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A Limnological Survey of Malagarasi River in Western Tanzania

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Abstract

The present study surveyed the limnological functioning of the Malagarasi River in Western Tanzania during the dry season from the river delta at the Lake Tanganyika confluence point to the source of the river at the Burundi-Tanzania Border. A total of 66 samples were samples from 8 different accessible sites using standard methods to determine dissolved oxygen (DO), turbidity, temperature, electrical conductivity (EC), redox potential (Eh), pH and transparency. Nutrients such as chlorophyll a, phosphate (PO_4^{3-}), nitrate (NO_3^-), silica (SiO_2) and iron (Fe^{2+}) and alkalinity (HCO_3^-) were determined in the laboratory. Data show sporadic variations in the abiotic parameter levels and river geomorphology amongst the sampled sites. The mean concentrations of Fe^{2+} and PO_4^{3-} were noted to increase with depth at some sites. These variations are attributed to processes including dissolution, diffusion, reduction, absorption, adsorption, photosynthesis, nitrification, denitrification and mixing effects. We also found that the geomorphology of the river system is strongly driven by both the geology of the area and the anthropogenic activities as shown by the measured parameters. Quantification of both climate variability and tectonic effects on the abiotic parameters of the river is highly recommended for effective evaluation of the limnological functioning of the Malagasi River System.

Keywords: *Limnology, Malagarasi River, Western Tanzania, abiotic parameters, processes, anthropogenic activities.*

1. Introduction

The heightened awareness of the deterioration of aquatic environment and the need for action has attracted engineers and a new generation of limnologists since 1970s (Horne & Goldman, 1994). It is essential that aquatic resources are managed more sensibly on both local and global scales. This problem is so pressing that it has greatly influenced contemporary research in limnology. Today limnology plays a major role in water use and distribution as well as in wildlife habitat protection amongst the tropical ecosystems. For example, the eutrophication of lakes has hampered water quality for both humans and fish (Wetzel, 2001).

Knowledge of the limnology of tropical rivers has increased substantially over the last decade consequent to increased pressures from land, atmospheric, and riverine inputs (Nkotagu & Athuman, 2007). Rivers accumulate pollutants and are easily damaged (Nkotagu & Athuman, 2004). Nevertheless, the limnology of Malagarasi River within the Lake Tanganyika Basin remains remarkably understudied, although there are notable exceptions (e.g. Nkotagu, 2008; Nkotagu & Athuman, 2007; Langenberg *et al*., 2003). Relatively few studies have characterized the abiotic features of the Malagarasi River system from the river source through various points to the confluence point of the river with the Lake Tanganyika.

However, the few studies conducted in some points of the river system within the Malagarasi-Muyovosi Wetland Ecosystem have found increased pollution in the river due to the process of development and population increase. The findings by Athuman and Nkotagu (2012) show that impacts from pollution influx within the ecosystem are quite alarming. According to Joseph (2005) the latter may cause water crisis. Gilliland and James (1997) define crisis as a perception of an event or situation as an intolerable difficulty that exceeds the person's resources and coping mechanisms. Caldwell as cited in Miller (2002) says, *"The environmental crisis is an outward manifestation of a crisis of mind and spirit and more importantly, the crisis is concerned with the kind of creatures we are and what we must become in order to survive".*

Further, in 1991, the Ecological Society of America, made up of many of the world's leading ecologists, issued the following warning to humanity (Miller, 2002): *"Environmental problems resulting from human activities have begun to threaten the sustainability of earth's life-support systems".* These human activities have compromised the quality and the productivity of many aquatic ecosystems and thus the question of quality of the environment has now become the concern of many people around the globe (e.g. Athuman, 2013; Athuman, 2012a, 2012b; Athuman & Nkotagu, 2012; Easton, 2011; Easton 2008).

In this regard therefore, this study focused on the following lines of inquiry in order to address the limnological fluctuations of the abiotic parameters for the entire river system from the mouth of the Malagarasi River in Tanzania at the delta to the source of the river: (i) What are the processes influencing the chemical character and the water quality of the river? (ii) What are the driving forces to the river geomorphologic behaviour?

2. Materials and Methods

2.1. Study site

The survey was conducted at 8 accessible sites from the lower to the upper reaches of the Malagarasi River for six weeks during the dry season. The study sites (Fig. 1) were coded as follows; 1=Malagarasi River at the Delta, 2=Malagarasi River at the Ilagala Ferry, 3=Malagarasi River at the Igamba Water Fall, 4=Malagarasi River at the Uvinza-Mpanda Bridge, 5=Malagarasi River at the Nyanza Salt Mine, 6=Malagarasi River at the Uvinza-Nguruka Bridge, 7=Malagarasi River at the Kasulu-Kibondo Bridge and 8=Malagarasi River at the Burundi-Tanzania Border. The Malagarasi River is about 450 km long from the Burundi-Tanzania Border at Manyovu area in Buhigwe District to the Lake Tanganyika at its delta. The river was chosen as a study area due to its accessibility and exciting environment which according to Nkotagu and Athuman (2007) supports life of many people and other organisms within the Lake Tanganyika sub catchment.

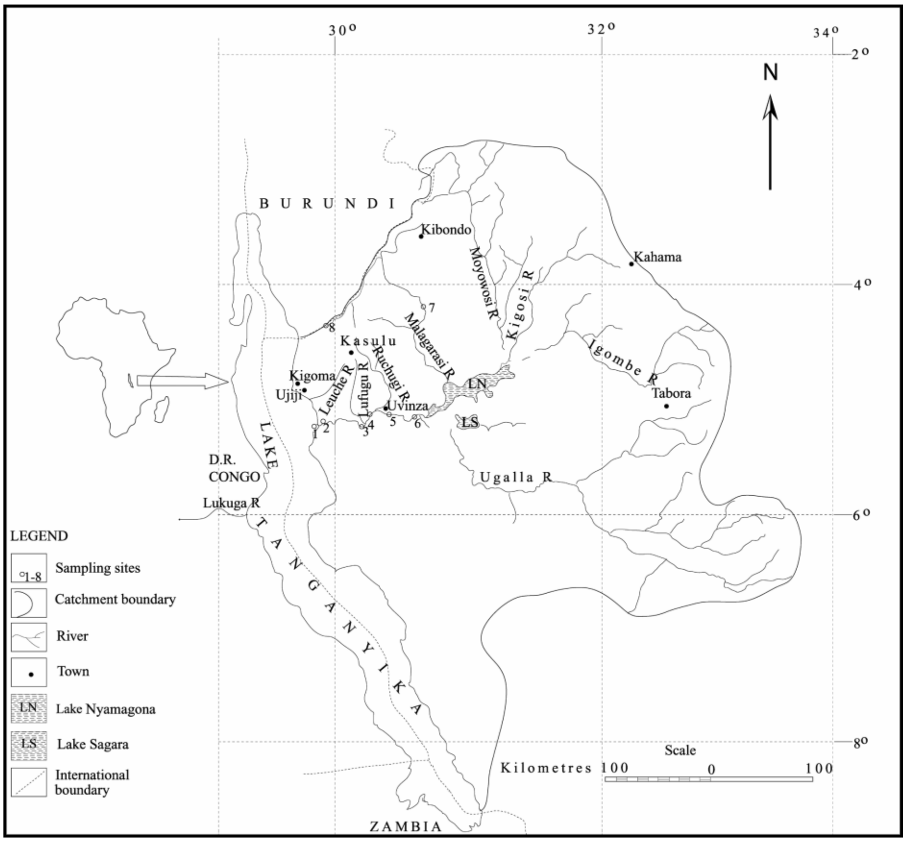

Figure 1: Location of the Malagarasi River System showing the sampling sites

2.2. Geology of the study site

The river is located along mesoproterozoic sandstones of about 1,200 million years old with lithology covering shales, quartzites, dolomitic limestones, gneisses and basalts along with quaternary sediments at some places (Pina *et al.*, 2004). These rocks are exposed differently at various places along the riverbed thus influencing the geomorphology of the river behaviour. Since the river is located within the western arm of the Eastern African Rift Valley System its geomorphologic behaviour is said to essentially be both geologically and tectonically controlled (Athuman & Nkotagu, 2012; Nkotagu, 2008).

2.3. Field work

Sampling sites were initially selected based on water depths as measured in metres from the water surface at various positions on the river using a SCUBA device. Sampling was generally conducted at appropriate available maximum depths at each site following Crosby and Patel (1995). The sites were then located with a Geographical Positioning System (GPS). A total of 66 water samples were collected depth wise at selected intervals up to the riverbed and across the river at three positions: right bank, left bank and centre.

The sampled water was collected in half and 1-litre capacity plastic bottles filled to the brim using a 2-litre water sampler. Aliquots of 400 ml and 800 ml of each water sample respectively were filtered using glass fiber 47 mm size filter papers. The filtrate aliquots were transported on ice to the laboratory for Silica (SiO_2), Nitrate (NO_3^-), Phosphate (PO_4^{3-}) and Iron (Fe^{2+}) determinations. The remaining unfiltered water samples were similarly transported to the laboratory for alkalinity determination.

Sample residues were each placed into a test tube after which 10 ml of 90% ethanol were added. The test tubes were then wrapped with aluminium foil, marked and stored overnight in a cooler for chlorophyll *a* readings.

In situ physical parameters including electrical conductivity (EC), redox potential (Eh), dissolved oxygen (DO), pH and temperature were measured at each sampling site using a Multi Probe meter 340i model lowered at different depths. In addition, turbidity was measured using a HACH turbidimeter 2100P model.

2.4. Laboratory work

The water samples were stored at 4 °C and analysed at Tanzania Fisheries Research Institute (TAFIRI) laboratory in Kigoma. Fluorescence readings for chlorophyll *a* were taken using a Fluorometer before and after acidifying the sample residues with 0.1 N HCl. The absorbance readings were then converted into concentrations as chlorophyll *a* using the formula (1) according to McIntyre (2004 unpublished data):

Chl a ($\mu g\ l^{-1}$) = 0.003 × ($F_{before\ acid}$ - $F_{after\ acid}$) × Extraction Volume (ml)/Water Filtered…………...…(l)

Where: F is the Fluorescence of the sample, which is equivalent to the absorbance on a Spectrophotometer and Chl a is Chlorophyll a in $\mu g\ l^{-1}$.

Unfiltered water samples were tested for alkalinity using a titrimetric method with 0.1 N HCl and results expressed as HCO_3^- (mg l^{-1}) as explained by APHA *et al*. (1998). Nutrients including SiO_2, NO_3^-, PO_4^{3-} and Fe^{2+} were determined from the filtered water samples using a HACH Spectrophotometer DR/2010 model according to Lin (2007), HACH (2002), APHA *et al.* (1998) and WHO (1993). The obtained data were averaged to obtain the mean values and then analyzed using Microsoft Excel packages and interpreted following Bluman (2007), Gupta (2006), Kothari (2004), Davis (1986) and Drever (1982).

3. Results and Discussion

3.1. Turbidity

The mean turbidity variation with depth in the river ranged from 2.1 to 23.5 NTU and increased with depth at almost all the sites. High values were measured at the Kasulu-Kibondo Bridge. This is attributed to increased suspended sediments or suspensoids in the water due to anthropogenic activities including agriculture and pastoralism and probably increased blooms of planktonic organisms (Cohen, 2003; Wetzel, 2001; Wetzel & Linkens, 1990).

The mean variation of chlorophyll a with turbidity showed a strong positive correlation (r^2=74%) at the Uvinza-Mpanda Bridge (Fig. 2). This indicates that the observed trend of turbidity at this site is a consequence of increased phytoplankton abundance. However, the reciprocal relationship between chlorophyll a and turbidity was observed at the Delta implying that turbidity at this site is mainly a function of suspended sediments. Increased agricultural activities are noted a few metres upstream of the Delta (Site 1) and close to the banks of the river thus contributing significantly to high siltation and erosion and consequently affecting the geomorphology of the river (depth and width). The fact that the river is located within the mesoproterozoic sandstones and the quaternary sediments at some places, this might favour the siltation and erosion processes especially during the wet season.

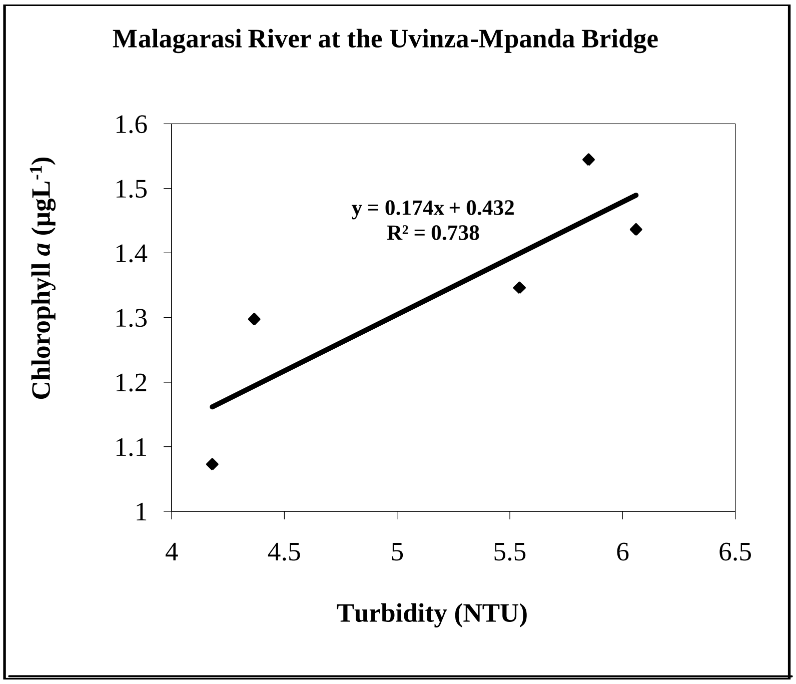

Figure 2: Mean variation of chlorophyll *a* (µg l^{-1}) with turbidity (NTU) (After Nkotagu & Athuman, 2007)

3.2. Dissolved Oxygen

The concentration of dissolved oxygen was high at most of the sampling sites in the river with a mean value of 7.23 mg l^{-1}. The oxygen levels decreased with depth at most sites of the river as indicated at the Delta with higher levels at the water surface than the bottom (Fig. 3). This may be attributed to increased photosynthetic activities of algae at the water surface. The low oxygen levels at the bottom may be due to oxidation of organic matter especially at the sediment-water interface (Wetzel, 2001). According to Horne and Goldman (1994) this may also be due to organic pollution of non point sources, such as dead leaves and animal excreta. Field observation at these sites shows presence of lots of leaf litter at this site due to falling aging trees at the banks of the river and presence of grazing animals.

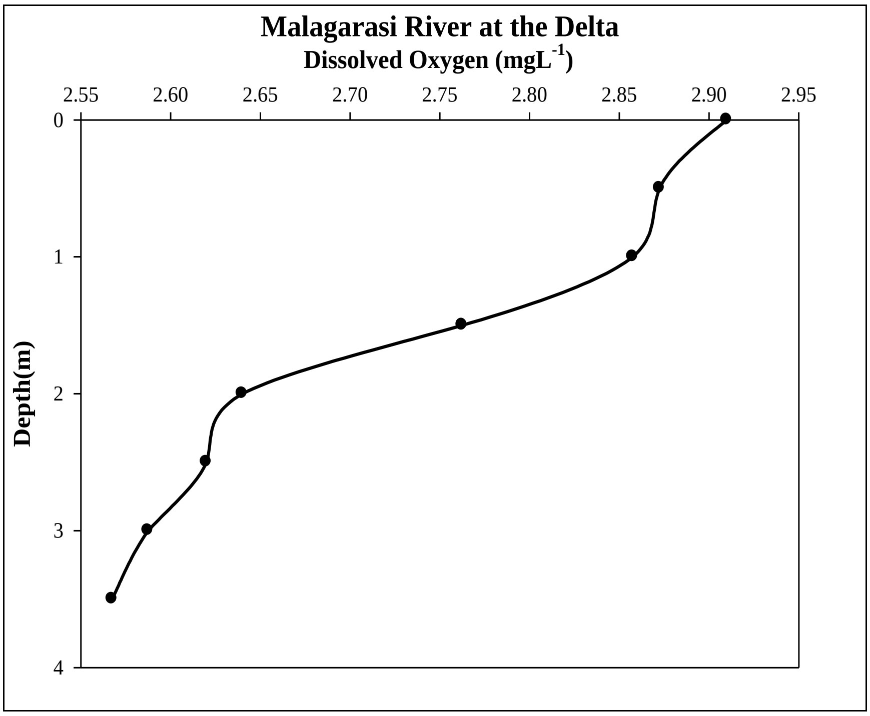

Figure 3: Mean variation of dissolved oxygen (mg l^{-1}) with depth (m)

The mean variation of chlorophyll *a* increased with dissolved oxygen concentration at most sites of the river and was strongly correlated $(r = 68\%)$ as shown at the Delta (Fig. 4). This supports the presence of increased photosynthetic algae activity as summarized in equation (2):

$$\text{Light Energy} + 6CO_2 + 6H_2O \rightleftharpoons C_6H_{12}O_6 + 6O_2 \qquad (2)$$

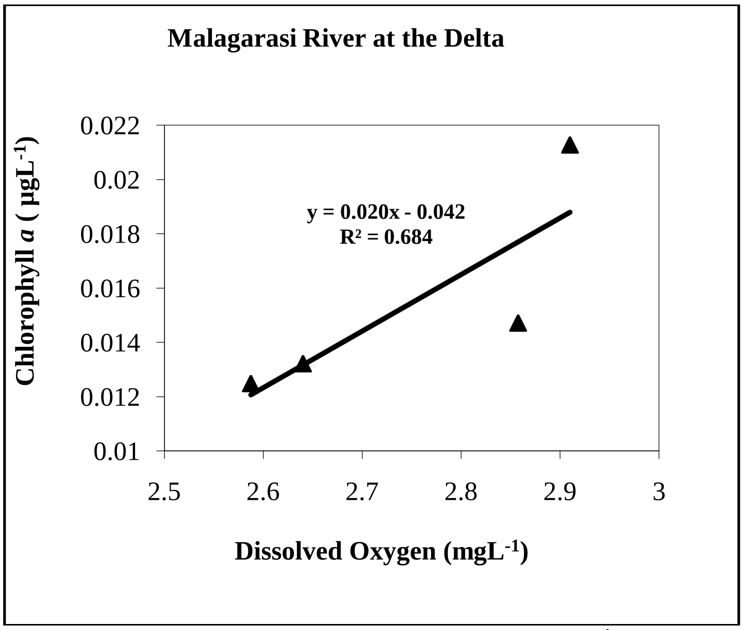

Figure 4: Mean variation of chlorophyll *a* (µg l^{-1}) with dissolved oxygen (mg l^{-1})

However, the orthograde oxygen profiles were observed at some few sites e.g. at the Igamba Water Fall. This may be due to fast circulation of aerated water as it falls from high elevated riverbed to deep depths below the water surface depending on the potential energy of the falling water. Water temperature also decreased with increasing dissolved oxygen at this site thus, supporting the observed oxygen profile.

3.3. Temperature

Temperature ranged from 22.26 to 27.3 °C. At some few sites a decreasing trend with depth was recorded as indicated at the Delta. Cohen (2003) and Horne and Goldman (1994) explain this phenomenon as a consequence of decreasing light intensity from the surface to deeper waters.

3.4. Electrical conductivity

Salinity of water increased from the upper to the lower reaches of the river system ranging from 70.0 to 495.2 µS cm^{-1} with the highest values observed at the Igamba Water Fall. This may be attributed to increased dissolution of minerals and washing in nutrients from anthropogenic sources as the river flows from the source to the river mouth and that the river is at most parts always under saturated. In addition, the high salinity values recorded at the Igamba Water Fall may also be due to mixing effects promoted by high energetic falling water that stirs the bottom sediments containing saline pore waters. Furthermore, salinity increased with depth at most sites especially at the Igamba Water Fall. This observation may be attributed to increased dissolved ions at higher depths promoted by favourable redox conditions (Langenberg *et al.,* 2003).

3.5. pH

The pH values ranged from 6 to about 9 throughout the river system at the sampling sites. High consumption of CO_2 by photosynthetic activities may explain the presence of high pH values at the river system. In addition the observation is supported by high pH values recorded at the Igamba Water Fall which increase with depth. This observation is also supported by higher values of alkalinity (HCO_3^-) in the river that ranged from 21.1 to 100.8 mg l^{-1} with high values at the Igamba Water Fall.

3.6 Silica

The mean variation of silica concentration with depth ranged from 7.6 to 24.4 mg l^{-1} for the entire river system and decreased with depth at most sites as shown at the Igamba Water Fall. The decrease of silica with depth at these sites indicates increased primary productivity as silica is used by diatoms for building their cell walls. This observation is supported by the strong positive correlation between silica and chlorophyll *a* as shown at Igamba Water Fall (Fig. 5) thus indicating that silica concentration may predominantly be biogenic at these sites. However, at some sites along the river system, the mean concentration of silica shows a weak negative correlation with chlorophyll *a* implying that at these sites silica concentration is essentially inorganic as demonstrated at the Delta.

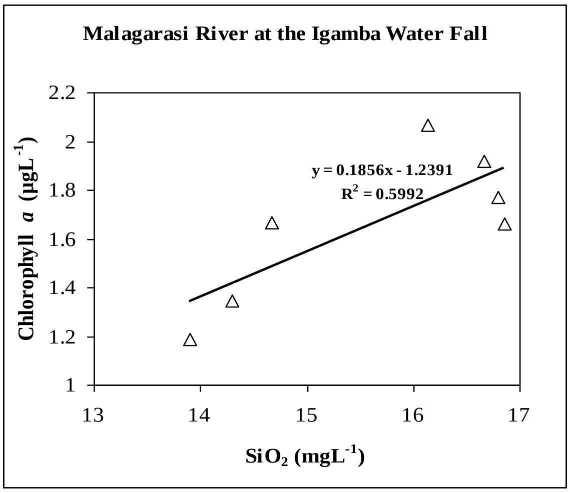

Figure 5: Mean variation of chlorophyll *a* (µg l^{-1}) with SiO_2 (mg l^{-1})

3.7. Nitrate

The mean variation of nitrate concentration with depth ranged from 0.4 to 1.75 mg l^{-1}. Higher concentrations were measured at the Kasulu-Kibondo Bridge, Uvinza-Nguruka Bridge and Igamba Water Fall suggesting wide use of fertilizers on the farms adjacent to the river banks as well as other land use impacts within the river catchment.The increased agricultural and pastoral activities are attributed to increase in population within the catchment. At sites including the Delta, Uvinza-Nguruka Bridge and Kasulu-Kibondo Bridge nitrate concentration decreased with depth. This may be attributed to decomposition of organic matter towards the riverbed resulting in the promotion of denitrification process and finally jeopardizing the chemical character and the water quality of the river.

However, at other sampling sites including Igamba Water Fall, Uvinza-Mpanda Bridge, and Nyanza Salt Mine, the mean concentration of nitrate was observed to increase with depth. This phenomenon indicates sediment water interface disturbance at these sites. For example at Igamba Water Fall, falling water disturbs the sediment water interface thus promoting diffusion of nutrients from the sediment pore waters into the overlying water.

3.8. Phosphate

The mean phosphate concentration varied with depth and ranged from 0.01 to 0.08 mg l^{-1} at the sampling sites. At most sites the mean concentration of phosphate decreased with increasing depth from the water surface as observed at the Kasulu-Kibondo Bridge and Nyanza Salt Mine along with Malagarasi Delta. This is attributed to adsorption of phosphate on to sediments enriched with ferric oxides and or ferrous hydroxide depending on the field stability conditions prevailing there. The increasing trend of phosphate from the surface to the bottom proves that the phosphate comes from the farms within the catchment area where the use of fertilizers is observed.

Further, the mean concentrations of ferrous (Fe^{2+}) iron and phosphate were noted to increase with depth at some sites as demonstrated at the Uvinza-Nguruka Bridge. According to Wetzel (2001), these observations may be attributed to reducing conditions as supported by the reciprocal correlation (r^2=92%) between redox potential and pH as shown in Figure 6 supporting the field stability of ferrous iron (Fe^{2+}). The inferred stable ferrous (Fe^{2+}) iron favours the release of adsorbed phosphate and hence its increase with depth at this particular site, albeit, the mean phosphate concentration that shows a weak correlation with ferrous iron (Fe^{2+}) values at most sites including at the Uvinza-Nguruka Bridge.

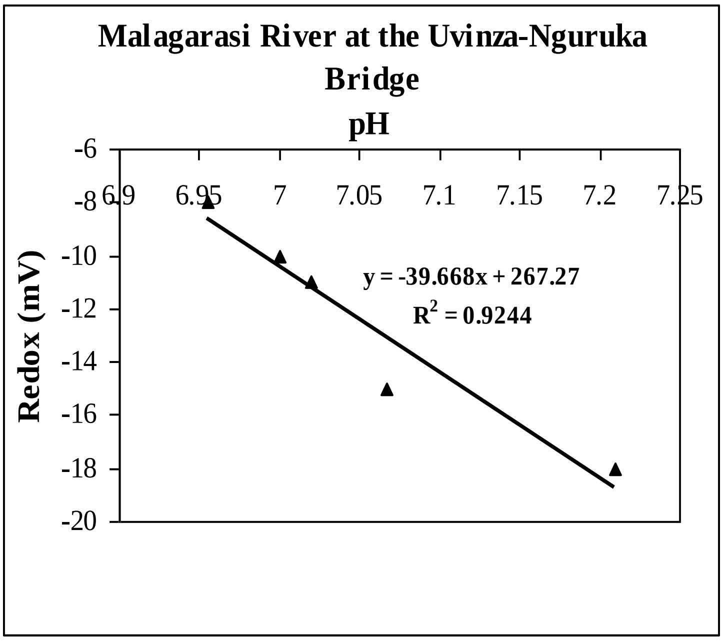

Figure 6: Mean variation of Redox (mV) with pH

4. Conclusions and Recommendations

The data show that several processes including dissolution, diffusion, reduction, absorption, adsorption, photosynthesis, nitrification and denitrification along with mixing effects control the levels of abiotic parameters at the studied sites as a result modifying the chemical character and the water quality of the river.

The river geomorphology varies both depth wise and width wise at the sampling sites and seems to be driven by tectonic activities including noted tremors and earthquakes typical in the Eastern African Rift Valley. Increased agricultural and pastoralism activities observed along the banks of the river result in increased sedimentation thus in turn decreasing the river depth. Increased sediments also may result from untimely increased heavy rainfall emanating from the observed weather changes hence increasing soil erosion in the catchment and deposition by surface runoff in the river contributing to the observed decreasing river depth and width.

Future work is recommended to focus on the quantification of both climate variability and tectonic effects on the abiotic parameters of the river for effective evaluation of the limnological functioning of the Malagarasi River System.

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