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Ecological risk assessment of trace elements in sediment: A case study from Limpopo, South Africa

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ABSTRACT

This study aimed to determine the ecological risk posed by metals, in sediments from the Nyl River system in Limpopo, South Africa. Metals were extracted from sediment samples by *aqua regia* microwave digestion and were analysed using standard ICP-OES techniques. The ecological risk indices applied to the data included Contamination Factor, Pollution Load Index, Geo-accumulation Index and Enrichment Factor. The results showed that the levels of Ni at STW and NYL in the HF period exceeded the Canadian Sediment Quality Guidelines by a factor of 1.36 and 1.83 respectively whereas NYL and MDD had 2.57 and 1.32 times the allowed limit of Ni in the LF period. During the HF period, the GC site exceeded the allowed limit of Zn by a factor of 1.04 and NYL had 1.21 times the allowed Zn in the LF period. The levels of metals are generally low near the origin of the river and increase moving downstream. The levels of metals in the Nyl River floodplain, a Ramsar accredited wetland, were high with CF scores ranging between 0.905 and 5.82, Igeo values with a range of −0.541 to 2.441 and EF scores ranging from 0.959 to 6.171. and posed a greater risk than the other sites. This indicated that the wetland is performing its ecological function by trapping and removing toxins from the water body. The Pollution Load Index determined that the Golf Course (PLI=4.586) and STW (PLI=2.617) sites were polluted only in the low flow period whereas the Nyl River floodplain (HF PLI=79.845; LF PLI=30378.768) and Moorddrift Dam (HF PLI=1.903; LF PLI=9.256) sites were polluted in high flow and low flow periods.

1. Introduction

The assessment of the health of aquatic ecosystems, in terms of the toxicology of water and sediments, is crucial to the continued supply of water for various purposes. According to Sanders (1997), metals occur in four main reservoirs in an aquatic ecosystem. These include suspended particles, surface water, interstitial water and sediment. The aquatic environment is reliant on the health of the sediments which is a vital component of the ecosystem (Pejman et al., 2015).

Wetland sediment studies considering metal contamination, are crucial in determining the condition of an aquatic ecosystem. Sediment acts as a natural pollution sink, which assists in maintaining the health of the aquatic environment by trapping, binding and removing toxic elements from the water system. Metals and sediment interact in different ways: firstly sediment traps metals physically, especially in wetland sediment by slowing the water and allowing impurities to settle out (Sanders, 1997). Contaminant particles such as metals can also interact with sediment by chemically binding to sediment particles (Buykx et al., 2002). This results in metals not being detected in water metal analysis. Metals in sediments can either be naturally occurring or anthropogenically introduced. The determination of metal contamination in sediments is crucial, as metals trapped both superficially and deeply in wetland soils, can be re-suspended during flooding events, potentially releasing high levels of toxic metals into the aquatic system (Greenfield et al., 2007).

The study of metal content in sediments gives a time integrated assessment of pollution in an aquatic system as metals are accumulated in sediments over time and can be released under certain environmental conditions caused by both natural and anthropogenic factors (Wang et al., 2007). Toxic metals can also accumulate in biota especially benthic organisms that have constant contact with sediment and can have effects throughout the entire food web (Wang et al., 2012). Metals that are trapped and bound to the sediment layer in an aquatic ecosystem, can be released through changes in pH and resuspension of sediment particles into the waterbody (Soares et al., 1999). The resistance of metals to degradation is a factor behind their increased lifetime in aquatic ecosystems. Metals spread throughout trophic levels through the processes of bioaccumulation and biomagnification, showing increased levels of metals in biota higher on the food web (Maceda-Veiga et al., 2012). Though some metals may be toxic in high concentrations, there are those that are essential life

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sustaining elements in trace amounts. Certain metals are essential to life forms but become toxic under certain conditions such as altered pH (Newman, 2009).

Due to the deposition of metal-bound suspended matter in sediment over time, core samples can reveal the historical metal pollution in a river system at different depths (Whittman and Forstner, 1976). The analysis of sediments for metal contamination can reveal sites with extensive metal contamination which require constant monitoring and can aid in identifying the sources of metal pollution in a system by determining spatial differences in metal contamination (Whittman and Forstner, 1976). Sediment studies can also give information on the enrichment of the sediment with metals that is relative to the specific river by including reference metal concentrations (Sanders, 1997).

There are however different sediment indices that incorporate background levels and give a relative contamination factor (Muller, 1979; Thomilson et al., 1980; Li et al., 2013). Another method of determining metal pollution in sediment entails the sequential extraction of metals from sediment samples (Sanders, 1997). During this process, the natural and anthropogenic metal levels in the sediment can be determined. A notable downfall of this method is that sample preparation can lead to variation in the results (Tessier and Campbell, 1990).

Metals contained in sediments pose a risk to aquatic systems if the metals contained in the sediment-store are released. Multiple studies have formulated methods of determining the degree of risk the metal pollution in sediment poses (Iqbal et al., 2012; Banu et al., 2013; Li et al., 2013; Cheng et al., 2015; Low et al., 2015). Sediment ecological risk studies are crucial in the Nyl River system, which is home to the 16,000 ha floodplain wetland with Ramsar accreditation. The Nyl floodplain is known for its variety of threatened and endangered waterfowl as well as being home to the endangered Roan Antelope (*Hippotragus equinus*) (Friends of Nylsvley, 2014).

The aim of this study was to determine the concentrations of metals contained in sediment from the Nyl River system by means of full acid extraction as adapted by Greenfield et al. (2007) from USEPA (1996) and the subsequent analysis of metal content with Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES). This study also aims to determine the potential risk the sediment poses to the ecologically significant Nyl River system and Nyl floodplain wetland by means of four sediment risk assessment indices namely: Contamination Factor, Pollution Load Index, Geoaccumulation Index (Igeo) and Enrichment Factor. These indices indicate the degree of metal pollution in the sampling area.

2. Materials and methods

2.1. Site selection

Sediment was sampled in the Nyl River system, Limpopo Province, South Africa (Fig. 1). Sediment samples were collected from seven sites in the upper reaches of the Nyl River system including sites from the Klein Nyl River before the confluence with the Groot Nyl River, as well as sites from the Nyl River after the confluence. The sites included in the study ranged from the origin of the Klein Nyl River outside of Modimolle to the Moorddrift Dam near Mokopane. The sites chosen are Klein Nyl Oog (KNO), Donkerpoort Dam (DPD), Golf Course (GC), Sewage Treatment Works (STW), Jasper (JAS), Nylsvley Nature Reserve (NYL) and Moorddrift Dam (MDD). These sites were chosen based on sites used in previous studies for comparison. Table 1 indicates surrounding land uses and possible impacts in the surrounding area.

Klein Nyl Oog (24° 42.97′ S; 28° 14.54′ E) is in the upper region of the river, roughly 2–3 km from the origin of the Klein Nyl River. The site is located on an agricultural farm where a small weir was built. The farmer abstracts water at the weir for irrigation purposes. The site had many aquatic macrophytes and contained sediment due to the weir. At this point in the system the only impacts should include agricultural and game farms (Vlok et al., 2006).

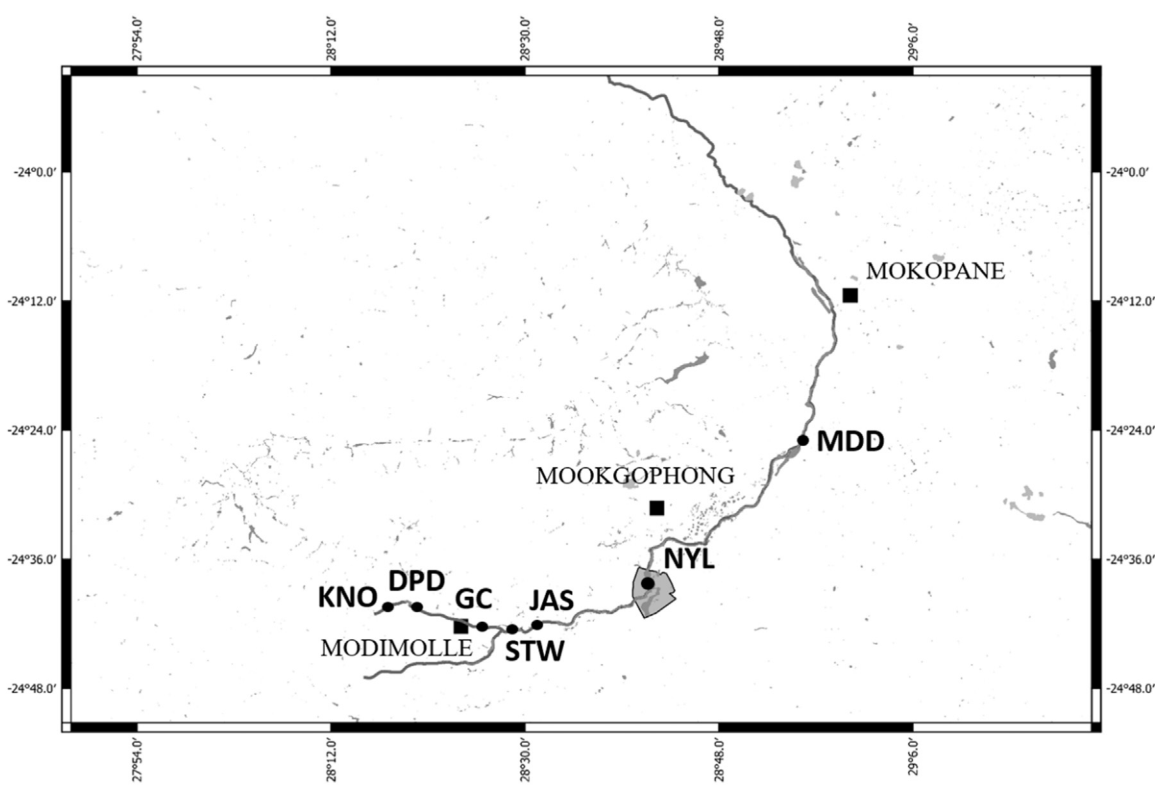

Fig. 1. A map of the Nyl River, Limpopo, South Africa with the seven sampling sites indicated by dots and the towns represented by squares.