Greenhouse gases, methane and carbon dioxide, and diminishing water resources in Lake Victoria basin, Kenya

A Technical Report

By

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20 November 2006

1.Introduction

1.1 Background

River Nzoia water basin covers the areas of Cherangany hills, Mt. Elgon and some parts of Uasin Gishu (Figure 1a), and lies between longitude 34^0 and 36^0 east and latitude $0^000'$ and $1^015'$ north. The altitude varies from 1070 m above sea level at the lakeshore up to 2700 m in the north end of the watershed. The annual rainfall ranges between 900 mm and 2200 mm. Following the altitude gradient, the watershed can roughly be divided into 3 different land use zones (Figures 1a-d). The small-scale subsistence maize and sorghum farming characterizes the lower part of the watershed, with an altitude of 1100 - 1300 m in the River Nzoia catchment and includes parts of Busia and Siaya. This zone experiences a local modified rainfall, dependent upon relief, from the expansive Lake Victoria and its distribution is influenced by altitude and wind direction.

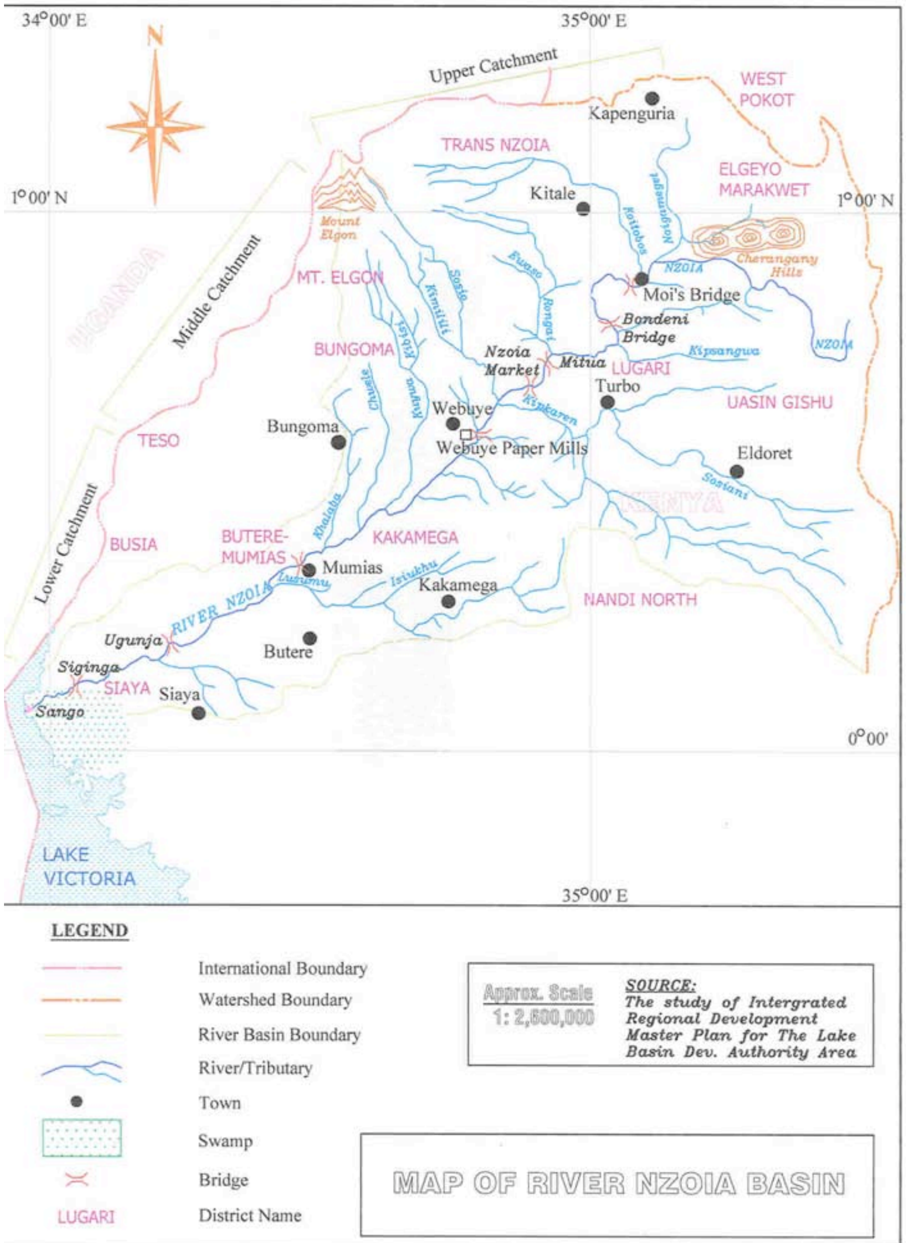

Figure 1a: Location of the River Nzoia basin in western Kenya

Figure 1b: The rivers and forests of the Nzoia River study area.

Figure1c: Western Kenya population, showing the higher numbers in Nzoia River watershed.

Figure 1d: The Nzoia River and its watershed.

The middle catchment consists of large-scale sugar plantations and smaller sugar schemes located between 1300 m and 1700 m, including Mumias, Kakamega and Bungoma. The relief and landforms affect climate and the general development potential of the region. The zone is characterized by gently sloping easily-erosional surfaces (Figure 2) consisting of wide, sometimes nearly flat land, separated by shallow river valleys. The soils are on volcanic foot ridges with well drained, extremely friable and slightly smeary clay soils. The flat and swampy soils lead to regular flooding and water logging. Sugar plantations are dominant in this zone. The third zone constituting the upper catchments has an altitude of

1600 to 2000 m. Areas above 2100 m, consisting of small-scale tea farmers and large tea estates, are located at 1900 – 2100 m. Relative large-scale maize and horticulture (potatoes, cabbage, etc.) farming mainly characterize the areas above 2100 metres. These parts include Lugari, Moiben and elevations as high as the Cherangany hills and Mt Elgon. Lugari has a forest which receives bimodal rainfall with equatorial related climate.

Figure 2: An example of erosion problems in the Nzoia River watershed.

River Nzoia drains to Lake Victoria and traverses five districts in western Kenya: Trans Nzoia, Uasin Gishu, Bungoma, Siaya and Busia. It has a total length of 334 km (Kirugara and Naveja 1995) and a catchment of 12,903 km^2 which is the largest among the rivers that drain from the Kenyan side of the lake (LBDA 1987). It dominates the northern half of the Lake Victoria basin with 24 tributaries (Kirugara and Naveja 1995). Its major tributaries include Ewaso Rongai, Koitobos, Kuywa, Sosio, which originate from Mt Elgon. Others such as Noigamneget, Sergoit, Sosiani, Nureri and Kipkaren originate from Cherangany hills.

Most of the watershed has been deforested and is continuously under crops. In the case of Trans Nzoia district within the Nzoia River catchment, 60% of the land is arable and mostly under cultivation for maize and sunflower (GOK 2002). The few remaining forested areas are Mt Elgon and Cherangany forests - these are currently being heavily deforested, and the steep sloping escarpments - originally Government trust land - are being quickly de-vegetated due to charcoal burning and illegal farming (Figure 3). This has lead to

Figure 3: Charcoal burning and illegal farming in the Nzoia River upper watershed.

high soil erosion and transport of sediments and nutrient loads to the water bodies including Lake Victoria, which impacts on the livelihoods of the lake basin communities (Figure 4).

Figure 4: Sediment plume from the Nzoia River entering Lake Victoria

The lake has all the signs of advanced eutrophication such as high algal biomass (high productivity) and changes in algal species composition (LVEMP and COWI 2002). This has been attributed to non-source pollution including nutrient loading from the watershed area, different land-based activities such as heavy application of fertilizers, animal grazing and washing in the rivers (Figure 5a), and internal loading due to anoxic conditions at the surface-sediment interface among others. The river banks are bare and heavily eroded.

Figure 5a: Bare river banks and human activities including washing and cattle grazing

Figure 5b: Example of severe erosion along the shores of the Nzoia River.

1.2 Spring waters and shallow wells

A spring is a point where groundwater flows out of the ground, and is thus a point where the aquifer surface meets the ground surface. A spring may be defined as a point of focused discharge of ground water. Springs may be classified as ephemeral (intermitted), perennial (continuous) or artesian, depending on the source of water (rainfall in case of the tropics) that infiltrates the earth.

When water leaves the ground it may form a pool or enter a stream. Minerals become dissolved in the water as it moves through the underground rocks. This gives flavor to the water, and even carbon dioxide bubbles, depending upon the nature of the geology. Shallow wells are underground sources of water, and these are usually dug by hand at home sites or public institutions. They may be as deep as 10 m depending on the water table in the particular area. Both spring waters and shallow wells are the common sources of public water supplies in most parts of developing countries, such as Kenya, which have no piped water supplies.

Increasing population impacts the surrounding land use. Land cover changes will likely change the natural ecology, including climatic factors and water resources. The integrated assessment of the seasonal variability of shallow wells and spring-water yields might be preliminary indicators of the impact of climate change on water resources in the region. Included in these assessments are the measurements of greenhouse gases (GHGs) and their emissions from tropical aquatic ecosystems, both shallow wells, spring waters and from river sediments. Water-to-atmosphere GHG flux studies are critical in understanding global climate change and in developing an overall understanding of biogeochemical carbon cycles in warm climates.

2. Literature review

Pollution of Nzoia River from human activities in the catchments has been reported in previous studies by Achoka (1998) and Mogere (2000). The study by Achoka (1998) established that wastewater from the Webuye Pulp and Paper Mills discharged into River Nzoia substantially increased the concentration of total solids (TS) downstream, while oxygen concentrations tended to decrease downstream. These pollutants are only part of the river's load, which includes other chemical residuals and the products of deforestation, resulting in deterioration of the aquatic environment. This has lead to critical ecological effects that are a serious impediment to sustainable development (Wandiga and Onyari 1987). In another study by Mogere (2000), who evaluated the sediment quality of River Nzoia, it was shown that wastewater treatment systems in the catchment were not effective to sustain benthic life, consequently the fertilizers and other agricultural wastes discharged into the River Nzoia posed a substantial health hazard to aquatic life.

A similar study by Momanyi (2002) on selected water quality parameters and heavy metals in Nzoia River in relation to the Webuye Pulp and Paper Mills pointed out a significant increase in TSS and TDS downstream due to effluent discharge. According to Momanyi (2002), the total suspended solids in the water downstream consisted of silt clay, fine particles of organic matter and plankton that constituted the plant biomass.

Apparently most of the reported pollution studies of River Nzoia have focused mainly on pollution levels from the Webuye Paper Mills and the associated health effects on aquatic life. However, there have been no studies linking the degradation of the Nzoia River and its catchment, including increased levels of TSS and TDS, to changes in greenhouse gas (GHG) emissions from the river's sediments or with diminishing water resources in the catchment area. There have been actually relatively few GHG studies in East Africa, especially dealing with aquatic ecosystems (Deuser et al. 1973, Hecky and Degens 1973, Rudd 1980, Tietze et al. 1980, Kling et al. 1991, Edmond et al. 1993, Evans et al. 1993, and Adams and Ochola 2002). These authors reported on the status of gases, mainly CH_4 in the water column, but most studies are 15-30 years old with the exception of Adams and Ochola (2002) who described, for the first time, the concentration of GHGs in the sediments of Lake Tanganyika and suggested that its source was mostly geothermal. None of these earlier studies undertook the critical issue of measuring or calculating gas fluxes across interfaces (sediments-to-water or water-to-atmosphere; Adams 2002). There have been some measurements of GHG concentrations in the sediments of the Rift Valley East African lakes, yet diffuse fluxes from the sediments to overlying water columns are yet to be evaluated.

Recent studies (2003-04) in 3 tropical Brazilian reservoirs have shown high aquatic surface emissions of GHGs and much greater sediment fluxes of CO_2 than observed in temperate zone ecosystems; the sediments were seen as high contributors of CO_2 to overlying waters (Abe et al. 2005a,b). In a recent study, Adams (2005) reported that fluxes of GHG carbon gases are related to the trophic conditions of aquatic system with higher fluxes observed within eutrophic ecosystems. An inventory of GHG emissions from reservoirs of the world was compiled by St. Louis et al. (2000) who concluded that fluxes from these aquatic systems represented about 10 x 10^{14} g/yr CO_2 and 0.7 x 10^{14} g/yr CH_4, or 7% of the anthropogenic global warming potential. It is necessary to measure and understand the carbon biogeochemical cycles related to GHG production and consumption, and knowledge of the fluxes (and total emissions) into and out of tropical environments is a critical component of the entire process (Seiler and Conrad 1987, Aselmann and Crutzen 1989, Street-Perrott 1992, Bartlett and Harriss 1993, Matthews 2000, Adams 1996, and Adams et al. 1996). An investigation of a British hypereutrophic lake led Casper et al. (2000) to conclude that lakes worldwide could emit 72 Tg CH_4 yr^{-1}, or 14% of the global budget (500 Tg yr^{-1}; Wuebbles and Hayhoe 2002). However, it should be pointed out that neither lakes nor reservoirs are included in global budget calculations. Yet, these measurements are of special importance where tropical waters are warm all year and stratified, and bottom water anoxia represents a common problem (Hecky and Bugenyi 1992, Adams 1996 and Hecky et al. 1996). It is likely that lake and reservoir water column thermal stability will become more persistent as the climate warms and anthropogenic C loading (Liikanen et al. 2002) increases, resulting in greater lake deoxygenation. Under these conditions, anoxic conditions promoting CH_4 formation will become more ubiquitous. It is also expected that river flooding could transport the highest sediment and nutrient loads which would be deposited in the lake and river delta. This would exacerbate subsequent dry season conditions, likely resulting in greater fluxes of GHGs with the additional influx of particulate carbon and nutrients.

3. Scope of the Project and Methodology

3.1 Scope

The project targeted the estimation of sediment and nutrient (TP and TN) discharges from the River Nzoia for a period of three months. Sampling was to cover the Nzoia River and its delta, Lake Victoria and two other locations: Lake Naivasha papyrus wetlands and the Owen Falls, source of the River Nile, in Uganda. After initial reconnaissance, the original study was scaled down to cover only the Nzoia River basin and its delta, mainly because of the work load, the lateness and level of funding and the limited time. Luckily, the program started almost two months before receipt of the required funding thanks to D.D. Adams' generous financial assistance. River water sampling, river cross-sections, current flow and sediment coring were effectively undertaken with a portable 12-ft boat and dc motor imported by D.D. Adams. Utilizing hand coring; local divers were trained at each sampling location as part of capacity building. These individuals were also trained to be part of the boat team (Figure 6).

Figure 6: Local individuals diving and collecting cores near the Nzoia River banks

This study focused on River Nzoia because of its importance, which includes fishing, water supply for domestic and animal use, irrigation and recreation. In addition the river basin is densely populated and thus water shortages within the catchments make the communities vulnerable during harsh climatic changes. This is significant considering that approximately 40% of Kenya's maize and sugarcane production is from the catchments of River Nzoia (Mogere 2000). Furthermore, the river drains into Lake Victoria which is also critical to the fisheries and the livelihoods of the coastal communities.

3.2 Study Methodology

Reconnaissance and Study Site Selection

The objective of this study was to identify as many river-fed springs as possible in the upper and middle reaches of the Nzoia River basin. The Nzoia River was surveyed from Moi's Bridge (240 km upstream) to Mumias (160 km upstream), and then from Mumias for another section downstream to the Nzoia River delta and Lake Victoria. The river length under study was approximately 240 km with a watershed area of approximately 84,000 km^2. One of the sites, Moi's Bridge is shown in Figure 7.

Figure 7: Moi's Bridge at the uppermost station on the Nzoia River.

Reconnaissance was conducted between the dates of 18 to 21 February 2006 along the main river channel to determine the sampling sites and sampling frequency. It was also meant to identify the field assistants at specific sampling sites. The extent to which research could be done at each site and testing of the research vessel, during river flood conditions, were also conducted. The following sampling sites were identified:

Table 1: Location of sampling sites

Sampling Site	GPS Locations	Town/landmark
Moi's Bridge	0o 55' N 35o 0' E; 1800m	Moi's Bridge
Bondeni Bridge		Matunda

Mitua bridge	N - 0º 44' E - 34º 55'	Naitiri
Nzoia market bridge	N - 0º 42' E - 34º54'	Lugari Station
Webuye bridge	0o 30' N 34o 40' E; 1600m	Webuye
Mumias Bridge	1o0' N 34o 48' E; 1260m	Mumias
Ugunja Bridge		Ugunja
Siginga crossing point		Sio Port
Sango	0o20' N 33o 54' E; 1130m	Nzoia River mouth

At some locations the GPS system was not operational; these GPS locations will be reported later with the GHG data in a subsequent publication.

River Coring Strategy for Greenhouse Gases

Techniques for sediment sampling, i.e. coring in a rapidly flowing river in a relatively remote area, were assessed during the initial program for the eventuality of collecting sediment samples for measuring the carbon gases (CH_4 and CO_2). Sampling had never been done before in a river situation. It was extremely difficult to core within these high current regimes, however, special adaptations were employed to obtain sediment cores: allowing the boat to move with the current, locating islands and other areas which blocked the currents, using heavy weights on the coring system, sequential coring until sediments were collected. All of these techniques were tested to facilitate the proper collection of high quality samples for later gas analysis. At times it was impossible to collect sediments in the main stream of the river, so protected areas along the banks were tested. At times it was only possible to collect cored sediments by hand utilizing local divers who were properly instructed. Since gas measurements were not determined at the time of this report, visual observations of gas bubbles in each of the sediment cores were evaluated for the purposes of this report. Greenhouse gas (CO_2 and CH_4) concentrations shall be incorporated into a forthcoming publication since they cannot be included in this report. It is expected that these measurements will be conducted in early 2007 when D. D. Adams makes his next visit to Moi University.

During this period substantial objectives were accomplished even thought the GHGs were not measured. Because of initial difficulties in obtaining a working laboratory at Moi University and locating good facilities at or near the field sites, gas chromatographs could not be set up for proper GHG analysis. All of the sampling gear and three gas chromatographs were moved from Nairobi to Eldoret (5 trips), a laboratory and office, side-by-side, were made available to D.D. Adams, and the rooms were made useable with painting and electrical wiring and circuits. Special security was incorporated with a sturdy door gate and window grills. The equipment moved into this laboratory/office, worth $130,000, needed a high level of security from possible theft. A folding research boat (from Porta-Boat, $5,000), easily transportable into the field, along with an electric motor, were shipped from New York. Without these, and locally purchased batteries, battery charger and life jackets, the river sampling, coring and river volume discharge calculations would not have been possible. A modest daily rental to the project was initiated to help in recovering the high initial costs.

The sediment coring/core processing/gas analysis protocol required that GHGs be analyzed within 24 hrs after coring, and cores should not be transported over rough roads (the sediments would be shaken and gases lost during transport). Ideally, the cores should be processed into gas-tight syringes at the river bank and the syringes stored in iced gas-tight bags. A gas chromatograph would be set up earlier in a nearby laboratory, with the gas-tight syringes transported to this laboratory for GHG measurements the following day. Graduate students would be trained in the gas analysis procedures.

Water Resources

Spring water

Catchment assessment included identification of shallow wells and springs in the study area. A total of 30 springs were identified from Moi's Bridge to Mumias. Sixteen springs were randomly selected for spring water discharge monitoring. Four of the selected springs in the network were undeveloped and measurements could not be done efficiently. In order to enhance spring water discharge determinations, the four undeveloped springs were protected (Figure 8), in joint collaboration with the local communities.

Figure 8: Protection of the spring water by planting trees, a combined effort with the community participants and Kenya Catchment Afforestation Department

The spring-water yields were estimated using a stop watch and measuring cylinder. Springs were classified in this report using a discharge rating system devised by the United States Geological Survey (USGS; Table 2).

Table 2: United States Geological Survey (USGS, 1927) spring water classification scale

Magnitude	Average Flow
1	2800L/s
2	280 - 2800 L/s
3	28 – 280 L/s
4	6.3 - 28 L/s
5	0.63 - 6.3 L/s
6	63 – 630 ml/s
7	8 - 63 ml/s
8	< 8 ml/s
0	No Flow

Boreholes

Water yields in boreholes were estimated by water depth measurement using a weighted cord. The cord was long enough to reach the bottom of the borehole. The water depth was calculated as the difference between the bottom depth and water surface depth.

Sampling and river gauging was done at specific sites along River Nzoia so as to determine the concentrations and total discharge of TSS and nutrients. A General Oceanics 10-liter water sampler was used, with water samples transferred into plastic sampling bottles and stored in a cooler box. Researchers, equipment and materials were transported to each of the river stations with a 4-wheel drive Pajero; this was needed because of the terrain and inaccessibility of the study area. Moi university or LVEMP Catchment Afforestation vehicles were used on the few occasions whenever they were available and there was need. protection materials.

Rainfall data

Rainfall data within the River Nzoia catchment are essential not only for the estimation of the sediment loads and the amount of nutrients discharged through the River channel but also for appreciating rainfall intensity in the study area during the study period. The data were collected from meteorological stations within the catchments and average annual rainfall was calculated. The rainfall data were correlated with the discharge of sediments and nutrients from the catchment for a certain period of time to appreciate impacts of storms on water quality.

Training

Two Moi university postgraduate students, one DPhil and another MPhil, were selected based on their area of study and trained jointly with Dr Simiyu on river gauging and river bed sediment coring (Figures 9 and 10).

Figure 9: Dr. Simiyu measuring water depth at selected locations across the Nzoia River to calculate the river cross-section.

Figure 10: Dr. Simiyu and research team practicing coring techniques for training..

In addition, research assistants were selected from local communities at each sampling site (Appendix 1) and trained in river gauging and sediment coring. Indeed the locals were handy in that they understood the river conditions, seemed to know where the fine-grained sediments were located and some of them were skilled divers; these individuals were appropriately utilized at sites where the electric boat could not easily access. Some of the research assistants (Appendix 1) were artisans who assisted in protecting the springs. This collaboration was highly motivating and indeed exciting because it made the research lively, and it seemed to be appreciated by the rural communities as they were ready to plant trees within the spring catchments (Figure 11).

Figure 11: Community participation in tree planting for protection of the spring catchment

Laboratory analysis.

Chemicals

Chemicals for the analysis of sediment and water samples were obtained from Aquatech chemicals in Nairobi. The equipment for the analysis of nutrients is available in the Moi University's School of Environmental Studies laboratory.

Sample containers made of either some form of plastic or Pyrex glass were acceptable. Because ortho-phosphorus has a tendency to "adsorb" (attach) to the inside surface of sample containers, the containers were acid-washed to remove adsorbed phosphorus. Therefore, the containers were able to withstand repeated contact with hydrochloric acid. Plastic containers, either high-density polyethylene or polypropylene, were preferable to glass from a practical standpoint because they better withstood breakage. The size of the container depended on the sample amount needed for phosphorus and other parameters for analysis.

3.3 Expected Outputs

This study is likely considered to be one of the first programs in sampling greenhouse gases from the surfaces of diverse aquatic ecosystems and sediments in East Africa, both in Kenya and Uganda. There has been only one other recent investigation of sediment gases, at 1800 stations (4200 gas measurements) in the southern basin of Lake Albert, Uganda, but this information is presently proprietary (Adams et al. 2005). When the GHGs are measured in 2007 this present study should provide the first evaluation of sediment gases in a major East African (Kenyan) river. The Nzoia River represents one of the important tributaries to the Nile River system. In addition, a well-educated cadre of young African scientists and important institutional linkages (Moi Univ., Maseno Univ., LVEMP, Nzoia Sugar Co. and LVEMP Water Quality Component Lab in Kisumu) ensures the continuity and expansion of long-term GHG studies, which will be undertaken to understand, holistically, the processes and global role of GHG concentrations and emissions from tropical East African ecosystems.

3.4 Limitations

Because of the limited time for sampling, the program was only able to be in the field five times, two of which were for reconnaissance. The field periods were:

Feb 17-19	Nzoia River to the delta area at Lake Victoria
Feb 23-26	Trip to Webuye / Bungoma to test the field boat at river flood stage
April 21-24	Trip to Bungoma /Webuye for Nzoia River sampling and coring
May 11-14	Trip to Bungoma/Webuye for further sampling and coring
June 22-26	Trip to Bungoma/Kisumu and Nzoia River delta for sampling and coring

4.0 Results

Spring and borehole water yields

The spring yields, for the sampling exercise done on 23 March 2006 are presented in Table 3). At the onset of rainfall, the highest discharging spring in the study area is rated 5th class category according to the Geological Survey of United States rating scale of 1927. This falls far below what may be considered as a 1st class spring (2800 L/s). The majority (58.8%) of the studied springs were in the 6th class (63 – 630 ml/s). However, in the course of heavy rains (August measurements), the ratings improved, so that a majority (76.5%) of the springs were rated as 5th class (0.63 - 6.3 L/s).This shows the dependence of the spring water discharges to the rainfall intensity, and therefore their vulnerability to extreme rainfall variability due to climate change. This is also discernable in the borehole water depth (Table 4). At onset of rainfall the highest water depth was 4.2 m in Mumias, located in the lower catchment of the Nzoia River. The water depth increased with amount of rainfall so that the highest water depth in August was 5.43 m leading a positive deviation +3.9 m.

Table 3: Spring water yields at the onset and after long rains

Spring	March-May		August		Rating Change
	Yield (L/s)	Class Rating	Yield(L/s)	Class Rating	
SP1	0.50	6th	0.65	5th	+1
SP2	0.25	6th	0.77	5th	+1
SP3	0.03	8th	2.42	5th	+3
SP4	0.16	6th	1.27	5th	+1
SP5	0.67	5th	1.12	5th	0
SP6	0.07	6th	2.03	5th	+1
SP7	0.08	6th	0.48	6th	0
SP8	0.40	6th	0.91	5th	+1
SP9	2.85	5th	5.40	5th	0
SP10	0.27	6th	0.54	5th	+1
SP11	0.41	6th	0.76	5th	+1
SP12	0.17	6th	0.85	5th	+1
SP13	0.25	6th	0.96	5th	+1
SP14	<8 ml/s	8th	0.12	6th	+2
SP15	1.54	5th	-	-	-
SP16	0.86	5th	0.73	5th	0
SP17	0.06	7th	<8 ml/s	8th	-1

Table 4: Borehole water depth at the onset and after long rains

Borehole	Sanitary State	Water Depth (m) May	Water Depth (m) August	Water Depth (m) Increase
B1	UnDev	1.23	1.83	+0.6

B2	UnDev	-	2.94	N.d.
B3	UnDev	1.53	5.43	+3.9
B4	UnDev	0.85	3.45	+2.58
B5	UnDev	1.07	3.77	+2.7
B6	UnDev	0.5	2.28	+1.78
B7	UnDev	2.73	2.05	-0.68
B8	UnDev	4.42	3.50	-0.92

N.D. -Not determined

Nutrients and TSS concentrations in the Nzoia River

The sulphur concentrations were relatively high, as shown in Table 5 and Figures 12 and 13, in the middle catchment of the Nzoia River particularly between Nzoia Market Bridge (NMB) and Webuye Bridge adjacent to the Webuye Paper Mill. This could be attributed to activities from possibly from agricultural and paper processing activities. In the case of nitrates, there was a general increasing trend downstream to the Nzoia River mouth. Normally, it would be expected that nitrates would decrease downstream, due to biological utilization, if the origin were from upstream point sources. Total phosphorus concentrations were relatively low and generally uniform downstream in both water and sediments.

The increase trend of nitrates indicates a continuous input along the river, likely from agricultural N fertilizer runoff. Or it could be a combination of point sources from municipalities and the sugar factories (Nzoia and Mumias) along with the diffused sources from maize, sugar and coffee plantations in the catchment. Thus, agricultural, municipal and industrial activities upstream seemed to contribute remarkably to nutrient concentrations in the Nzoia River. In general, more of the nutrients were in the water column than in the sediments, which likely showed that they could be transported the entire distance towards the river mouth.

Table 5: Nutrient concentrations (total phosphorus, nitrates and sulphates) and total suspended solids in Nzoia River

Sampling Locations	Total Phosphorus (mg/l)		Nitrates (mg/l)		Sulphates (mg/l)		TSS (mg/l)
	Sediment	Water	Sediment	Water	Sediment	Water	Water
Moi's Bridge	0.55	0.24	3.2	4.8	37	21.5	99.5
Bondeni Bridge	0.87	0.66	4.3	5.8	29	39.5	127.5
Mitua Bridge	0.48	0.25	11.7	5.4	54	29.5	257
Nzoia Mkt Bridge	0.54	0.31	11.4	13.3	96.5	39.5	159.7
Webuye Bridge	0.44	0.29	17.8	6.2	52	38.5	293
Mumias Bridge	0.47	0.22	21.7	5.4	56	38.5	314.5
Ugunja Bridge	0.21	0.41	7.3	4.8	18	37	308
Siginga C. Point	0.12	0.34	13.6	4.3	36	27	297
Sango River Mouth	0.07	0.13	16.3	8.87	24.3	29.3	126.3

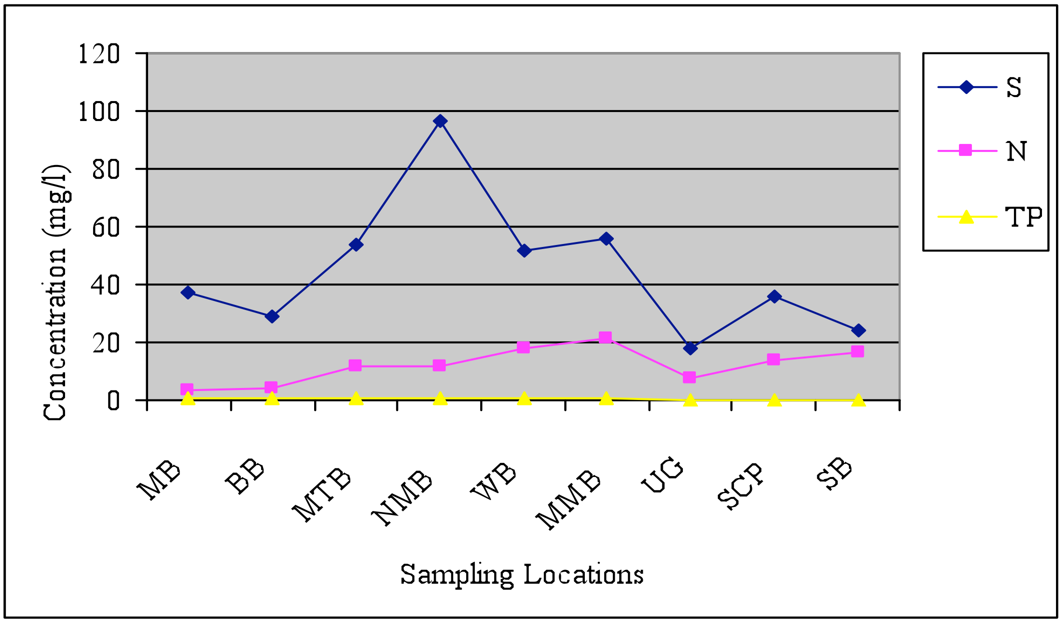

Figure 12: Variations of nutrients(S, N and TP) in water along the Nzoia river

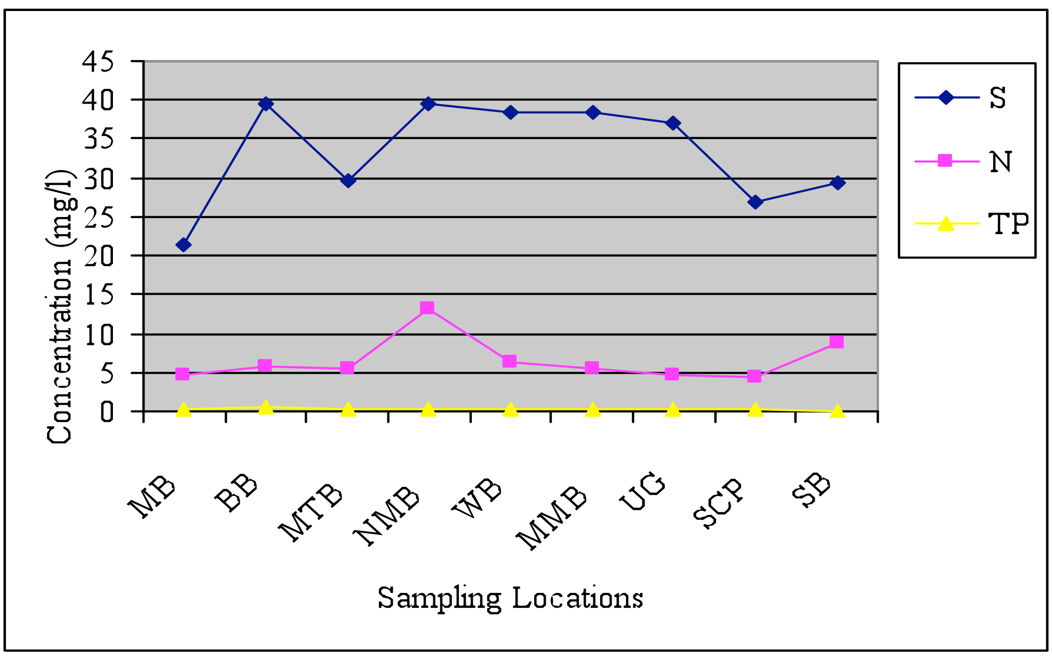

Figure 13 : Variations of nutrients (S, N and TP) in sediments along the Nzoia river

As regards the total suspended solids in the Nzoia river the trend was similar to that of nitrates, whereby the concentrations increased up to the delta. The increase was most marked in the middle catchments beginning from Webuye to Mumias (Figure14), which points to inputs from agricultural run-off and municipalities yet there seems to be sizeable additions from the industrial discharges located at the Webuye Paper Mill (Figure 14) and the two sugar factories at Nzoia and Mumias.

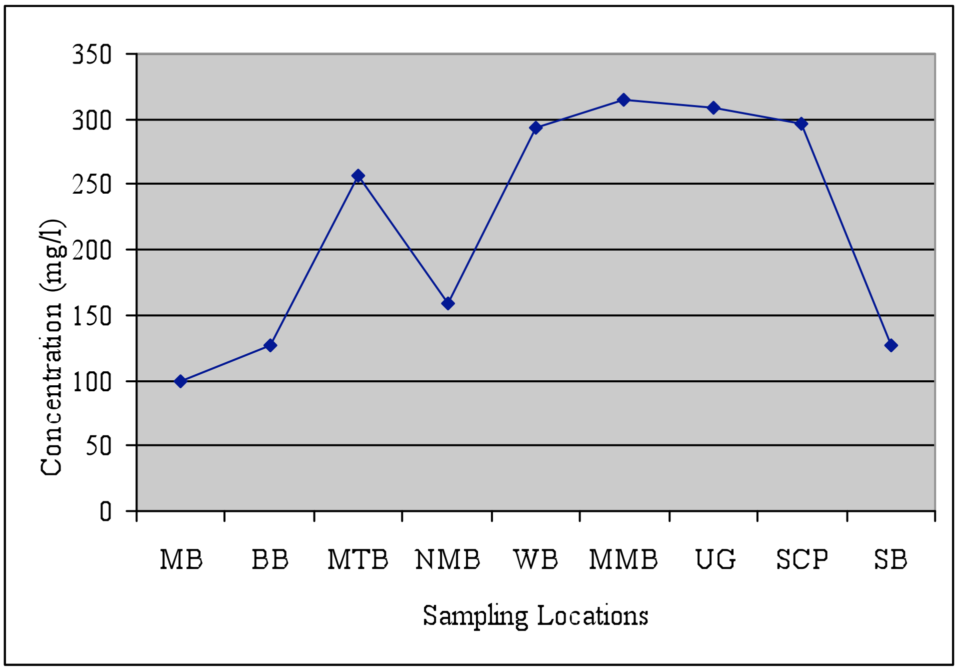

Figure 14 : Concentration of total suspended solids (TSS) in Nzoia river water

Figure 15   Pollution from the pipe outfall from the Webuye Paper Mill into the Nzoia River

Rainfall

Rainfall data during the study period were obtained from the Moi university weather station within the Nzoia catchment. The monthly mean rainfall was unevenly distributed with peaks in the months of April, June and August (Figure 16). Normally, August marks the end of the long rains and the beginning of short rains.

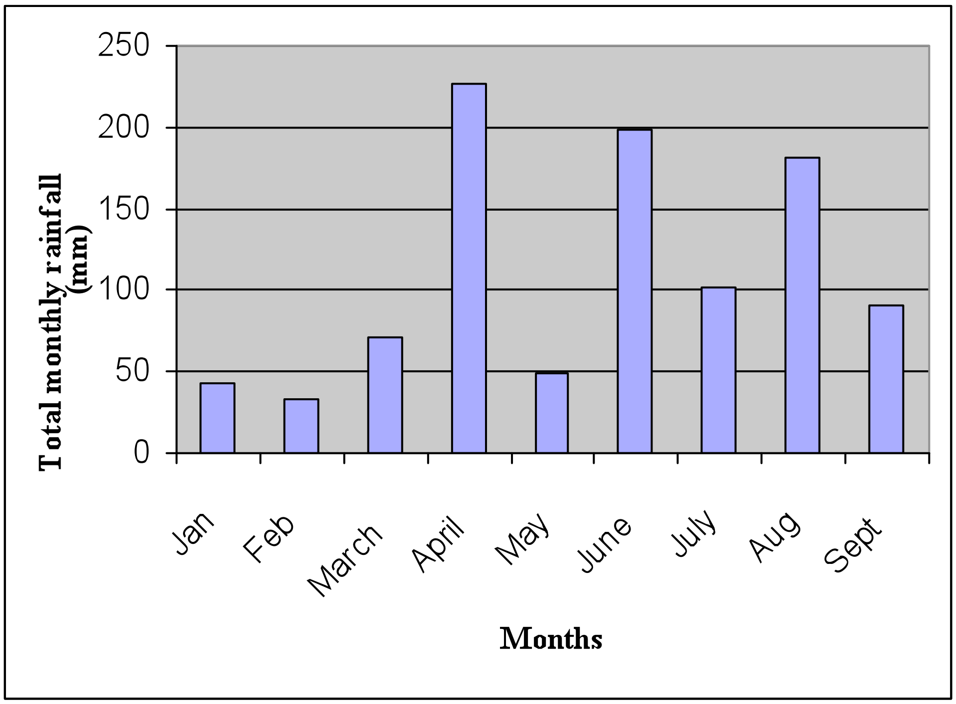

Figure 16: Monthly mean rainfall in the Nzoia river catchment for Jan - Sept 2006

Source: Moi University meteorological station

Greenhouse Gases in the Nzoia River Sediments

Cores collected from the upper to lower reaches of the Nzoia River showed dramatic changes in sediment gases, as observed with bubble formation on the inside of the plastic core liners. Larger concentrations of gas bubbles were seen as one proceeded downstream; these were observed as the sediments warmed up. Because of the lack of gas chromatography instrumentation at the field sites, sediment gases could not be analyzed immediately after sediment coring. Plans have already been developed to continue with sediment coring on the Nzoia River, followed by immediate GHG analysis, when D.D. Adams returns to Kenya in 2007. Included in this agenda will be sediment sampling, gas analysis, emission measurements and training of selected individuals in Jinja, Uganda, as itemized in the original proposal. It is also planned to measure sediment gas emissions from water surfaces with flux boxes (Figure 17), since this is important to understanding C budgets in these tropical environments.

Figure 17. Collection of gases with a floating flux box to measure GHG emissions at the water-atmosphere interface – this system will be used in future studies.

As far as it is known there have been no gas flux measurements in any of these areas, and certainly not on any reaches of the numerous rivers in East Africa.

Links to Catchments Degradation

It is evident from the results of this study that catchment human activities and hence catchment degradation contributes to nutrients and TSS concentrations in the Nzoia river. The flooded river carries biomass that constitutes part of the TSS. This study focused on inorganic phosphates. In an aquatic ecosystem, inorganic phosphate is rapidly taken up by algae and larger plants, resulting in algal blooms, increased biochemical oxygen demand and significant impacts on water quality. The anoxic conditions would promote CH_4

formation since methane is generated by microorganisms living in environments devoid of oxygen (Seiche and Kingston 1987).

GHG concentrations and eventual emissions result not only from the flooded biomass, but also from carbon transported by the river from the catchment area. Seiche and Kingston (1987) have observed increases in sediment gases, and explained their general emissions to the water and atmosphere in relation to the volume of submerged biomass within the river system and the degradability of the carbon sources carried to the river from the watershed areas. This would include both dissolved and particulate organic carbon washed out of the catchment. The current understanding is that these emissions are based not only on the carbon in the flooded biomass, but also on the degradation of organic debris swept downriver from the catchment area, which is then trapped in the river sediments and slowly decomposed into C gases by the anaerobic bacteria.

8. Conclusions

The study established pollution trends, particularly nutrients (sulphur, nitrates) and total suspended solids, along 70% of the Nzoia River, or 240 km of its 334 km length. These pollutants were markedly evident in the middle catchment section of the river, which coincides with intense human activities (paper mills and sugar factories). Visual gas bubbles in the cored sediments became profuse starting in this section of the study area. This was also the area that indicated a high stress on local surface and groundwater conditions since both the boreholes and spring water yields decreased immediately after the long rains in August (Tables 2 and 3). It is expected that climate changes would have direct affect on water availability in the study area; however, further longer term studies would be needed to verify these assumptions. Although concentrations of sediment gases showed a dramatic change downstream, emission levels of GHGs could not be concluded at the present time. It is, however, evident that spring water and borehole water resources in the study area are sensitive to climatic conditions, as observed during this period when rainfall depletion were directly related to lowering in groundwater levels.

9. Recommendations

The GHGs (CH4 and CO2) quantitative measurement should be carried to reliably establish trends downstream in order to effectively relate with the established pollution trends. The borehole and spring water measurements in relation to climate changes should be replicated in other catchments in the Lake Victoria basin. Organic carbon in sediments and water samples should be assessed to ascertain catchment contributions to carbon content in potential GHGs emission pockets with the lake basin.

10. Acknowledgements

We acknowledge START International for funding this project. We are also grateful to LVEMP (Lake Victoria Environmental Management Plan, Kisumu) and the Catchment Afforestation program who significantly contributed to protected the spring network in the study area, besides providing tree seedlings that were planted in the protected spring catchments. We also acknowledge Moi University for allowing the research team time off to undertake this study. Mr. Charles Juma and Mr. Pius Mamati provided key roles in procuring resources in the local areas and ensuring that they and local research assistants were available during the sampling periods; their assistance was highly appreciated.

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Appendices

Appendix 1: List of field research assistants

S.N.	Name	Role
1	Julius Langat	Boat testing
2	Abedi Mohamed Ali	Sediment coring
4	Hussein Nyangweso	Sediment coring
5	Pius Wekesa Mamati	Spring protection, Discharge sampling
6	Albert Milisa	Water Sampling and sediment coring
7	Raymond Misiko	Water Sampling and sediment coring
8	Mourice Wabwile	Water Sampling and sediment coring
9	Charles Juma-	Water Sampling and sediment coring
12	Peter Ogutu Ouma-	Water Sampling and sediment coring
15	Joseph Nyangweso	Water Sampling and sediment coring
17	James Ogola Nayweni	Sediment coring
18	George Karanu	Spring protection, Discharge sampling ,,
19	Peter Mwangi	Spring protection, Discharge sampling ,,