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Long term treated wastewater impacts and source identification of heavy metals in semi-arid soils of Central Botswana

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ABSTRACT

Industrial and domestic wastewater is a potential contaminant capable of degrading the quality of the soil environments, if not properly treated. This study reports the 20 years cumulative effects of treated wastewater discharge on heavy metal (HMs) concentration in the proximal environment of Palapye Wastewater Treatment Plant (PWTP), Central Botswana. Soil samples were collected from eight sites: four along the treated wastewater channel and four on an adjacent well-drained channel (control). Selected physico-chemical properties of the soils were determined using routine laboratory procedures and rapid HM concentrations with portable XRF. Results showed that HM concentrations in the two drainage classes did not vary significantly ($p > 0.05$). There was strong correlation between organic matter (OM) and Fe ($R^2 = 0.896$, $p < 0.01$), OM and Cu ($R^2 = 0.908$, $p < 0.01$), OM and Zn ($R^2 = 0.956$, $p < 0.01$) and OM and Mn ($R^2 = 0.954$, $p < 0.01$) in control soils, while treated wastewater affected soils showed strong correlation for OM and Fe ($R^2 = 0.765$, $p < 0.01$), OM and Zn ($R^2 = 0.770$, $p < 0.01$) and OM and Mn ($R^2 = 0.802$, $p < 0.01$). Source apportionment of HMs using PCA shows one component in the control soils accounted for 77% of the total variance, while two components accounted for 97% of the total variance in treated wastewater affected soils. The geoaccumulation (Igeo) and pollution load (PLI) indices used to assess potential pollution show all soils to be unpolluted. Manganese which showed enrichment at two sites might indicate possible pollution, but their speciation and bio-accessibility, rather than total concentrations, have to be established.

1. Introduction

Soil is a natural occurring body that facilitates plant growth, water and nutrient movement in the environment (Wang et al., 2003), and provides other ecosystem services including carbon sequestration, water purification and soil contaminant reduction, climate and flood regulation, biogeochemical nutrient cycling habit for organisms, and sources of pharmaceuticals and genetic resources (FAO, 2015; Legaz et al., 2017). The ability to effectively carry out the listed functions is a strong indicator of good soil quality. Globally, issues on soil quality are increasingly attracting great attention (Liu et al., 2016) as alterations primarily brought about by various anthropogenic activities continue to affect soil properties. For instance, there is a huge reliance on wastewater for urban agricultural projects in arid, semi-arid and Mediterranean regions where water availability is usually a challenge (Farahat and Linderholm, 2015). Although reusing treated wastewater supplements some deficient nutrients required by plants in soils, its unceasing use proves detrimental to the soil environment with regards to quality (Andrews et al., 2016).

Single and at times combined techniques used to treat wastewater for environmental and domestic suitability do not ensure overall cleanliness of these waters due to limitations arising from complexity of the effluents (Ahmed and Ahmaruzzaman, 2016). In view of this, some of the non–degradable metallic pollutants as well as organic compounds tend to be masked and retained in treated wastewater at the end (Klay et al., 2010). Particular to metallic pollutants are heavy metals (HMs) widely sourced from a range of activities including metal plating, application of agro chemicals, mining, tanneries, smelting and alloy industries (Hegazi, 2013). Heavy metals are considered detrimental (World Health Organization, 2011; Järup, 2003) because of their non–biodegradable nature (Liu et al., 2016). Therefore, irrigation or discharge of treated wastewater into the environment may result in long term accumulation and persistence of these potentially toxic metals in soils to eventually affect general soil physical and chemical properties (Ding et al., 2017; Khan et al., 2008).

The Palapye Wastewater Treatment Plant (PWTP) directly discharges treated wastewater into the immediate environment where it has created a wetland channel within the Lotsane sub – basin

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(catchment). Meanwhile, the area is predominantly agrarian in nature. Therefore, if by any chance the discharged treated wastewater is harbouring HMs like lead (Pb), Arsenic (As) and Uranium (U), due to flaws in treatment techniques used, possibilities of eventually posing threat to the entire food chain due to accumulation is feasible. It already has been ascertained through several studies that wastewater is capable of increasing the levels of various HMs in agricultural soils (Zhou et al., 2007; Yang et al., 2006). Determination of the heavy metal contents of soils hitherto relied on the use of rather sophisticated laboratory procedures including ICP-AES, ICP-MS and X-ray fluorescence. The relatively high cost of these facilities makes them unavailable for most people in the developing economies. Today, portable XRF (PXRF) makes analysis of metals in soils quite easier. In the last few years, PXRF has become a widely used instrument for measuring heavy metal content of soils, since it gives rapid and accurate results with minimal sample preparation procedures. It can be used both in the field and laboratory and this feature gives it another advantage (Eze et al., 2016a, 2016b; Udeigwe et al., 2015).

There is still a level of uncertainty as to whether the benefits of treated wastewater use outweigh its potential to degrade soil quality (Gharaibeh et al., 2016), thus a greater level of understanding is still needed before strongly recommending it for use. The cumulative effects of 20 years of treated wastewater discharge in soil environments near PWTP have not been documented. This study therefore seeks to address this issue by using PXRF, for the first time in Botswana, to rapidly assess HM concentration in soils affected by treated wastewater from PWTP. The specific objectives include: (1) to characterise the macromorphology, physical and chemical properties and heavy metals content of soils exposed to long term discharge of treated wastewater; (2) to assess treated wastewater impacts on studied soil properties by comparing soils from two drainage classes and; (3) to undertake potential risk assessment of HM pollution in the soils around PWTP.

2. Materials and methods

2.1. Site description

The study was carried out within 1 km^2 periphery of PWTP in the Central District of Botswana. The area is found approximately within latitude 22°31′ and 22°32′ S, and longitude 27°10′ and 27°12′ E (Fig. 1). Palapye is predominantly a tropical semi-arid climate characterised by erratic rainfall patterns annually averaging between 371 and 396 mm and temperature ranges from 32 to 39 °C (Zhai et al., 2009). The area is prone to dryness in synchrony to occasional prolonged periodic droughts (Mphale et al., 2014). Soils of Palapye are predominantly sandy, sandy loam to sandy clay loam (alluvial and colluvial) in nature and mostly made up of ochric horizon (Burgess, 2006). The geology of the area is the Palapye Sandstone Formation of the Palapye Group which is composed mainly of sandstone of a lower arenaceous unit (Ermanovics and Skinner, 1980). Vegetation is predominantly mixed mopane bushveld consisting of *Colophospermum mopane* permanent stands mixed with other species (e.g. *Acacia nigrescens*, *Combretum apiculatum*, *Acacia tortilis*) (Bekker and De Wit, 1990).

2.2. Soil sampling

A total of eight soil profiles within 1 km^2 periphery of the treatment plant (Fig. 1) were sited: four along the treated wastewater channel (affected by treated wastewater) and four on an adjacent well – drained channel (control, not affected by treated wastewater). In accordance with *Soil Taxonomy* soil classification system, the eight pedons all qualify as Ustic Quartzipsamments, an FAO/WRB equivalent of Ferralic Arenosols (De Wit and Nachtergaele, 1990). Soil macromorphological properties were described following the guidelines for soil profile description (FAO, 2006). A background sample (parent material) of the study area was also identified and collected for total elemental analysis. Samples were collected from each horizon of the profiles and transferred to the laboratory in plastic zip-lock bags for laboratory analyses. Soil colour was determined using Munsell soil colour system (Munsell Colour Company, 2015).

2.3. Laboratory analyses

All soil samples were pre-treated by gently grinding and passing them through 2 mm sieve to separate soils from gravels and roots/ rhizomes. Each soil sample was then stored separately in a corresponding pre labelled plastic bottle container to await routine laboratory procedures. Soil particle size distribution was determined by the Bouyoucos hydrometer method (Bouyoucos, 1962). Soil bulk density (BD) followed the core sampler method. Soil potential hydrogen (pH) was determined in water and in 0.01 M CaCl$_2$ solution (both at 1: 2.5 soil to solution ratio: w/v) using a Bante 210® Benchtop pH meter. The

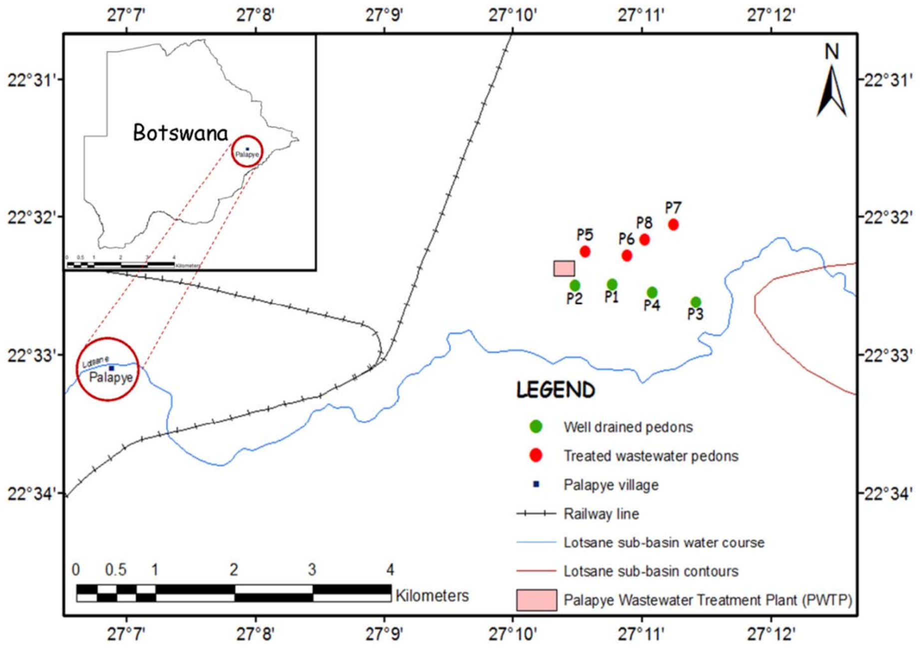

Fig. 1. Location map of the sampled soils relative to the wastewater treatment plant.