SALT BALANCE, FRESH WATER RESIDENCE TIME AND BUDGET FOR NON-CONSERVATIVE MATERIALS FOR MAKOBA BAY DURING WET SEASON.

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ABSTRACT

Water and salt budgets suggest that in order to balance the inflow and outflow of water at Makoba bay, there is net flux of water from the bay to the open ocean during wet season. Residual salt fluxes between the bay and the open ocean indicate advective salt export. Exchange of water between the bay with the open ocean plays a role of replacing exported salt via mixing. Calculated freshwater residence time for the bay is 63 days during wet season. Budget results for non-conservative materials indicate net DIP flux from the ocean to the bay and a net DIN flux from the bay to the open ocean. Therefore Makoba Bay acts as a sink for dissolved inorganic phosphorus and a source of dissolved inorganic nitrogen during wet season. Stoichiometry calculations suggest that the bay is net autotrophic and fixing nitrogen during the wet season.

INTRODUCTION

There is a growing trend for population, to be increasing in many parts of the world and for a greater proportion of people to live close to the sea. As a result, anthropogenic impact on the coastal areas has become severe over the past few decades (Goudie 1990. Coastal environments are therefore being altered by man in all parts of the Earth due to a combination of human and natural (climate, sea level) effects (Glantz 1992, Paw and Thia-Eng 1991, GESAMP 1990). The resultant ecological modifications affect the diversity and stability of coastal ecosystems and also contribute in turn to global change as a result of feedback effects on climate, geomorphology and the value of living resources to humans (Beukema et al. 1990). The long-term environmental implications are very uncertain. In addition, there is inadequate worldwide availability of data on types, rates and causes of change in coastal ecosystems. Information on the dynamic properties and present state of coastal systems and on feedback processes that result from natural and anthropogenic modification is clearly required in order to know the rate of change of the different parameters and the effect on the ecosystem. New methods to simulate and predict the responses of the coastal zone to global change need to be developed and implemented in order to guide the formulation of rational and integrated long-term strategies for the human use of coastal areas (Holligan and Reines 1991).

The present study describes the biogeochemical budgets for Makoba bay in Zanzibar. Information is presented here on the rate of water movement at Makoba bay, how fast the nutrient elements (carbon, nitrogen, and phosphorus) move with the water and performance of the bay by examining discrepancies between water and nutrients movement. The overall goal is to determine the material fluxes between land and sea, the capacity of bay to transform and store particulate and dissolved matter

This paper specifically describes the salt, water and nutrient budget for Makoba bay. The water and salt budgets are used here to estimate the water exchange in the bay. Nonconservative flux of dissolved inorganic

Where K is the hydraulic conductivity given to be 6 x 10^{-4} m sec^{-1} for mainly coralline deposits (Woodward-Clyde, 1999). h_1 and h_2 are the lower and upper hydraulic heads which for inner and outer bays the difference is estimated to be 2 m (tidal range). d is the watershed which is 15 km, L is the length of the coastline, which is about 20 km and W is the width of the flow, which for Makoba Bay is about 2 m. The calculation using this relation is good for estimation of typical annual ground water flows only and unrealistic for estimating monthly averages. The same obtained values were therefore applicable for quantifying the average ground water flow for both dry and wet seasons. It is however noted that the values for wet season should be practically higher than those during dry season. The calculations done for Makoba Bay gave $V_G = 0.3 \times 10^3\ m^3\ d^{-1}$.

The salinity-input values for the calculation of salt balance between the Makoba Bay and the open ocean are shown in Figure 2. The salinity of the bay and open ocean is indicated as S_{syst} and S_{ocn}, respectively. Similarly, the volume and surface area of the bay are indicated as V_{syst} and A_{syst} respectively.

The water balance for each season is calculated using Equation (1) from Gordon *et al.* (1996):

$$dV/dt = V_Q + V_P + V_G + V_O + V_E + V_R \quad (1)$$

where V_Q is rate of river discharge, V_P is precipitation, V_O is sewage discharge, V_E is evaporation and V_R is residual flux. Assuming steady state (i.e. $dV/dt = 0$), then the residual flow is:

$$V_R = V_E - V_Q - V_P - V_G - V_O \quad (2)$$

Substituting terms in Equation (2) with data in Table 2, the values of V_R can be obtained for the wet and dry seasons.

On the other hand, the salt balance is calculated from Equation (3), in order to balance salt input via mixing with salt output from residual outflow. It is assumed that the salinity of out flowing water (S_R) is the average of the salinities between the bay and open ocean [$S_R = (S_{syst} + S_{ocn})/2$].

$$dVS/dt = V_Q S_Q + V_P S_P + V_G S_G + V_O S_O + V_E S_E + V_R S_R + V_X (S_{ocn} - S_{syst}) \quad (3)$$

where V_X represents the mixing volume exchanged between the bay and the ocean, $V_R S_R$ is the salt flux carried by the residual flow. The general principle is that salt must be conserved so the residual salt flux is brought back to the system through the mixing salt flux across the boundary [$V_X (S_{ocn} - S_{syst})$] via the tides, wind and general ocean circulation pattern.

Table 2. Summary of calculated (*p-r*) and (*nfix-dinit*) values for Makoba Bay for April 1997 (wet season).

Calculated Values	Wet Season
ΔDIP (mol d^{-1})	-990
ΔDIP (mmol m^{-2} d^{-1})	-0.07
ΔDIN (mol d^{-1})	+29,400
ΔDIN (mmol m^{-2} d^{-1})	+2
(*p-r*) (mmol C m^{-2} d^{-1})	+7
(*nfix-dinit*) (mmol N m^{-2} d^{-1})	+3

Since the salinity of freshwater inflow terms can be assumed to be 0, then Equation (3) can be simplified to:

$$dVS/dt = V_R S_R + V_X (S_{ocn} - S_{syst}) \quad (4)$$

Assuming that S_{syst} remains constant with time (steady state)

$$0 = + V_R S_R + V_X (S_{ocn} - S_{syst}) \quad (5)$$

By re-arrangement:

$$V_X = -V_R S_R / (S_{ocn} - S_{syst}) \quad (6)$$

Substituting terms in Equation (6) with salinity data, the mixing volume (V_X) can be obtained as illustrated Figure 2 for both wet and dry seasons.

The water exchange or freshwater residence time (τ) in days for both wet and dry seasons can be calculated from Equation 8, where $|V_R|$ is the absolute value of V_R:

$$\tau = V_{syst}/(V_X + |V_R|) \qquad (8)$$

V_{syst} is the total volume of the bay.

RESULTS AND DISCUSSION

Water and salt balance

Figure 2 summarizes the water and salt flux for this system and gives the water exchange time based on the data. The Makoba Bay water and salt balance has demonstrated that in order to balance the inflow and outflow of water during the wet season there is net flux of water from the bay to the open ocean ($V_R = -223 \times 10^3\ m^3\ d^{-1}$). The residual fluxes of salt (V_RS_R) between the bay and the open ocean indicate advective salt export; the exchange of bay water with the open ocean plays a role of replace this exported salt via mixing. The calculated water exchange time (flushing time or freshwater residence time) for Makoba Bay is 63 days during the wet season.

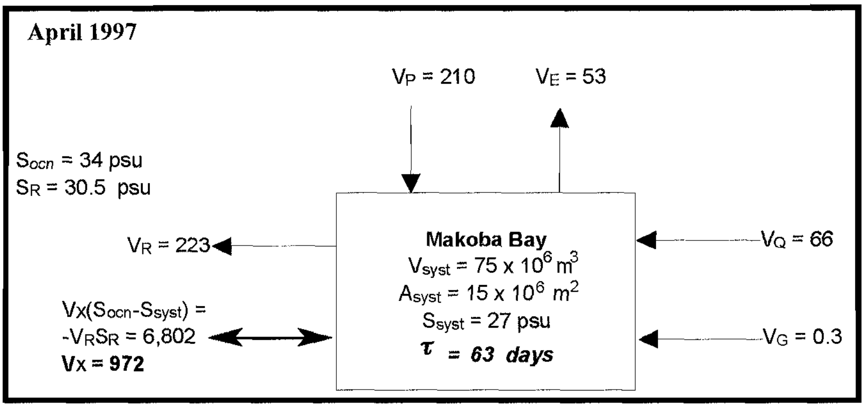

Figure 2. Water and salt balance for Makoba Bay for April 1997 (wet season). Water flux in $10^3\ m^3\ d^{-1}$ and salt flux in 10^3 psu-$m^3\ d^{-1}$.

Budgets of non-conservative materials

The dissolved inorganic phosphorus (DIP) and dissolved inorganic nitrogen (DIN) budgets are termed the budgets of non-conservative materials. While this might be done with any reactive material, the particular interest here is in the balance among the essential elements C, N, and P. The general principle behind the budgets is that the DIP and DIN will exchange between the system and the adjacent ocean according to the criteria established in the water and salt budgets. Deviations are attributed to net nonconservative reactions of DIP and DIN in the system. DIP is defined as the PO_4^{-3} concentration and DIN as the $\sum(NO_3^- + NO_2^- + NH4^+)$.

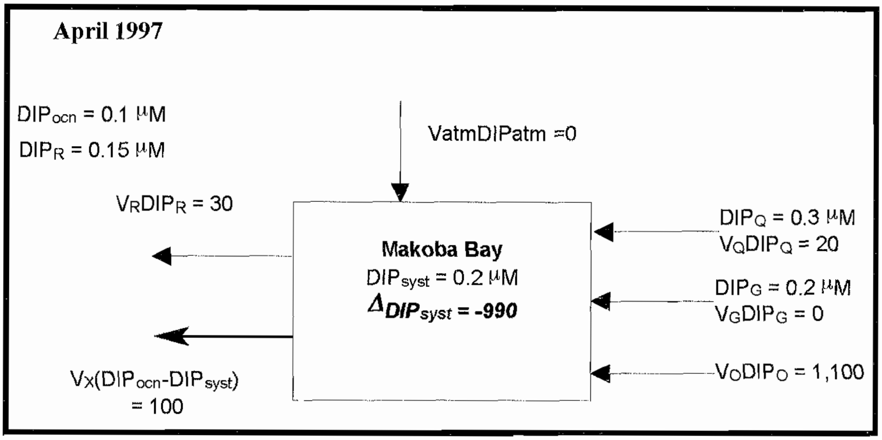

Figure 3. DIP budget for Makoba Bay for April 1997 (wet season). Flux is in mol d^{-1} and concentration in mM or mmole m^{-3}.

Due to unavailability of data, the discussion of nutrient budget for Makoba Bay is limited to the wet season only. The data from Makoba Bay show the concentration of DIP in the Bay to be DIP_{syst} = 0.2 mM during the wet season (Figure 3). Likewise, the concentration of DIN in the Bay is DIN_{syst} = 32 mM for the wet season (Figure 4). Following Wyrtki (1971) the concentration of DIN and DIP in the open ocean (Zanzibar channel) are DIP_{ocn} = 0.1 mM and DIN_{ocn} = 0.5 mM. The concentrations in the rivers were estimated at DIP_Q = 0.3 mM and DIN_Q = 6 mM.

This system poses a challenge for estimating fluxes of nutrients because the groundwater nutrient and nutrient loading associated with waste discharge concentration are unknown. The DIP_{atm} and DIN_{atm} were assumed to be zero because atmospheric contribution is normally small. The population around Makoba Bay is fairly small (10,000 people), nevertheless the waste load from solid waste, domestic waste and detergents were estimated using a method suggested by McGlone *et al* (1999). Since the waste is dumped directly to the Bay, it was assumed that 100% of the waste load does actually reach the Bay waters. The values of $V_O DIP_O$ = 1,100 mol d^{-1} and $V_O DIN_O$ = 4,400 mol d^{-1} were obtained and used in the calculation for the budget. Note however that because of lack of data, the DIP and DIN contribution from the agricultural and industrial activities were not included in the budget. Although the DIP_G flux in ground water flowing through carbonate terrain is known to be low, the concentration of Nitrogen (DIN_G) in the underground water could not be neglected. For the nutrient calculations reported here, DIP_G concentration of 2 mM and DIN_G concentration of 37 mM were used. These values are comparable to reported groundwater PO_4 for similar systems (DIN_G = 1-10 mM; DIP_G = 37-72 mM: Lewis 1985, Tribble and Hunt 1996).

DIP and DIN balance

The budget results for non-conservative materials in Makoba Bay are illustrated in Figures 2 and 3. The calculated Δ*DIP* and Δ*DIN* for the wet season is –990 mol d^{-1} and +29,400 mol d^{-1}, respectively. Indicating that there is a net DIP flux from the ocean to the bay during the wet season. Therefore Makoba Bay acts as a sink for dissolved inorganic phosphorus during wet season (Δ*DIP* is negative). There is also a net DIN flux from the bay to the open ocean during the wet season. Makoba Bay is therefore a source of dissolved inorganic nitrogen (ΔDIN is positive) during the wet season.

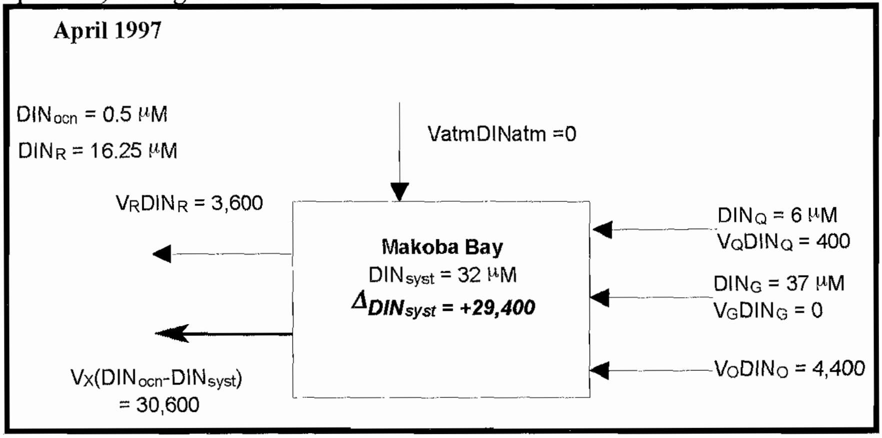

Figure 4 DIN budget for Makoba Bay for April 1997 (wet season). Flux is in mol d^{-1} and concentration in mM or mmole m^{-3}.

Stoichiometric calculations of aspects of net system metabolism

Biogeochemical modelling guidelines suggested by Gordon *et al.* (1996) are used here to calculate the stoichiometrically linked water-salt-nutrients budgets. In these mass balance budgets, complete mixing of the water column is assumed. The general principle is that the non-conservative flux of DIP with respect to salt and water is an approximation of net ecosystem metabolism (production-respiration) at the scale of the system in question. The net ecosystem metabolism can therefore be calculated from *DDIP* using the following basic formulation,

$$(p\text{-}r) = -DDIP \times (C:P)_{\mathrm{part}}$$

where $(C:P)_{\mathrm{part}}$ represents the C:P ratio of organic matter that is reacting in the system, which is expected to be near 106:1.

On the other hand the non-conservative flux of DIN approximates net nitrogen fixation and denitrification in the system. The basic formulation is as follows,

$$(nfix\text{--}denit) = DDIN - DDIP(N:P)_{\mathrm{part}}$$

where $(N:P)_{\mathrm{part}}$ represents the ratio of both planktonic and waste derived organic matter reacting in the system, which is expected to be near 16:1.

Table 2 shows the summary of the stoichiometric calculation made for Makoba Bay. The results suggest that (*p-r*) is positive during wet season. This indicates that Makoba Bay is net autotrophic during the wet season. Makoba Bay is also fixing Nitrogen during wet season, where (*nfix–denit*) is estimated to be 3 mmol m^{-2} d^{-1} in excess of denitrification. Nitrogen fixation is known to provide the nitrogen requirement in areas dominated by seagrass beds and mangroves (Hanisak, 1993). The occurrence of mangroves and seagrass beds at Makoba Bay is a possible ecological reason behind the nitrogen fixation over denitrification in the bay.

ACKNOWLEDGEMENTS

The authors thank Vilma Dupra, Prof. Steve Smith and Drs. Chris Crossland, Laura David and Malou San Diego-McGlone for their advice and encouragement. We wish to aknowledge the support of LOICZ project which allowed ASN to visit Philippines and

Hawaii during the preparation of the manuscript. This work form part of the contribution of Tanzania estuaries to the global biogeochemical budget under the International Geosphere-Biosphere Programme.

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CONCENTRATIONS OF METALS IN RIVER SEDIMENT AND WETLAND VEGETATION IN MINING SITES, LAKE VICTORIA BASIN, TANZANIA.

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ABSTRACT

Levels of metals were determined in river sediment, rice and sugarcane juice from Lake Victoria basin where small-scale gold processing activities are carried out to assess levels of contamination. Concentrations of metals in river sediments were generally high in areas that were closest to gold ore processing sites. For instance, mercury was highest (36.3 ±12.8 µg/g dw) in river sediments of Tigiti River in Mugumu District. Other heavy metals (Cd, Pb, Zn and Cu) had highest concentrations (2.20±0.71, 208±19.3, 412±20.1 and 132.7±11.9µg/g dw, respectively) in sediment samples from Kagota. The concentration of arsenic was highest (985.0±67.2 µg/g dw) in Mugusu River sediment. Mercury concentration in rice was highest (378.5±15.1µg/kg dw) in samples from Lwamgasa wetland and lowest (47.9±2.9 µg/kg dw) in samples from Saragurwa wetland. Cadmium concentrations in rice ranged from 2.3-5.5µg/kg dw, Zn and Cu ranged from 16340-27280µg/kg dw and 1150-2240µg/kg respectively. Arsenic was not detected in any rice sample. Lead was only detected in rice from Sengerema (150±12µg/kg dw), in a wetland that is close to the main road. Mercury concentrations in sugarcane juice were below the limit of detection (0.01µg/l) in all samples even those that were harvested closest to the gold ore-washing site at Samina. It is concluded that small-scale gold mining activities contaminate watercourses close to ore washing sites

INTRODUCTION

A small-scale mining site essentially means an area that is used for gold ore processing or reprocessing of mine tailings. Currently, the information on the contribution of gold mining activities in Lake Victoria basin to concentrations of metals in the lake has not been adequately construed. In most cases, insufficient environmental materials are sampled, hence giving inconclusive results.

Lake Victoria Gold Fields (LVGF) consists of auriferous ores that are won from primary and secondary gold deposits. Primary gold deposits are those where gold is found in quartz veins especially in shear zones within the greenstone belts (Condie 1981; Bell and Dodson 1981; van Straaten 1983; Borg *et al* 1992). Secondary gold deposits consist of gold that was liberated from original rock type and re-deposited in several secondary environments. Gold deposits of LVGF are chiefly auriferous quartz veins containing free milling gold or refractory gold hosted in sulphides such as pyrite, chalcopyrite, pyrrhotite, arsenopyrite or even in traces of galena and sphalerite (Kahatano and Mnali, 1997). Therefore, depending on the mineralogy, gold mining can release a variety of heavy metals (e.g. Cu, Zn, Pb and As) in the environment. Metallic mercury is used for purification of gold ores by small-scale miners, therefore, is also released to the environment. Mercury is mixed with the concentrate in a pan to form a Hg-Au amalgam. Finally Au is recovered through the process of amalgam roasting in open air (or by the use of a retort), a process that is likely to cause atmospheric contamination of Hg (Stevens et al. 1982; Campbell 2001;

Tamatamah 2002; Ikingura and Akagi, 2002).

Laterite soils found in LVGF have excellent metal adsorption capacity. Metals are strongly adsorbed onto both goethite (a major component of lateritic crusts) and humic acids present in the top few centimeters of the LVGF soils. For instance, DHV consultants (1998) observed in the dry season that the dispersion of heavy metals was characterized by a steep gradient from the source, indicating that Hg did not move far from the source. This report presents concentrations of metals in river sediment and soil samples from small-scale gold ore processing sites in Lake Victoria basin.

MATERIALS AND METHODS

Study sites

The sampling stations on rivers (numbers prefixed with T) were proximal to small-scale gold ore processing sites. The rivers directly or indirectly discharge into Lake Victoria at station numbers prefixed with L (Fig. 1). Sampling in areas that are currently being mined or have been abandoned was conducted in May and June 2002.

T1: Sirorisimba, Mugumu District (01°44'30.3"S, 034°13'56.4"E)
Gold ores at Sirorisimba are present in surface deposits that are now being worked on to a limited degree. No gold ore processing site was located.

T2: Ring'wani, Mugumu District (01°43'13.9"S, 034°26'33.6"E)
This area was once worked for some period of time, currently is not being actively mined. Sediment samples were collected in the river about 1 km from the former mine and soil samples were collected 20 m from the river bank in the direction away from the former mine.

T3: Nyigoti, Mugumu District (01°58'41.8"S, 034°38'45.4"E)
This area was once worked for some period of time, currently is not being actively mined. Maruru River drains this mineralized area via Fort Ikoma and discharges into Grumeti/Rubana River. Sediment samples were collected in Maruru River adjacent to the mine and soil samples were collected about 15 m from the riverbank.

T4: Tigiti, Mugumu District (1°29'29.2"S, 034°33'25.9"E)
This mining area was active in the past, currently is not being actively mined by artisanal gold miners. Sediment samples were collected from Tigiti River at Nyamongo and soil samples were collected at about 15 m from Tigiti River bank.

T5: Kagota (Kibaga village), Tarime District (01°22'39.9"S, 034°23'16.0"E)
This is an emerging area that is currently being mined. Rivers draining Tarime town are tributaries of Mori River which discharges in Lake Victoria. Sediment samples were collected in Nyangwe River adjacent to Kibaga village and soil samples were collected 20 m from the River bank.

T6: Samina, Geita District (02°54'01.9"S, 032°09'06.00"E)
This area is actively used for gold ore processing. Sediment samples were collected about 1 km downstream of the gold ore washing/sluicing area and upstream of the washing site.

T7: Nungwe/Nyakabale, Geita District (02°50'14.0"S, 032°09'16.2"E)
Large scale mining is operated at Nungwe, gold processing is by use of cyanide method.

T8: Nungwe, Geita District (02°47'55.0"S, 032°01'24.9"E)
This area (Nungwe wetlands) is used extensively for rice cultivation, it is a flood plain which is close to the large and small-scale gold mines of Geita.

T9: Saragurwa, Geita District (02°50'38.2"S, 032°02'06.7"E)
This wetland is used for paddy cultivation, it is located within the flood plain of Mugusu River.