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History of human impact on Lake Kutubu, Papua New Guinea: The geochemical signatures of oil and gas mining activities in sediments

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HIGHLIGHTS

- Lake Kutubu is located within the largest oil and gas project facilities in PNG.
- Trace elements in lake sediments are related to mining and development activities.
- Ba is the best tracer of mining activities in sediments.
- Ba is the element of most concern in Lake Kutubu.

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ABSTRACT

Lake Kutubu, a large tropical lake in Papua New Guinea, is well known for its ecological importance; however, there have been recent changes to the pristine nature of this lake due to activities associated with the largest oil and gas project in PNG. The aim of this study was to determine the geochemical profile of sediment cores of Lake Kutubu and to comprehend the contamination changes undergone in this lake due to mining activities utilising the hydraulic fracturing method. Sediment core profiles of Na, Mg, Al, Si, P, Ca, Ti, Cr, Fe, Mn, Ni, Cu, Zn, As, Se, Sr, Cd, Ba, Ce, Pb and U, grain size and dating analyses were conducted for five sites in the lake. Grain size and dating demonstrated that the northwest side of Lake Kutubu has sediments of allocthonous origin while the southeast sediments are of autochthonous origin. Ba was the element with the largest changes in concentrations since 1990 and the best tracer of mining activities near the lake. Sites KTB 02 and KTB 10 northwest of the lake showed the most distinct changes in element concentrations. Element enrichment factors (EF = 2.8, 4.2 and 3.2 respectively) demonstrated that Mn, Se and Ba have undergone a moderate enrichment in the lake since mining activities started. Ni, Cd and Se concentrations exceed sediment guidelines in some samples. No guideline is available for Ba, and special attention should be given to this element in this lake. This study demonstrated that Lake Kutubu oil/gas extraction activities are significant sources of elements to this lake and highlights the need for studies on the partitioning and speciation of elements to understand organism metal exposure.

1. Introduction

The past decade has witnessed significant shifts in the economic and political structures of many developing countries (Bury, 2005). These countries have changed economic course through the adoption of neoliberal free-market reforms, with rapidly integration into global markets and foreign direct investment flows. In Papua New Guinea (PNG), mineral extraction activities have become the key sector for future economic growth, export-led earnings, and foreign investment (Imbun, 2007). As a consequence, the increase in mining exploration has led to intensive pressure on the environment, and if not properly managed, it can adversely affect natural environments (IEA/OECD, 2013; Schneider

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et al., 2014).

The operation of these large-scale oil extraction projects in developing countries has an inevitable impact on local ecologies (Gilberthorpe, 2007). The challenges faced by both the local population, and mining companies in reducing the impact to the environment are magnified in PNG, due to the combination of sensitive environments, limited infrastructure, and the absence of comprehensive regulatory guidelines. This creates a situation where designing and implementing effective environmental and safety policies is a difficult task. This in turn creates conflict between the mining companies and the local population. The Bougainville disaster is a clear example of this conflict between industry and locals in PNG, forcing unscheduled closure of the Panguna Copper Mine in 1989 and sparking a decade of civil war (Bossip, 2015).

Lake Kutubu is a large oligotrophic lake in PNG well known for its ecological importance (D'cruz, 2008); however, it is situated adjacent to oil and gas fields which were discovered in 1986 (WWF, 2008). Activities associated with commercial extraction of oil and gas commenced in 1992 by the Australian-owned oil and gas company Oil Search Pty Ltd (WWF, 2008). This area was formally recognised as a Wildlife Management Area under the PNG conservation laws in 1992 in recognition of its rich biodiversity (Beehler and Swartzendruber, 1993). International recognition followed in 1998 with the listing of Lake Kutubu as a wetland of international importance under the Convention on Wetlands (Ramsar, 2014). Its use for mining activities, however, has intensified pressures on the ecosystem and nowadays Lake Kutubu is part of the largest oil-gas project in PNG (D'cruz, 2008).

A subject of debate at Lake Kutubu is the source of trace elements found in this lake. The local population blamed the mining company for ecological changes in the area, including an acute contamination event in 2007 that caused many people to fall ill and a massive fish kill (Cubby, 2009). The local population suffered from severe vomiting, diarrhoea and skin and eye irritation, including skin-sores, after swimming or eating fish and drinking from the lake (Cubby, 2009). Environmental investigations by the oil company, however, did not reveal any change to the water quality (WWF, 2008).

Changes in trace elements concentrations in sediments are also known to occur when Lake Kutubu undergoes stratification/destratification during pronounced changes in weather conditions (Osborne, 2012a,b). This natural process usually involves anoxic events and metal turnovers, causing the mortality of fish and other aquatic organisms (D'cruz, 2008) and is believed to be partially the cause of the 2007 ecological catastrophe in the lake (WWF, 2008).

Although the possibility that the health of Lake Kutubu has declined has been a subject of constant debate, the only study of trace element concentrations in lake sediments was prior to the start of the oil/gas mining activities (Osborne and Totome, 1991). This study showed that trace element distribution in sediments is controlled by three main processes: catchment supply, intra-lacustrine processing of elements by the redox conditions prevailing in the lake and the activity of aquatic organisms in concentrating elements in the littoral region of the lake.

As the mining sector has become such an important force of change in PNG, it is important to understand the ways in which it is likely to impact the environment of the country. In this paper we seek to accomplish this task by evaluating changes in trace element concentrations in Lake Kutubu and establish the main drivers of the changes which have been advocated as posing health risks to humans and local biota. The elements studied were Na, Mg, Al, Si, P, Ca, Ti, Cr, Fe, Mn, Ni, Cu, Zn, As, Se, Sr, Cd, Ba, Ce, Pb and U. We were especially interested to test the hypothesis that mining and associated activities have changed the concentrations of trace elements in the lake. Four aspects were considered: (1) to establish the background concentrations of selected trace elements pre-mining; (2) to establish the history of trace element concentrations in recent sediments of Lake Kutubu; (3) to establish the pattern of maximum concentration (hot spot area) of any trace element contamination in the lake and; (4) determine the enrichment factors of trace elements and compare these against environmental guideline values.

2. Materials and methods

2.1. Historical setting

Lake Kutubu is a pristine highland lake located in the Southern Highlands Province of Papua New Guinea (Fig. 1). This lake, located at an altitude of 808 m, is approximately 19 km long and 4 km wide and is flanked by high hills along its length. Lake Kutubu with a surface area of 4924 ha, is the fifth largest lake in Papua New Guinea (D'cruz, 2008) and is drained by the Soro River, a tributary of the Kikori River. The estimated volume of the lake is 1.825 km^3, with a mean depth of 36 m. It has the largest collection of endemic fish species in a freshwater water body (except floodplains) in New Guinea with 11 endemic species (D'cruz, 2008).

Lake Kutubu's catchment encompasses one of the largest remaining tracts of undisturbed tropical rainforest. There is no human activity at present in this forest, therefore, land runoff should not reflect any change in trace element concentrations from the background values (Osborne, 2012a,b). The climate in the Lake Kutubu catchment is warm and wet, with little variation throughout the year. The mean annual temperature is 23 °C, with the minimum temperature recorded of 5 °C, and the maximum of 39 °C. The mean annual rainfall is 4500 mm, with rain being recorded throughout the year (D'cruz, 2008).

Droughts associated with El Niño-Southern Oscillation events occur regularly in PNG and tend to recur at an interval of between 7 and 10 years. Previous El Niño Southern Oscillation event years were 1965, 1972, 1982 and 1997. In the latter half of 1997, the Kikori basin experienced a severe drought, which was reflected in the monthly rainfall for August at Moro: in August 1997, the total rainfall was 27 mm, while in August 1995 (before the drought) it was 787 mm and after the drought, in August 1998, it was 717 mm. Periodic swings in rainfall from one year to the other caused by El Niño Southern Oscillation events cause serious disruptions to village food supplies and traditional sources of drinking and domestic water to dry up.

Lake Kutubu is classified as an oligomictic lake, characterised by distinct thermal stratification with irregular periods of mixing (Osborne, 2012a,b). These prolonged stratification and irregular periods of mixing have pronounced effects on the spatial distribution of elements in the water column and the sediments (D'cruz, 2008). Therefore, although Lake Kutubu's stratification appears to be generally stable, overturning can occur (Osborne, 2012a,b). Mixing may be triggered when abnormally cold and stormy weather occurs, resulting in mixing of the deoxygenated hypolimnion with the epilimnion (D'cruz, 2008). In Lake Kutubu, turnover events were recorded in 1978 and 1998, and studied in 1990 (Osborne and Totome, 1992). The turn over event in 1990 was marked by cold weather and strong winds from the southeast that caused vertical mixing in the lake and effects were noticed towards the middle of September 1990 (D'cruz 2008).

Besides the turnover events that naturally affect the spatial distribution of trace elements in sediments of Lake Kutubu, mining activities in the area may also affect the source and distribution of trace elements in this lake. Prior to mining, Lake Kutubu was entirely undeveloped, with a low population of subsistence farmers