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Full Length Research Paper

Spatial distribution of heavy metals in soil with distance from Tazama pipeline through the Mikumi National Park, Tanzania

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A total concentration of six studied heavy metals Arsenic (As), Lead (Pb), Chromium(Cr), Mercury (Hg) Cadmium (Cd) and Copper (Cu) were measured in soil across distances from TAZAMA pipeline in transects which have incidences of oil spillage and those which have no history of oil spillage. All studied heavy metals were detected in the study area. As, Pb and Cr were detected in both transects, that is, with oils spills and those with no history of oil spillage to a distance of 0-35 m from the edge of the pipeline, with higher mean concentration in transects with oil spillage compared to those with none. From 50-200 m away from the pipeline these four metals were detected in transects with oil spillage only. Hg and Cd were detected in transects with history of oil spillage only. Cu was detected in all transects and at all ranges of distance. Concentration of studied heavy metals decreased with increased distance from the edge of the pipeline in both transects to all directions. The decrease was statistically significant in transects with oil spillage and insignificant with transects of no history of oil spillage.

Key words: Soil contamination, pollution, oil spill effects, Mikumi National Park ecosystem, endangered species.

INTRODUCTION

The global increase of oil need has resulted in exploration of new crude oil production sites and construction of new pipelines as a means of transportation. Pipelines are widely used due to their advantages like low cost, high efficiency and large volume of transportation (Saadi et al., 2018). Despite their advantages pipelines pose many challenges to the biotic and abiotic environment that they pass through.

Likewise, protected areas worldwide are under pressure of oil development. More than 25% of World heritage

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sites are in the pressure of existing or future oil activities (Osti et al., 2011). Major challenges facing protected areas from oil pipelines are pollution and habitats destruction, raising a concern among biodiversity conservationists all over the world (Hebblewhite, 2017).

The Tanzania Zambia Mafuta (TAZAMA) pipeline started operation in 1968; by the year 1973 it had experienced 100 spills at different locations along its route (TAZAMA 2016). Oil spillage in the soil contributes to the addition of heavy metals, some of which are very hazardous to flora and fauna inhabiting a particular soil (Gordon et al., 2018). Moreover, oil pollutants present a major threat to many ecosystems (Xie et al., 2018). The effects of pollution are extended to many flora and fauna since some of oil pollutants including heavy metals can persist in soils for decades (Buskey et al., 2016; Pennings et al., 2014). Studies have documented effects of crude oil pipelines leakages on soil health and plants biological diversity (Allison et al., 2017; Asadirad et al., 2016; Oriaku et al., 2017). Crude oil spillage from pipelines is experienced along pipelines during times of construction, operation and maintenance (Vaezi and Verma, 2018).

Mikumi National Park is an important ecosystem as it shares boundary with Selous Game Reserve – a world heritage site. Crude oils contain hazardous pollutants including heavy metals and hydrocarbons. These pollutants are very toxic and are furthermore not easily degraded once in soil (Bai et al., 2019).

Despite the importance of the global ecosystem in Mikumi, the sensitivity of the general infrastructure element running through the area and the possible pollutants from oil, little is known about the amount of heavy metals that have been released to the environment and its spatial distribution in Mikumi National Park. Therefore, this study was conducted to examine the spatial distribution of heavy metals across the segment of the TAZAMA pipeline through the Mikumi National Park (MINAPA). Moreover, no Environmental Impact Assessment was conducted during the construction of the pipeline and hence no baseline information is available (TAZAMA, 2016). To cover that gap, the study involved a comparison between segments of the pipeline with history of and segments, which never experienced leakages. The following objectives were addressed during the study:

(i) What is the concentration of total heavy metals in soil in oil spilled compared to non-oil spilled segments of the pipeline?
(ii) Does the concentration of heavy metals in soil vary significantly with distance from the edge of the pipeline?

MATERIALS AND METHODS

Study area

The study was conducted in Mikumi National Park, Tanzania across the segment of the TAZAMA pipeline. Five transects across the pipeline were studies, three with known history of oil spillage and two, which never experienced oil spills (Figure 1).

Soil sampling and heavy metals analysis

Transects were set at each site perpendicular to the pipeline. Soil was sampled at a distance of 0 m, 5, 20, 35, 50, 100 and 200 m away from the edge of the pipeline to the North and South. At distance of 0 m, soil samples were taken by auger to a depth of 80 cm in spilled transects and 60 cm in non-spilled transects. More depth was possible at 0 m on oil spilled transects because there were piles of soil above the general soil surface resulting from re-covering of the sites after addressing the spillage by the TAZAMA staff. At distances 5, 20 and 35 m from the pipeline soil profiles were excavated to a depth of 1.5 m or a limiting layer, total of 30 soil profiles were excavated. At 50 m, 100 m and 200 m soil samples were also taken by auger to a depth of 60 cm. Soil samples were taken from each designated horizon described using the FAO guidelines for soil profiles description (FAO 2006) (Figure 2).

Heavy metals checked were the ones, which reflect the chemistry of the oil through the TAZAMA pipeline. Six heavy metals were analysed from the soil samples including Hg, As, Pb, Cd, Cr and Cu. Total trace elements were extracted from soil by acid digestion Nitric/Perchloric acid 5:1 as described by Stewart et al. (1974). During digestion large amount of the sample was taken, that is 100 g of soil was mixed with 50 ml Nitric/Perchloric acid and digested using hot plate until the sample became colourless. After digestion the samples were filtered through suction pump and the leaching of minerals facilitated by adding 100 ml of dionazed water. The filtrate was collected in to 250 ml flask after which metals were concentrated by removing excess water using rota vapour at 60°C. The resulting concentrated solution of 10 ml was analysed for heavy metals. Metals' concentration were done to offset the detection limits using AAS which is 0.01-0.001 depending on metal detection limits according to the calculation below.

$$\text{Heavy metalsconc. (mg/g)} = \frac{\text{Concentration from AAS x Extraction volume}}{10^4 \text{ x Sample wt(g)}}$$

The analysis of the levels of heavy metals was done at the University of Dar es Salaam Tanzania, using Perkin-Elmer 3100 Atomic Absorption Spectrophotometer. For each sampling point, samples were analysed in triplicates; therefore the values presented are the means of three samples.

Data analysis

Continuous vertical variability of heavy metals was modelled using equal area spline functions to get values for each soil depth (Bishop et al., 1999). Descriptive statistics were involved in calculating the mean and range of concentration of heavy metals. Linear regression analysis was involved in determination of the rate of change concentration of heavy metal along the distances from the edge of the pipeline.

RESULTS

Comparison between spilled and non-oil spilled transects

All six studied heavy metals were detected in the study

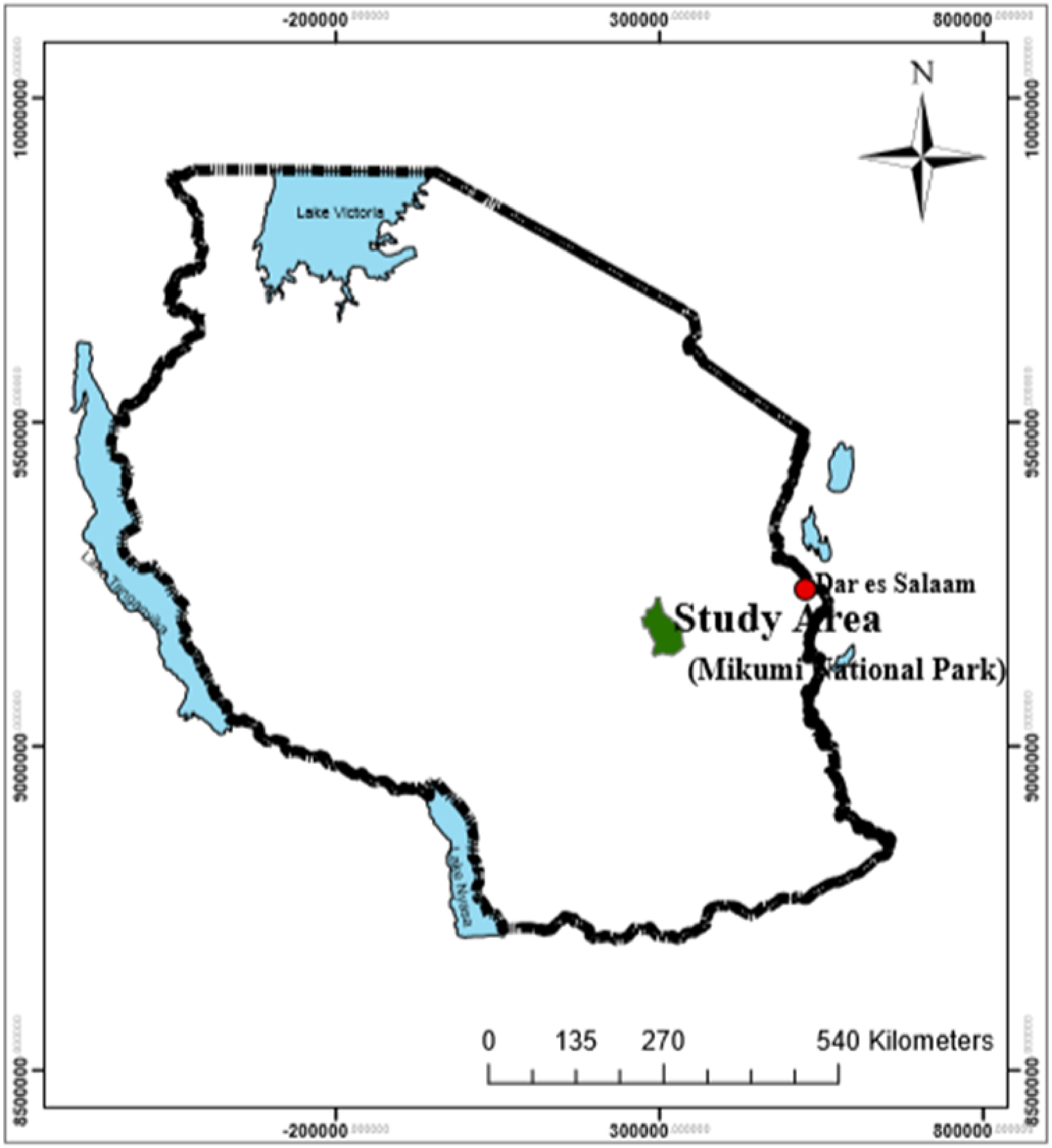

Figure 1. Map of the study area within the Mikumi National Park.

area. As, Pb and Cr were detected in both transects, that is, with oils spills and those without history of oil spillage to a distance of 0-35 m from the edge of the pipeline, with higher mean concentration in transects with oil spillage compared to those without (Table 1). From 50-200 m away these four metals were detected in transects with oil spillage only. Hg and Cd were detected in transects, with history of oil spillage only. Cu was detected in all transects and at all ranges of distance. In the manner of abundance metals were Cu>Pb>Cr>As>Hg>Cd. Copper was the most abundant metal of all and Cadmium was the least found.

Variation of concentration of heavy metals with distance from the edge of the pipeline

Concentration of all detected heavy metals decreased with increased distance from the pipeline to both North and South direction. The rate of change of concentration of each metal per 1 m increases in distance, at each transects in both direction (Table 2). Rate of change of concentration was statistically significant in transects with oil spills for As, Pb and Cr; in transects with no oil spillage the change was not statistically significant. Hg and Cd decreased with increased distance but the increase is not

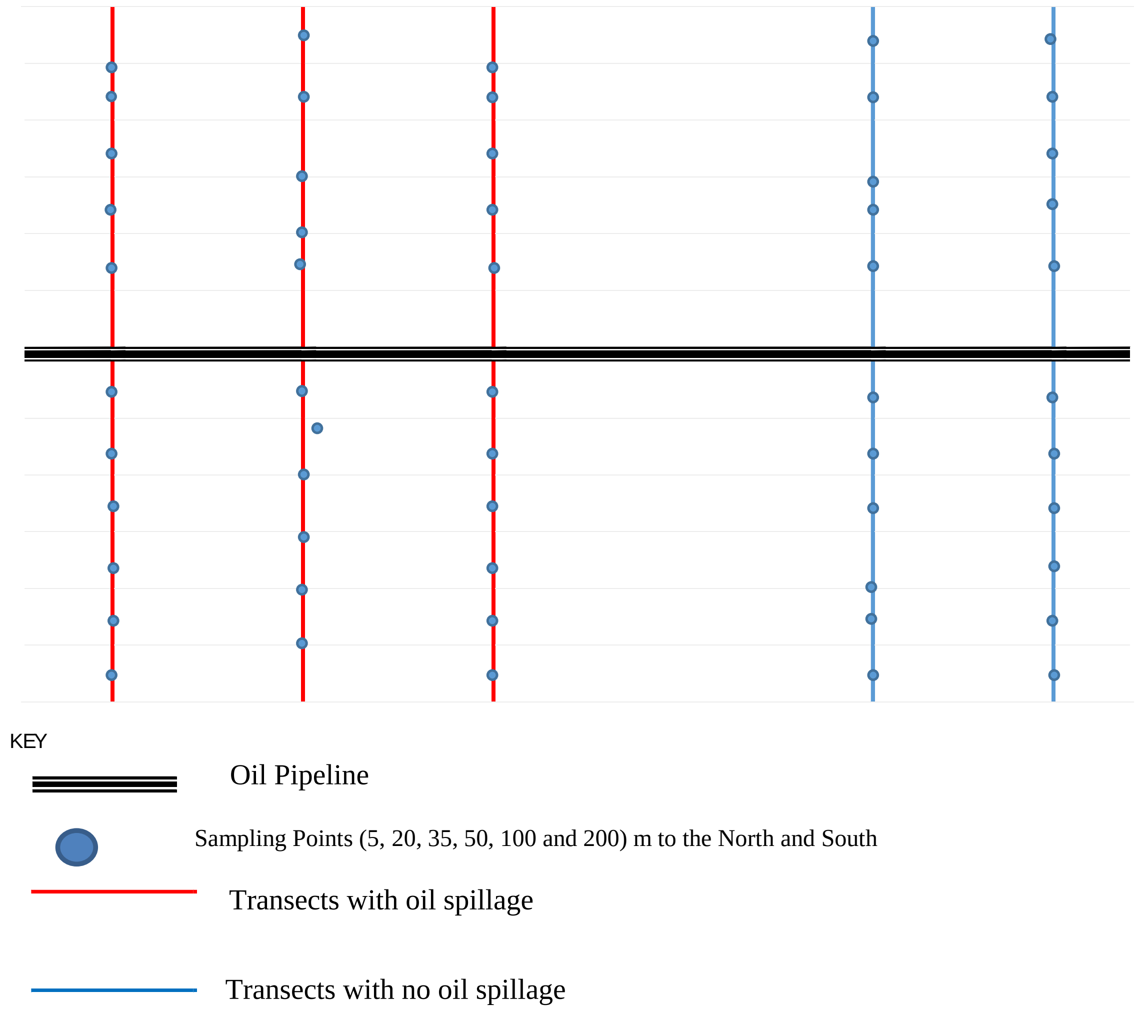

Figure 2. Sketch of arrangement of transects and sampling points along the pipeline.

statistically significant. Cu decreased with increased distance on both transects but the increase is not statistically significant (Table 4). Total concentration of all detected heavy metals were below those established by World Health Organisation WHO (Solek-Podwika et al., 2016) and Tanzania soil quality-limits for soil contaminants in habitat and agriculture (Tanzania Bureau of Standards, 2007) maximum permissible levels (Table 3).

DISCUSSION

Crude oils vary in their Chemistry hence their heavy metals contents vary from one to another. The oil transported through the TAZAMA pipeline is a murban crude oil, which is composed of gas oil and naphtha. Total heavy metals contained in the TAZAMA pipeline are Pb, As, Hg, Cr and Cu (TAZAMA, 2016). Therefore, these were the selected metals which were checked in sampled soils. Transects with oil spillage had higher mean heavy metals concentrations compared to those without. This suggests crude oil from the pipelines contributes to the addition of concentration of heavy metals in soils (Fei et al., 2019). Total heavy metals concentration decreased with increased distance from the pipeline in both transects. This may be due to the increased distance from the source of pollution. Same findings were reported by Sun et al. (2019) when assessing the level, source and distribution of heavy metals from a typical coal industrial city of Tangshan China. The decrease of concentration of heavy metals in both transects suggests that the pipeline leads to the increase of heavy metals with and without oil spills. According to Jasper (2012), oil leakage happens in pipelines during their check-ups and maintenance. This can lead to the emission of heavy metals to the soil even when a recorded oil spillage has not occurred. Metals like Hg and Cd were only detected in transects with oil spillage. This may be due to the fact that their presence

Table 1. Mean concentration of heavy metals at each sampling point in (µg/g) in each transect.

Metal	**0 m**	**20 m**		**35 m**		**50 m**		**100 m**		**200 m**	
		North	**South**	**North**	**South**	**North**	**South**	**North**	**South**	**North**	**South**
Pb. *sp*	9.628	6.651	10.382	0.404	7.889	0.025	0.017	0.0004	ND	0.109	ND
Pb. *sp*	9.056	7.831	8.287	7.822	7.859	0.015	0.276	0.0002	0.001	0.001	0.001
Pb. *sp*	8.523	8.544	7.834	9.048	7.455	0.007	0.001	0.004	0.001	0.003	ND
Pb. *unsp*	8.339	9.840	12.441	6.712	6.712	ND	ND	ND	ND	ND	ND
Pb. *unsp*	6.807	8.334	7.007	7.739	ND	ND	ND	ND	ND	ND	ND
As. *sp*	1.269	0.870	0.634	1.015	1.063	0.009	0.002	ND	ND	0.002	ND
As. *sp*	1.202	1.269	1.363	1.226	1.308	0.003	0.005	0.001	0.002	0.0003	0.0001
As. *sp*	1.319	1.361	1.223	1.218	1.312	0.001	0.001	0.001	0.002	0.001	ND
As. *unsp*	1.216	0.721	1.363	1.210	0.821	ND	ND	ND	ND	ND	ND
As. *unsp*	1.369	0.747	1.368	ND	ND	ND	ND	ND	ND	ND	ND
Hg. *sp*	0.293	0.132	ND	ND	ND	ND	ND	ND	ND	ND	ND
Hg. *sp*	0.724	0.0001	0.001	ND	ND	ND	ND	ND	ND	ND	ND
Hg. *sp*	0.164	0.075	0.261	ND	ND	ND	ND	ND	ND	ND	ND
Hg. *unsp*	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Hg. *unsp*	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cd. *sp*	0.293	0.132	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cd. *sp*	0.228	0.0003	0.0004	ND	ND	ND	ND	ND	0.0003	ND	0.0002
Cd. *sp*	0.164	0.749	0.261	ND	ND	0.0001	ND	0.0001	0.0004	ND	ND
Cd. *unsp*	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cd. *unsp*	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cr. *sp*	8.696	5.744	4.006	6.819	7.174	0.775	0.041	0.009	ND	0.141	ND
Cr. *sp*	8.207	8.693	9.390	8.376	8.987	0.021	0.394	0.0003	0.002	0.0002	0.0001
Cr. *sp*	9.064	9.376	8.356	8.316	9.013	0.001	0.011	0.005	0.019	0.004	ND
Cr. *unsp*	8.230	4.650	9.394	8.255	5.434	ND	ND	ND	ND	ND	ND
Cr. *unsp*	5.297	9.879	4.407	4.842	ND	ND	ND	ND	ND	ND	ND
Cu. *sp*	41.931	22.431	19.004	12.987	13.096	0.007	0.006	0.037	0.038	0.130	0.001
Cu. *sp*	136.395	1.830	2.245	3.926	1.765	0.002	0.405	0.0003	0.004	0.0002	0.001
Cu. *sp*	5.228	3.140	7.534	3.141	2.149	0.102	0.011	0.006	0.019	0.005	ND
Cu. *unsp*	3.884	2.564	2.465	2.191	2.195	0.006	0.005	0.003	0.002	0.002	0.002
Cu. *unsp*	3.135	2.349	2.110	2.334	0.002	0.002	0.002	0.002	0.001	0.005	ND

Key: sp - transects with oil spillage
unsp - transects with no oil spillage
ND- not detected (below detection limit)
For each sampling point, samples were analysed in triplicates, therefore the values presented are the means of three samples.

is mainly attributed by anthropogenic sources particularly petroleum (Yadav et al., 2019). Fernández-Martínez et al. (2019) suggest that Hg total concentration in soils is mainly due to petroleum activities and mines than other anthropogenic activities. Higher concentration of heavy metals in transects with oil spillage than without may be due to presence of petroleum pollutants. Cu was detected in abundance in both transects; the rate of change of Cu was insignificant in all transects at all intervals. This may be due to the fact that it is an essential micronutrient in the soil. According to Chrysargyris et al. (2019), Cu is among the essential micronutrients though its availability in excessive levels may be harmful to the plants (Wyszkowski, 2019). The concentration of heavy metals in all transects were below the WHO and TZS maximum permissible limits in soils. Moreover, the TZS limits are too general and do not specify the kind of land use for a particular soil. However, more attention should be paid to the pipeline safety and maintenance since the concentration in transects with oil spillage is higher compared to the ones without.

Conclusion

The level of heavy metals concentration detected in all the transects is below the WHO and the Tanzania soil quality-limits for soil contaminants in habitat and agriculture (TZS) maximum permissible limits. However, the concentration is higher in transects with history of oil

Table 2. Rate of change of total concentration of heavy metals away from the pipeline to north and south direction at each transect.

Metal	SP1		SP2		SP3		UNSP1		UNSP2	
	North	South	North	South	North	South	North	South	North	South
Pb	-0.042	-0.053	-0.048	-0.050	-0.048	-0.046	-0.051	-0.119	-0.046	-0.035
As	-0.006	-.0005	-0.007	-0.007	-0.008	-0.008	-0.006	-0.006	-0.006	-0.006
Hg	-0.001	-0.001	-0.002	-0.003	-0.001	-0.001	ND	ND	ND	ND
Cd	-0.001	-0.001	-0.001	-0.0004	-0.001	-0.001	ND	ND	ND	ND
Cr	-0.041	-0.034	-0.048	-0.051	-0.053	-0.051	ND	ND	ND	ND
Cu	-0.014	-0.189	-0.285	-0.487	-0.026	-0.031	-0.018	-0.018	-0.029	-0.013

Key: sp - transects with oil spillage
unsp - transects with no oil spillage
ND **-** not detected (below detection limit).

Table 3. Mean concentration of heavy metals in spilled and non-oil spilled transects in both directions in comparison to WHO and TZS maximum permissible levels in (µg/g).

Metal	SP1		SP2		SP3		UNSP1		UNSP2		Maximum permissible levels	
	North	South	North	South	North	South	North	South	North	South	WHO	TZS
Pb	3.565	5.156	4.699	4.882	4.804	4.522	4.921	16.948	4.553	3.002	100	200
As	0.062	0.504	0.698	0.743	0.751	0.739	0.551	0.578	0.506	0.604	20	1
Hg	0.009	0.070	0.146	0.199	0.054	0.083	ND	ND	ND	ND	2	2
Cd	0.009	0.70	0.009	0.039	0.062	0.083	ND	ND	ND	ND	3	1
Cr	4.062	3.341	4.771	5.104	5.159	5.076	3.688	3.891	3.499	2.732	100	-
Cu	12.521	16.443	21.507	37.633	2.379	2.871	1.709	1.698	2.589	1.096	100	200

(Sołek-Podwika, Ciarkowska, & Kaleta, 2016; Tanzania Bureau of Standards, 2007)
Key: sp - transects with oil spillage
unsp - transects with no oil spillage
ND **-** not detected (below detection limit)
For each sampling point, samples were analysed in triplicates, therefore the values presented are the means of three samples.

Table 4. P and T values for Statistical test for rate of change of heavy metals with distance at each transects.

Metal	SP1		SP2		SP3		UNSP1		UNSP2	
	North	South	North	South	North	South	North	South	North	South
Pb	INSG	P<0.05 T=-2.64	P<0.05 T=-2.65	P<0.05 T=-2.65	P<0.05 T=-2.55	P<0.05 T=-2.74	P<0.05 T=-2.68	INSG	INSG	INSG
As	P<0.05 T=-2.67	P<0.05 T=-2.61	P<0.05 T=-2.64	P<0.05 T=-2.69	P<0.05 T=-2.72	P<0.05 T=-2.68	INSG	INSG	INSG	INSG
Hg	INSG	INSG	INSG	INSG	INSG	INSG	INSG	INSG	ND	ND
Cd	INSG	INSG	INSG	INSG	P<0.05 T=-2.42	INSG	ND	ND	ND	ND
Cr	P<0.05 T=-2.65	P<0.05 T=-2.01	P<0.05 T=-2.64	P<0.05 T=-2.69	P<0.05 T=-2.72	P<0.05 T=-2.69	INSG	INSG	INSG	INSG
Cu	INSG	INSG	INSG	INSG	INSG	P<0.05 T=-2.69	P<0.05 T=-2.75	INSG	INSG	INSG

Key: sp - transects with oil spillage
unsp - transects with no oil spillage
ND **-** not detected (below detection limit).

spillage compared to those without. This calls for more attention since prevention of heavy metals pollution is currently a global agenda. For the Mikumi National Park in particular, more attention should be given for the TAZAMA pipeline since it is a home for various species of flora and fauna including the endangered and critically endangered species.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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