Links Between Land Management, Sedimentation, Nutrient Flows and Smallholder Irrigation in the Lake Victoria Basin

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Abstract

Over the last few decades, sedimentation and nutrient runoff, urban and industrial point-source pollution and biomass burning have induced rapid eutrophication of Lake Victoria. Recent studies indicate that severe erosion and land degradation are responsible for about half of the nutrient load into the lake. In western Kenya, the sedimentation of the Nyando river has negatively affected the performance and sustainability of several irrigation schemes, which were converted from natural wetlands. These wetlands have important filter functions, which are critical for the viability of the irrigation schemes as well as for the ecology of the lake. The last 20 years have witnessed a high rate of conversion of wetlands into irrigated agricultural land, reaching an area of over 6,500 hectares in the Nyando river basin. However, a sizeable portion of the reclaimed area is rapidly reverting to swamps due to a multitude of reasons, the most prominent being sedimentation. The long-term future of these irrigation schemes is bleak unless the high sediment load in the Nyando river is controlled. Several interventions to prevent the lateral flows of water, sediments and nutrients from the landscapes into the lake are described.

Introduction

Irrigation schemes in the Lake Victoria basin are mainly derived from wetlands. Wetlands are lands characterized by water saturation, which determine the nature of soil development and the type of plant and animal communities living in the soil and on the surface. Such lands are unsuitable for agriculture because the conditions for plant growth, cultivation and any undertaking of other activities related to crop production are not ideal. With an estimated 2.6 percent annual growth rate in world population (Ritzema 1994), the greatest challenge facing the world today is meeting the needs of food and wood for the ever-growing population, predominantly in developing countries. In addition to inappropriate technology, the scarcity of both water and agriculturally productive land is the main obstacle to be overcome to produce

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enough food to satisfy demand. Therefore, wetlands are increasingly drained and converted for agricultural purposes (Maltby 1986).

Wetlands play an important role in the ecosystem. They absorb and slow downstream flow, filter and remove sediments and degrade pollutants. They are highly productive systems with a high nutrient-fixing ability. The key to good filtering is related to the retention time of water in the wetlands; the longer the water takes to evaporate and infiltrate the longer it takes nutrients to be absorbed by plants. Wetlands provide a good source of plant material for local economies and are recognized for their biodiversity and wildlife functions. Wetlands also have variable efficacies dependent on the conditions and connectivity due to exploitation for household products and conversion to other land uses. Wetlands can remove between 20 and 80 percent of nitrogen by denitrification and uptake. With phosphorus, the slower flow rate of water in a wetland allows soil particles to drop out of suspension; but it also releases phosphorus from its less available forms into its bio-available form. If there is vegetation or algae to take this up and remove it from the system, there may be a reduction in phosphorus. If not, the wetland may become a source of phosphorus.

For agriculturists and ecologists, the conversion of wetlands for agriculture has elicited considerable controversy: agronomists regard the wetlands as the potential area for crop production whereas ecologists are more interested in conserving the ecology and biodiversity of wetlands. Therefore, some attempts exist to prevent further conversion of wetlands and to restore areas lost through reclamation or other human interventions.

Conversion of wetlands for agriculture may lead to negative effects such as:

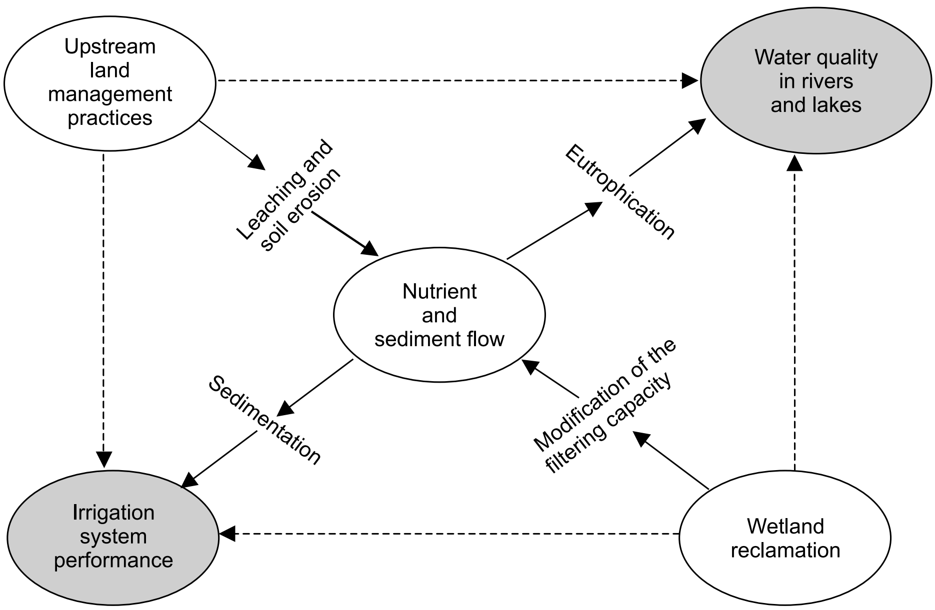
- *Change of the habitat conditions* within the area thus adversely affecting plant and animal life (flora and fauna).
- *Land subsidence due to oxidation,* particularly if an area with peat soils is drained, making the area more prone to inundation as a result of water seeping in from adjacent areas.
- *Salinization* of the soil due to the lowered water table that induces saline seepage outside the area making the reclaimed area unsuitable for crop production.
- *Acidification* of soils that contain pyrites, which oxidize on being brought into contact with air, thereby triggering the formation of sulphuric acid that makes the soil pH condition unsuitable for either crop or animal life, thus affecting the quality of the surrounding water.
- *Leaching and free movement of nutrients,* pesticides and other elements, which increase through the loss of the filtering capacity of the swamps, thereby allowing the nutrients to find their way into water systems causing eutrophication and affecting the quality of water in such systems.

Drainage of wetlands for agriculture is often accompanied by the development of an irrigation system to provide water for the production of agricultural crops. Therefore, most of the drained areas in Kenya are major irrigation schemes that suffer recurring inundation problems.

One of the major problems affecting the physical performance of most irrigation systems is the clogging up of the irrigation canals, particularly if the water flowing into the system is loaded with sediment, thereby reducing its flow. The removal of sediment from the water delivery channels may raise the level of the fields due to the continued sediment deposition on the land. Cultivation of steep slopes could also increase sediment delivery into irrigation channels, particularly in instances where soil conservation measures are not practiced. Although channels and other irrigation structures may approach their design dimensions after sediment removal, they cannot deliver water to the fields as the field levels keep rising due to sediment deposition.

While the effects of wetland reclamation on drainage for agricultural purposes may be simple to quantify, it is more difficult to predict the overall environmental impacts. Studies have shown that in the Lake Victoria basin the degradation of wetlands has affected their filtering capacity (LBDA 1992). The challenge for wetland utilization is to increase agricultural land in such a way that ecological functions are maintained. The first step is to identify how upland management and wetland reclamation for development impact on the performance of irrigation schemes and on the water quality in rivers and lakes. Figure 1 illustrates some of the linkages.

Figure 1. Effects of nutrient and sediment flow on water quality and irrigation performance.



Therefore, the combined effect of poor upland management and wetland degradation permits free movement of sediment and nutrients through the water systems (canals, drains, rivers and streams) into both the irrigation schemes and the lake. The effects of all these interactions may be either sediment accumulation in the irrigation systems and/or nutrient accumulation in the water systems (eutrophication).

Objectives of the Paper

Recently, the environment of Lake Victoria has attracted the attention of policy makers following its colonization by the water hyacinth (*Eichhornia crasipes*), which blocked water transport and fishing activities. The predominantly fishing community living around the lake was the most affected because the people of this community can no longer go out to fish and the quality of fish has become unfit for either export or local consumption.

Colonization of the lake by the water hyacinth is largely attributed to:

- increased levels of nutrients (particularly of phosphorus and nitrogen) that enter the lake from urban, agricultural and industrial sources, and
- sediment deposits originating from soil erosion due to poor upland management practices.

It has been argued that poor practices of land-use management (on both irrigated and nonirrigated lands) and the free flow of nutrients and sediment have a negative impact on the eutrophication of Lake Victoria. It is also postulated that the irrigation schemes developed within the area have also been affected by the sediment problem and have damaged the wetland's natural filter function. Against this background, therefore, the paper sets out to assess:

- how the land management practices in the Nyando river basin have contributed to the sediment load into the lake
- how the sediment load in the Nyando river and all the other rivers within the basin has affected the performance of the irrigation schemes developed within the river basin
- the level of usage of fertilizers and other chemicals and how this has contributed to the nutrient flow into the lake
- whether the conversion of wetlands into irrigation schemes has a negative impact on the quality of water in the lake and the sustainability of the irrigation schemes

Lake Victoria and Its Environment

The Lake Victoria basin supports an estimated population of 27 million people, who produce an annual gross economic product of around US$3–4 billion (SIDA 1999). With the exception of Kampala, the lake catchment economy is principally an agricultural one, with a number of cash crops, fisheries and subsistence agriculture. The quality of the physical environment is crucial in maintaining and increasing the living standards of the growing population. It is estimated that a 5-percent reduction in the productivity of the region would lead to a loss of $150 million annually. The lake basin is also used as a major source of food, energy, drinking and irrigation water, shelter, transport, and as a repository of human, agricultural and industrial waste. The Lake Victoria Environmental Management Program (LVEMP), which is a basin-wide project funded by the World Bank and the European Union since 1995, recognizes the fundamental importance of wetlands in relation to the lake's ecology, and is responsible for implementing policy for the sustainable development of wetlands. This policy includes due regard to their economic value, ecological importance and buffering value to the lake. In their recommendations, the consultants to LVEMP (Bullock et al. 1995) highlighted the importance of monitoring the buffering capacity of the lake-basin wetlands and integrating the socioeconomic considerations of wetlands.

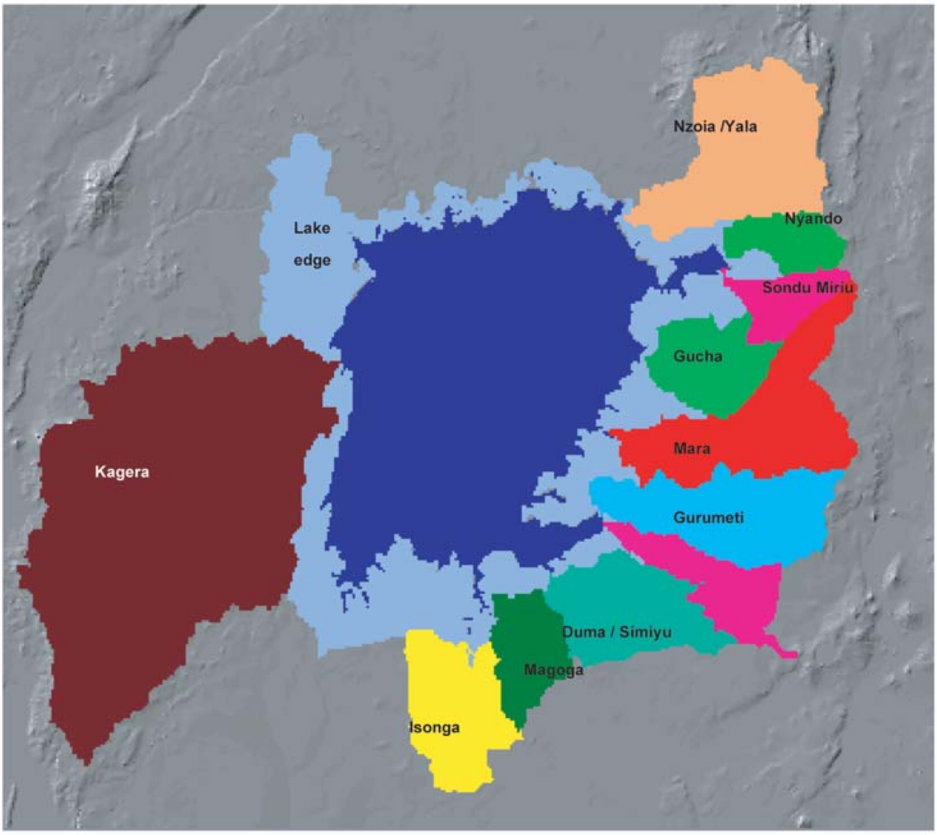
Lake Victoria, surrounded by the three east African countries (Kenya, Uganda and Tanzania) is the world's second largest freshwater lake in the world with a surface area of 68,000 km^2 and an adjoining catchment area (comprising 12 major river basins) totaling 155,000 km^2. One of these includes the Nyando river basin (figure 2), which is the focus of this review. Three other smaller rivers and tributaries of the Nyando river (Asawo, Awach-Kano and Nyaidho rivers) also contribute to the hydrology of the basin. The Nyando river basin has an area of 3,517 km^2 with the river and its tributaries originating from the western slope of the Mau escarpment and the Nandi hills. These are the two main mountain ranges lying between the Rift valley on the east and Lake Victoria on the west.

The area around the lake and within the river basin is characterized predominantly by poorly drained, fine textured, deep and fertile black cotton soils. The condition of the soils together with the multitude of rivulets and low-lying lands that characterize the area brings about water stagnation. Therefore, flooding is a common occurrence, and the area is known to suffer from periodic inundation, particularly after heavy rains in the adjacent escarpments and hills. Despite this shortcoming, the area is considered to have a very a high potential for irrigated agriculture, as irrigation water is abundant. For instance, it is possible to undertake irrigation by:

- pumping water from Lake Victoria
- gravity abstraction of water from the rivers, e.g., from the Nyando river and its tributaries
- using drain water from other irrigation and drainage schemes
- using pond water and water emerging from adjacent swamps

The ecosystem around the Lake Victoria basin has undergone substantial change during the last three decades due to two major human interventions in the basin. The first was the introduction of the Nile perch, which altered the food web structure. The second was the increased nutrient flows from the surrounding catchments into the lake. Although the most urgent problems in Lake Victoria are the water hyacinth, fishery and water quality, the lake is not the *source* of the problem. The root causes of eutrophication stem from continuing land degradation, resulting from deforestation, settlement, farming and accelerated soil erosion.

Figure 2. Map of Lake Victoria basin showing the location of the Nyando river basin.



Sediment and nutrient loads on the lake are high and will further accelerate the process of eutrophication. Urban runoff is also an important component of pollution and will worsen the situation in the next few years. Industrial discharges and sewerage will exacerbate the problem, especially when considering the number of agro-industries in the Nyando river basin.

Although there is a wide consensus that nutrient levels in the lake have increased in recent decades, we do not have reliable information on the major sources and sinks of nutrients. Nutrients enter the lake from different sources (agricultural, atmospheric, urban and industrial) but there is some controversy about the relative importance of these different sources. Most methods are flawed or inadequate either because they were based on values extrapolated from North America (Bullock et al. 1995), small catchments in Tanzania (Scheren 1995) or on minor streams during a single year in Uganda (Lindenschmidt et al. 1998) (table 1). The three major riparian countries have very different agro-ecosystems, topography and discharge into the lake. Such extrapolations are therefore grossly unreliable for the whole basin, but the latter two might reflect differences in land use between the two countries. Nevertheless, these rough estimates indicate that the contribution from agricultural lands accounts for about half the nutrient loads into the lake. Of the total water input into the lake, 85 percent comes as direct rainfall into the lake while the remainder comes from 12 major rivers. There is an urgent need to have more reliable data on the relative importance of each source, especially from the major rivers such as the Kagera on the west. A recent analysis, using topography and satellite images, of these major river basins indicates that the Nyando and Kagera river basins stand out in terms of sediment transport capacity and average slope (Walsh, personal communication, 2001, ICRAF).

Table 1. Rough estimates of nutrient contributions (%) from various sources to Lake Victoria.

	Agricultural	Urban	Atmospheric
1. Bullock et al. 1995	50	30	20
2. Scheren 1995	25	na	75
3. Lindenschmidt et al. 1998	57	6	37

na=Data not available.

Ongoing studies of land management practices in the Lake Victoria basin (ICRAF 2000) reveal serious land degradation on the fragile slopes and extensive gully formation in the Nyando river basin. While this evidence supports the fact that the sediment load of the Nyando river has increased over the last 15 years, the source of the sediment remains unclear as it varies greatly in place and time. However, the general consensus is that the origin of sediment is the uplands of the watercourses within the Nyando river basin.

It is widely believed that the large changes in hydrology and sedimentation of the lake basin are due to conversion of forests into agricultural lands. There is considerable evidence, especially from Kenya, of the strong relationship between land use, runoff and sedimentation from drainage basins. For example, sediment yield from undisturbed forest catchments loses sediment at a rate of 20 to 30 t km^{-2} yr^{-1}, while that from agricultural basins loses between 10 and several thousands t km^{-2} yr^{-1}, depending on the topography, runoff, and the proportion of the basin that is cultivated. Average sediment yield from agricultural regions was only 90 t km^{-2} yr^{-1}, with a range of 1,000 to 5,000 t km^{-2} yr^{-1} from the steepest and wettest slopes. Rangelands have similar variability, but sediment yields are generally higher. In the Nyando district, the area under agricultural lands has increased from 38 to 63 percent during the last 40 years (Hai et al. 2000) and, therefore, the adoption of soil conservation measures on cultivated land alone could have a major impact on sedimentation into the lake. In addition, the dense network of roads and footpaths, which constitutes about 1 percent of the basin area, has a low infiltration capacity and might contribute between 25 and 50 percent of the sediment yield of the basin.

Current monitoring by ICRAF and its partners of the water flow and quality of streams and rivers should establish the relationships between land use and nutrient loads. This information should allow the sediment load on riparian vegetation to be established. Knowledge of the buffering capacity of the wetlands and riparian strips will provide estimates of the ultimate loading on the lake. Combined with data from point-source pollution, management decisions can be formulated that will determine the future development of the lake catchment and the environmental impact of converting wetlands into agricultural use.

The impact of human activities on the land and lake may be easily overshadowed by the huge natural fluctuations in climate and sedimentation, which are features of other lakes in the region. For example, the lake levels rose by 2.5 m following successive doubling of rainfall from 1961 and 1962 (Sene and Plinton 1994) and the levels have remained relatively high ever since. This long residence time (about 20 years) suggests that the impact of interventions on the eutrophication problem might take years to have a measurable effect. A recent analysis of the level of the lake using fossil diatoms as proxy records of rainfall over the last thousand years suggests even greater natural fluctuations in climate and sedimentation in the east African lakes (Verchuren et al. 2000). For the near future, the impact of El Niño rains on sedimentation rates in the basin should be assessed to establish the relative importance of such events compared to current land use change. Scientists are currently comparing the long-term trends in hydrology and sedimentation due to long-term changes in rainfall versus changes in land use.

In a review of more than 60 studies of sediment yields in Southeast Asia, Bruijnzeel (2000) concluded that the time scale for the downstream benefit from upland rehabilitation depends on the size of the river basins and sources of nutrients: the number of sediment storage opportunities also generally increases with catchment size. For large river basins, there may be so much sediment stored in the drainage basin itself that it effectively forms a long-term supply, even if all human-induced sediment inputs in the headwater were eliminated. Results from major land rehabilitations in China suggest that a reduction in sediment yield of up to 30 percent may be expected after 20 years for very large catchments (100,000 km^2) (Bruijnzeel 2000).

Experience in the Baltic Sea illustrates the inertia of the terrestrial and aquatic systems that control the exports of nutrients from the land to the seas (Stalnacke 1996). Late in the 1980s, a goal of a 50-percent reduction of the nitrogen and phosphorus export to the North Sea and the Baltic Sea was adopted by HELCOM (Helsinki Commission) and action programs were initiated to achieve this goal by 1995. Results so far suggest that the reduction actually achieved was much smaller than anticipated, and the export of nitrogen has been particularly difficult to reduce despite major changes in land-based activities. In Sweden, massive reduction in point emissions of phosphorus by 200 t yr^{-1} to less than 10 percent in the mid-1970s failed to reduce the riverine load even after 20 years! This evidence suggests that the present load is due to diffuse emissions to water or possibly internal loading from the riverbed. In Eastern Europe, the response of water quality to lowered nitrogen is even slower because of large amounts of organic nitrogen that have accumulated in the soil during periods of higher application rates, and that have resulted in the accumulation of nitrate in groundwater aquifers with a long residence time. In the Lake Victoria basin, fertilizer input is negligible compared to that in Europe and, therefore, the response to upstream land rehabilitation is expected to provide an earlier benefit to water quality in the lake. There is little reliable information on the time lag between land rehabilitation and any subsequent reductions in streamflow and sediment transport at increasingly great distances downstream.

Irrigation and Drainage Development in the Nyando River Basin

When compared to the other areas around the Lake Victoria basin, the Nyando river basin has experienced the highest level of development in irrigation and drainage schemes. The last 20 years have witnessed a high rate of conversion of the Nyando basin wetlands into irrigated agricultural land, reaching an area of over 6,500 hectares. In the mid-1960s, the National Irrigation Board (NIB) reclaimed over 1,700 hectares to start the two pilot irrigation schemes (Ahero and West Kano irrigation schemes). The "success" of these two projects prompted the emergence of more schemes in the whole river basin. From the mid-1980s, over 4,000 hectares of government-assisted schemes have been developed with the support of the Provincial Irrigation Unit (PIU) of the Ministry of Agriculture, Livestock Development and Marketing. Several schemes (some as small as 3 ha) have also been constructed by the local community through their own initiatives and with little or no external support. The Lake Basin Development Authority (LBDA) has also earmarked a number of schemes for development following the feasibility study carried out in 1992 by the Japan International Cooperation Agency (JICA)—an exercise that may put more area under irrigation if the recommendations are implemented. Except for two schemes that were developed for vegetable production, it should be mentioned that all schemes in this river basin are meant predominantly for irrigation of rice fields.

Despite the above record of irrigation development, a sizeable portion of the reclaimed area is, however, rapidly reverting to swamps due to a multitude of reasons, the most prominent being sedimentation.

Flood Control and Wetland Reclamation

As already mentioned, the Nyando river basin and, particularly, the lower reaches of the river basin are prone to flooding. In addition to the poorly drained cotton soils, flooding is mainly the result of the many rivers and rivulets that traverse the area—most of which frequently overtop their banks as they flow on relatively flat topographies. The high rainfall intensity, characteristic of the Lake Victoria region is yet another factor, though of minor consequence. The stagnation of water and flooding have, to a large extent, resulted in the growth of swamps at several locations around the lake, with the Nyando swamp being the largest, covering an area of over 10,000 hectares (LBDA 1992). Therefore, this area has developed into a prominent wetland, dominated by papyrus and bulrush vegetation.

Traditionally, the communities around the flood-affected area have existed by adopting various ways to overcome flooding. These include raising banks around their houses and lands, building houses on higher grounds or raised floors and evacuation during flooding to higher grounds. The government, through the Ministry of Water Development has made attempts to provide flood-protection measures through the construction of dykes, particularly along the Nyando river but this has been ineffective because the dykes do not cover the whole course of the river. Because of the frequency of the floods the reclamation of the wetlands has been considered one of the most effective ways of management. Most of the flood-control interventions generally stem from the reclamation of wetlands and the development of irrigation and drainage schemes.

Construction of canals through the wetlands, which act as either irrigation or drainage channels, is common. During the rainy season, when the capacity of most rivers causes overtopping of the banks, the channels convey the excess water away from the farmlands and homesteads into the lake. These channels are also used to convey water from the rivers or swamps into the irrigated lands during the dry season. Consequently, less and less water stagnates on the land, resulting in the drying out of the wetlands. A large section of the wetlands in the Nyando river basin has therefore been reclaimed through such interventions. In 1986, the area under wetlands was 10,000 hectares but 60 percent had since been converted to agricultural use.

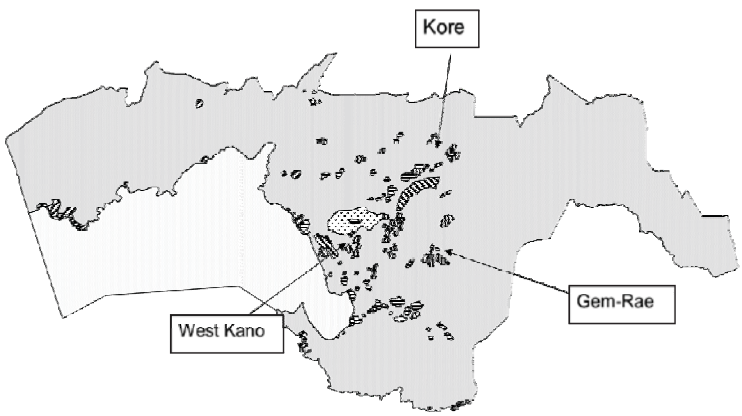
Sustainability of Irrigation Schemes

The following sections have identified two very related activities, i.e., wetland degradation and irrigation development, particularly at the lower reaches of the Nyando river basin. This development has persisted despite the inherent problems due to the high sediment load in most rivers draining into the area (and particularly the Nyando river). Therefore, it is crucial to establish how sedimentation has influenced the performance of the irrigation and drainage schemes because of the reduced buffering effect of the wetlands.

Several community-managed irrigation schemes were visited and field observations made in addition to holding discussions with different stakeholders. Three interesting cases are described below to illustrate the problems and challenges ahead. The three schemes indicated in figure 3 are:

- the Gem-Rae irrigation scheme,
- the southwest Kano irrigation scheme, and
- the Kore irrigation scheme

Figure 3. Irrigation schemes.



Kisumu district showing irrigation schemes

Case 1. Gem-Rae Irrigation Scheme

Developed in 1985 under the EEC-funded Smallholder Rice Project (SRP), Gem-Rae is one of the four cluster schemes in the Awach-Kano delta scheme designed to irrigate 350 hectares of rice. This scheme, like the other cluster schemes (i.e., Oyani-Nyachoda, Alara and Kopudo), shares the same source of water as from the Awach-Kano river.

The Awach-Kano river originates from within the Nyando basin and carries an appreciable amount of sediment, mainly sand and pebbles. The round-shaped pebbles indicate that the sediment has been transported as bed-load over a long distance. Due to this load, the intake (comprising a 6-m long concrete weir structure) started clogging up at the onset of the scheme. In the initial years, because of the frequency of sediment deposition, irrigation was undertaken only once every 2 years after removal of the sediment. However, after 4 years, sediment deposition at the intake as well as the main canal became so frequent that its removal had to be done at the start of every planting season (commencing July, every year). From 1992, the amount of sediment accumulation accelerated (suggesting that the erosive effect upstream of the river was also increasing) to the point that it had to be removed as often as three or four times during the entire 4-month growing season. From 1995, the removal of sediment was as frequent as twice a week.

The high rainfall patterns experienced in Kenya in 1997 due to the El Niño phenomenon sounded the death knell for the scheme. During this period, clogging of the intake became a weekly event and farmers were clearing sediment daily at the expense of farming. Maintenance records from the scheme indicate that as much as 200 m^3 of sediment was being removed weekly during this period from the intake as well as a section of the main canal.

From its inception until 1995, the Ministry of Agriculture financed the farmers to undertake maintenance work (mainly removal of sediment). Though sedimentation was controlled after the withdrawal of the financial support and the El Niño rains, the farmers could no longer cope with the situation.

Since 1997, sediment clearing stopped and the intake and part of the main canal have been completely clogged up. No water is therefore received within the scheme and the canals, and other irrigation structures (division boxes, offtake structures, etc.) have become nonoperational and are either clogged up with earth or overgrown with vegetation. Formerly well-demarcated rice fields have been overgrown with reeds and the once popular irrigation scheme has now been abandoned.

Driven by the hunger now prevalent in the area, several farmers are attempting to clear a part of the new swamp in a bid to produce some rice using residual water in the swamp. The yields are less than 0.5 t ha^{-1}, compared to 3.5 t ha^{-1} obtained previously. Less than 30 hectares are currently under this type of rice production and the *Quelea* birds that now inhabit the swamp consume most of the crop before it is harvested.

It can be concluded that the Gem-Rae irrigation scheme has been virtually abandoned because of the high sedimentation problems experienced. Another reason is the weak management structure. However, the principal reason seems to be sedimentation originating from the uplands. Rice production is one of the few livelihood alternatives in the area and, thus, farmers remain interested in reviving the irrigation scheme although the cost of rehabilitation is beyond their resources.

Case 2. Southwest Kano Irrigation Scheme

The southwest Kano irrigation scheme forms the single largest farmer-managed irrigation scheme in the region. Developed by the PIU, it became operational in 1993 and was planned to cover a total area of 530 hectares. However, due to the enlargement of individual cluster schemes the total area was 825 hectares. The Nyando river is the major source of water to the scheme though additional water is received from the Nyatini drain (drain water from Nyatini irrigation scheme, a scheme developed by farmers and located right upstream of the southwest Kano scheme).

Soon after the scheme started it became evident that the southwest Kano scheme experiences a high level of sediment deposition. The sedimentation problem necessitated the formation of the Smallholder Irrigation Support Organisation (SISO), an organization established in 1993 with support from the Ministry of Agriculture to manage the project. On completion of the project, the major infrastructure was handed over to the organization with responsibilities to:

- operate and maintain the major irrigation infrastructure,
- ensure equitable supply of water through the major infrastructure to the different cluster schemes and farmers, and
- charge all farmers (through their cluster schemes), receiving water from the irrigation infrastructure, a maintenance fee to meet the O&M costs.

An O&M agreement was signed between the SISO and the farmers in different cluster schemes. Under this agreement, the farmers were solely responsible for the O&M of secondary works, in addition to remitting the "maintenance fee" to SISO for the O&M of the major infrastructure. On the other hand, the SISO was supposed to use these funds to meet the O&M costs of the schemes (including the removal of silt from the main system) as well as meeting its own overhead costs.

Despite the existence of this maintenance arrangement no serious maintenance work (particularly the desilting of the main canal) has been undertaken, because the SISO has never been able to raise enough money to meet the maintenance cost of the main canal, which is 3.5-km long. Due to the ever-increasing sediment deposition in the main canal, its capacity and the discharge that goes through it have been declining over the years, and consequently the area actually under production keeps changing (table 2).

Table 2. Performance of the southwestern Kano irrigation scheme.

Season	1995/1996	1996/1997	1997/1998	1998/1999
No. of schemes under production	19	16	-	19
Total area cropped (ha)	176	544	-	545
Average yield (tons/ha)	4.7	4.3	-	5
Maintenance fees collected (KSh)	336,505	408,059	-	318,454
Default in maintenance fee payment (%)	43	20	-	85

Source: Manager, SISO/PIU, Nyanza.

For instance, during the 1995/96 season, only 176 hectares (33% of the total area) were irrigated because only part of the main canal was cleaned. Very few cluster schemes actually paid the maintenance fee. Farmers in others schemes felt that despite making their payments previously, the amount of water delivered through the system did not improve as expected and therefore they defaulted payment. The intervention of the PIU in the following year, by attaching one of their staff as the manager to assist in collecting the maintenance fees, resulted in a marked improvement in the number of cluster schemes that paid up that season. A bigger section of the main canal was therefore desilted, albeit using manual labor, and more area was therefore irrigated during the 1996/97 season.

However, the 1997/98 season was a complete failure as no irrigation water was delivered to the schemes. The season came during the time the country was experiencing the El Niño rains, which dramatically increased the level of sediment deposited at the intake and along the main canal. The high sediment levels discouraged the farmers from paying maintenance fees and, therefore, no irrigation took place because no maintenance work was done.

The cost of mechanically dredging the entire main canal is estimated at KSh 700,000 (a cost that has been way above SISO's seasonal income). The only maintenance work so far undertaken has been manual removal of vegetation, which leaves most of the silt in the canals.

The area irrigated and the yield from the southwest Kano irrigation scheme depend on how effective the sediment is removed to give the main canal enough capacity to deliver the required discharge. However, this depends on the level of payment of the maintenance fees, which can only be improved if the maintenance is adequate enough to deliver the required amount of water. Therefore, the future of the scheme depends on a vicious circle that can only be broken by good management of the sediment in the Nyando river basin.

Case 3. Kore Irrigation Scheme

The Kore irrigation scheme was started in 1991 and covered an area of 300 hectares. It is located on the upper side of the NIB-managed Ahero pilot scheme and was developed through the farmers' own initiative. It sources its water from a swamp fed by the Ombeyi river. No major irrigation structures were constructed because the water was derived from a swamp. The main work undertaken included the construction of 10 concrete offtaking structures with spindle gates to control the flow of water into various sections of the scheme, and the excavation of water delivery and distribution canals. A cutoff drain-cum-delivery canal, around a swamp adjacent to the scheme, was constructed to convey water into the different distribution canals through the spindle gates.

Unlike most other schemes in the area (particularly those receiving water from the Nyando river), Kore is one of the schemes that is least affected by the sediment problem. Most of the sediment in the Ombeyi river is trapped as the water filters through the swamp and the amount of sediment reaching the scheme is quite small. In consequence, little maintenance work (particularly earth removal) is necessary, except for the uprooting of vegetation. However, this is done during the annual land preparation and the farmers consider this as a part of the routine land-preparation activity.

As far as rice production is concerned, there was no delay in starting the season because the irrigation system is able to deliver water punctually and rice yields have been relatively high (averaging 5.5 tonnes ha^{-1}) as compared to other farmer-managed schemes whose average yields are relatively low.

In conclusion it has to be stated that the scheme's sustainability seems to be protected naturally by the filtering role of the wetlands unlike other schemes where the sedimentation problem is acute.

Impacts of Sedimentation on the Sustainability of Irrigation Schemes

The three cases illustrated above highlight the impact of sedimentation problems on irrigation schemes and their potential solutions. In the Gem-Rae case, the scheme was abandoned barely 12 years after its inception. Although the southwest Kano irrigation scheme is still operational, the long-term future is bleak unless the high sediment load in the Nyando river is controlled. The Kore case provides a small, but promising, example of the benefit of a well-designed irrigation scheme, which utilizes the natural filtering capacity of the wetlands.

It can be said that, in general, the sediment problem has negatively affected irrigation schemes in the following three ways:

Infrastructural System

In the Gem-Rae irrigation scheme, the heavy sediment load in the river blocked the intake structure rendering it ineffective. It is possible that the poor siting of the intake channel contributed to the siltation problem. In the case of the southwest Kano scheme, the continued deposition of sediment in the main canal has changed the canal dimensions to the point where the flow through them is less than the designed flow. The performance of the irrigation structures is dependent on the attainment of the correct flow levels and the reduction particularly affects the division structures. Little or no water is being delivered to the various tertiary units and fields due to this problem. Not surprisingly, the farmers have resorted to damaging the weir sills of the division boxes or constructing new canals that bypass such structures.

In summary, it has to be stated that increased sedimentation arising from poor upland practices has a major impact on the viability of many irrigation schemes.

System O&M

Effective management of community investments like irrigation systems requires institutional arrangements and incentives to encourage the participation of all users in the day-to-day operational and regular maintenance work. Such arrangements are important if the water, which is generally scarce in most irrigation systems, is to be shared equitably to meet the needs of users. It is crucial to have a management arrangement that encourages all users to participate actively in the O&M of the irrigation structures. Studies (Orego 2000) have established that inequity in water distribution is a major disincentive to farmer participation and contribution in maintenance activities. The sediment problem does not promote equity or ensure adequacy in water delivery and, hence, the participation cannot be achieved by all.

Project Sustainability

It is not surprising that the performance of most irrigation schemes abstracting water directly from the sediment-laden water sources is declining because the quantity delivered falls below the designed discharges.

The high rate of sedimentation from the Awach-Kano river dramatically increases the labor requirement and the cost of maintenance of the irrigation infrastructure in the case of the Gem-Rae scheme. Since there is little improvement in water delivery after the removal of sediment and vegetation, farmers have been discouraged from further participation in maintenance work. Little or no money is collected to meet the maintenance costs due to the increased labor requirement.

Effects on Water Quality of Lake Victoria

As indicated in table 1, the contribution from agricultural lands accounts for about half the nutrient loads into Lake Victoria. Generally, agricultural development (and particularly irrigated agriculture) may bring about an increase in water pollution due to increased land use accompanied by high application of fertilizers and the use of other chemicals. In addition, the water flow regime of the rivers can be reduced due to greater water abstraction, which may consequently increase the concentration of nutrients in water that enters the lake.

The growing number of sugar and other agro-based industries within the river basin and their consequent discharge into the Nyando river will undoubtedly increase their contribution to the pollution of the lake. While there are no recent detailed studies to establish how the quality of water in the lake has deteriorated due to agricultural activities, the few studies on water-quality assessment already undertaken indicate that there has been an increased pollution of the lake waters since 1985. A pollution assessment study undertaken by JICA (LBDA 1992) established that the water quality in the Nyando river was relatively poor as compared to all other rivers within the lake basin. Particularly, the level of suspended solids was quite high, as indicated by the highest sediment transport index of 0.3 for all the rivers within the lake basin (ICRAF 2000). Therefore, it is possible that the high sediment load carries along with it an equally high nutrient load, which greatly affects the water quality in the lake.

The "Winam Gulf Baseline Study" conducted from 1984 through 1985 provides comprehensive water quality data in the lake and particularly in the Winam Gulf. The "Secchi depths" (a scale for measuring the transparency of water) were found to be low in the gulf; about 0.3 to 0.4 at the eastern lakeshore as compared to 1.6 to 2.4 at the central part of the gulf. This low transparency value can be attributed mainly to suspended load and the algae blooms that were promoted by high levels of nutrients in the water. The total nitrogen (T-N) was found to range from 0.5 to 0.63 mg/l and the total phosphorus (T-P) from 0.02 to 0.04 mg/l. The high level of nitrogen could be a result of the use of animal manure as well as other nitrogen-based fertilizers. The actual source of the nutrients however needs to be investigated, even though fertilizer usage among smallholder farmers in the area (both in irrigated and nonirrigated fields) is reported to be low.

Analysis of satellite images taken around the lake between 1986 and 2000 revealed a sediment plume in the Winam Gulf (through which the Nyando river drains into Lake Victoria) on the eastern part of the lake (ICRAF 2000) while qualitative (verification work is underway), evidence indicates that the Nyando river is a major contributor to the sediment load in Lake Victoria.

There are no data on the buffering capacity of the wetlands around Lake Victoria. However, it is possible for the swamps to have a high buffering capacity and degradation of the wetlands around the lake though the development of irrigation and drainage schemes contributes to the deterioration of the water quality because the buffering capacity is reduced. Additional studies are needed to quantify this hypothesis.

Intervention Strategies

Many reports have argued for the need to conserve wetlands around the lake. Since the main livelihood in the communities along the Nyando river basin is farming, wetlands will continue to be converted into agricultural lands to meet food needs. Reducing the flow of nutrients by erosion from the impoverished rural landscapes and from untreated sewage from the growing population would not only improve the water quality and ecology of the lake but also benefit food security, health, income and productivity of the land. Although the amount of inorganic fertilizer application in irrigated areas is negligible to nonexistent, large amounts of soils are lost from the once-fertile lake basin. Therefore, interventions should simultaneously raise agricultural productivity and reduce erosion. In Kenya, considerable productivity and economic success have been achieved by the National Soil and Water Conservation Program (NSWCP) using the "catchment approach," which is based on an area covering one or two villages rather than in the hydrological sense. With this approach, resources and soil conservation efforts are concentrated within a specific focal area for a limited time and the local communities are involved in the identification and implementation of interventions (Thompson and Pretty 1996). A recent study of the effectiveness of the catchment approach in terms of targeting areas of high erosion risk in the Nyando district by the NSWCP showed that less than 8 percent of the erosion-risk area is covered by the catchment approach (Hansen 2000). Thus, better targeting of interventions on the erosion hot spots is necessary to ensure a greater reduction in sedimentation from the Nyando river basin. Several opportunities exist to prevent the lateral flow of water, sediments and nutrients from the landscapes into the lake (Van Noordwijk et al. 2000).

Controlling Surface Erosion: Filter Strips

Recent studies in Sumatra, Indonesia show that simple land-based activities, using natural filter strips or vegetation are effective in reducing sediment transfer even on steep slopes (Utomo et al. 1999). Surface cover, condition of the land use system and farming activities (tillage, weeding, fertilizer application) have a great impact on sediment transfer, in addition to other soil-erosion factors such as slope and soil type. For example, retaining weed/grass strips or delaying weeding in coffee plantations can substantially reduce sediment movement. Furthermore, agroforestry systems, such as multistrata and mixing calliandra and coffee, also produced a very low sediment yield. A short filter cover is more effective in trapping the sediment than a very long one because runoff will have opportunity to accumulate in the longer slope and a rill will be created if there is concentrated flow.

Gully Erosion

Gully erosion is common in the Nyando river basin. Active gullying may be related to soil compaction by overgrazing or improper discharging of runoff from roads, trails and settlements. If gullies are not treated promptly, they may reach a stage when restoration becomes difficult and expensive. The use of vegetation on actively eroding gullies is limited and additional mechanical measures, such as check dams, retaining walls and diversion ditches, are required.

Riparian Zones for River Banks

Numerous studies have shown that riparian zones play an important role in shaping stream ecosystems, influencing habitat complexity, biodiversity and in restoring eutrophic lakes (Haycock et al. 1997). Appropriate riparian management could reduce sediment load by 85 percent, phosphorus by 47 percent and nitrogen by 40 percent. Riparian areas can buffer streams from a variety of land-use impacts, especially in improving the infiltration of compacted grazing lands and storing sediments. However, riparian zones should not be regarded as inexhaustible sinks for high nutrient inputs, and it is vital to match nutrient inputs to sustainable rates of nutrient removal if long-term benefits of water quality are to be improved. Two considerations are central to the adoption of riparian zones: community ownership and ongoing maintenance, and developing profitable incentives because farmers do not rank them highly in terms of income generation.

Afforestation

There still remains much folklore and many myths about the role of land use and its relation to hydrology, especially in relation to deforestation and afforestation, which hinder rational decision making in land use (Calder 1997; Bruijnzeel 2000). When scrutinized, many of these myths are found to be either exaggerated or lacking in evidence. These include the roles of forests in increasing rainfall and runoff, regulating low flows, reducing floods, improving water quality and reducing erosion. Two points are worth mentioning in terms of the Lake Victoria basin. First, although reforestation and soil conservation measures are capable of reducing the enhanced peak flows and stormflows associated with soil degradation, there is no well-documented case where this has also produced a corresponding increase in low flows. This is possibly because storage opportunities of soil water have declined as a result of soil erosion during the post-clearing phase. Second, the most crucial factor in terms of soil erosion is to have a good plant cover to prevent surface erosion rather than tree cover, as mentioned earlier.

Controlled Use of Fertilizers

There is no documentary evidence to suggest an excessive use of inorganic fertilizers and chemicals in the Nyando river basin but a controlled use will have a positive effect on the contribution of agricultural activities towards pollution of the lake. Information from the field indicates that fertilizers provided to the tenant farmers in the NIB-managed schemes are not actually used within these schemes. Rather, most of the fertilizers are sold to smallholder farmers outside these schemes and their application methods, coupled with the water management systems used, may provide easy avenues for the fertilizers to find their way into watercourses.

Wetland Conservation

The case of the Kore irrigation scheme highlighted above showed that the sustainability of irrigation schemes developed in sediment-loaded river basins can be feasible if the irrigation water is filtered through swamps and not abstracted directly from the run of the river. It shows that it is possible to simultaneously undertake irrigation development and wetland management. However, this calls for very pragmatic policies and programs that can be easily implemented to ensure sustainable development and conservation work, particularly involving the local communities.

Farmers within irrigation systems already appreciate the negative effects of sedimentation on their irrigation systems. The Kore case illustrates the enormous benefits to farmers that can be achieved by conserving some wetlands around their irrigation schemes. Therefore, each drainage activity for the development of an irrigation scheme should be accompanied by maintaining or recreating a wetland upstream of the irrigation scheme. This will ensure that sediment does not enter irrigation systems and that its movement into the lake is controlled.

The potential area that should be put under wetlands needs to be investigated. The study should determine the nutrient and sediment level that can be achieved through improved land management practices and controlled fertilizer use. The filtering capacity of the swamps around the lake basin also needs to be investigated.

Further Research

This paper has attempted to raise issues of the impact of poor land-management practices and the degradation of wetlands on the sustainability of irrigation systems and the water quality in rivers and lakes. While the evidence highlighted here provides some arguments on the need to adopt a concerted approach in the management of the hydro-ecological system of the lake basin, further research work is still necessary if more specific and tangible intervention measures are to be recommended. The following research work is therefore recommended:

1. Although nutrient flow from agricultural lands is the major source to the lake there is still insufficient data for a reliable estimate of the mass balance of the nutrient loading into and out of the lake, especially from industrial and atmospheric sources. Therefore, actual point sources and the contribution of nutrient pollution from agricultural lands should be investigated and quantified.

2. It is beyond question that the wetlands have a filtering capacity against sediment and nutrients. The effectiveness of wetlands in sediment and nutrient filtering should be assessed.

3. There is an urgent need to establish a relationship between land use and nutrient loads, and the buffering capacity of the wetlands and riparian vegetation.

4. The sources of sediment (erosion hot spots) within the river basin and the lake basin as a whole must be identified and quantified as a means of identifying the most appropriate measures of erosion control. Although there are numerous opportunities to prevent the lateral flow of water, sediments and nutrients into the lake there is an urgent need to develop methods that increase the incentives attractive to smallholders to adopt them without loss of crop production.

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