

Review of Estimation of Pollution Load to Lake Victoria

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Abstract
Lake Victoria is a shared East African transboundary freshwater lake. Its basin lies within Burundi, Kenya, Rwanda, Tanzania and Uganda. In the past, studies and projects done on Lake Victoria focused mostly within the lake but recently they have extended to the basin to facilitate holistic understanding. Estimation of pollution load has been with respect to total nitrogen, total phosphorous and biodegradable organic matter which are considered to be critical pollution parameters. This study reviewed methods used in the past studies to estimate pollution load to Lake Victoria to highlight shortcomings and possible ways of improvement. The baseline models used in the methods were elaborated with respect to their merits and demerits. Methods used in the studies vary and their outcomes are of the same order of magnitude but with notably significant differences with respect to some pollution load parameters. The variances are mainly attributed to methods and scarce data used. Alternative methods that would improve the quality of the output by incorporating technology advancements in Remote Sensing and Geographical Information Systems (GIS) were also considered. GIS based tools are one of the options to overcome challenges in describing spatially and temporally varying environmental attributes.
Keywords: Data scarcity, Estimation method, Lake Victoria, Point and non-point source pollution

1. Introduction

Lake Victoria is a freshwater lake in East Africa and has surface and basin areas of 68,800 km^2 and 194,000 km^2 respectively. The lake is located at an altitude of 1,134 m asl and its average depth is 40 m while volume is 2,760 km^3 (Muyodi *et al*., 2010; Scheren *et al*., 2000). It is the second largest freshwater lake by surface area in the world and the largest in Africa. The lake is an economic zone to the three riparian countries, namely, Kenya, Tanzania and Uganda. Lake Victoria basin also extends to Burundi and Rwanda (Fig. 1). The basin supports livelihoods of about 40 million people whose socio-economic activities have direct linkage with the lake's ecosystem (Kayombo and Jorgensen, 2005). The densely populated basin has good soil and climatic conditions which highly favour agricultural activities. The lake benefits both the basin countries and the entire global community. The lake is a source of fish, freshwater, irrigation water and hydro electric power, provides routes for transportation and is also a cleansing system for municipal, industrial and agricultural pollution.

Intensive natural and human activities compounded by ever growing population, poor livelihoods and less investment in sanitation have accelerated environmental degradation through deforestation, siltation, wetlands destruction and direct disposal of sewage to the lake. These result in increased pollution load to the lake to the extent of compromising its ecosystem integrity. Lake pollution has led to deterioration of water quality, as manifested by algal blooms and periodic massive fish kills caused by oxygen depletion (Ochumba, 1988). The lake and its ecosystem show evidence of dramatic changes, with infestation by water hyacinth being one of the major concerns in recent years. The threats facing the lake have also hampered efforts to improve livelihoods of the population dependent on the lake (Kayombo and Jorgensen, 2005). Recently many cases of fishermen being trapped offshore by water hyacinth in their fishing boats have been reported. To address these challenges, several studies and projects have been implemented, focusing both within the lake and the basin. The Lake Victoria Environmental Management Project, Phase II (LVEMP, 2009-2017) is one of the major ongoing interventions on the lake being implemented by all the five basin countries.

Figure1. Lake Victoria Basin

Estimation of pollution load to Lake Victoria has been carried out by several studies in the past. However, most of the findings of the studies are published in official reports that are not easily accessible to the general public. The main pollution parameters of concern considered in the studies are Total Nitrogen (TN), Total Phosphorous (TP) and Biodegradable organic matter (BOD). Estimation of pollution load has always been hampered by scarcity of data which adversely affects the accuracy and reliability of results. One of the recent comprehensive project is Lake Victoria Environmental Management Project, Phase I, LVEMP (1995-2005), which set a framework for future estimation of pollution load (COWI, 2002). Other similar past studies include: Africa Water Network (AWN) (1998), Bootsma *et al*. (1996), Calamari *et al*. (1995), Scheren (2005, 2003) and Scheren *et al*. (2000, 1995). Several weaknesses were noted in the studies, the major one being inadequate data (Cheruiyot *et al*., 2011).

This paper reviews past efforts on estimation of pollution load to Lake Victoria and discusses their strengths and weaknesses in tandem with advancement in technology in hydrological modelling. The paper proposes possible methods based on Remote Sensing (RS) and Geographical Information Systems (GIS) modelling tools as options for future improvement. The paper also aims at sharing with a wide audience the existing efforts on estimation of pollution load to Lake Victoria, most of which are contained in publications that are not easily accessible to the general public.

2. Baseline Models in Existing Studies

This section reviews baseline models used in the reviewed studies to estimate both point and non-point pollution loads to Lake Victoria in terms of TN, TP and BOD. The models are elaborated below.

2.1 Standard Unit (per capita) Load

Standard unit load represents amount of annual load generated by one person or a unit of product. This approach is applicable to estimation of municipal and industrial point pollution loads. For municipal load, populations are identified by their modes of waste disposal (for example; pit latrine, sewer and septic tank) with their corresponding standard per capita load (Eq. 1).

$$\text{Pollution Load (TN, TP and BOD)} = \textit{Population} \times \text{Standard per Capita Load} \quad (1)$$

For industrial load, industries are identified by their periodic (say annual) production and matched with their corresponding Standard unit load for the product (Eq. 2).

$$\text{Pollution Load (TN, TP and BOD)} = \textit{Production} \times \text{Standard Unit Load} \quad (2)$$

Where applicable, penetration factors are applied to account for reduction by artificial systems (stabilization ponds, septic tanks and pit latrines) and natural treatment systems (wetlands for TN and TP reduction, river for BOD reduction).

2.2 River Water Quantity and Quality Measurements

This method is applicable to estimation of riverine (runoff) pollution load. Pollution load is derived from field monitored river flow (hydrology) and river nutrient concentration (Eq. 3). The load is extrapolated to cover the whole river watershed area if the monitoring point is upstream of river mouth.

$$\text{Pollution Load (TN, TP)} = \textit{River Discharge} \times \text{Concentration} \quad (3)$$

2.3 Unit Area Load (UAL)

The concept is applicable for estimation of runoff load. In this approach land cover in the basin is characterized into various categories (land uses). UAL represents annual amount of runoff nutrients generated per unit area of land surface. Runoff load is estimated by matching land use area with relevant UAL (Eq. 4).

$$\text{Pollution Load (TN, TP)} = \sum_{\text{Land use}} \textit{Land Area} \times \text{Unit Area Load} \quad (4)$$

2.4 Unit Load Deposition

This approach is used to estimate pollution load generated from wet and dry atmospheric deposition. Unit load deposition is annual amount of nutrients deposited over a unit surface area of a lake from the atmosphere. Atmospheric pollution load is expressed as a function of deposition per unit area (Eq. 5).

$$\text{Pollution Load (TN, TP)} = \sum_{\text{Dry}}^{\text{Wet}} \textit{Unit Load Deposition} \times \text{Lake Area} \quad (5)$$

3. Summary of Reviewed Literature

This study relied on review of published literature and project reports and discussions with relevant experts in relation to methods of estimating pollution load for Lake Victoria. The literature considered here in detail are Calamari *et al*. (1995), COWI (2002), Scheren (2005, 2003) and Scheren *et al*. (2000, 1995). They are introduced below with consideration to their data sources and methods and key features summarized in Tables 1 and 2.

3.1 Calamari et al. (1995)

The study assessed pollution risk on river basins flowing into Winam Gulf on the Kenyan side of Lake Victoria. The main aim of the study was to identify potential lake pollutants. Pollution loads were estimated from municipal (point load), industrial (point load) and agricultural (non-point load) sources. Atmospheric deposition was not estimated. Municipal loads from towns were estimated using methods outlined in existing literature (Iwugo, 1990). Standard unit loads were used to quantify industrial loads from industries which included sugar millers. UAL concept was used to estimate runoff load in which land use was classified into cultivated and non-cultivated. The study also estimated the contribution of human inhabitants and livestock to runoff load using annual per capita load. Only phosphorous runoff load was estimated because it was considered to be the main limiting nutrient for production in the lake.

3.2 Scheren (2005, 2003) and Scheren et al. (2000, 1995)

The study, noting limitation of data, used rapid assessment methods. Based on extensive literature review and field visits, the authors came up with inventories of pollution data which the study considered adequate for their methodology. Municipal and industrial sources were classified as point sources while land runoff and atmospheric deposition were classified as non-point sources. An inventory of pollution intensities (unit loads) of various pollution sources were matched with their corresponding functional variables (for example, production of goods). The unit loads and functional variables were sourced from literature, field surveys, relevant institutions and rough estimates. Field visits were mainly meant to ascertain industrial production, agricultural management practices and conditions of municipal and sewerage systems.

The study came up with a range of typical per capita loads for municipal load sources categorized into sewered and unsewered population. The range consisted of three values, namely, the lowest and the highest unit loads that had been reported in other regions, and a most likely value (best guess). Where data existed, they were used as the most likely value otherwise literature values considered applicable were used. Industries were grouped as per International Standard Industrial Classification (ISIC) to determine their corresponding BOD unit loads. Unit loads for TN and TP were sourced from World Health Organization (WHO) guidelines (WHO, 1989; WHO, 1982). For both municipal and industrial loads, penetration factors were applied to account for purification of pollution load by both artificial systems (stabilization ponds, septic tanks and pit latrines) and natural treatment systems (TN and TP reduction by wetlands BOD reduction by rivers).

UAL and deposition per unit area concepts were adopted for land runoff and atmospheric loads respectively. The study classified landuse into cultivated and non-cultivated. Like municipal load, ranges (low to high) of UAL and unit load deposition were borrowed from literature values reported in regions outside Lake Victoria. The most likely values (best guess) were borrowed from regions with conditions similar to or close as possible to those of Lake Victoria, such as studies on Lake Malawi by Bootsma *et al*. (1996).

3.3 COWI (2002)

The study was done under LVEMP (1995-2005) and its aim was to provide quantitative information on nutrient loading and recycling within the lake. Meteorology (rainfall), hydrology (river flow) and river nutrient concentration in the basin were monitored. Population census data (Kenya – 1999; Tanzania – 1988; Uganda – 1991) were projected to determine urban population size and type of waste disposal system. Industrial records were sourced from government departments and field surveys. The records included: type, production and information on their wastewater disposal systems. The study used field measured data and estimates (approximated) where data were not available. Point loads comprised of effluent discharge from towns (with more than 10,000 persons) and wet industries. Urban population and industries were grouped by mode of waste disposal (sewerage, septic and pit latrine). Municipal load was estimated using population matched with per capita (TN, TP & BOD) loads while production was matched with standard unit load for industrial load. Treatment efficiencies for both municipal and industrial discharge systems were considered where data were available. Reduction of pollution load by discharge systems including (wetlands) was considered in cases where the systems are used for treatment but reduction by rivers was not considered.

Non-point pollution comprised of diffuse runoff and atmospheric deposition load. Diffuse runoff was estimated by matching river flow and river water quality. The data were taken at points along the rivers and not necessarily at river mouths. By this method, estimated diffuse runoff pollution load (TP and TN) included point loads discharged to the rivers upstream. However, the amount of point loads was considered negligible as compared to the quantity of diffuse runoff pollution load. Atmospheric deposition was derived from laboratory tests on samples collected using an open container for both dry and wet deposition, and ultimately extrapolated to cover the whole lake area. The samples were collected from landbased stations within lakeshores of Kenya, Tanzania and Uganda. The lake was subdivided into rain boxes (equal rainfall units) and rainfall data collected based on the sub divisions. The rainfall data together with laboratory water quality data for dry and wet deposition were then matched to estimate atmospheric deposition load over the whole lake.

Table 1. Summary of Methods (point loads)

Study			Calamari *et al*. (1995)	Scheren (2005, 2003) & Scheren *et al*. (2000, 1995)	COWI (2002)
Scope			Winam Gulf	Lake Victoria Basin	Lake Victoria Basin
Pollutant			BOD	TN, TP, BOD	TN, TP, BOD
Industrial	Generation	Scope	6 Industries	50 No. industries (12 groups of industries as per ISIC[a])	68 No. wet industries
		Load	Load=Production∗pollution intensity[b]∗penetration factor[b]	Load=Production∗pollution intensity[c]∗penetration factor	Load=Production[d]∗pollution intensity∗penetration factor[d]
	Reduction		Artificial treatment systems	Artificial treatment systems, rivers and wetlands	Artificial treatment systems
Municipal	Generation	Scope	10 No. towns	40 No. towns in all 5 basin countries	87 No. towns (Kenya, Tanzania & Uganda)
		Disposal	Sewer, Pit latrine and Septic tank	Sewered and Unsewered	Sewer, Pit latrine and Septic tank and open defecation
		Load	Load=∑(persons∗p.c.l[e])	Load=Population∗penetration factor∗p.c.l[e]	
	Reduction		Not considered	Artificial treatment systems, rivers and wetlands	Artificial treatment systems

[a]International Standard Industrial Classification; [b]As per WHO (1989); [c]BOD as per ISIC while TN & TP as per WHO (1982); [d]Based on measured or estimated data; [e]Per capita load (TN, TP or BOD)

Table 2. Summary of Methods (non-point sources)

Study		Calamari *et al.* (1995)	Scheren (2005, 2003) & Scheren *et al*. (2000, 1995)	COWI (2002)
Scope		Winam Gulf	Lake Victoria Basin	Lake Victoria Basin
Pollutant		TP	TN & TP	TN & TP
Land Runoff	Land use	Cultivated and Non-cultivated	Cultivated and Non-cultivated	Not classified
	Load	Load=Area*UAL[b] + {Population (persons, sheeps,cattle)}*p.c.l[a]	Load=Area*UAL[b]	Load=River discharge*Nutrient concentration
	Data source	Literature (p.c.l[1]; UAL[a])	Literature (Low & High values were used)	Field monitoring (water quality & quantity)
Atmospheric deposition	Load	Not estimated	Load=surface area*annual deposition per unit area	Load=(nutrient concentration*rainfall) + (surface area*annual dry deposition per unit area)
	Data source	Not estimated	Literature (most likely values borrowed from closely related regions)	Field monitoring (water quality & quantity)

[a]Per capita load (TP); [b]Unit Area Load

4. Discussion

Pollution loads are conveniently classified into point and non-point load depending on the ease and clarity of identity of their origin. All the studies reviewed classified municipal and industrial sources as point sources while land runoff and atmospheric deposition were classified as non-point sources. However, differences emerge among the studies regarding the methods of estimation of total load from the various sources. The different approaches taken by the studies are discussed in the sections below. Summaries of typical per capita loads and estimated pollution loads in the reviewed literature are given in Tables 3 and 4 respectively.

4.1 Point Pollution Load

Sewerage systems are an important consideration for point load estimation. However, not all towns and industries within the lake's basin have sewage treatment facilities. Alternatives such as wetlands, pit latrines and septic tanks are used. For households connected to municipal sewers, it is easy to comprehend how municipal waste ends up in the lake through the treatment plants, wetlands or river course. It is also possible to monitor the effluent quantities and quality. Pit latrines provide an underground storage of human excreta and in some cases they also store wastewater from points such as bathrooms and kitchens. In an ideal case where there is neither overflow nor flooding, the pollution load in pit latrines would not find its way into the lake. The challenge would be how to estimate load where there is input from pit latrines. Typical septic tanks also do not flow directly into water courses but are discharged underground through soak pits. Conventional sewage treatment plants within the lake basin are poorly maintained and operate below optimal performance (Scheren *et al*., 2000). This implies that the theoretical treatment efficiencies considered may not be accurate. Based on the nature of pit latrines and septic tanks, it is expected that relatively more load should come from the main sewer as compared to pit latrines and septic tanks. Consequently the per capita loads for each disposal system should reflect their relative contribution. However, some of the studies reviewed used the same unit load for sewers, septic tanks and pit latrines (Table 3).

COWI (2002) used the same per capita BOD load (11 kg/person/yr) for persons using main sewer, septic tanks and pit latrines. This means people using pit latrines and main sewers pollute the lake equally. On the other hand, Calamari *et al*. (1995), Scheren (2005, 2003) and Scheren *et al*. (2000, 1995) used differentiated per capita loads with respect to type of disposal system. The flat rate used by COWI (2002) for all disposal systems do not represent the realistic scenario. This extends to TN and TP parameters. Scheren (2005, 2003), Scheren *et al.* (2000, 1995) and COWI (2002) used a flat rate with respect to all the disposal systems. This again does not reflect the relative capacities of different disposal systems to pollute the lake.

Challenges of estimating industrial pollution load were noted by the studies reviewed. This is in relation to records of polluting industries which were not available in a central place. It is necessary to identify the industries to adequately estimate pollution load from industries. Either annual production data or the wastewater flow and quality data for treatment facilities including their treatment efficiencies are needed. However, these data are not always available or complete because not all industries keep records. In the absence of such data, the studies used standard unit loads from literature and estimated industrial production. The approach may not capture the actual hot spot pollution centres. However, this seems to be the only available option to adopt until industry data collection is improved.

Table 3. Typical per Capita Unit Loads of BOD, TN and TP (Kg/person/yr)

Study	Calamari *et al*. (1995)			Scheren (2005, 2003) & Scheren *et al*. (2000, 1995)		COWI (2002)		
Disposal system	Sewered	Septic tank	Pit latrine	Sewered	Unsewered	Sewered	Septic tank	Pit latrine
TN	-	-	-	Low-High: 2.2-4.4 Most likely=3.3		1.8	1.8	1.8
TP	-	-	-	Low-High: 0.2-1.6 Most likely=0.4		0.73	0.73	0.73
BOD	11	8.6	7.3	Low-High: 8-20 Most likely=16	Low-High: 7-11 Most likely=8	11	11	11

4.2 Non-point Pollution Load

COWI (2002) estimated runoff pollution load based on monitored water quality and water quantity data in river watersheds. Sampling was done at points along inflowing rivers and not necessarily at river mouths. However, the estimated load was extrapolated to cover the total area of the watershed. Most wetlands in the lake basin are located close to the river mouths. Papyrus wetlands are dominant and play a big role in the removal of nutrients (Kansiime and Nalubega, 1999; Kiwango, 2007). Therefore monitored data at points upstream to river mouths do not give a representative estimate of nutrient loads that enter the lake. It was further assumed in COWI (2002) that river water quality and river discharges are constant throughout the year. However, in reality river nutrient concentration and river discharges vary with the seasons of the year. Furthermore, due to lack of data, water quality data for eleven river watersheds were borrowed from neighbouring catchments. Borrowing data creates bias error and may not give a true representation of the actual situation.

Calamari *et al*. (1995), Scheren (2005, 2003) and Scheren *et al*. (2000, 1995) used UAL concept. UALs as function of land use were sourced from literature because there were no local UAL estimates for Lake Victoria basin. Idealy UAL is not only a function of land use but also a function of other environmental and management attributes. The other relevant environmental attributes are rainfall parameters (rainfall intensity, depth and frequency), slope, catchment size, drainage density, soil type and erosivity factor (Baginska *et al*., 2003; Young *et al*., 1996). However, the borrowed literature values were not adjusted relative to parameters of region of origin in order to fit into local parameters. This shortcoming again hampers reliability and accuracy of runoff load estimates.

Estimated runoff pollution load by COWI (2002) for TN - (TN: 49,509 t/y) - was almost two times that estimated in the study by Scheren (2005, 2003) and Scheren *et al*. (2000, 1995) - (TN: 26,292 t/y). On the other hand the estimates for TP by both studies were closely equal (TP: 5,693 & 5,634t/y respectively). The estimates are summarized in Table 4.

Watershed parameters such as slope, soil, drainage geometry may be static but meteorology and hydrology parameters are not. Therefore the assumption with UAL concept that a unit area of land under a given land use generates constant load would not be realistic. The influencing factors vary temporally and spatially and UAL borrowed from a different location may not replicate the actual conditions. The borrowed UAL should be adjusted in consideration of the parameters at the point of origin and receiving region. These are areas that will need further improvement in future. It is easily understood that given limitations faced by past studies it was prudent for them to use methods they adopted. However, their weaknesses should be continuously improved by enhancing data collection and adoption of latest technologies.

One of the options in future would be to use Geographical Information Systems (GIS) and Remote Sensing (RS) tools for accurate determination and representation of land use, meteorology and hydrology aspects among others. GIS is a powerful mapping tool with capability to analyze geographic (e.g. land use) data and has a capacity to handle a large quantity of information. Additional components such as Soil Water Assessment Tool (SWAT) in a GIS platform would improve the process of estimation of pollution load. SWAT is a GIS interface model that simulates hydrological-land processes. SWAT is a distributed parameter hydrologic model which subdivides watersheds into sub-basins. It has been widely used in the USA and less in Africa for water resources management and has proved to be efficient. Combining GIS, RS and tools like SWAT creates a versatile framework to analyze various scenarios of human and natural activities and their impacts on water resources. Use of GIS tools in Lake Victoria basin has not found much practise, but few studies have been undertaken. For example, Jayakrishman *et al*. (2005) applied SWAT to model Sondu river watershed in Lake Victoria basin. The study assessed the impact of change in landuse driven by adoption of modern technology for smallholder dairy industry. Although the study was faced with data scarcity due to detailed model data requirements, more similar studies are needed in Lake Victoria. GIS and RS tools would improve estimation of runoff pollution load because they have a better capacity to replicate landuse, natural terrain and rainfall-runoff and nutrient generation process.

Atmospheric deposition has consistently been reported by past studies as a significant contributor of pollution load to Lake Victoria. This seems reasonable given the large ratio of the lake's surface area relative to area of the basin. Such significant contribution calls for reliable and timely estimates and monitoring. COWI (2002) collected laboratory samples for wet and dry deposition to estimate atmospheric deposition. The samples were only collected from landbased and island stations and none from within the lake. Given the expansive nature of the lake, samples collected only from landbased stations and used to estimate atmospheric load for the whole lake would not be truly representative. In lake samples would improve the reliability on the estimates. Scheren (2005, 2003) and Scheren *et al*. (2000, 1995) used annual deposition per unit area as borrowed from literature. Again atmospheric deposition coefficients borrowed from literature suffer the same shortcomings as those of UAL.

TP (atmospheric) estimated by Scheren (2005, 2003) and Scheren *et al*. (2000, 1995) were about seven times those of COWI (2002) but TN estimates were close (Table 4). The variance may be attributed to borrowed coefficients but not the period they were estimated since the methodologies do not consider period. However, the variations are significant. Despite the limitations, the method by COWI (2002) which relied on monitored data is reasonable, but their methodology requires comparatively more resources. The shortcomings of the method by COWI (2002) may be addressed by collecting more samples within the lake and islands to make them more representative.

The study by COWI (2002) provides useful information for preliminary determination of atmospheric deposition load that should inform future studies. Atmospheric deposition is mainly attributed to long range transport of airborne nutrients. The nutrients mainly originate from burnt biomass (phosphorous), windblown dust and industrial and automobile exhaust gases (nitrogen). Recent GIS and RS technologies have capacity to monitor distribution of airborne particles and night fires. They are important tools to inform studies on atmospheric deposition in the lake.

Table 4. Comparative Estimates of Pollution Load to Lake Victoria (tonnes/yr)

Study			Calamari *et al*. (1995)	Scheren (2005, 2003) & Scheren *et al*. (2000, 1995)	COWI (2002)
Scope			Winam Gulf	Lake Victoria Basin	Lake Victoria Basin
Point loads	Municipal	TN	-	7,600[a]	3,515
		TP	-	920[a]	1,623
		BOD	3,577	12,800[a]	17,938
	Industrial	TN	-	-	413
		TP	-	-	342
		BOD	2,600	3,170[a]	5,606
Non-point loads	Runoff	TN	-	26,292[a]	49,509
		TP	1,190	5,634[a]	5,693
	Atmospheric	TN	-	85,513[a]	102,148
		TP	-	3,647[a]	24,402
Total load (without Atmospheric)		TN	-	33,892	53,437
		TP	-	6,554	7,658
Total load (with Atmospheric)		TN	-	119,405	155,585
		TP	-	10,201	32,060

[a]Most likely values

5. Conclusion and Recommendation

The differences and at the same time closeness observed in the results of the past studies on estimation of pollution load to Lake Victoria makes it is difficult to determine which estimates are reliable and accurate. However, this demonstrates that in situations of inadequate data different methods give different results. Reliable estimates are dependent on the quality of data and on use of methods that simulate the actual process dynamics as much as possible. Prompt data collection and incorporation of latest technologies would complement current efforts to estimate pollution load to Lake Victoria. Total point loads seem far much less than non-point loads in Lake Victoria but more accurate and reliable estimates of both loads would be important for policy making. Proper management of point loads would not only lead to reduced stress on the lake but aso improved public health. Non point loads come from diffuse sources with characteristics that vary in spatial and temporal dimensions. Therefore, incorporation of GIS and RS tools in the process of estimation of non-point loads will address many of the weaknesses of the past studies. Preliminary estimates show that atmospheric deposition contributes significantly (30-80%) to the TN and TP loads to the lake. Such significant contribution calls for an urgent need to come up with more reliable estimates of various pollution loads to inform policy making for this very important lake.

References

Africa Water Network (AWN) (1998), “The Lake Victoria Basin Hot Spots Study Report” Swedish International Development Agency, Stockholm, Sweden.

Baginska, B., Pritchard, T. & Krogh, M. (2003), “Roles of Land use Resolution and unit-area Load Rates in Assessment of Diffuse Nutrient Emissions”, *Journal of Environmental Management* **69**, 39-46.

Bootsma, H.A., Bootsma, M.J. & Hecky, R.E. (1996), “The Chemical Composition of Precipitation and its Significance to the Nutrient Budget of Lake Malawi”, in: Johnson T.C., Odada E.O. (Eds.), *The Limnology, Climatology and Paleoclimatology of the East African Lakes* pp. 251-265.

Calamari, D., Akech, M.O. & Ochumba, P.B.O. (1995), “Pollution of Winam Gulf, Lake Victoria, Kenya: A case study for Preliminary Risk Assessment”, *Lakes & Reservoirs: Research and Management* **1**, 89-106.

Cheruiyot C.K., Muhandiki V.S., Ballatore T.J. & Nakamura M. (2011), “Estimation of Pollution Load to Lake Victoria, East Africa”, *Proceedings of the 4th IWA-ASPIRE Conference, Tokyo, Japan, 2–6 October 2011*, 144-145.

COWI Consulting Engineers (2002), “The Integrated Water Quality/Limnology Study”, Technical Report, Part II, Lake Victoria Environmental Management Project, East African Community, Arusha, Tanzania.

Iwugo, K.O. (1990), “Basic Concepts of Environmental Quality Control in Relation to Baseline Studies on Land-Based Sources of Pollution”, *Lecture Presented at the IOC-SAREC-UNEP-FAO-IAEA-WHO Workshop, Regional Aspects of Marine Pollution, Port Louis, Mauritius, 20 October-9 November 1990.*

Jayakrishman, R., Srinivasan, R., Santhi, C. & Arnold, J.G. (2005), “Advances in the Application of the SWAT Model for Water Resources Management”, *Hydrological Processes* **19**, 749-762.

Kansiime, F. & Nalubega, M. (1999), “Wastewater Treatment by a Natural Wetland: Nakivubo Swamp, Uganda”, *PhD Thesis*, International Institute for Infrastructural, Hydraulic and Environmental Engineering, Delft: Wageningen Agricultural University.

Kayombo, S. & Jorgensen, S.E. (2005), “Lake Victoria: Experience and Lessons Learned Brief”, In: Lake Basin Management Initiative: *Experience and Lessons Learned Briefs* (on CD). International Lake Environment Committee Foundation, Kusatsu, Japan, pp. 431-446.

Kiwango, Y.A.F. (2007), “The Role of Papyrus Plants (Cyperus Papyrus) and Internal Waves in Nutrient Balance of Lake Victoria, East Africa”, *Master’s Thesis*, Norway: University of Algarve.

Muyodi, F.J., Bugenyi, F.W.B. & Hecky R.E. (2010), “Experiences and Lessons Learned from Interventions in Lake Victoria Basin: The Lake Victoria Environmental Management Project”, *Lakes & Reservoirs: Research and Management* **15**, 77-88.

Ochumba, P.B.O. (1988), “Periodic Massive Fish Kills in the Kenyan Portion of Lake Victoria”, Fisheries Report FIPL/R388, 47-60, FAO, Rome, Italy.

Scheren, P.A.G.M., Zanting, H.A. & Lemmens, A.M.C. (2010), “Estimation of Water Pollution Sources in Lake Victoria, East Africa: Application and Elaboration of the Rapid Assessment Methodology”, *Journal of Environmental Management* **58**, 235-248.

Scheren, P.A.G.M. (2005), “Integrated Water Pollution Assessment in Data and Resource Poor Situations” *Proceedings of the 11th World Lakes Conference (Vol. II), Nairobi, Kenya, 31 October-4 November 2011*, **2**, 315-320.

Scheren, P.A.G.M. (2003), “Integrated Water Pollution Assessment in Data and Resource Poor Situations: Lake Victoria and Gulf Guinea Case Studies” *PhD Thesis*. Eindhoven: Technische University.

Scheren, P.A.G.M., Bosboom, J.C., Njau, K.N. & Lemmens, A.M. (1995), “Assessement of Water Pollution in the Catchment area of Lake Victoria, Tanzania”, *Journal of Eastern Africa Research and Development* **25**, 129-143.

World Health Organization (WHO) (1989), “Management and Control of the Environment”, *Publication WHO/PEP/89-1,* WHO, Geneva, Switzerland.

World Health Organization (WHO) (1982), “Rapid Assessment of Sources of Air, Water and Land Pollution”, *Publication No. 62*, WHO, Geneva, Switzerland.

Young, J.W., Marston, M.F. & Richard, J.D. (1996), “Nutrient Exports and Land use in Australian Catchments”, *Journal of Environmental Management* **47**, 165-183.