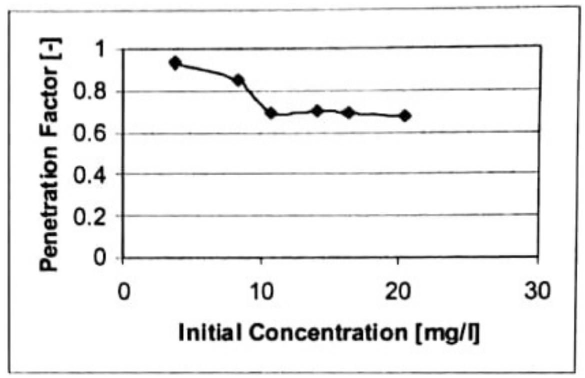

Figure 5: Penetration factors due to N-soil binding characteristic

Comparing pollution loading by RA (with PF) and DM methods

Table 3: compares the results of RA (with PF) and DM methods. It can be seen from Table 3 that with the inclusion of PFs the estimated results using RA are close to those obtained from the DM method (compare the differences in Tables 2 and 3). The penetration factors considered in this report are the results of the self-purification potential of rivers and streams for BOD reduction and adsorption process, which has been used to develop the binding characteristics of soil in the river bank for Phosphorus and Nitrogen.

CONCLUSIONS

It can be concluded that, the RA (with PF) method gives reasonable estimates of pollution loads in the absence of sophisticated and expensive monitoring equipment. Within ± 10 % RA may be used to provide reliable data based on which environmental management strategies may be drawn. The procedure requires minimum data, time and other resources for investigation and provides a general overview of the magnitude of water pollution in a given region or country. Both RA and DM methods declare anthropogenic activities taking place in the catchment area to be the potential sources of pollution of Msimbazi River. RA method gives rough estimations of pollution loads. Penetration factors have refined the data to the reasonable agreement to the values for DM within $\pm$ 15%. Nevertheless, the results show that the concentrations of target pollutants i.e. BOD5, N and P are above those permissible under the Tanzania Temporary Standards.

RECOMMENDATIONS

- The results show that domestic pollution into Msimbazi River is a serious problem. Priority should be given to the reduction of waste load of the source in order to improve the water quality of the river.
- Since the accuracy of the RA model will depend on the data used for validation, it is therefore recommended that the data on pollutants concentration and river flow should be studied for longer periods to cover all seasons.
- More studies should be done to refine the penetration factor(s) and to include such factors as effect of phosphorous found in sediment.
- To reduce the time needed for data analysis it is recommended that a RA software should be developed.
- The emission factors for pollution and waste load estimation, as applied in the RA method, are derived from models developed in more developed countries. There is a need to study emission factors or pollution indices which will take into account local circumstances.

ACKNOWLEDGEMENT

The authors would like to acknowledge the Even Project and the Sida-SAREC for the financial support.

ABBREVIATIONS AND SYMBOLS

BOD_5	Five day biochemical oxygen demand, mg/l
C	Concentration, mg/l
DM	Direct Measurement
Kc	Mass Transfer Coefficient
PF	Penetration Factor
RA	Rapid Assessment
N	Nitrogen
N_A	Number of moles
P	Phosphorous

REFERENCES

1. Drizo, A., C.A. Frost, J.Grace and K.A. Smith, *Physico-Chemical Screening of Phosphate-Removing Substrates for Use in Constructed Wetland Systems*. Water Sci. Tech. Vol. 40, No. 3, 1999, pp 301-309
2. APHA (American Public Health Association), *Standard Methods for the Examination of Water and Wastewater*, 16th ed, Washington, D.C., APHA, AWWA & WPCF, 1985.
3. Bureau of Statistics, Ministry of Finance, Economic Affairs and Planning. *Population Census*, Government Press, Dar es Salaam, 1988.
4. *CPE Chemical Laboratory Price List*, Unpublished, 1997/98
5. David J., Graczyk and W.C. Sonzoghi, *Reduction of DO concentration in Wisconsin Stream During Summer Runoff*. Journal of Environmental Quality, Vol. 20 pp. 444-454, 1991
6. Katima, J.H.Y. and T. Mtitu, *Assessment of Pollution Loading in Mirongo River by Rapid Assessment and Direct Measurement Methods*, in Press, Tanzania Journal of Science, 2002

7. Lemmens A.M.C., HA Zanting, J.H.Y. Katima, JS Balwira, FW Bugenyi, AGM Scheren. A, *Rapid Assessment Methodology for Environmental Pollution Inventory in Tanzania, Lake Victoria Catchment Area as a Case Study*. Proceedings of the International Symposium on Engineering Research partnership for Sustainable Development, Dar es Salaam, Tanzania, pp 119-147, 1998.

8. Mbele, H.O., *Evaluation of Pollution Loading into Msimbazi River by Rapid Assessment and Direct Measurement Methods*, M. Sc. Dissertation, University of Dar es Salaam, Tanzania,2002.

9. Scheren, P.A.G.M., *A Systematic Approach to Lake Water Pollution Assessment. M. Sc. Dissertation*, Eindhoven Institute for Continuing Education, Eindhoven University of Technology, 1995.

10. Mtitu, T.V.M. *Assessment of Pollution in Mirongo River by Rapid Assessment and Direct Measurement Methods*. M. Sc. Dissertation, University of Dar es Salaam, Tanzania, 2000.

11. Vighi M., P.Soprani, P. Puzzarini and G. Menghi, *Phosphorous Loads From Selected Watersheds in the Drainage area of the Northern Adriatic Sea*. Journal of Environmental Quality, Vol. 20 pp. 439-451, 1991.

12. Word Health Organization, *Rapid Assessment of Sources of Air, Water, and Land Pollution*. WHO, Geneva, 1982.

13. World Health Organization, *Management and control of Environment*. WHO, Geneva. WHO/PEP/89,1989.

14. Zanders, M.O, *An Assessment of Domestic Wastewater Pollution for the lake Victoria. M. Sc. Dissertation*, Eindhoven University of Technology (EUT), 1997.