STUDY OF NUTRIENT POLLUTANTS AND THEIR IMPACTS ON THE WATER QUALITY OF THE MINDU RESERVOIR AT MOROGORO MUNICIPALITY

Consolatha J. Ngonyani[1] and Hudson H. Nkotagu[2]

[1] = Ngonyani Consolatha, J., University of Dar es Salaam CoET Chemical and Process Engineering, P.O. Box 35131 Dar Es salaam Tanzania (konsolatha@yahoo.com).

[2] = Nkotagu, H. H., University of Dar Es Salaam, Faculty of Science, Geology Department, P. O. Box 35052, Dar Es Salaam, Tanzania (hudson@.udsm.ac.tz).

ABSTRACT

The physical-chemical parameters characterization of Mindu Reservoir, whose 50% of its waters is being plagued by aquatic weeds, involved the analyses of water and sediment samples that were collected during the dry season. As the nutrients levels of Mindu waters were determined, phosphorous (TP - PO_4^{3-}) levels were found to be high enough for supporting eutrophication process. Likewise Nitrogen/Phosphorous ratios average of 8.51 ± 4.32 suggested a Redfield behavior of nutrients with nitrogen being a limiting one. The dominant clay minerals of the Mindu surficial sediments were found to be kaolin and illite, where as the Cation Exchange Capacity values were found to be high enough for the sorption of nutrients and pollutants. Both river inflows, overlay-flows and sediments forms the mode of transport of nutrient, with the later behaving as sinks of nutrients through out the year. The evaporation, bio-geo-chemical and Nitrogen fixation processes along with macrophyte productivity, support the hypotheses that physical-bio-geo-chemical processes influences the spatial distribution of major ion in the Mindu Reservoir. These findings classify Mindu as eutrophic, calcium magnesium bicarbonate type. A detailed multidisciplinary study that involves more than one year cycle was recommended, to capture inter seasonal variability, and for the modeling of the sequestration of nutrients in various trophic levels.

Key words: Mindu reservoir, eutrophication, Redfield ratio, macrophyte, downstream evaporation hydro biogeochemistry.

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INTRODUCTION

Mindu water reservoir was constructed with the aim of solving water shortages and to control flow on the Ngengere River (MOWASA, 2001). Currently it is the major water source, supplying more than 90% of domestic and 70% of industrial water requirements for Morogoro municipality. However, within the 18 years since its construction 50% of its volume has been invaded by macrophytes, e.g. water lilies (*Nymphaea sp*), musk grass (*Chara sp*) horntail and (*Ceratophyllum demersum,* L). The Reservoir has also been impacted by various anthropogenic activities (Sibuga, 1997; Mbago, 1999; MOWASA, 2001). None of the previous studies has made the quantitative assessment of nutrients levels of the entire Reservoir in relation to the current macrophyte invasion. This paper aims at discussing the status of nutrient pollution of Mindu Reservoir and its impacts on both water quality and the macrophyte invasion levels.

GENERAL DESCRIPTION OF MINDU RESERVOIR

Mindu Reservoir is located 500 m above sea level, between latitudes 6° 51' S to 6° 52' S and longitudes 37° 30' E to 37° 40' E, southeast of Ngerengere River, about 7 km from Morogoro town; has both the surface and catchments areas of 0.2224 and approximately 303 km^2 respectively. The Reservoir's deepest point measures at 12 m during the rain season. The evaporation is 5 mm per day (0.5% of total volume per annum) while siltation rate measures at 0.5 % of total volume per annum (MOWASA 2001). The inflowing and out flowing Rivers are clearly shown in (Figure **1**). Similarly Mindu geology, climate and land use are well covered by several authors (Sampson and Wright, 1964; Rapp *et. al.*, 1973). A very long dry period between June and October, and persistent afternoon hot-dry local breezes and strong SE trade winds of June to September gradually displaces surface waters (towards the outlet), in a manner that they modify the hydraulic retention times and causes nutrients re-suspensions the phenomenon that has been explained in work by Verburg and Hecky, (2003). Mindu Reservoir's water is maintained almost entirely by surface water from inflowing Rivers that passes through the nearby suburban habitat/villages, paddy fields and the Mzinga military industrial complex. The Reservoir vegetations seen during the dry season included aquatic macrophytes and algae (Plate **1**). The most

abundant seen were horntail (*Ceratophyllum demersum,* L), musk grass (*Chara species*), water lilies (*Nymphae sp*) mosquito fern (*Azolla sp.*), water spinach (*Ipomoea aquatica,* Forsk.), water cabbage (*Pistia statiotes,* L), Knotweed (*Polygonum Senegalese* Meisn), reeds (*Phragmites sp.*) and cattail *(Typha latifolia*). Some were also reported in Sibuga, (1997) and Mbago, (1999).



Plate **1** Northeast zone engulfed with both floating and submersed macrophytes that is water lilies (*Nymphaea sp*), mosquito fern (*Azolla sp*) and horntail (*Ceratophyllum demersum,* L).

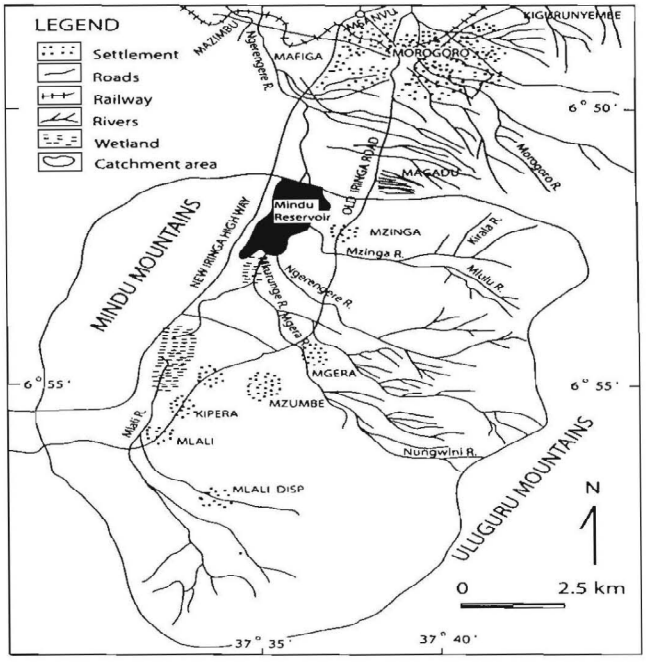


Figure 1 Location map of Mindu Reservoir and its surroundings

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MATERIALS AND METHODS

A portable geographical positioning system (GPS) unit was used to locate relative distance from River entry points (Figure 2). A three-dimension water-sampling regime was instituted and four sampling zones demarcated as **A**, **B**, $\mathbf{C_1}$, $\mathbf{C_2}$ and **D**. A standard 1.5-liter Van Dorn water and Peterson grab samplers were used for water and sediment sampling consecutively during the dry season (between10 am and 1 p.m). The analysis of the pH, EC, DO and Turbidity - NTU were done *in situ*, using a portable field probes by HANNA Scientific instruments (UK) (APHA, 1995). One liter water samples were filtered through 0.45 μm glass fiber filter paper (Whatman ® GF/C), residue and filter paper were soaked in a darkened-test-tube containing 5 ml acetone and stored in a cool box for subsequent chlorophyll-a determinations (APHA, 1995). The filtered samples were preserved with conc. HCl drops (cations) and unfiltered samples in clean 1 liter sampling nalgene bottles, preserved using 1 ml chloroform per liter of water, transported to SUA laboratory and water analyses performed the same day (anions). Atomic Absorption - Spectrometric methods (cations); Flame emission spectrometric methods (Na^+ + K^+); other parameters alkalinity, (titrimetric); SO_4^{2-} (Ba $(ClO_4)_2$ method); NO_3^- (Ion Selective Electrode); TN, (KJeldahl); OC, (wet oxidation); Cl, (Ag NO_3); both methods by (APHA, 1995). As a peristaltic pump was used for pore water samples, one kg composite sediment samples from 11 representative sampling points, was air dried crushed and sieved using standard ASTM set of sieves with (mesh sizes 63μm - 2mm). The Andersen pipette was used in clay fractionation and clay mineral determinations undertaken on particle sizes 2-20 μm and > 63 micron fractions, using the XRD and XRF respectively (Klute, 1986); parameters OC, SO_4^{2-} and NO_3^- (APHA, 1995). Heavy metal content of sediments was determined using XRF technique for elements Co, Cu, Mn, Mo, Fe, Pb and Zn (Klute, 1986); the facility that was located at the Southern and Eastern Africa Mineral Center in Dar es Salaam. Data analysis was done as per Davis, (2002).

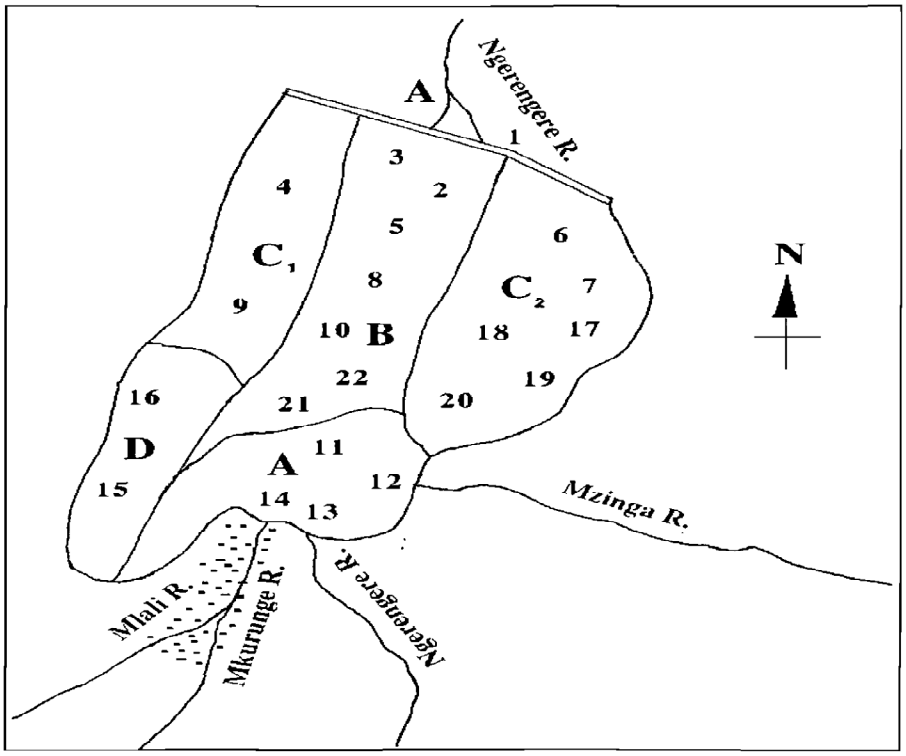


Figure 2 Water and sediment sampling point sketch: (zone **A**) represents the inflowing rivers Mlali, Mkulunge, Ngerengere and Mzinga; the spillway and out-flowing points. (Zone **B**) represents the old river-line and lacustrine zone; (zone $\mathbf{C_1}$) incorporates the macrophytes stands of the northwest (NW); (zone $\mathbf{C_2}$) represents the densely macrophytes of northeast (NE), east (E) and southeast (SE); zone (**D**) the fish landing and village location.

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RESULTS AND DISCUSSIONS

Eutrophication of Mindu Reservoir

Phosphate and nitrate averaged at (0.05±0.03) and (0.44±0.08) mg/l respectively, suggesting that the Reservoir was already eutrophic. Mindu surface waters productivity involved various macrophyte species and algae communities. The average value for Chlorophyll-a, were measured at 4 ± 0.03 μg/l, which strongly reflected high blue green productivity. The N; P ratios values averaged 8.51 ± 4.3 and followed a Redfield behavior with N as a limiting nutrient (Table **1**). The observed slight variation at Mzinga Ngerengere and Mlali/Mkurunge Rivers could just be statistically insignificant, due to small sample size for each trend line (n = 3). However, invariable and yet low HCO_3^- levels at the Reservoir outlet could be due to low photosynthesis rates and high mixing.

Table **1**: Descriptive statistics of Mindu dam waters during the dry season

		Minimum	Maximum	Mean		Std. Dev
	units	Statistic	Statistic	Statistic	Std. Error	Statistic
Distance	km	0.01	3,00	1.36	0.10	0.88
Depth	m	0,00	8,00	1.36	0.21	1.81
pH	-	7.5	9.5	8.76	0.05	0.44
Temp	-	23.5	28.9	26.15	0.22	1.84
EC	mS/Cm	1.76	1.99	1.926	0.01	0.05
Turb	NTU	2.78	57.48	11.08	1.24	10.6
TDS	mg/l	88,00	107,00	101.43	0.45	3.86
DO	mg/l	3.23	9.35	6.33	0.14	1.21
TP	mg/l	0.01	0.07	0.02	0,00	0.01
CO_3^{2-}	mg/l	2.2	19.8	6.96	0.44	3.76
HCO_3^-	mg/l	180,00	359.9	250.04	4.52	38.61
TC	mg/l	10,00	13,00	10.63	0.10	0.83
SO_4^{2-}	mg/l	0.24	11.58	2.15	0.22	1.87
Mg^{2+}	mg/l	6.08	17.12	8.18	0.24	2.04
Ca^{2+}	mg/l	14.08	19.05	18.2	0.10	0.84
Na^+	mg/l	1,00	16.9	12.79	0.27	2.32
K^+	mg/l	1.62	3.81	2.38	0.05	0.47
TN	mg/l	0.05	0.19	0.102	0.002	0.018
NO_3^-	mg/l	0.21	0.81	0.439	0.009	0.076
SiO_2	mg/l	3.65	11.43	7.123	0.196	1.672
PO_4^{3-}	mg/l	0.02	0.21	0.048	0.004	0.032
N/P	-	1.74	31.66	8.51	0.61	4.32
Chll-a	mg/l	0.002	0.007	0.004	0,000	0.002

Mindu Reservoir Water's Hydro Geo Chemical Properties

Mindu Reservoir waters were hence defined as calcium magnesium bicarbonate type (Table **2**). Reservoir waters were found to be ideal for the normal physiology of most aquatic plants and animals. Varieties of surface, benthic and submerging macrophytes for example mosquito fern (*Azolla sp.*), horntail (*Ceratophyllum demersum,* L), musk grass (*Chara species*), water lilies (*Nymphae sp*) water spinach (*Ipomoea aquatica,* Forsk.), water cabbage (*Pistia statiotes,* L), Knotweed (*Polygonum Senegalese* Meisn), reeds (*Phragmites sp.*) and cattail (*Typha latifolia*) were clearly seen. Aquatic animals for example ducks and fowls were in abundances in areas with dense macrophyte stands (south and south east zones). Various snails' species including *Biomphalaria pfeifferi* Krauss species were rampaging during the sampling expeditions. Such snails are associated with the frequent Bilharzias epidemic threats among Mindu populations which was also reported by Nduku and Harrison (1976)

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Table 2: Mindu waters compared to representatives of African surface waters

	Cond(K20)	Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	$HCO_3^- + CO_3^{2-}$	Units
COMMON									
Kagera	85.6	7.1	3.4	5.0	3.9	5.1	3.7	48.0	mg /l
		0.309	0.087	0.250	0.321	0.106	0.104	0.786	me /l
SODIUM CHLORIDE									
Singida	5740	1240	10.0	56.4	68.8	140.0	1890	345	mg /l
		53.94	0.256	2.814	5.663	2.915	53.31	5.66	me /l
DILUTE SODIUM BICARBONATE									
Enchanted	27.5	6.6	0.8	0.2	0.0	0.1	0.6	17.7	mg /l
		0.287	0.022	0.010	0.002	0.002	0.017	0.290	me /l
CONCENTRATED SODIUM BICARBONATE									
Nanyuki+Njek	1758	460	84.0	7.6	2.1	130.0	91.0	951	mg /l
		20.00	2.148	0.379	0.173	2.707	2.567	15.6	me /l
SODIUM – POTASSIUM – MAGNESIUM BICARBONATE									
Katanda	393.0	14.0	19.5	18.2	35.0	8.9	6.2	283.1	mg /l
		0.609	0.499	0.908	2.881	0.185	0.175	4.64	me /l
**CALCIUM – MAGNESIUM BICARBONATE									
Wisila	350.0	7.5	2.0	41.9	22.4	9.7	4.5	252.6	mg /l
		0.326	0.051	2.091	1.844	0.202	0.127	4.14	me /l
UNUSUAL SPRINGS									
Shatanda	1980	394.0	15.0	59.0	0.6	613.0	209.0	104.0	mg /l
		17.14	0.384	2.944	0.050	12.77	5.895	1.71	me /l
** (CALCIUM – MAGNESIUM BICARBONATE)									
Mindu-Average	193 ±05.0	12.82 ±2.32	2.39 ±0.47	18.21 ±0.84	8.27 ±2.04	10.63 ±0.83	11.58 ±1.85	256.03±38.6	mg /l *=µS/cm
		0.56 ±0.08	0.06 ±0.12	0.90 ±0.04	0.67 ±0.19	0.05 ±0.04	0.303 ±.024	4.25 ±0.68	me /l.

** Two rows compared

Physicochemical Characteristics Mindu Reservoir Waters

The three dimensional (surface waters, across the water column and downstream) increasing trend was clearly observed for the parameters; Turbidity (turb), Total Dissolved Substances (TDS), Electrical conductivity (EC), pH, Dissolved Oxygen (DO) and phosphate (PO_4^{3-}).

However the highest PO_4^{3-} levels were observed at the bottom waters in regions with high biodiversity and massive macrophyte stands that were represented by sampling sites 17 and 10 respectively. This trend corresponded with high Chlorophyll and lower N: P ratios (Figure **3**).

The lower values for DO decreased across the water column in both upper and lower River-line zones.

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This indicated the prevailed anoxic conditions of the deep lacustrine zones. However the measured lower DO levels at the southeast zone could be due to decomposition of biomass (Figure **4**).

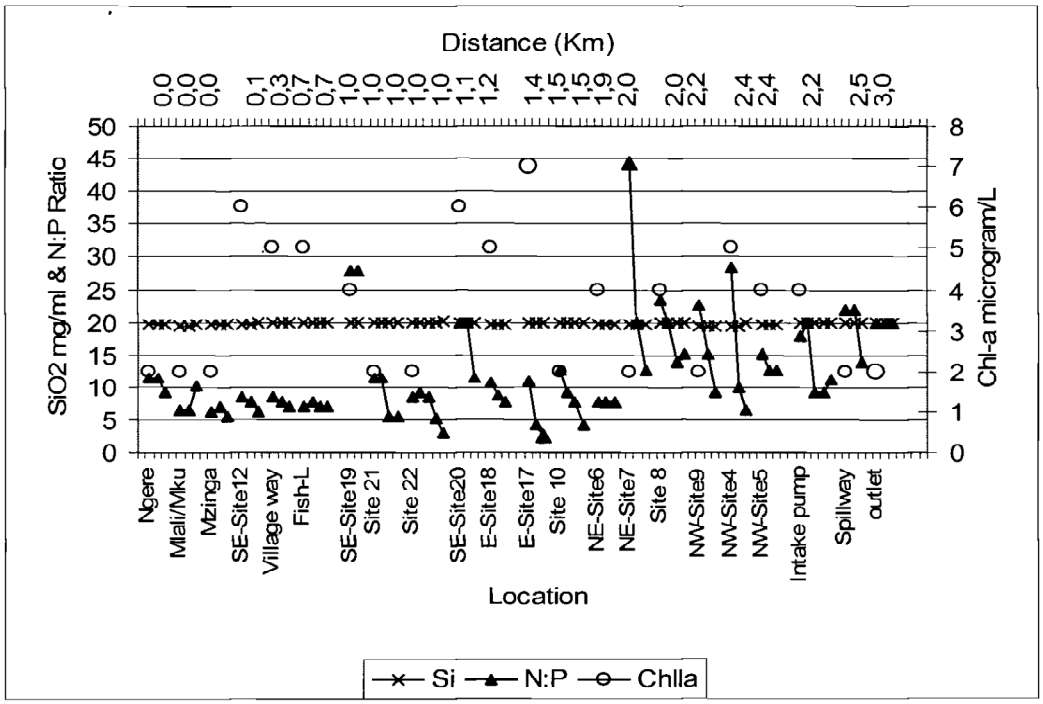


Figure 3 the spatial variations in levels of Nitrogen/Phosphorous ratio (N/P), Silica (SiO_2) and chlorophyll-a (Chll-a).

Slight water column stratification was evident in lacustrine zone at sampling sites 8 and 10 probably due to; temperature and density differences between (incoming and resident waters). Highest levels in Chlorophyll-a (Chll-a), was observed in east tern and south eastern macrophyte infested zones. These values also corresponded with moderate to low N/P ratios, which suggested a very high productivity trend during that season. However some irregularity in N/P ratios were observed at the South East zone could also be due to phosphorous loading from aquatic fowl wastes *guano* breeding grounds just near the Ngerengere inflowing zone (Figure **4**).

High Ca^{2+} levels at lacustrine zone (sites 8, 10, 21 and 22) are associated by inputs from decomposing shells washed from the breeding zones by bottom currents. This is supported by the snail shells deposits that were found there. Decrease in Mg^{2+} and Ca^{2+}, with depth at the (South East macrophyte infested zone) suggested nutrients utilization by macrophytes (Figure **5**). The observed slight variation at Mzinga Ngerengere and Mlali/Mkurunge Rivers could just be statistically insignificant, due to small sample size for each trend line (n = 3). However invariable and yet low HCO_3^- levels at the Reservoir outlet could be due to the respective low photosynthesis rate that has been hampered by the relatively higher Reservoir's flowing rate, at the outflow.

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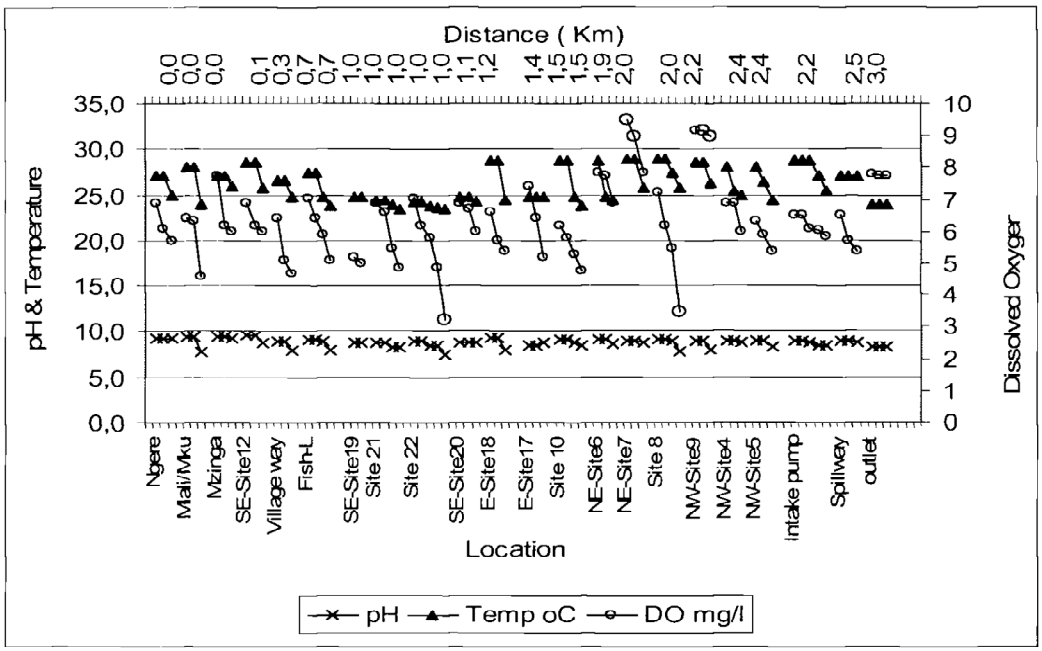


Figure 4 the spatial variations in Mindu Reservoir's physical parameters pH, Temperature (Temp) & Dissolved Oxygen (DO).

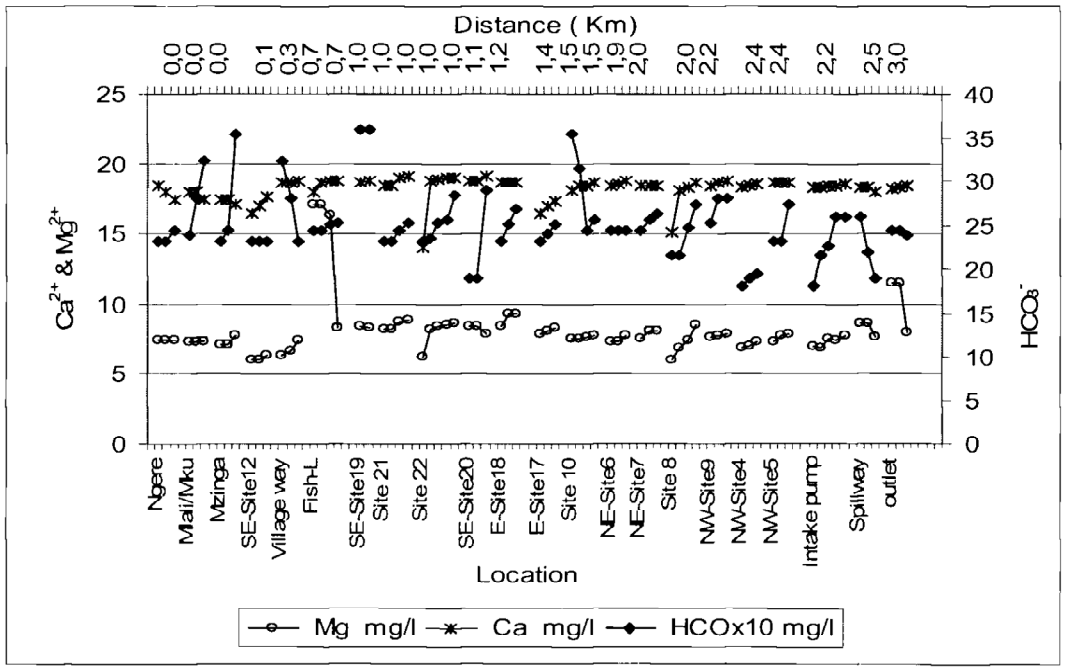


Figure 5 the spatial variations in levels of Magnesium (Mg), Calcium (Ca) and bicarbonate (HCO_3).

Sediments Characteristics in Respect to Nitrogen and Phosphorous loading

As high pH, EC and CEC values in macrophyte and in-flowing Rivers zones coincided with the deposition of dominant clay minerals kaolin and illite (Ngonyani, 2003). The comparatively low pH in deep zone sediments were found to be due to sulfur mineralization, where as TN levels in sediments of both the inflowing Rivers was linked to the anthropogenic reasons (Figures **6** and **7**)

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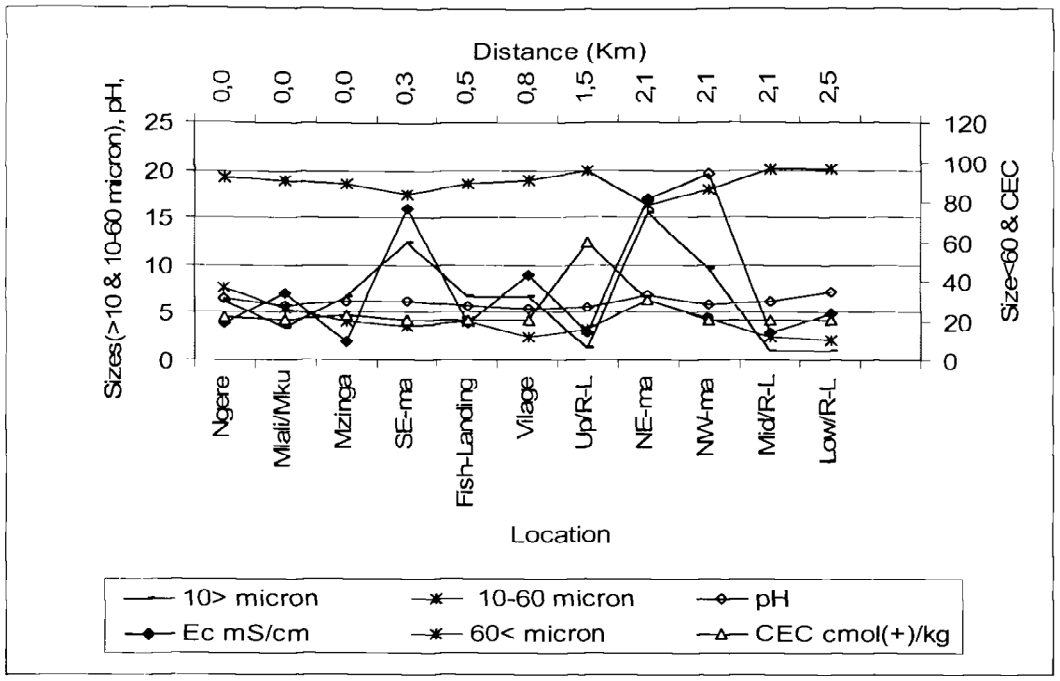


Figure 6 Cation Exchange Capacity (CEC), pH, Electric conductivity (EC) Level and sediment particle sizes variations with sampling locations.

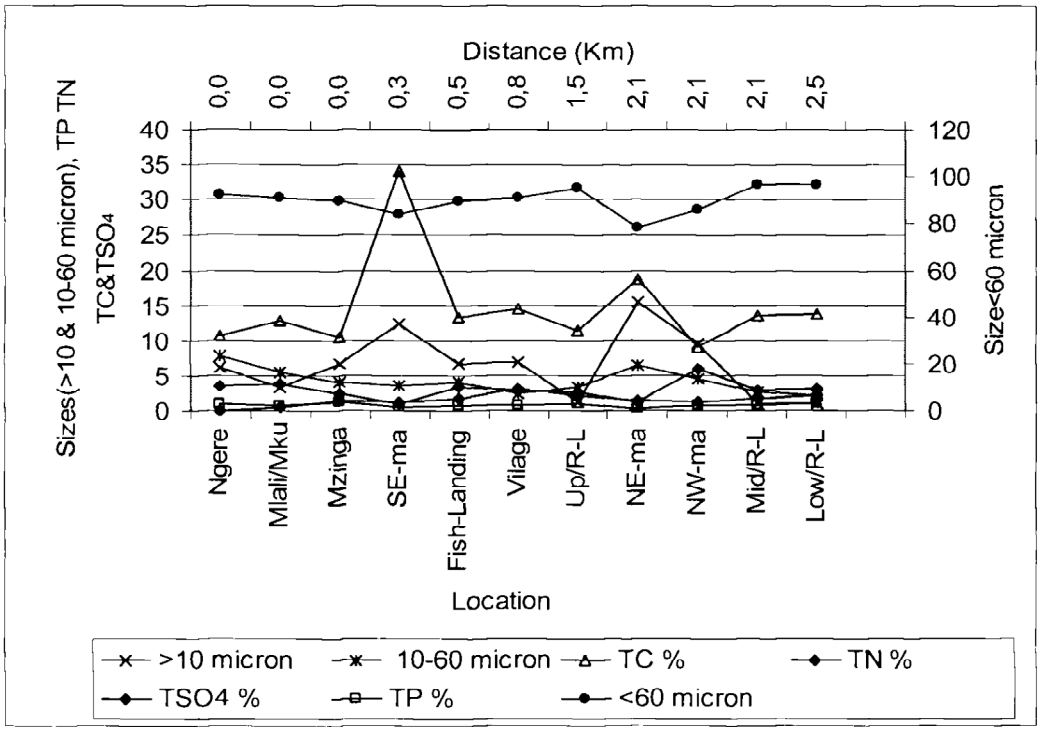


Figure 7 Nutrients Total Nitrogen (TN), Total carbon (TC), Total Sulphur (TSO_4).

Total Phosphorous (TP) and sediment particle sizes variations with sampling locations

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Chemical Ecology of Mindu Waters in Respect to the Eutrophication

From these findings chemical ecology of Mindu Reservoir depends on the bio-geo chemical processes. The alkaline behavior was implicated by high productivity of both macrophytes and algae species equation [1].

However in the lacustrine zones organic matter (OM) decomposition process involves both DO consumptions as well as other electron acceptor reactions shown by the general equations [1 & 2]

$$CO_2 + H_2O \rightarrow CHO_2 + O_2 + \Delta H \quad [1]$$

$$CHO_2 + O_2 + \Delta H \rightarrow CO_2 + H_2O \quad [2]$$

Such reactions consequently trigger other important redox reactions e.g. the reduction of iron oxides, sulfates and nitrates from the sediments. The production of CO_2 from decomposition of OM has a great influence on the carbonic acid reactions involving carbonates equations [3].

$$CO_2 \rightarrow HCO_3^- \rightarrow CO_3^{2-} \quad [3]$$

Presence of high biodiversity in Mindu (macrophytes, fowls, ducks, fishes, snails could plays a primary significant role in the loading of various nutrients through the trophic levels. Concurrently the redirection of PO_4^{3-}, SO_4^{3-}, Mg^{2+} and Ca^{2+} is achieved through decompositions and redox reactions in the Reservoir water sediment interfaces.

As the Reservoir lacustrine ecosystems eventually becomes the sink and supplier of the end products of biogeochemical processes; consequently these products controls the geological processes and vice versa (Hecky *et. al*, 2003; Bootsma and Hecky, 2003; Hecky, 1993; Kilham, 1990; Nduku and Harrison, 1976).

This study furthermore identified sediments as another significant source of N and P loading into the water column through internal recycling mechanisms, driven by wind mixing normally experienced in shallow water bodies.

The continuously internal loading of nutrients from sediments into Mindu water column supports both algae and macrophyte's productivity during the dry season. The comparative high concentrations of nitrogen relative to phosphorous in macrophyte infested areas, suggests the supper abundance in blue green algae at the Reservoir surface waters which is common to eutrophic water bodies as was also reported in work by Andre, *et. al* (2003).

CONCLUSIONS AND RECOMMENDATIONS

From the data obtained it was concluded that Mindu Reservoir behaved like the eutrophic shallow alkaline lake whose features suggests a continuous strong interactions, between biota and their geo-chemical environments. Mindu Reservoir water chemistry and limn logical parameters were greatly influenced by the catchments' climate, hydro geo-chemical processes and ecology, which were also supported by the hydro chemical ratios, multivariate and bivariate data analyses by Ngonyani (2003). We recommend a more detailed hydro-bio-geo-chemical study preferably for more than one cycle to capture inter seasonal variability both temporal and spatially, for the sequestration of nutrients at various trophic levels. The proposed continuous research study for Mindu Reservoir could be used in the construction of an comprehensive integrated Mindu Resources management program, which will involve all the riparian communities.

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KEY

E-site17	East macrophyte infested zone sampling point 17
Fish-L	Fish landing/market
Low R-L	Lower river line Outlet

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Mid/R-L	Middle river line Lacustrine zone
Mlali/MK	Mlali and Mkurunge Rivers entry point
Mzinga	Mzinga River entry point
NE-ma	North East macrophyte infested zone
NE-site6	North East macrophyte infested zone sampling point 6
Ngere	Ngerengere River entry point
NW-ma	North -West macrophyte infested zone
NW-site5	North West macrophyte infested zone sampling point 5
SE-ma	South East macrophyte infested zone
SE-site19	South East macrophyte infested zone sampling point 19
Site8	Middle river line Lacustrine zone sampling point 8
Village-way	Vilage way Human habitats and wash area
Site12	Sampling point 12
Site22	Sampling point 22
Site19	Sampling point 19
Site20	Sampling point 20

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