

Specific Transverse Distribution of Nutrients and its Major Impact on the Sustainable Development of the Lake Kivu Methane Gas Exploitation

Digne Rwatangabo Rwabuhungu

Senior Lecturer, Faculty of Applied Sciences, National University of Rwanda. P.O. Box 117, Huye/Rwanda.

Corresponding author email: drwabuhungu@nur.ac.rw

ABSTRACT.

Lake Kivu is located between 1 ° 34 'and 2 ° 30' south latitude and between 28 ° 50 'and 29 ° 23' east longitude. Northwest border of Rwanda with the Democratic Republic of Congo, it has a unique specificity: its deep waters contain an enormous quantity of dissolved gases including carbon dioxide and methane gas deposits. The structure of the water column of Lake Kivu has a permanent stratification that leads to the fact that water bodies do not completely homogenized. The existence of several natural phenomena maintaining the stratification of the lake, and also causing the warming of deep waters appears to be obvious. The sustainability of stratification is partly related to the density, therefore the salinity and the presence of dissolved salts. The present study on the distribution of major nutrients in the water column biogeochemicals analyzed from their appearance during the different seasons that prevail on the Lake sheds new light on their likely origin and correlated sustainability exploitation for instance; methane gas from Lake Kivu and the preservation of special stratified the water column. Our study on the transverse distribution of specific nutrients, ammonium found more than 1.500 μM , phosphorus more than 100 μM and silica more than 800 μM from the cover layer to the bottom of the water column, may serve, as a tool for efficient monitoring of the exploitation of methane gas from Lake Kivu.

Keywords: Biogeochemistry, Lake Kivu, Methane, Stratification.

1.0 INTRODUCTION

Lake Kivu is located at 1,463 m in the western branch of the East African Rift that represents the border between the Republic of Rwanda and the Democratic Republic of Congo (DRC). Its maximum area is 2370 km², with a length of 95 km, a width of 48 km and a total volume of 550 km³. The maximum depth of Lake Kivu is 485 m with an average depth of 220 m. The lake is located between 1 ° 34 'and 2 ° 30' South latitude and between 28 ° 50 'and 29 ° 23' East longitude. The weather on the lake is a temperate highland climate with average annual temperatures oscillating between 19.5 °C and 20.5 °C with very low monthly variations. The lake is under the influence of permanent and regular south to east winds. There are four climate seasons, namely two rainy seasons and two dry seasons in following order: a short dry season from mid-December to mid-February, a long rain season from mid-February to mid-June, a long dry season from mid-June to mid-September and a short rain season from mid-September to mid-December. Wind, flooding of the river and, or thermal effects create a certain movement of different water masses and turbulence. The resulting diffusion would tend to homogenize the water column, but this is not the case in Lake Kivu, where the stratification is permanent and water bodies do not homogenize. The existence of one or several natural phenomena which not only maintain the stratification of the lake, but are also causing the warming of deep water appears to be obvious.

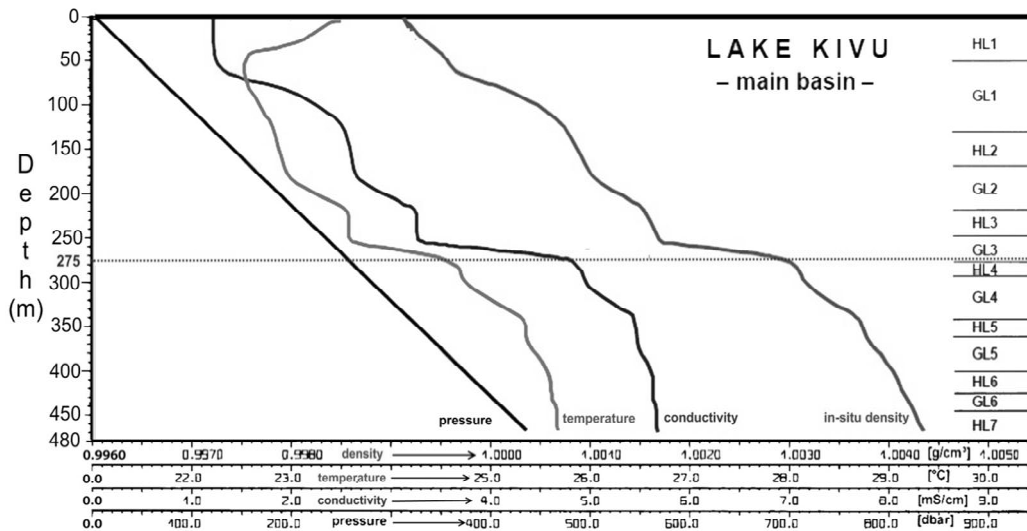


Figure 1: Thermal stratification of the water column of Lake Kivu are represented by parallel vertical profiles of pressure (dbar), temperature (°C), electrical conductivity (in mS/cm) and density (g/cc), and the different layers Mixed (HL) and gradient layers (GL), as defined by Tietze and Meir, (1977).

The sustainability of stratification is partly related to the density (Figure 1) and the salinity and the presence of dissolved salts. As a fact, at this stage of our knowledge this phenomena, can be explained only partially. The most likely hypothesis for the origin of salts is the leaching of volcanic soils by rainwater and the flow of water through permeable layers of soil formed from volcanic ash layers to feed tables. As this is an active volcanic region, groundwater is heated, which increases the dissolution of surrounding rocks and also the release of various magmatic gases, including CO₂ (Halbwachs *et al.*, 2002). The main feature of Lake Kivu is the variation of some physicochemical parameters identified by specific profiles (Figure 1) that Tietze and Meir (1977), explain precisely by juxtaposition of several layers. They, referred to "mixed layer" when the variation in the physical parameters (temperature, pressure, density and conductivity), on a given depth is small, and they speak about "gradient layer", when the physical parameters vary significantly. In the main basin of Lake Kivu, They identify seven mixed layers alternating with 6 gradients layers (Figure 1). This study addresses the particular structure of Lake Kivu in its biogeochemical aspects by considering the structure of 4 distinct layers (Rwabuhungu D. *et al.*, 2004); clears the transverse distribution of key nutrients during all seasons, on three sites in the main basin which, as a matter of fact, the only basin contain methane gas into usable proportions. The explanation and understanding of the transverse distribution of nutrients involved in the environmental life of the lake is a reliable tool for monitoring the sustainable exploitation of methane gas.

2.0 METHODOLOGY

2.1 Coordinated Action

This study based on samples taken at three fixed points within the main basin of Lake Kivu, namely off the island of Iwawa, off the towns of Gisenyi and off the towns of Kibuye, see Table-1. The choice of measurement points was dictated by the fact that these are the selected locations to serve in the relatively near future as offshore sites for the extraction of methane gas from Lake Kivu (Tietze, 2000). The average coordinates of the two main sampling points are 01 ° 44 '04.09" South and 029 ° 13' 18.9"East off of Gisenyi, and 01 ° 00 '57.0"South and 029 ° 12'02 .6" East is off the town of Kibuye. Time tracking has been performed for several seasons for the sampling points off the towns of Kibuye and Gisenyi. For two of the four measurement campaigns, data have been collected during the same season, both in Kibuye to

Gisenyi. This was done during the months of May and December in order to study the spatial variation of the parameters measured.

Table 1: Positions and dates of collecting the data

Dates	Corresponding Season	Site
May 2001	Great rains season(GSP)	Gisenyi, Iwawa, Kibuye
February 2002	short dry season (PSS)	Kibuye
December 2002	short rains season (PSP)	Gisenyi, Kibuye
September 2004	Great dry season (GSS)	Gisenyi

All samples were filtered immediately after collection and stored frozen, except for samples to be used for the determination of silica, which were in turn, kept in the fridge. When necessary, the biological activity was blocked with a saturated solution of mercuric chloride, HgCl_2 , after filtration. The samples were transported to Brussels by plane in insulated boxes (in frigolite) to be analyzed in the laboratory of Chemical Oceanography and Water Geochemistry (LOCGE) at Free University of Brussels (ULB).

2.2 Ammonium

The determination of ammonium is a sample filtered through a membrane of 0.45 microns porosity, blocked by the addition of HgCl_2 and stored frozen at -18°C . The Koroleff method (1976) was used. This is a manual colorimetric method based on the response in absorption of colored complexes derived from NH_4^+ . The method of phenolate indophenol blue that is based on the reaction of ammonium with phenolate and alkali in the presence of an oxidizing agent (HClO) was chosen. The use of sodium nitroprusside dihydrate ($\text{Na}_2\text{Fe}(\text{CN})_5\text{NO}\cdot 2\text{H}_2\text{O}$) accelerates the reaction at room temperature. The solution turns in blue, and ammonium can be measured at 630 nm.

2.3 Orthophosphates

The determination of dissolved orthophosphate is a sample filtered through a membrane of 0.45 microns porosity, blocked by the addition of HgCl_2 and stored frozen at -18°C . The dissolved orthophosphate was assayed following the colorimetric method of ascorbic acid (Greenberg, *et al.*, 1985). Ammonium molybdate and antimony potassium oxytartrate react with orthophosphate to form phosphomolybdic complex (or molybdophosphoric). This complex is then reduced by ascorbic acid in a blue colored compound, which can be measured by colorimetry at 880 nm.

2.4 Silica Dissolved

The determination of dissolved silica was performed on a sample filtered through a membrane of 0.45 microns porosity, blocked by the addition of HgCl_2 and refrigerated in a polyethylene bottle. The colorimetric method known as molybdosilicate (Greenberg *et al.*, 1985) was used for measuring the concentration of silica. This method is based on the principle of the reaction of silica dissolved in acid with molybdate to give a silicomolybdic compound, which can be reduced to molybdenum blue by ascorbic acid. The compound was detected by absorbance at 810 nm. The presence of oxalic acid eliminates interference caused by the formation of molybdophosphoric acid in the presence of orthophosphates in the water.

3.0 RESULTS AND DISCUSSION

As stated above, this study investigates the variation of various parameters with regard to the period of sampling and location of sampling sites. It uses the distribution of biogeochemical water column of Lake Kivu (Rwabuhungu *et al.*, 2004) into 4 layers: surface layer (from surface to 70 m deep), the transient layer (of 70 to 150m depth), the cover layer (150 to 250 m depth) and deposit layer (from 250 at the bottom of the lake) that contain methane gas. Our results are discussed in comparison with those previously established at ad hoc basis, without taking into account the spatial and temporal variation, (relatively recently by Schmid *et al.*, 2005 and earlier by Degens *et al.*, 1973).

The main nutrients are nitrogen, phosphorus and silica. Only ammonium was measured in the samples because nitrate and nitrite concentrations are too low to be properly quantified.

3.1 Ammonium

In the surface layer, and whatever the season considered, ammonium is absent. From the transient layer, ammonium starts to appear some time with some variation of its concentration. Figure 2 shows a comparison between our measurements and those of Degens *et al.*, (1973) and Schmid *et al.*, (2005).

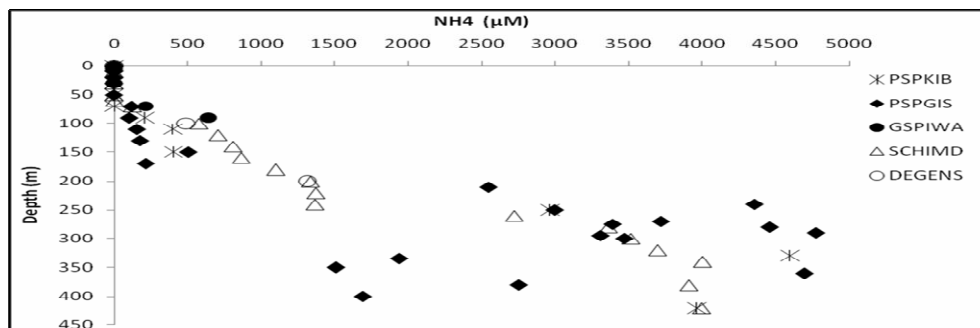


Figure 2: Comparison between ammonium (PSP KIB; PSPGIS; GSPIWA) contents: our study and that of Schmid *et al.*, (2005) and Degens *et al.*, (1973)

All data in the surface layers are identical. In the deeper layers some variation is visible. In the transient layer, ammonium measurements of this study are all lower than those obtained by Schmid *et al.*, (2005), whatever the time of year or place of sampling considered. In the cover layer and the deposit layer, our data and those of Schmid *et al.*, (2005) are based on the period of the year and hence the climate. During the short dry season concentrations of ammonium in the deep layers are lower compared to those of Schmid *et al.*, (2005). During the short rain season, our NH₄ data, whatever the place of sample collection site, Kibuye or Gisenyi, are similar to those of Schmid *et al.*, (2005). The most likely explanation could be derived from the sampling period of the above study and confirm the existence of even a small temporal variation of the ammonium in the deep waters of Lake Kivu completely anoxic. Indeed the study of Schmid *et al.*, (2005) presents data collected during the month of December 2004.

It is also possible that the lava from the Nyiragongo eruption of January 17th, 2002, had not yet affected the whole lake in February 2002, when sampling in Kibuye, which is relatively distant from entry of lava into the lake. In December 2002, the influence would have reached across the lake causing very high concentrations of ammonium in the deep layers. This could have then remained stable for two years (December 2004) and is the cause of similar results between our measurement and those of Schmid *et al.*, (2005). It is not there a plausible indication of the general increase of nutrients in the lake.

3.2 Orthophosphate

Orthophosphate is also, like ammonium, nonexistent in the surface layer of the water column of Lake Kivu. One reason is the consumption of these nutrients by phytoplankton in the surface layer in the presence of oxygen and light. Figure 3 shows a comparison between data collected in this study and those measured by Degens *et al.*, (1973) and also with more recent data supplied by Schmid *et al.*, (2005). It appears from this comparison that in the surface layer, orthophosphate is still absent. In the transitional layer our data and those found in the literature are similar. In the first part of this second layer, 100 m deep at most, the phosphate concentrations in any place and at any time increase in the same proportions. Between 100 and 250 m measurements of Schmid *et al.*, (2005), are still higher than Degens *et al.*, (1973) and this study measurements. Schmid *et al.*, (2005) explained the general increase of nutrients in the lake that it was caused by population growth in the region and the pollution brought by the two cities bordering the lake, namely the Congolese city of Goma and the Rwandan town of Gisenyi. These arguments are not sufficiently substantiated to explain the measured values of orthophosphate in waters between 100 and 200 m depth only. In addition this study measurements are close to those measured earlier by Degens *et al.*, (1973), that seem to indicate no significant changes on all the nutrients and particularly on the phosphate at these depths. Kibuye data are lower than those measured in Gisenyi. In deep water, especially in the layer that contains methane gas, the data from this study are similar to that of Degens *et al.*, (1973) to those of Kibuye. The samples which came from Gisenyi during the short rainy season are very close to the measurements of Schmid *et al.*, (2005) as it was the case for ammonium.

3.3 Silica

In surface waters of Lake Kivu, at least one of the three major nutrients is present; silica. Its mere presence in these waters provides a first indication of the origin of the binder dissolved silica waters of Lake Kivu to the erosion of surrounding land which, as indicated by geology, are rich in silicates. Indeed, the runoff flowing into the lake arrive after crossing a region whose geological formations are predominantly Precambrian and Cenozoic time and are very rich in silica. In the surface layer, the dissolved silica is present and its concentration does not vary with depth. This implies that it is consumed because of runoff and with it, silica contributions, is continuous since the runoff with erosion are not interrupted and that therefore the burden it carries only dried point. However, the study of different silica flux as other nutrients entering and exiting the lake remains to be established. From the transient layer, consumption of silica becomes almost zero, and then begins its accumulation. The silica concentrations increase with depth. In the first part of this second layer, up to 100 m depth, the data of Schmid *et al.*, (2005) are similar to Degens *et al.*, (1973) and this study measurements. Beyond this depth all measures of Schmid *et al.*, (2005) are superior to the other two results subject of this comparison. However, in the deposit layer, spatial variation is clearly visible. The data of the silica in Kibuye, independently of the season, is lower than that measured in Gisenyi. In this last layer in Gisenyi, silica data from this study are similar to those measured by Schmid *et al.*, (2005).

4.0 CONCLUSIONS

This study indicates a good correlation between dissolved silica, phosphorus and ammonium in the water column of Lake Kivu, which shows that in surface waters of Lake Kivu, phosphorus and nitrogen is the limiting production instead of silica. Ammonium is absent from the surface layer for all seasons. Only from the transient layer begins to appear some time variation of its concentration. During the great rainy season, ammonium concentrations are highest as well as in Kibuye and Gisenyi. Phosphorus is almost always absent from the surface layer. In the first part of the second layer, 100 m deep at maximum, phosphorus concentrations in any place and at any time increase with depth. The silica is present in the surface layer.

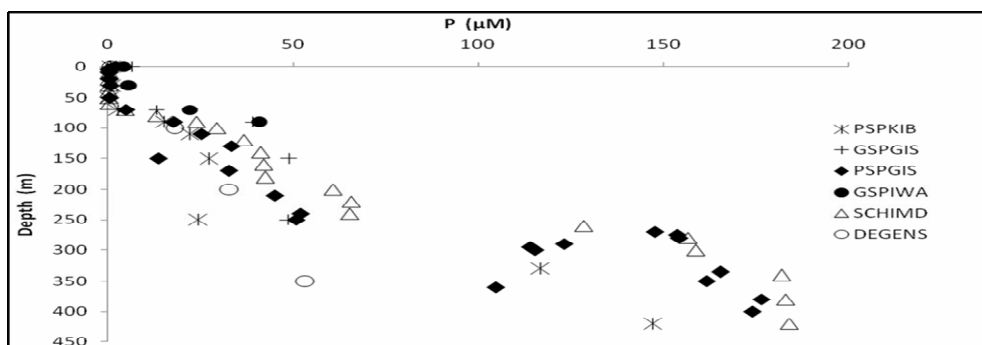


Figure 3: Comparison between phosphate (PSPKIB; GSPGIS; PSPGIS; GSPIWA) contents: Our study and those of Degens *et al.*, (1973) and Schmid *et al.*, (2005)

The silica concentration clearly increases in successive stages with increasing depth. In the surface layer, its concentration does not, however, varies with depth. This implies that it is consumed because of runoff and with it, contributions in silica, is continuous. From the transient layer, consumption of silica becomes almost zero, and then begins its accumulation. Silica concentrations increase with depth. Yet in the reservoir layer, a spatial variation is clearly visible. The data of the silica being in Kibuye, whatever the season, lower than those measured in Gisenyi.

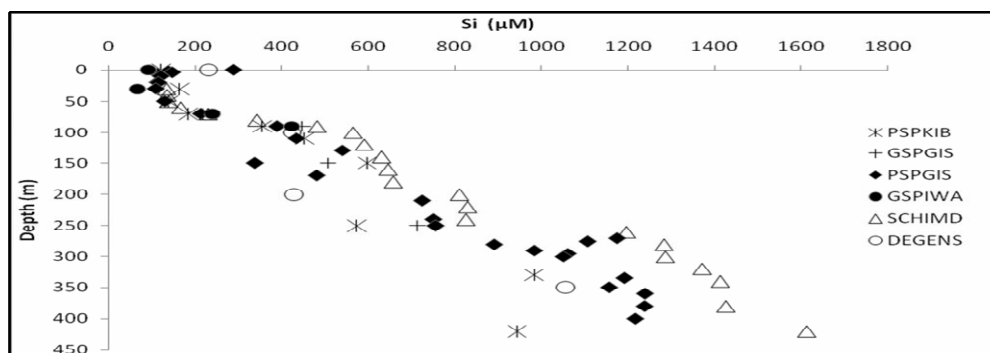


Figure 4: Comparison between silica (PSPKIB; GSPGIS; PSPGIS; GSPIWA) contents: collected data and that of Schmid *et al.*, (2005) and Degens *et al.*, (1973)

Safeguard keeping the structure of the lake involving the nutrients in the water column is an absolute necessity. This study provides a precise indication of the spatial and temporal variation of nutrients. It offers a tool for direct monitoring a sustainable exploitation of methane gas from Lake Kivu. This study did not indicate, for all seasons of the year, any significant change in the biogeochemical structure of the water column which prevents an operation that is on the verge of upsetting the balance of the precarious water column of Lake Kivu, particularly in the cover layer and the layer containing the methane gas deposit.

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