Tracking sources of excess nitrate discharge in Lake Victoria, Kenya for improved Nitrogen use efficiency in the catchment

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Abstract

A study was conducted in three major rivers (Nzoia, Nyando, Sondu) draining the Kenyan side of L. Victoria catchment to establish sources of excess nitrate deposition into the Lake using isotopic techniques and hydrochemistry. Results show spatial variation in isotope signatures with enrichment in $\delta^{15}N$ and $\delta^{18}O$ values near towns and industries. For instance R. Nzoia after Eldoret town had $\delta^{15}N$ and $\delta^{18}O$ values of 13‰, 6‰ respectively while the river after Mumias sugar factory had 9‰, 10‰ isotope values respectively. A plot of $\delta^{15}N$ versus $\delta^{18}O$ indicates that most of nitrate from the three catchments originates from Soil Nitrogen and manure or sewage. This may be due to deforestation, charcoal burning, untreated effluent discharges amongst other environmental degradation and poor sanitary practices rampant in the area. However, sewage and industrial effluents has high contribution to river and ground water nitrate near towns and densely populated areas as observed by the enriched $\delta^{15}N$ values for Kisumu City Rivers ranging 10‰ to 18‰. Low nitrate content with corresponding high $\delta^{15}N$ and $\delta^{18}O$ signatures was observed in ground water near Kisumu city indicating denitrification takes place in the area. In addition, surface water in Kisumu had similar and enriched nitrate isotope signatures to ground water indicating high ground water susceptibility to pollution by surface water. This observation is supported by stable water isotope data ($\delta\ ^{18}O$, $\delta\ ^{2}H$) which show that the source of groundwater in Kisumu area is evaporated surface water.

Key Words: nitrate, stable isotopes, $\delta^{15}N$- and $\delta^{18}O$-NO_3^-, denitrification

Introduction

Lake Victoria is Africa's largest fresh water body shared by three East African countries: Kenya (6%), Uganda (45%) and Tanzania (49%). The Kenyan catchment contributes more than 40% of lakes surface water inflow estimated at around 778.3 m^3s^{-1} and accounts for 60% of the country' surface water resources (COWI., 2002). Studies show an increasing trend in both nitrate and phosphate in the lake with a minimum of 10(µgL-1) NO3-N and 4(µgL-1) PO4-P, respectively, in 1990 to a maximum of 98(µgL-1) NO3-N and 57(µgL-1) PO4-P µg L-1, respectively, in 2008 (Juma et al., 2014). In East Africa, particularly the watershed of Lake Victoria there is too little nitrogen for crop production, animal and human nutrition. In contrast there is too much of nitrogen in selected water bodies including Lake Victoria due to the enrichment effect. As a result, the lake experiences eutrophication related problems like the rapid proliferation of water hyacinth and decreasing fish population. Regional and national institutions responsible for environmental management and control of water quality regarding nitrate run a water quality monitoring network both inside the Lake and in the catchment. In addition, studies have been conducted to investigate nutrient concentrations and nutrient budget of the Lake (Njuru et al., 2013; Zhou et al., 2014). However, from chemical data alone, it is generally hard to distinguish to what extent different sources are contributing to the observed nitrate level in the Lake. For instance, differentiating urban and agricultural origin of nitrate is extremely difficult based on monitoring data due to transformations, transport and mixing processes. There is need therefore to identify and quantify nitrate pollution sources and study associated transformation processes in order to propose effective intervention measures and strategies for improved nitrogen use efficiency in the Lake Victoria catchment. Research has proven the great added value of using isotopes to precisely identify, apportion and quantify nitrate sources in both surface and groundwater water (Xue et al., 2009; Widory et al., 2013). Different nitrate sources (i.e. manure, sewage, fertilizers, soil N, and atmospheric deposition) show characteristic nitrogen ($\delta^{15}N$) and oxygen (δ^{18}) isotope ratios. However, mixing and conversion processes (like denitrification) usually modify isotopic composition of dissolved nitrate thereby complicating nitrate source apportionment. Boron isotope ($\delta^{11}B$) is not affected by nitrate conversion processes and is used in combination with $\delta^{15}N$ and $\delta^{18}O$ to improve the identification of nitrate sources. This study demonstrates the application of isotopic techniques to identify major sources of excess nitrate discharge in Lake Victoria catchment, Kenya.

Methods

The study was conducted in three contrasting major river basins (Nzoia, Nyando, Sondu) draining the Kenyan side of Lake Victoria shown in Figure 1.

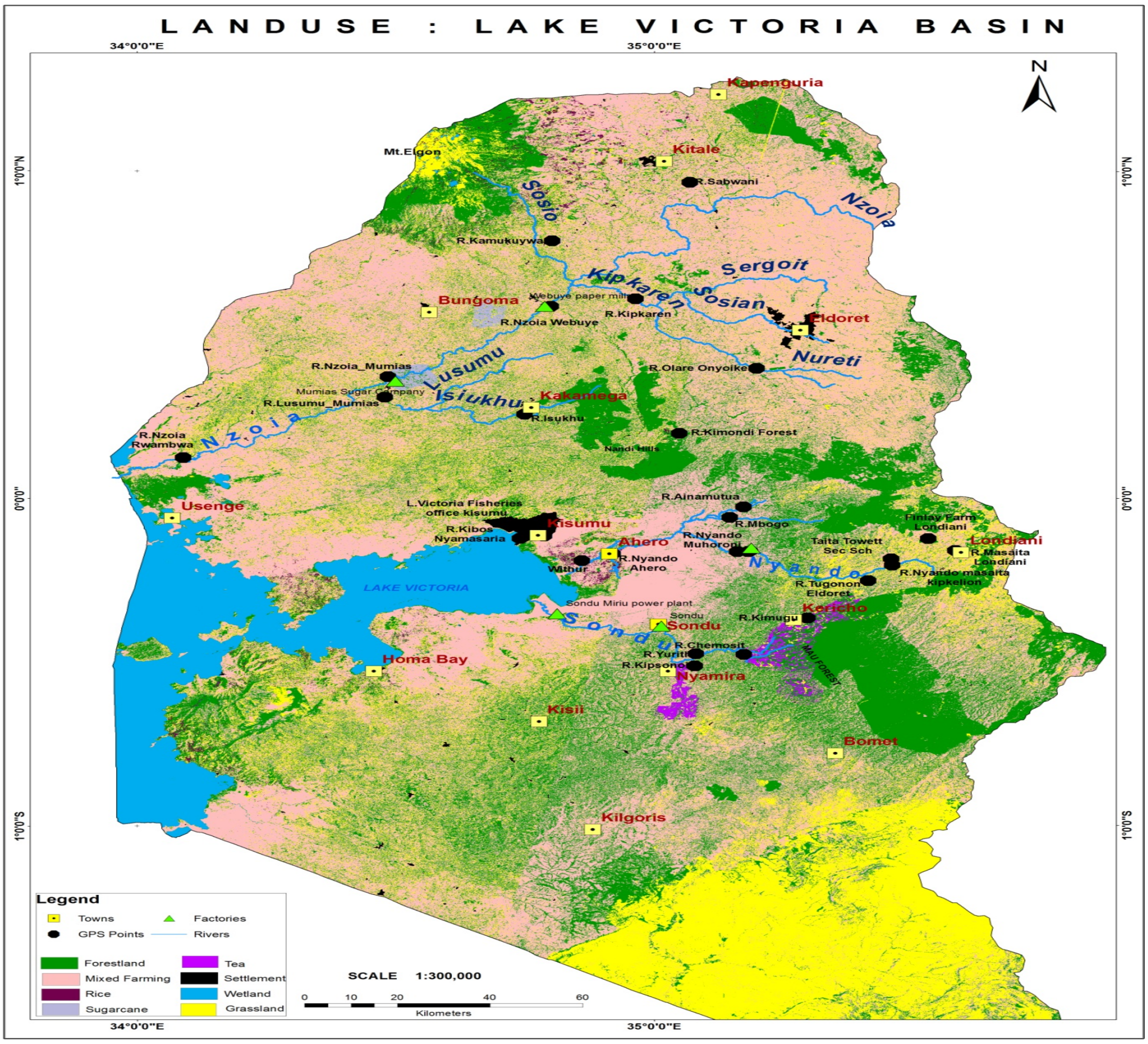

Figure1. Land use Map of Lake Victoria basin, Kenya showing three major rivers (Nyando, Sondu, Nzoia). Major features include; Mt. Elgon, Mau forest, Nandi hills, small scale to large scale farms (tea, sugarcane, maize and rice), fast growing cities (Kisumu, Eldoret, Kericho, Kakamega) and industries (sugar, tea, rice, molasses, paper mills, agro-chemical and lime factories, hydroelectric power plant). Characterized by high population density, bimodal rainfall, Sampling stations are indicated GPS points (black points)

Selection of sampling points was guided by land use and captures spatial variations in isotopic and hydro-chemical parameters. In the field, water was taken as a grab sample, filtered through 0.45-µm membrane filters and stored below 4º C in 1 litter HDPE bottles for determination of physic-chemical parameters and δ^{15}N- and δ^{18}O-NO3. In situ measurements included temperature, electrical conductivity, pH and dissolved oxygen. NO_3^- was determined using a Bran + Luebbe Auto Analyzer 3 continuous flow spectrophotometer. The δ^{15}N- and δ^{18}O-NO_3^- values will be determined by the "Bacterial denitrification method" (Xue et al., 2009) and analyzed using a trace gas preparation unit (ANCA TGII, SerCon, UK) coupled to an isotope ratio mass spectrometer (IRMS) (20-20, SerCon, UK).

Results

Form table1, Auji stream in Kisumu and Taita towett borehole gave the highest nitrate contents and relatively enriched δ^{15}N and δ^{18}O values. River nitrate ranged from 0.6 mg/L (Nzoia@Rwambwa) to 2.7 mg/L (Nyando-Masaita@Londiani). It's notable that Nzoia@Rwambwa gave corresponding low δ^{15}N and δ^{18}O while Nyando-Masaita@Londiani had higher isotopic signatures. However, Withur borehole which had the lowest nitrate content of 0.58 mg/L gave the highest δ^{15}N and δ^{18}O values. Figure2 identifies three major sources of nitrate in the catchment: Ammonia in fertilizer or rain, Soil nitrogen and Sewage. Kisumu City Rivers (Kisat, Auji, Kibos) are enriched isotopically plotting in the manure and sewage nitrate source.

Table1. Water quality and stable isotope results for Lake Victoria catchment, Kenya

Name	Date	EC (µS/cm)	Temp	pH	DO (mg/l)	NO3- (mg/l)	δ15N-NO3-	δ18O-NO3-	δ2H-H2O	δ 18O-H2O
Auji stream@kisumu	1/23/2015	603	27	7	6.2	14.60	15.10	9.92		
Finlay Farm Bhl@Londiani	1/22/2015	395	22.2	7.02	5.5	0.70	7.53	9.52	-10.5	-2.85
Kibos@Nyamasaria	4/16/2015	93	25	8.2	6.8	1.16	9.73	9.03	-0.8	-1.99
Kisat@airpot Rd	4/16/2015	330	23	7.9	6.5	1.90	18.08	12.38		
L.Victoria@Hippopoint	1/23/2015	163.2	27.7	6.87	6.7	0.86	1.09	3.65	26.9	3.66
Nyando@1GD07 after musco	1/20/2015	347	26.6	7.44	6.8	1.17	5.38	4.91	-3.0	-1.72
Nyando@1GD07 after musco	4/15/2015	320	29	7.5	5.3	1.09	6.56	3.71		
Nyando@Ahero	4/15/2015	296	30	7.8	5.6	1.26	7.74	8.94	-1.1	-1.74
Nyando@Muhoroni	1/20/2015	356	24.7	7.46	7.2	1.01	6.10	4.20	-3.4	-1.78
Nyando@Muhoroni	4/15/2015	302	29.4	7.25	6.1	1.05	8.43	5.11	-3.1	-1.91
Nyando-Ahero	1/21/2015	338	26.8	7.04	6.8	1.18	5.31	6.17	-3.1	-1.78
Nyando-Ainamutua	1/20/2015	317	23.3	7.41	7.3	1.01	6.33	6.82	-6.4	-2.40
Nyando-Ainapsiwa	1/20/2015	280	22.2	7.32	7.3	1.07	7.27	7.46	-4.9	-2.09
Nyando-masaita@kipkelion	2/1/2015	248	21.61	8.43	12.9	1.72	4.99	4.83	-3.9	-2.18
Nyando-Masaita@Londiani	1/22/2015	142.2	19.5	7.05	6.5	2.73	8.43	7.95	-11.3	-3.01
Nyando-Mbogo	1/20/2015	272	22.5	7.26	7.1	1.19	2.99	2.88	-5.7	-2.36
Nyando-Tugonon@Eldoret	2/1/2015	235	22	8.43	7	1.14	6.05	4.47	-1.2	-1.47
Nzoia@Mumias	1/28/2015	132	23.3	7.56	5	0.74	8.67	9.66	-3.2	-1.76
Nzoia@Rwambwa	1/28/2015	126	24.18	7.68	5.1	0.60	3.34	2.07	-2.8	-1.81
Nzoia@Webuye	1/28/2015	126	21.2	8.22	6.3	0.93	9.54	8.18	-3.3	-1.78
Nzoia-Isukhu	1/29/2015	90	19.79	7.59	8.4	1.43	6.06	5.88	-2.6	-2.05
Nzoia-Kamukuywa	1/29/2015	158	19.17	7.96	4.5	1.88	7.75	8.77	-3.7	-1.84
Nzoia-Kapngorion@Savani	1/30/2015	65	18.49	7.36	8.5	2.29	5.46	7.54	-4.1	-2.27
Nzoia-Kimondi@Forest	1/30/2015	60	16.5	7.17	5.4	0.66	7.28	10.29	-3.7	-2.06
Nzoia-Kipkaren	1/29/2015	97	21.1	8.73	4.1	1.02	12.90	5.96	-3.2	-1.72
Nzoia-Lusumu@Mumias	1/29/2015	107	23.33	7.87	4.9	1.77	6.50	5.13	-3.1	-1.89
Nzoia-Sabwani	1/29/2015	163	20.27	7.89	6.5	0.75	8.04	8.36	-4.2	-1.92
Sondu-Chemosit	2/2/2015	41	18.22	7.31	7.2	1.35	8.11	6.48	-5.8	-1.95
sondu-Kimugu	2/1/2015	48	17.1	6.96	10.5	0.94	2.99	4.01	-3.3	-1.67
Sondu-Kipsonoi	2/2/2015	70	21.8	7.55	7.6	2.37	6.03	8.39	-6.5	-2.60
Sondu-sondu market	1/21/2015	53.1	22.6	7.05	7.4	1.40	7.20	9.94	-4.0	-2.18
sondu-Yurith	1/21/2015	47	21.6	7.03	7.3	1.60	5.71	7.31	-5.1	-2.28
Taita Towett Bhl@kipkelion	1/22/2015	680	21.8	6.96	6.7	12.48	10.12	9.42	-9.0	-2.73
Withur Bhl@Ahero	1/22/2015	2520	28.1	7	4.9	0.58	18.00	19.70	2.2	-0.68

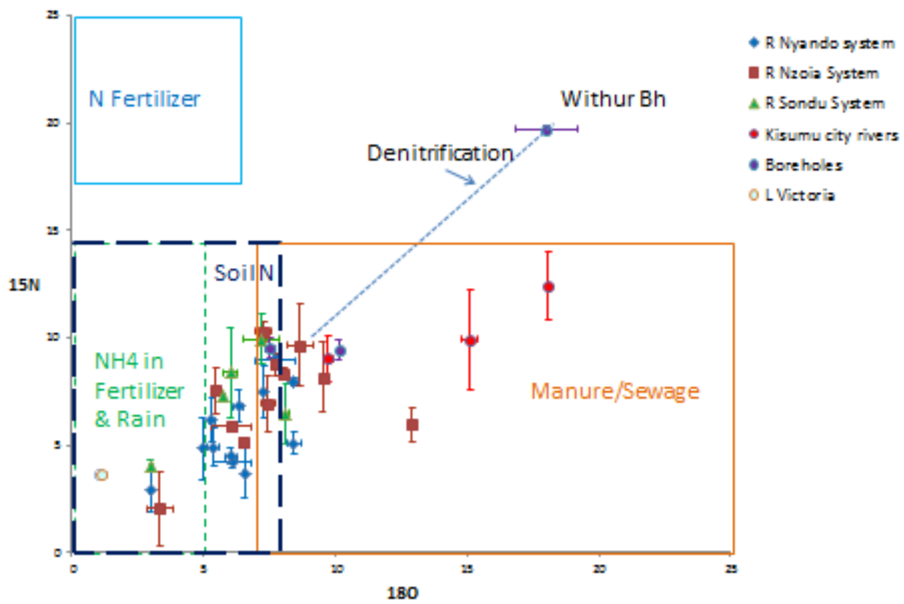

Figure2. Nitrate isotope (15N) versus Oxygen isotope (18O) (Average and standard deviation) of major rivers feeding Lake Victoria, Kenya. Ranges of isotopic composition for three potential sources are indicated by boxes (Xue et al., 2009). Enriched isotopic signatures (δ15N=18, δ18O=20) with corresponding low nitrate content (0.6mg/l) observed in Withur borehole is characteristic of denitrification taking place.

Withur groundwater has the most enriched isotope signatures plotting above manure/sewage nitrate source. The enriched isotopic signatures (δ^{15}N=18‰, δ^{18}O=20‰) with corresponding low nitrate content (0.6mg/l) observed in Withur borehole is characteristic of denitrification process taking place which causes parallel enrichment in $\delta^{15}N$ and $\delta^{18}O$ at a 1:1 ratio (Granger et al. (2008). In addition, Withur borehole is within Kisumu municipality and shows same nitrate source as Kisumu City Rivers implying the probability of groundwater contamination by human and industrial wastes in a densely populated (465 people per square kilometer) lakeside city with poor sanitation and inefficient effluent treatment plants. The observation is supported by stable water isotope data in Figure3 which shows Withur groundwater having an evaporation signature deviating from the local meteoric water line (GNIP_Entebbe). This indicates that the source is surface water which had undergone evaporation prior to recharge and therefore supports nitrate isotope data findings that groundwater in the area is susceptible to surface water nitrate pollution.

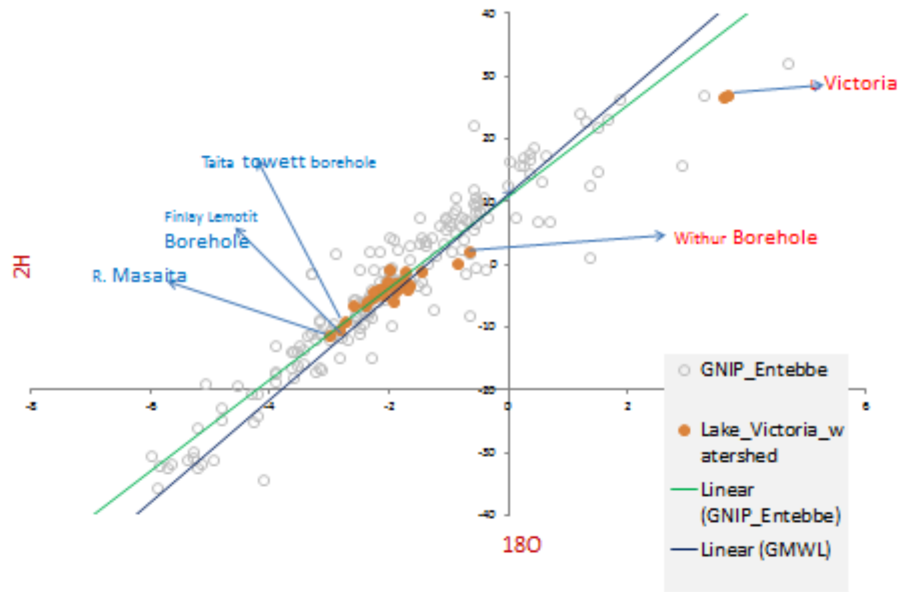

Figure3. δ^2H versus $\delta^{18}O$ of L. Victoria catchment (Kenya) relative to local meteoric water line (GNIP Entebbe) and global meteoric water line (GMWL

Groundwater from Finlay lemotit farm plot is placed within the source areas of soil N and manure/sewage while that of Taita Towett is placed within the source area of only manure/sewage (Figure 2). Finlay lemotit is a commercial flower growing farm under irrigation and therefore soil N through leaching may contribute significantly to the groundwater nitrate. The high nitrate content in Taita Towett High school borehole with a corresponding sewage source signature suggests contamination from pit latrines which are the common sanitation system in this part of the catchment. Groundwater in this area (Figure3) is recharged from local precipitation since it plots along the local meteoric water line (GNIP_Entebbe). Figure1 indicates that most of river nitrate is sourced from soil nitrogen. This is highly possible due to high turbidity in the rivers(50-1100 NTU) caused by deforestation, sand harvesting, cultivation on steep slopes and river banks amongst other land degradation practices in the catchment. It is also in agreement with work done by Zhou et al (2014) who report that due to too little synthetic N application in the Lake Victoria basin, mining of soil N stocks is the main source of excess nitrogen discharge in the catchment. However, enrichment in $\delta^{15}N$ and $\delta^{18}O$ values occur as rivers drain areas with major industries (Mumias sugar factory, Webuye paper mills) and fast growing towns (Eldoret, Kericho, Londiani, Muhoroni) indicating manure/sewage nitrate source. This is caused by poor sanitation and inefficient effluent treatment systems characteristic of the Lake's basin towns which discharge their untreated wastes into the rivers. On the other hand, river water in areas less impacted by human population and activities (tributaries; Nyando-Mbogo, Sondu-Kimugu) is relatively depleted isotopically and plot in the ammonia in fertilizer & rain nitrate source. Lake Victoria water gives relatively the most depleted $\delta^{15}N$ and $\delta^{18}O$ isotopic signal. This is because the lake is a mixture of different nitrate sources from the catchment key among them being atmospheric N ($\delta^{15}N$= -13 to 13 and $\delta^{18}O$= 25 to 75) which has been reported to contribute more than 65% of total nitrogen (TN) loading in the Lake (LVEMP, 2005). Nitrate content in R. Nyando at Ahero (last sampling point to the lake) was 1.2 mg/l, discharging 4.1 m^3/s; while in R. Sondu at Sondu market was 1.4 mg/l, discharging 10.7 m^3/s and in R. Nzoia at Rwabwa was 0.6 mg/l discharging 35.873 m^3/s. This translates to Rivers Nzoia, Sondu and Nyando discharging 78, 54 and 18 Kg/hour of nitrate respectively into Lake Victoria.

Conclusion/ Recommendation

Excess nitrate discharge in the L .Victoria catchment, Kenya mainly originates from Soil N and manure/sewage. Groundwater nitrate is mainly sourced from manure/sewage and therefore susceptible to surface water contamination. It is recommended that soil conservation measures (like reforestation, soil erosion control) and enactment of strict rules governing effluent discharges should be implemented in the Lake Victoria catchment for improved management of excess nitrate discharge.

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