Effects of physical mixing on the environment of satellite lakes and dams of lake Victoria, Kenya

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Abstract

In the Lake Victoria catchment are found several small lakes and dams. The satellite lakes and dams are important aquifers and buffer zones for the lake. Besides the water bodies are important water sources both for livestock and domestic use. A study conducted in the water bodies between January 2003 and December 2004 showed that effects of eutrophication are wide spread in the lakes and dams. An investigation of primary productivity and effects of physical mixing and material transport was done. In Lake Sare, Lake Victoria waters are transported to the satellite lake during both day and night through Goye causeway that connects the two. The water bodies have higher rates of primary productivity than Lake Victoria. Spatial extent of oxygen depletion due to respiration of organic matter in the water column is lower than the rates of primary productivity. Variability of oxygen depletion is dependent on local thermal and hydrodynamic processes that appear to be controlled by seasonal and short-term wind regimes. Advective transport and convective mixing augmented by wind effects control distribution of nutrients. An analysis of sediment grab samples showed that nutrient fluxes and loading is primarily external rather than from sediments. From the chemical parameters that were measured, soluble reactive phosphorus concentrations ranged from 4.44 to 35.28, Nitrate/nitrite ranged from 4.69 to 335.88 µg/l, ammonia from 29.18 µg/l to 473.14 µg/l and silica from 5.01µg/l to 50.06 µg/l. Fish catches particularly indigenous fish species like *Schilbe intermedius, Labeo Victorianus, Protopterus aethipicus and Clarius gariepinus* depicted stunted growth possibly due to heightened eutrophication and reduced dissolved oxygen levels due to reduced mixing on the water/air interface as a result of macrophyte cover.

Key words : dams, eutrophication, satellite lakes

Introduction

Lake Victoria is the second largest (surface area, 68, 800 km^2) freshwater lake in the world. It lies across the equator between 0^{o}20'N-3^{o}0'S and 3^{o}0'S and 34^{o}53'E at an altitude of 1135 m above sea level (Crul, 1992). It is shared by Kenya (4 100 km^2), Uganda (31 00 km^2) and Tanzania (33 700 km^2). The lake contains numerous islands (Welcomme, 1972) and a catchment of about 192 200 km^2.

In the Kenyan sector of the lake's catchment are located several small lakes and dams. These water bodies include both natural freshwater wetlands and constructed/transformed water supply dams. Some of the studied dams include Futro, Maranda, Masawa, Mwer, Ochilo, Ochot, Ugege, Uranga among others. Most of the dams were communally constructed mostly in the 1950s and 1960s to provide water supply for domestic use and livestock. Others were formed naturally by rivers and under ground water sources that filled natural depressions. Areas in which they are located contain hydric soil with a high water table subject to water logging which is a common indicator of wetland hydrology. The most notable of the water bodies include Lake Sare (500 ha), Lake Kanyaboli (1050 ha), and Lake Namboyo (200 ha) located at 00^{o}02'36''S 034^{o}03'32''E, 00^{o}04'30''N 034^{o}09'36''E and 00^{o}00'23''N 034^{o}05'09''E respectively. These lakes are located within the Yala swamp which covers an area of 17 km^2. They are vital life support and natural assets to communities that live in their vicinities. They are vital sources of water for domestic use and livestock and fishing.

Worldwide observations indicate that water quality continues to deteriorate everyday (Falkenmark, 2000). The situation is even worse in third worlds countries. Populations surrounding the water bodies are some of the poorest. A rapid increase in human and livestock population, open access system and weak legislation have led to a situation in which the satellite lakes and dams are either fully or heavily exploited or over exploited. Water abstraction levels have recently reached an asymptote level and have thus led to high primary productivity. Conflicts over ownership of watering points both for livestock and domestic are a common feature in some of the water bodies. These are manifestations of over-exploitation of the water resources. The effects on the ecosystems have been exacerbated by land-based resource alterations. These have had negative effects on the livelihoods of the surrounding communities and a risk in food security of the poorest. The changes taking place in the ecosystems are likely to lead to reductions in maximum sustainable yields expected from the water bodies, modifications of the resource species composition, health and diversity, increases in the ecosystem instability and variability and a reduction in water quality and safety.

Fallow areas surrounding the water bodies are covered by woody vegetation mainly savanna woodland made of Acacia, Albizzia and Butyrospermum. Others consist of herbaceous vegetation (*Cymbopogon, Hyparrhenia, Londetia* and *Cyperus papyrus*). The areas under natural vegetation are decreasing due to high population pressure and resultant excessive cultivation. The areas are utilized in growing a variety of crops maize, cotton, sisal, tobacco, beans, sugar cane, coffee, sorghum, millet, wheat and root crops mainly cassava with varying levels of fertilizer application containing high levels of Nitrogen, Phosphorus and potassium.

Management of the water bodies has been inadequate or even poor. Though it is generally agreed among the communities on the importance of the water bodies, no serious management measures are in place to control pollution both from run-off from the surrounding farms, direct watering of livestock and washing of house-ware and bathing in the water bodies.

The paper recognizes that, if the water bodies are to be restored to and managed for optimal benefit, there is no alternative to rationalization of the water bodies. This must ensure that the communities that depend on the resources bear the costs of the ecosystems impacts as far as possible. There is also need to ensure that land-based and shore-based activities such as agriculture and washing respond in a similar manner and are held accountable for their impacts on the ecosystem and take appropriate measures to reduce these to the required limits.

Materials and methods

Study area

Sampling for various physical and biological parameters was done at specific sites in several small lakes and dams found in the Kenyan Lake Victoria water catchment (Table 1). Identification of sampling sites was done by a GPS Magellan Model 315 on board a 25-horse power fibre-optic dingy. Sampling was done at specific sites in Lakes Sare, Namboyo and Kanyaboli and in several dams in the Lake Victoria Kenyan water catchment.

Methodology

A portion of water sample collected with a 3 litre van Dorn water sampler was preserved in Lugol's solution and a 2 ml phytoplankton sub-sample was placed in an Utermol sedimentation chamber and left to settle for at least 2 hours. Phytoplankton species were then identified and enumerated using a Zeiss Axioninvert 35 inverted microscope at 400X magnification. Phytoplankton taxa were identified using methods of Huber-Pestalozzi (1968) and Cocquyt *et al.*, (1993). Water temperature and dissolved oxygen were measured with a Hanna HI 9143 oxygen meter, conductivity with a LF 96 meter, pH with a Hanna 8014 pH meter. In Lake Victoria these parameters were determined with a Hydrolab water quality-measuring instrument. Water transparency was determined by a 20 cm diameter *Secchi* disk. Total hardness was determined by EDTA titration with Eriochrome T black and HCL mixture as indicator. Water samples in 500 ml plastic bottles were fixed with acid for laboratory analysis.). Wind speed and direction were recorded with an Anderaa wind speed sensors model 3070 and 2070 respectively. In Lake Victoria, *in situ* current velocities and direction (cms^{-1}, a) were determined with an Anderaa™ minstrommer current meter model SD 4A. Measurements were taken at 1 m depth intervals. The wind velocities were then separated into the four direction components by equaling negative values to the west and south in order to investigate relative contribution of each four-wind direction to wind direction prior to averaging. Surface area and water volumes of the water bodies were calculated from several GPS positions taken on the water bodies' perimeter fence. The water bodies were then stratified and random bottom depths determined by a graduated mast. These were averaged and used to calculate maximum and average depths. The average depths and surface areas were used to determine average water volumes.

Water exchange across the Goye causeway that connects Lake Sare with Lake Victoria was made by taking depth and widths to determine the cross-sectional area of the causeway. Measurements were taken to calculate water exchange (cms^{-1}) using the following formula described in Jeffries and Mills (1990):

$$Dsc=AV$$

where DSc = water discharge (cm^3s^{-1}), V= velocity (cms^{-1}), and A= cross-sectional area of the causeway (cm^2).

Results

From the study it was found that most of the water bodies are communally owned. These communites practice no management regimes and the water bodies are openly accessed. The communities living in the vicinity of the ecosystems, majority who are extremely poor, fetch water for domestic use, bath, wash clothes and water their livestock directly on the watering points. Human settlement, livestock rearing, subsistence agriculture, both planned and unplanned residential areas, informal industrial activities such as sand harvesting characterize utilization of areas surrounding the wetlands.

Macrophytes consisting of *Cyperus papyrus, phragmites australis,* have formed thick walls along the perimeter fences of the satellite lakes. The macrophytes have made L. Namboyo virtually inaccessible and impenetrable.

Some water bodies exhibited anoxic (< 1 mgl^{-1} DO) features in the bottom waters while others had near super saturation throughout the water column. In the dams dissolved oxygen ranged from 6.25 mgl^{-1} to 10.25 mgl^{-1} and surface total ions measured as conductivity ranged from 150 μScm^{-1} to 220 μScm^{-1} while in the satellite these ranged from 6.73 mgl^{-1} to 8.95 mgl^{-1} and 98 μScm^{-1} to 169 μScm^{-1} respectively. During the same period in Winam Gulf, surface dissolved oxygen and conductivity ranged from 8.25 mgl^{-1} to 5.74 mgl^{-1} and 158 μScm^{-1} to 98 μScm^{-1} respectively.

Rainy months were between April to June. May recived the highest amount of rainfall an average of 125 mm while December 2004 had the lowest 14mm. January to March received no rainfall. During the rainy months of April to June DO In Winam Gulf becomes depleted in the lower column layers.

In all the water bodies studied there was dissolved oxygen super-saturation in the surface waters possibly a result of the increased primary productivity enhanced by eutrophication. However, at L. Kanyaboli, Kalenjuok and Ochillo dams there were observed anoxic levels (<1.9 mg^{-1}) in the deeper waters especially in areas covered by macrophytes. Soluble reactive phosphorus concentrations ranged from 4.44 to 35.28, Nitrate/nitrite ranged from 4.69 to 335.88 µg/l, ammonia from 29.18 µg/l to 473.14 µg/l and silica from 5.01µg/l to 50.06 µg/l.

Wind measurements indicate a general northeasterly (average 3 cms^{-1} at L. Sare and 6 cms^{-1} at L. Kanyaboli) and a southwesterly pattern (average 4 cms^{-1} at L. Sare and 8 cms^{-1} at L. Kanyaboli) in the morning and afternoon hours, respectively. Westerly winds were highest on a 24 hour-cycle. The results indicate westerly and easterly wind patterns in the morning and afternoon hours respectively. Winds systems do not indicate major hourly shifts. Diel wind speeds were highest between 14.00 and 18.00 hours. In the satellite lakes water movement exhibited an horizontal water movement corresponding to wind direction. At L. Kanyaboli, the largest of the satellite lakes, an average current speed of 4 cms^{-1} and 6 cm^{-1} was recorded in the afternoon and afternoon hours, respectively.

Table 1. Showing some of the small water bodies and their geographical locations, sizes and other features.

Water body	Latitude	Longitude	Maximum depth, m	Average depth, m	Approximate surface area (ha and or x 1000m^2	Approximate water volume X 1000 m^3
L. Sare	00°01'45''S	034°03'01''E	5.5	3.5	500 h	
L. Kanyaboli	00°04'30''N	034°09'36''E	6	4	1050 ha	
L. Namboyo	00°00'25''N	034°05'32''E	11	7	200 ha	
Ochot dam			2.9	1.9	47.780 m^2	90.145
Maranda dam	00°05'42''S	034o13'35''E	1.7	1.05	16.674 m^2	17.507
Ochilo dam	00°00'30''S	034°16'06''E	1.9	1.2	17.732 m^2	21.279
Uranga dam	00°05'19''N	034°16'22''E	2.5	0.6	3.653 m^2	2.192
Masawa dam	00°04'54''N	034°14'00E	1.5	1.1	4.764 m^2	50.446
Futro dam	00°04'07''N	034°16'03''E	1.2	0.7	23.919 m^2	16.673
Kalenyjoouk dam	00°04'31''N	034°13'05''E				
Mwer dam	00°07'11''N	034°10'15''E	5	1.5	122.051 m^2	186.564
Mauna dam	00°12'31''N	034°09'21''E	4	2.3	46.685 m^2	110.693
Yenga dam	00°13'00''N	034°12'36''E	4.5	2.1	18.732 m^2	39.337

Concentration of chlorophyll-*a* in various dams found in Lake Victoria basin is shown in table 2. An analysis of biological (chlorophyll, productivity and algal biomass) and chemical parameters (temperature, DO and pH levels) suggests occurrence of intensive biological activity. In the dams chlorophyll-*a* ranged from 6 μgl^{-1} to 300 μgl^{-1} with an average of 42 μgl^{-1}.

Table 2. Chlorophyll-*a* concentration μgl^{-1}. in two major satellite lakes in the Lake Victoria catchment.

Water body	Ecological site	Concentration, μgl^{-1}. during the day	Concentration, μgl^{-1}. at night
Lake Sare	River mouth	15.1	11.1
Lake Sare	mid-lake	24.4	17.8
Lake Kanyaboli	River mouth	27.3	15.1
Lake Kanyaboli	mid-lake	17.4	13.4

Algal species richness in the water bodies varied from 12 to 43 with the highest number recorded at L. Namboyo. Variations in blue green algae were high as opposed to other groups (Table 1). Dinoflagellates were represented mainly by *Strombomonas* sp. Concentrations of algal cells were particularly high at Maranda dam located at Bondo District. Concentrations of up to 5000 cells ml^{-1} (Figure 2) were recorded. In most of the dams algal cells were stunted, small in size and unhealthy. Algal species composition in some selected water bodies is given in Figures

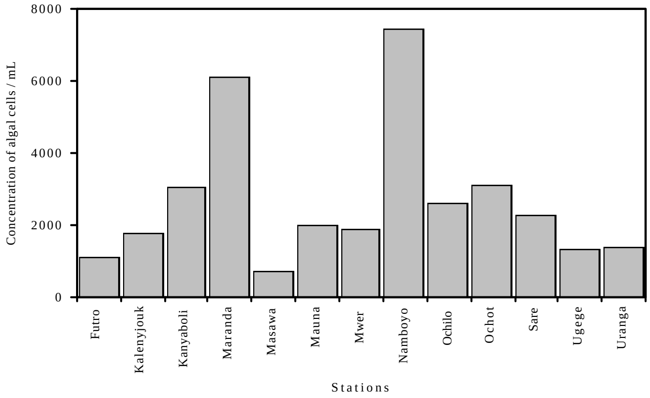

Figure 1. Algal composition of major taxa and concentration cells (cell mL^{-1}) in some satellite lakes and dams of the northern catchment of L. Victoria, August/September 2004.

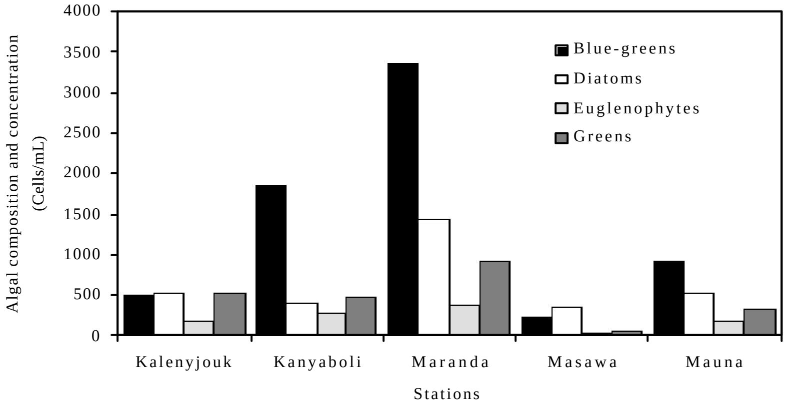

Figure 2. Concentration of algal cells (Cell mL^{-1}) in stations in the satellite lakes and dams of the northern catchment of L. Victoria in the period August-September 2004.

In many stations blue-green algae were found to be predominant in the composition by over 50%. There was a wide range in the concentration of chlorophyll-*a* varying from with an average of (Figure 5). Diel changes in chlorophyll-*a* concentration were minimal indicating that there is no significant difference (Table 2). The chlorophyll-*a* concentration was higher in the dams (6 μgL^{-1} to 300 μgL^{-1}, with an average of 42 μgL^{-1}) compared to those recorded in Lake Victoria (5 - 230 μgL^{-1} with an average of 36) during the same period.

The fish, mainly *Lates niloticus* and *Oreochromis niloticus* caught in Lake Victoria were of comparatively longer lengths than those caught in the satellite lakes and dams (Table 3). Fish caught in the dams particularly endemic fish species like *Schilbe intermedius, Labeo Victorianus, Protopterus aethipicus* and *Clarius gariepinus* depicted stunted growth characteristics. In Lake Victoria fish were observed to mature at much smaller sizes compared to those in Lake Victoria (Table1).

Table 3. Sex and maturity levels of fish in various water bodies in the Lake Victoria catchment and those in Lake Victoria.

Water body	**Fish, n=30**	**Sex**	**Mean length, cm**
Kalenjuok Dam,	Nile Perch *Lates niloticus*	male	28.4
Kalenjuok Dam	Nile Perch *Lates Niloticus*	female	41.5
Kalenjuok Dam	Nile Tilapia, *Oreochromis niloticus*	male	38.6
Lake Victoria, Nyanza Gulf	Nile Perch *Lates niloticus*	Male	32.3
Lake Victoria, Nyanza Gulf	Nile Perch *Lates Niloticus*	female	43.1
Lake Victoria, Nyanza Gulf	Nile Tilapia, *Oreochromis niloticus*	male	41.5

This can be attributed to both natural and human induced factors. The water bodies in the lake's water catchment are mainly re-charged by rainfall and seasonal rivers..Evaporation in the region (located close to the equator) coupled with the shallow nature of the water bodies and heightened eutrophication may have resulted in deterioration of water quality thus rendering the ecosystems inhabitable especially in the epilimnetic waters.

Flow rates across the Goye causeway were between 0.3 cms^{-1} and 40.2 cms^{-1} with a maximum of 120 cms^{-1}. The latter was observed to flow in the direction of the lake. Thus water exchange across the causeway with a cross-sectional area of approximately 533 000 cm^2 was approximately between 15900 cm^3s^{-1} and 2 142 660 cm^3s^{-1} with a maximum o f 63 960 000 cm^3s^{-1}. Swift flow rates were recorded especially in the afternoon hours. The direction of flow was observed to depend on wind direction and differences in water level between the lake and Lake Victoria. An increase in water level in Lake Victoria triggered a flow into Lake Sare and vice-versa.

Besides run-off rainwater contributes significantly to eutrophication of the water bodies. Studies carried out by the Kenya- Belgium joint project in the early 1990s revealed that rainwater contributes an appreciable amount of nutrients in the Lake Victoria basin (table 4)

Table 4. Mean chemical composition of rainwater onto Lake Victoria (Kenya). N=9 (values in parentheses indicate the range)

Parameter	pH	Conductivity μScm^{-1}	Total alkalinity $CaCO_3$ mgl^{-1}	Total hardness $CaCO_3$ mgl^{-1}	NO_3-N µg NL^{-1}	SRP μgPL^{-1}	Reactive sil;ica (Rsi) mgl^{-1}
Constituent	(5.6-7.1) 6.58	(6.29-31.5) 17.9425	(5-24) 14.5	(5-17) 11	(0.607-5) 170.2	(6.3-50.3) 9.064	(0-2.5) 0.944

Discussion

The principal seasons in Lake Victoria and its catchment consist of dry and rainy period. (Ogalo, 1981). Most cooling and mixing take place in the dry season and maximum stratification during the rainy season. Most influential factors are rainy and wind as opposed to the earth's rotation (Lewis, 1987).

Wind fields play an important role in the hydrodynamic process. In the Lake Victoria water catchment, these winds blow with considerable force especially in the afternoon hours.It creates surface and internal waves in the water, which result in currents and water movements, transport of dissolved substances, mixing of the water column and suspension of bottom sediments.The prevailing winds tend to alternate between morning ad afternoon hours possibly influenced by diurnal heating and cooling of the land surface.

In almost all the water bodies studied, blue-green algae were dominant by over 50%. This is thought to be a direct result of direct supply of nutrients from agricultural lands that surround the water bodies. Livestock that water the water bodies directly deposit high amounts of waste that is fodder for the rapid proliferation of the phytoplankton. The situation is compounded by the shallow nature of the water bodies and the constant perturbations from winds, human and livestock causing re-suspension of nutrients from the bottom sediments. High algal proportions as was recorded in the water bodies can produce and release sufficient toxins causing deterioration in both water quality and safety.

The spatial variability of the oxygen depletion ($<$ 1 mgl^{-1}) that some water bodies exhibited is partly due to respiration due to decomposing organic matter and the nature of the soils.) The hydric soil of wetlands are saturated, flooded and tend to develop anaerobic conditions in the upper part (Gichuki, in press) Possible consumption of DO by bacteria that decompose organic matter entrapped in the bottom water contributes to this anaerobic condition. Reduced mixing on the water/air interface as a result of macrophyte cover is also a contributory factor in the anoxic condition.

Main causes of pollution in the small water bodies include effluents and run-off containing nutrients such as nitrates and phosphates. These nutrients have stimulated a massive growth of aquatic plants and algae. The vegetation are subsequently clogging watering points our waterways. Decomposition of dead vegetation due use up dissolved oxygen as they decompose and block light to deeper waters. This, in turn, proves very harmful to aquatic organisms particularly fish as it affects the respiration ability or fish and other invertebrates that reside in water. Hence fish caught in most of the water bodies depict stunted growth.

Anthropogenic activities on the terrestrial environment of the water bodies have resulted in increased run-off, sedimentation and nutrient fluxes into the water bodies. Wash-off from plowed fields, charcoal and logging sites and eroded riverbanks when it rains have led to high levels of sedimentation. When the sediments enter the various water bodies lead make fish respiration becomes difficult, plant productivity and water depth become reduced, and aquatic organisms and their environments become suffocated. This is possibly one of reasons for reduced fish catches in the small water bodies.

Lake Kanyaboli, the largest of the three satellite lakes is charged by direct precipitation, backwash waters from Lake Victoria through the Goye causeway and R. Yala. As in the other satellite lakes, winds induce a corresponding horizontal water movement. A change in direction in the wind direction results in a similar response in the water mass Water exchange between the Lake and Lake Victoria seems to be controlled by water level changes between the two. A rise in Lake Victoria water level leads to a backwash flow into Lake Kanyaboli and vice versa.

An annual series of fish deaths were reported in Lake Victoria (Ochumba, 1987) caused by de-oxygenation. Studies to determine the cause of the deaths attributed them to sudden upwelling of deep anoxic waters to the surface thereby suffocating the fish (Ochumba, 1987). Though no fish deaths have been reported in the satellite lakes and dams, the lack of life exhibited by minimal fish catches, stunted growth characteristics, severity of algal blooms and infestation of macrophytes e.g water hyacinth, *Eicchornia crassipes,* (Mart Solms), papyrus, *Cyperus papyrus* that are often known to inhabit extremely polluted and unsafe water sources are common.

In Winam Gulf, which is relatively shallow and comparable to the satellite lakes, water circulation system is responsive to the large-scale monsoon system and the cooling rainy season. Isothermal features and high oxygen levels throughout the water column characterize the water column. This scenario is replicated in the satellite lakes. However in the dams, which are extremely shallow, the surface waters exhibit dissolved oxygen saturation in the surface waters and anoxic tendencies in the deeper waters. This can be attributed to the possible high levels of primary productivity in the surface waters due to algal blooms. However the sub-surface waters get depleted of oxygen due to inhibition by macrophyte cover and high oxygen demand due to respiration of decomposing organic matter.

The underlying reason why most communities who live in the vicinity of the satellite lakes and dams have been slow to adopt effective management regimes is probably because, firstly, it takes time to realize that the water bodies are exhaustive and secondly, because transitions towards new management systems can be costly. For a long time the water bodies were considered inexhaustible and the perception was that controls were not necessary. However slowly and painfully, the communities have realized that this is necessary. This scenario is compounded by a lack of comprehensive environmental policies as well enough and reliable information (Gitonga, 1992; Odera *et al*, 2000; El-Fadel *et al*., 2001)

These ecosystems constitute vital life support and natural assets that should be conserved. Though the water bodies in the Lake Victoria basin are fully exploited, access remains practically open with no or minimal restrictions on water use and conservation. Though human and livestock populations in the Lake Victoria Basin have grown at an unprecedented rate, conservation legislations and management regimes have not been enacted to keep pace with their usage.

Conclusion

The proportion of blue-green algal cells in many water bodies around Lake Victoria is alarmingly high possibly as a consequence of abundant supply of nutrients from rich agricultural lands near them. The situation is exacerbated by the shallow nature of many of the water bodies and the constant perturbations from both livestock and humans causing re-suspension of nutrients. Similarly, chlorophyll-a values observed during this survey were high and strong indicated that most of the water bodies are eutrophic. This situation calls for urgent intervention measures to avert health and environmental problems.

The open access and communal ownership of the water bodies pose a major handicap in the management of the water resources. This is mainly because at the lowest levels of communities, the village, weak legislations are applied across the board. This is mainly because communities that live within vicinities of the resources are often the poorest of the poor and are therefore pre-occupied with survival. Since the water resources are often small water masses with no obvious national importance to the central government, implementation water management regulations are minimally felt.

Nutrient enrichment run-off from the surrounding farms remains the main cause of eutrophication in the small water bodies. Contribution by rainwater is a also a possible contributor.

As a management measure, better agricultural methods should be practiced with a view to protecting the water bodies from pollution effects. As a first step, surrounding communities should be encouraged to make water points for livestock away from the dams. A return to optimum environmental conditions should see an improvement in ecological efficiency thereby enabling higher fisheries production in addition to enabling and sustaining diversity.

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