Lead Pollution: A Growing Concern Along the Namibian Coastal Waters

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Abstract

The accumulation of lead within specific strata of the Namibian coastal waters during the winter and summer months (2012) of the Southern Hemisphere was investigated using inductively coupled plasma optical emission spectrometry (ICP-OES). The black mussel, *Choromytilus meridionalis* was used as indicator organism to ascertain levels of bioaccumulation. Accumulation levels in collected sediments and the water column were used as indicators for the partitioning of lead within the coastal water ecosystem. For this investigation, the Central Namibian coastline was demarcated into four sampling stations (Walvis Bay, Swakopmund, Henties Bay and Cape Cross). Results obtained indicated significantly higher levels of lead in sediment samples collected from the Walvis Bay harbour compared to the other sampling stations ($p < 0.05$), with Cape Cross and Henties Bay relatively in a more pristine stage in terms of lead pollution. Although not significant ($p > 0.05$), worrisome levels were observed in *C. meridionalis* tissues collected from Walvis Bay harbour. Maximum mean values of lead detected in sampled *C. meridionalis* collected from the Walvis Bay harbour was 0.70 mg/Kg of sample dry weight during the summer months. The mean values within the sediments ranged from 79.30 to 0.30 mg/Kg detected from the Walvis Bay harbour to Cape Cross respectively. Though *C. meridionalis* farmed in and around Walvis Bay harbour could be regarded safe for human consumption as observed lead levels did not exceed permissible WHO limits. However, industrial activities involving discharges of untreated

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effluent into the harbour could pose health concerns over the long term if these practices are not checked. The major outcome of this investigation is the need for continued monitoring of activities in and around the Walvis Bay harbour that could aggravate increased lead pollution to avoid human risks and irreversible ecosystem destruction.

Keywords: Lead pollution, mussels, *Choromytilus meridionalis*, coastal pollution, sediments, marine environment, Namibia

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1 Introduction

In natural aquatic ecosystems, certain metals such as lead, occur in low concentrations, normally at the nanogram to microgram per litre level. In recent times, however, the occurrence of metal contaminants' especially the heavy metals in excess of natural loads, has become a problem of increasing concern as documented by the Food and Agriculture Organisation (FAO, 1994) and the World Bank (2009). The main reason for this is rapid expansion of industrial activities, exploration and exploitation of natural resources, as well as the lack of environmental regulations in several countries (FAO, 1994). Some heavy metals such as Zn, Cu, Mn and Fe are essential for the growth and well-being of living organisms including man. However, they are likely to show toxic effects when organisms are exposed to levels higher than normally required (Omoregie and Ufodike, 2000).

Marine pollution in Namibia is not very widespread. Most of Namibia's coast is virtually free from pollution because it is contained within the Skeleton Coast Park or the Namib/Naukluft Park. The toxicity of lead in the aquatic environment is mostly determined by its chemical form. Lead bound to organic compounds is much more toxic than inorganic lead (Kennish, 1996). As a result some organisms can accumulate high concentrations of inorganic lead without any apparent harm (Omoregie and Ufodike, 2000; Aires, 2003 and Akueshi et al. 2003). Mussels in Norway have been shown to contain up to 3000 mg/kg of lead (Clark 1999). Mussels have a detoxifying mechanism for lead whereby they store large quantities as granules (solid form) in their digestive gland. Hence, mussels are good indicators of lead pollution in the aquatic environment (Mubiana and Blust, 2006). However, environmental concentrations above 10 mg/L are shown to be detrimental for the growth of some organisms as reported by Clark (1999). In a recent study, Chen et al. (2012) reported the health risks associated with trace metal poisoning in humans. Winneke et al. (1990) reported that level of 1.5 mg/L of lead could affect human nervous system.

The rich Benguela currents yield a large number of black mussels, *C. meridionalis*, along the Namibian marine coastline. This study aimed to compare concentrations of lead between specific stations along the Namibian coastline using mussels as indicator organism and partitioning of lead within the sediments and the water column from the different stations. Such studies will provide the needed baseline information for the monitoring of metal pollution of Namibian coastal waters. The study also highlights the importance of seasons and environmental factors in modifying the relationship between lead concentrations in the environment and that obtained in certain indicator organisms.

Figure 1: Map of the Study Area: Walvis Bay (latitude 22° 56' 50.3"S, longitude 14° 30' 04.3"E), Swakopmund (latitude 22° 42' 02.7"S, longitude 014° 31' 14.9"E), Henties Bay (latitude 22° 24' 34.8"S, longitude 014° 26' 38.7"E) and Cape Cross (latitude 21° 45' 22.5"S, longitude 013° 58' 08.2"E) (Source: Google Maps)

2 Materials and Methods

Four sampling stations along the Central Namibian marine coastline were selected for this investigation (Fig. 1). The Walvis Bay station was chosen based on the fact that there are comparatively more industrial activities taking place around the Kuiseb Area including the harbour. The Swakopmund station was selected because of the Swakopmund River that discharges its effluents into the ocean and also considering the mining activities that take place in its catchment area such as the Gruben and Khan areas in addition to the human settlements in this coastal town. Henties Bay and Cape Cross were partly chosen as points of reference considering that there are comparatively little industrial activities compared to the two other stations.

The sediment samples from Walvis Bay, collected during both seasons, consisted of very fine particles and were dark in colour with some silt-clay and gravel while samples from the rest of the stations mainly constituted of gravel and sand; and were brownish in colour. Sediment samples from Henties Bay and Cape Cross stations mainly constituted of large sized particles. All sediment samples contained some amount of debris. Sixteen sediments samples were collected from each sampling station. The odour intensity of sediment from the Walvis Bay station was the highest followed by Swakopmund's samples and the remaining two station's sediment were odourless.

Figure 2: The black mussel, *Choromytilus meridionalis*, collected from the Central Namibian coastal waters

Live samples of the black mussels, *C. meridionalis* (Fig. 2), seawater and sediment samples were collected from each sampling stations using standard sampling procedures (APHA

1999) during the Southern Hemisphere's winter and summer months from April to November of 2012. All samples were collected on a monthly basis except in July and August to demarcate the two seasons. Mean weights of *C. meridionalis* collected during winter and summer months were 28.33 $\pm$ 2.46 and 20.39$\pm$1.13 g respectively, while the mean lengths were 5.98$\pm$ 0.88 cm and 6.19$\pm$ 0.28 cm respectively. *In situ* observations of surface seawater temperature, dissolved oxygen and pH were measured during each sampling period. The pH was measured using the Voltcraft PH-100 ATC pH meter while dissolved oxygen was determined by the YSI 550-12 model DO meter.

Live specimens of collected mussels were transported in sea water containers to the Sam Nujoma Marine Research and Coastal Resources Centre (SANUMARC) Laboratory of the University of Namibia at Henties Bay. Collected mussel samples were placed in clean polythene bags and kept in the refrigerator ($4°C$) for 24 hours to sacrifice them. Excess water was drained from the shells before preservation at $-4°C$ prior to being submitted to the acid digestion process.

Prior to digestion, sediment samples were prepared by removing stones and other debris. Both the mussel and sediment samples were air dried thoroughly and separately in the Incubator 2000 Series model at $70°C$ for 48 hours and $110°C$ for 48 hours respectively. The mussel samples were pulverized into fine particles using the metal free mortar and pestle while the sediments were also pulverised in the same way but had to pass through a 250 μm mesh sieve to obtain fine and uniform particles. Twelve replicate samples were prepared for each variable i.e. mussels, water and sediments.

Prepared samples were digested using the Environmental Protection Agency (EPA) 3050B acid digestion method (Edgell, 1988). Sediment and mussel samples were further air-dried and manually ground once again and passed through a 1.7 mm sieve to ensure very fine particles were obtained. The digestate was then diluted to a final volume of 25 ml using purified water. Levels of lead in samples were determined using a Perkin Elmer Optima 7,000 DV model Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES), at a wavelength of 220.353 nm. No digestion was performed on water samples as the samples had no visual turbidity ($<$ 1 NTU) and could therefore be analysed directly. All mussel samples were analysed for Near Total Concentration (NTC) and as such there was no separation of the tissue and the shells.

Additionally, all glassware used was of analytical grade and each instrument was calibrated first before use from sampling phase to assimilation of trace metals. A multi-element standard solution was prepared from certified single element standards (10, 000 mg/L). For water samples, the matrix adjusted standards were prepared in artificial seawater whilst for sediment and mussels the standards were prepared in nitric acid. All calibration curves were verified utilizing a calibration verification sample and blank. Sixteen water samples were collected from each sampling station, it included one artificial seawater blank per sampling site while for sediment and mussels, one method blank per sampling site was used. Again, all samples involved the inclusion of two laboratory duplicates per sampling site. For sediments however, the iron levels exceeded the upper standard and thus the samples were re-analysed in a 1:100 dilution. Duplicate samples were prepared to assess the precision of the method used for the analysis.

Data were analysed using multivariate analysis and Pearson's correlation coefficient, performed using the computer software package GENSTAT Discovery Edition 4 (VSN International, Hertfordshire HP1 1ES, UK).

3 Results

During the sampling period, water physico-chemical parameters monitored were all within acceptable limits for maximum primary productivity in the water body with minimum mean temperatures of $14.43 \pm 0.30°C$ and maximum mean temperature of $18.87 \pm 0.09°C$ during the months of Southern Hemisphere's winter and summer in Henties bay and Walvis bay respectively (Table 1). Detected pH values were significant ($p < 0.05$) between the months of winter and summer with water samples from Henties Bay and Cape Cross being slightly acidic during the months of summer.

Table 1: Mean values (Standard Error) of surface water temperature, dissolved oxygen and pH from the various sampling stations

	Winter	Summer
Temperature ($°C$)		
Walvis Bay	16.10 (0.06)	18.87 (0.09)
Swakopmund	17.13 (0.18)	16.90 (0.06)
Henties Bay	14.43 (0.03)	15.00 (0.62)
Cape Cross	15.63 (0.09)	15.13 (0.30)
Dissolved Oxygen (mg/L)		
Walvis Bay	4.18 (0.16)	8.59 (0.71)
Swakopmund	7.69 (0.45)	8.67 (0.14)
Henties Bay	6.11 (0.00)	7.94 (0.00)
Cape Cross	7.48 (0.12)	8.65 (0.67)
pH		
Walvis Bay	8.06 (0.02)	7.92 (0.03)
Swakopmund	8.67 (0.14)	8.59 (0.01)
Henties Bay	7.94 (0.00)	5.80 (1.06)
Cape Cross	8.65 (0.67)	4.67 (0.03)

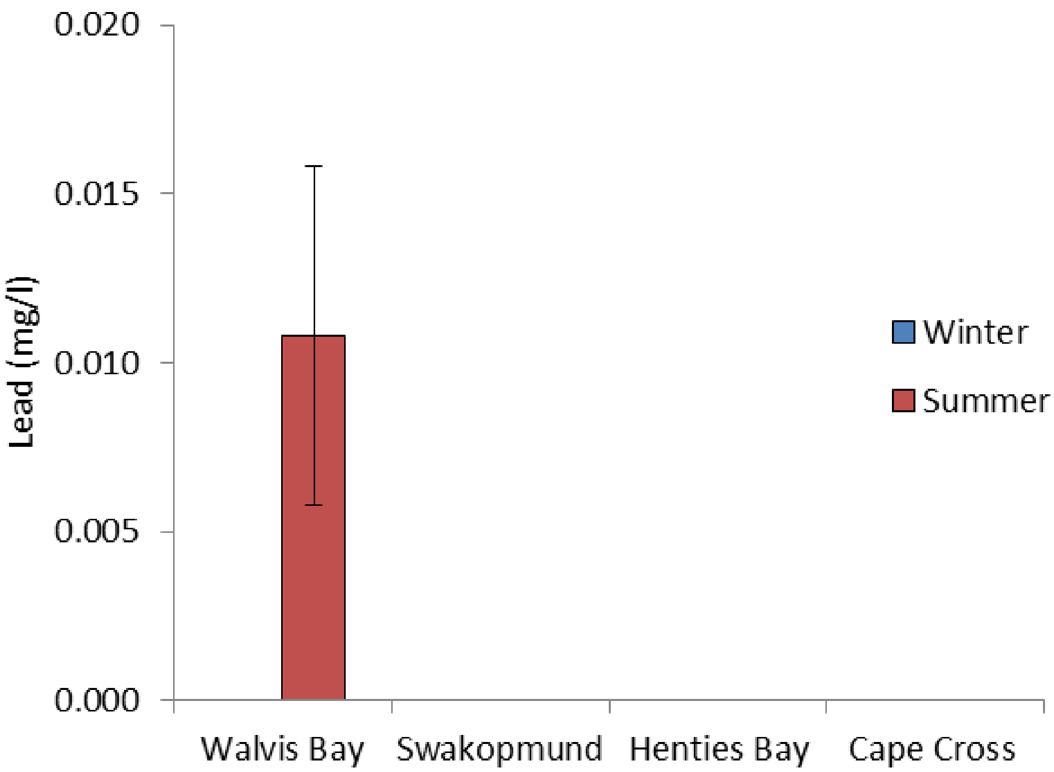

Figure 3: Mean levels of lead detected in water samples from the Central Namibian coastline during the Southern Hemisphere winter and summer, 2012

Results from this investigation indicated that during the months of winter in the Southern Hemisphere, water samples analyzed did not show presence of lead (Fig. 3), while during the months of summer, non-significant ($p > 0.05$) mean lead level were detected in water samples from Walvis Bay (0.01 $\pm$ 0.001 mg/L).

Analysis of sediment samples indicated significantly higher ($p < 0.05$) levels of lead during the months of winter and summer of 47.25 $\pm$ 2.63 and 39.08 $\pm$ 4.89 mg/Kg respectively in Walvis Bay (Fig. 4), while significantly lower levels were detected for Swakopmund and Henties Bay respectively for the months of winter and summer ($p < 0.05$). While Sediments from Swakopmund detected values of 1.08 $\pm$ 0.26 and 1.40$\pm$ 0.13 mg/Kg for winter and summer months respectively, sediments from Henties Bay detected values of 1.83$\pm$ 0.50 and 3.03$\pm$ 0.14 mg/Kg winter and summer months respectively. Using the methods reported here, no lead could be detected in the sediment samples collected from Cape Cross during the winter months, while an insignificant level of 0.27 $\pm$ 0.08 mg/Kg was detected during the months of summer.

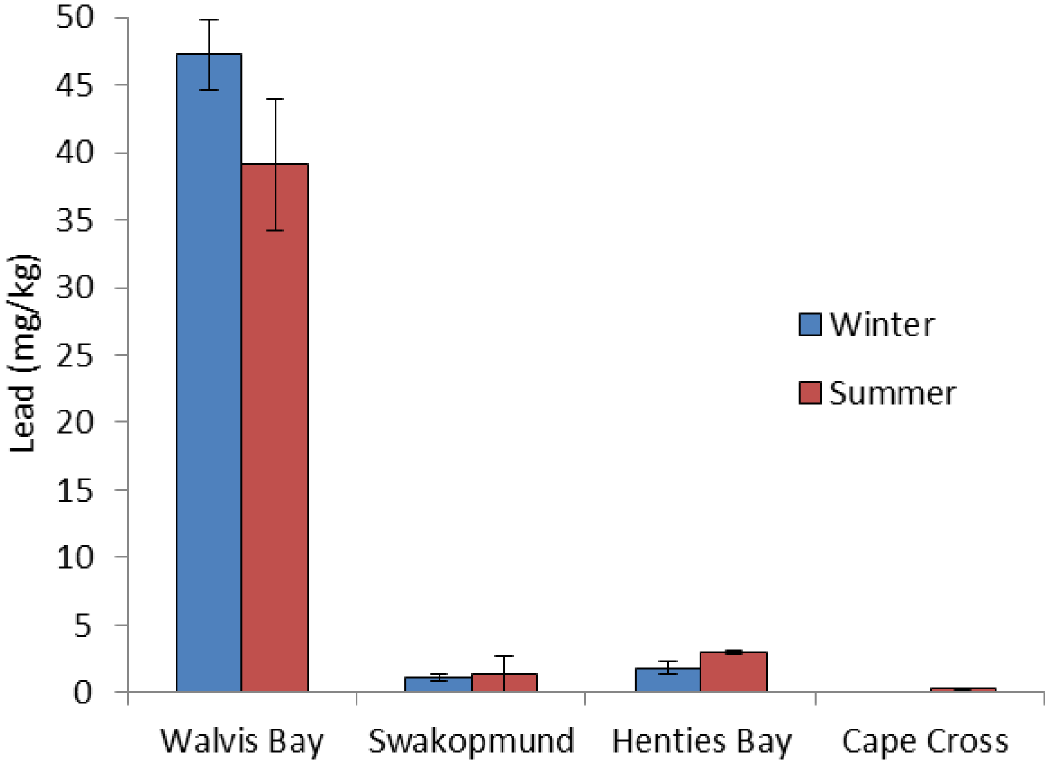

Figure 4: Mean levels of lead detected in sediment samples from Central Namibia coastline during the Southern Hemisphere winter and summer, 2012

Additionally, this study indicated that no levels of lead were detected in *C. meridionalis* samples in all stations during the months of winter (Fig. 5). However, summer months showed significantly higher values ($p < 0.05$) of lead in the samples collected from Walvis Bay Swakopmund. Mussel samples collected during the months of summer detected mean values of 0.24 ± 0.08 and 0.13± 0.05 mg/Kg from Walvis Bay and Swakopmund respectively.

Nevertheless, the grand mean value of lead across the stations was 12.55 mg/Kg during winter season and 10.4 mg/Kg during summer season. It should be noted that the values accumulated in sediments were significantly higher ($p < 0.05$) in concentration than those detected in *C. meridionalis* and water samples.

Remarkably, no lead could be detected in the sediment samples collected from Cape Cross while those collected from the Swakopmund and Henties Bay stations contained detected mean lead levels of 1.07 mg/Kg and 1.83 mg/Kg (during the winter season) respectively. However, these values had doubled during summer months in the Henties Bay station while

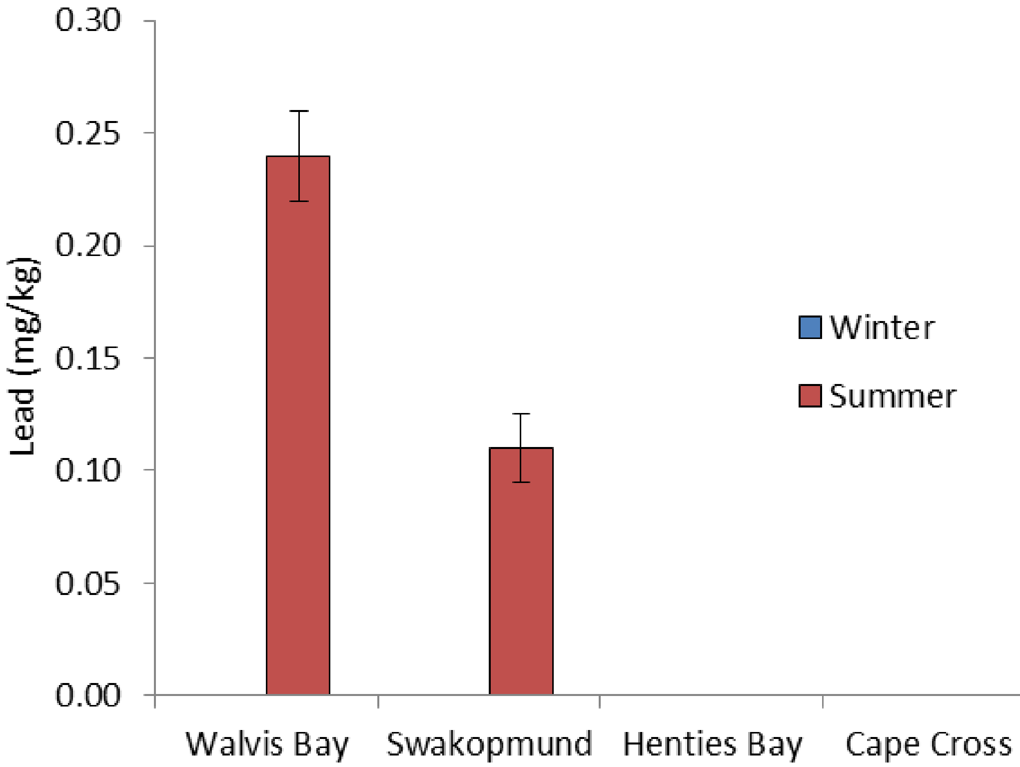

Figure 5: Mean levels of lead detected in the black mussel, *Choromytilus meridionalis* samples from Central Namibia coastline during the Southern Hemisphere winter and summer, 2012

in the samples from the Cape Cross station, detected only 0.3 mg/Kg was detected.

4 Discussion

Mussels are usually attached to substrates e.g. rocks and rooted macrophytes; like in this investigation, except for mussels that were collected from Walvis Bay station that were suspended in the water column in the Kuseib Fishing Enterprise Mussel Farm. This means that they are not in direct contact with the sediment nor attached to the rocks but rather only exposed to fine sediments that are resuspended by wave action or the Benguela upwelling currents instead. In both seasons, it was observed that mussels from Walvis Bay station were of relatively larger sizes in length and weight while Henties Bay mussels were smaller in size although those from Swakopmund station had very hard shells than the rest.

Natural waters become contaminated when the contaminant material disturbs the natural balance of living organisms near or in the water or when it makes the water unsafe for human consumption or recreation. Lately, it is evident that human activities are considered to be the most driving factors of water pollution in addition to the natural factors. Human activities originated from different sources such as industrial and farming practices affect water quality and usually such activities occur in the catchment areas. The analysis of dissolved oxygen in water samples is a key test when it comes to water pollution. Dissolved oxygen is an important component to the survival of most aquatic organisms. Generally, dissolved oxygen plays a vital role in the process of cellular respiration, and if insufficient, aquatic life would not thrive and survive. Aquatic plant populations, precipitation, rocks in the riverbed, time of the day, water velocity and temperature of the water are all contributing factors that influence total dissolved oxygen in an aquatic body.

C. meridionalis species collected at Cape Cross and Henties Bay stations did not pick up any significant lead and most probably indicate that the areas are lead free zones since this trace metal was also not detected in water samples and sediments in these stations. Furthermore, it should be explained here that the values detected in Henties Bay sediments could be due to the ability of sediments to act as an adsorptive sink for most trace metals. Black mussel samples found along the central Namibian marine coastline had lower levels of lead compared to those mussels reported from various sources in Taiwan (Lin, Wong and Li 2004) and in the Spanish North-Atlantic coast of 1.3 mg/Kg of dried weight limit for *Mytilus galloprovincialis* (Besada et al. 2011). Lead has a tendency to bioaccumulate but at low levels in terms of distribution in the marine environment (Cardellicchio et al. 2008).

Several studies have documented that sediments act as a scavenger and an adsorptive sink for trace metals (Giarratano and Amin 2010; Olowu et al. 2010); and that paint scrapping off from vessels and boats eventually contribute to the accumulation of lead in a water body (Lloyd 1992). In addition, it has also been reported that in bays there is a limited water exchange to clean up the system (Sulochanan et al. 2007) which probably explains why there is an increase in metal content in Walvis Bay than the other stations which are not bays. Also, Walvis Bay town is an industrial town coupled with a high number of people residing in this area such that factories and industries discharge their effluents into this part of the ocean. Several recreation activities in this area including the port works all act as anthropogenic sources for these contaminants and this could possibly explain the high level of lead detected in sediment samples for this station. Swakopmund station's lead levels could probably be attributed due to its adjacent location with Walvis Bay station in which there is no clear boundary to demarcate the water flow. In addition, the area has some major rivers in the catchments which tribute their waters into the Swakopmund River and town alongside its well-known recreation activities. As for Cape Cross station, no major activities take place in this area and no significant human settlement for one to assume that the activities could be sources of lead contamination although there are fishing and accommodation businesses in the area. Perhaps these activities do not significantly contribute to lead levels and hence no traces of lead were detected in winter and little in summer. Mean values of lead in Walvis Bay stations sediments show that the area is far more polluted as they were twice as high as those reported in Beagle Channel of Argentina (Giarratano and Amin 2010) while the rest of the stations detected way less lead content in sediments and could be regarded as less polluted.

Various studies (Cardellicchio et al. 2008; Giarratano and Amin, 2010; Boateng et al. 2011) have documented seasonal changes in trace metal levels in mussels as has been reported with lead accumulation in this study between winter and summer season. In this study, the two seasons had both detected significant mean lead value differences across all the stations. One notable observation is that the percentage lead accumulation change by mussels was higher than in sediments which indeed substantiate some claims that metal levels in mussels do accumulate at the end of winter season. Thus, a very possible explanation of this development could partly be due to the reproductive activity of mussels (Cardellicchio et al. 2008) as gonadal development might be attributed to the accumulation of proteins and carbohydrates during spawning; and for gonad tissue production and energy consumption (Boateng et al. 2011).

In comparison with *C. meridionalis* and water samples across the stations, this study could therefore report that mean values of lead were higher in sediment samples followed by mussels with the least values detected in water samples. This substantiates earlier findings (Giarratano and Amin 2010) that trace metals in sediment samples are many times more than the same metals in the water column because sediments act as scavenger agents for trace metals and an adsorptive sink in aquatic ecosystems. Furthermore, no significant accumulated lead in the mussel samples were detected between winter and summer seasons during this investigation as compared to other studies (Cardellicchio et al. 2008).

Overall, this research study has established that the central Namibian marine coastline is generally less polluted in terms of lead accumulation compared to other coastlines and coastal waters around the world. However, the study has also noted some significant increases in metal accumulation in water, mussel and sediment samples across the stations within the two seasons, most especially at Walvis Bay and Swakopmund. This finding should cause an alarm to all so that precaution measures can be put in place to control the situation, monitor and prevent it from reaching critical point as the clean-up is usually costly. Once measures are put into place then it will also monitor the levels of these metals so that they do not exceed their permissible limits for human consumption and ensure the Namibian coastline is environmentally pollution free. Further, this study has also found out that Walvis Bay station is far more polluted mainly due to the activities that take place in the area. The least polluted station in this study is Cape Cross mainly because this part of the coastline does not have much activities taking place as compared to Henties Bay, Swakopmund and Walvis

Bay stations.

Mean lead values detected in the Namibian *C. meridionalis*, water and sediment samples have all been analysed and compared thoroughly. Thus, it can be conclusively be stated that this study has ultimately provided very significant data which will act as a benchmark for further investigations in this field to monitor the Namibian marine coastline pollution status. The data and information in this report will most probably also help the country to set possible measures that will regulate some foodstuff limits in terms of trace metal compositions where needed for Namibia. Finally, lead levels have also been compared with the permissible limit of 1 mg/Kg set by the European Community Commission Regulation (EC) No. 466/2001 and regarded safe for human consumption; and the values were found to be slightly lower than this standard though this metal increase should set an alert for monitoring.

5 Conclusions

There is an increased level of lead along the central Namibian marine shoreline. Although these levels do not pose any threat currently, the increased accumulation of these metals should however cause an alarm of concern especially in Walvis Bay where the mussels are farmed for human consumption. Thus, there is a need to carry on with monitoring studies of the coastline before reaching irreversible and harmful or costly actions which might deprive the present and future generations' needs.

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