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Differences in prenatal exposure to mercury in South African communities residing along the Indian Ocean

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HIGHLIGHTS

- Mercury pollution and its impacts in South Africa have not been extensively studied.
- Most studies are initiated from emergency incidents.
- Here maternal and cord blood mercury levels are reported for three sites.
- Mercury was detectable in 100% of samples.
- Environmental conditions and dietary factors influence foetal exposure.

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ABSTRACT

Mercury is a persistent environmental pollutant that has the potential to adversely affect human health, particularly, foetal neurodevelopment. The purpose of the study was to investigate prenatal mercury (Hg) exposure in the population in three sites along the South Africa coast. Study subjects included women ($n = 350$) who were admitted for delivery at the local hospitals. Maternal and cord blood samples were collected to measure total mercury and each participant was required to answer a questionnaire. The 90th percentile of mercury levels in maternal and cord blood of the total population was 1.15 μg/l and 1.67 μg/l, respectively. Site 1 (Manguzi) participants had the highest maternal geometric mean (GM) values of 0.93 μg/l, which was significantly different from Site 2 (Port Shepstone) (0.49 μg/l) and Site 3 (Empangeni) (0.56 μg/l) (ANOVA test, $p < 0.001$). Umbilical cord blood GM Hg level for Site 1 (1.45 μg/l) was more than double the GM Hg level in Site 2 (0.70 μg/l) and Site 3 (0.73 μg/l). Univariate analysis indicated that the following maternal characteristics were positive predictors for elevated umbilical cord Hg levels: maternal blood Hg levels, living with a partner, residing in Site 1, living in informal housing, using wood and gas for cooking, borehole water as a drinking source, and a member of the household being involved in fishing. Maternal dietary predictors of elevated Hg levels in umbilical cord blood included consuming fresh fish, tinned fish, fruit or dairy products, daily. This study provides baseline data and reveals that 2% of the study population were above the EPA's reference value (5.8 μg/l) suggesting low level exposure to mercury in pregnant women and the developing foetus in South Africa. Further research is required to explore the sources of elevated Hg levels in Site 1.

1. Introduction

Mercury originates from natural and anthropogenic sources and is considered to be of a persistent and toxic nature in the environment. The ability of mercury to bioaccumulate and biomagnify in the environment and living organisms is of great concern. Mercury can travel considerable distances, and redistribute in land, freshwater and marine systems that are far removed from its actual sources. This is evident in the Arctic, where its population is exposed to mercury originating from long-range transport (AMAP, 2011). It is understood that mercury can also easily move from warm to colder climatic regions (AMAP, 2011). In addition, it is expected that many of the processes in the mercury cycle that are temperature dependent, will

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intensify with global climate change (Rylander et al., 2011). Currently, the European Union (EU) has called for the reduction of the regional mercury emissions, so as to mitigate present and future adverse health effects (European Commission, 2012).

Mercury, which is naturally found in the earth's crust, is released via the weathering of rocks and from volcanic activities. In addition, mercury from these natural sources is constantly remobilised and reemitted from aquatic and terrestrial surfaces (UNEP). Microbial methylation of mercury to monomethylmercury (MMHg) in aquatic sediments, which is subsequently bio-accumulated and biomagnified in aquatic food webs, is a major concern (Benoit et al., 2003; Mergler et al., 2007; Watras et al., 1998).

Gaseous mercury from anthropogenic sources include: fossil fuel combustion, particularly coal used for energy production; manufacture of non-ferrous metals; mercury use in small-scale artisanal gold mining; cement production; and from the use and disposal of medical and consumer products containing mercury (Butler Walker et al., 2006; Kim et al., 2011).

Globally, the consumption of fish contaminated with mercury is considered to be a significant source of human exposure. Consumption advisories are being issued in Europe and North America, but no data or advisories exist for developing countries, including Africa (EFSA, 2004; Streets et al., 2009). Recently, it has been reported that mercury emissions in Africa are greater than in Europe and North America, but data on mercury bioaccumulation in African aquatic systems are still very limited (Streets et al., 2009). It is estimated that global climate change will affect African regions with greater intensity, and the excessive flooding of wetlands will enhance production of MMHg, affecting food security in this region (Black et al., 2011).

Mercury is an exclusively toxic heavy metal to humans, ecosystems and wildlife. Its toxicity greatly depends on the chemical form, whether it is present in its inorganic or organic form, with methylmercury (MeHg) being the most toxic form (European Commission, 2005). Mercury is known to be neuro-, nephro- and immunotoxic to humans. Of particular concern is its negative effect on reproductive health, as the prenatal stage is known to be the most sensitive phase of human development, due to the high degree of susceptibility. Mercury can be transferred across the blood–placenta barrier, making the developing foetus particularly vulnerable to maternal mercury exposure during pregnancy (Al-Saleh et al., 2011; Butler Walker et al., 2006; Rudge et al., 2009). Prenatal mercury exposure has been associated with delayed neurodevelopment (Bjornberg et al., 2003) and low birth weight (Ericson and Kallen, 1989; Seidler et al., 1999). Reports have also shown that in utero exposure can result in irreversible damage after birth, ranging from defective cerebral nerve development to retarded growth, while causing no visible symptoms in the mother (Jedrychowski et al., 2007; Lederman et al., 2008; Schober et al., 2003; Weil et al., 2005). Mercury has no direct effect on hormones, but its interaction with brain cells may lead to a disruption of endocrine function (Tan et al., 2009).

1.1. Possible sources of mercury exposure in South Africa

Although in South Africa exposure to environmental mercury has not been investigated to any great extent, the emission of mercury from fossil fuels is considered to be a primary source. Current energy production, for both industrial and household use in the country, is based on up to 79% on fossil fuels, utilising South Africa's abundant coal deposits (SACRM, 2008). In the past, mercury was used extensively in formal gold mining processes, but this practice was discontinued around the 1960s with the development of new mining processes. However, at present there is an increase in informal small-scale mining activities in the disused gold mines, not only in South Africa, but also in the neighbouring countries (MiningMX, 2013; Pienaar, 2011). These illegal mining operations use exclusively mercury and rudimentary methods for gold recovery. These procedures result in mercury being released into the environment, causing environmental contamination, not only locally, but also globally (van Straaten, 2000).

According to a recent update of historical global inventories, South Africa is considered a significant global contributor of anthropological mercury emissions into the environment (Pacyna et al., 2006, 2010). Although country emission estimates from gold production and combustion processes have shown a decrease of 169.2 tonnes and 130.6 tonnes respectively since 1990, these estimates continue to be significantly elevated (AMAP, 2010).

A few studies have reported environmental mercury contamination and subsequent human mercury exposure in South Africa (Johnston et al., 1991; Oosthuizen and Ehrlich, 2001; Papu-Zamxaka et al., 2010a,b; Williams et al., 2010). For example, it has been shown that small-scale artisanal gold mining operations are releasing significant amounts of mercury into the environment (Mutemeri and Petersen, 2002; Nellie Mutemeri, 2002). Mercury measurements in potable water reservoirs that are situated in close proximity to coal-fired power stations and to artisanal gold mining activities in the Mpumalanga Province of South Africa, found that 38% of water samples collected contained more than 5 ng/l (global average) of mercury, and 19% of the water samples contained more than 12 ng/l (a concentration that could result in chronic effects to aquatic life) of mercury (USEPA, 1992; Williams et al., 2010). At present in South Africa, the water quality guidelines for the upper limits for mercury in aquatic ecosystems is 40 ng/l (DWAF, 1996; Williams et al., 2010).

Oosthuizen et al. (2010) determined blood and urine mercury concentrations in community members residing within a 5 km radius of formal gold mining activities and of eight coal-fired power stations situated in the same province. The author reported elevated mercury levels in blood ($\geq$10 μg/l) and urine ($\geq$5 μg/g creatinine) in 15% and 50% of participants, respectively (Oosthuizen et al., 2010).

As mercury is known to bioaccumulate and persist in the environment, Papu-Zamxaka et al. (2010b) conducted a study in the KwaZulu-Natal province, examining the impact of environmental contamination and human exposure to mercury, two decades after an accidental spillage from a mercury waste processing plant. The author reported elevated mercury concentrations in 62%, 50% and 17% of river sediment, fish and human hair samples, respectively. The study also found that the ratio of the MeHg to total mercury in human hair ranged between 75% and 100%, which suggests contamination through diet (Papu-Zamxaka et al., 2010b).

A year later, Williams et al. (2011) repeated the study by Papu-Zamxaka et al. (2010b) and also reported elevated levels of mercury in sediment and fish, albeit in lower concentrations. Both studies confirm that previously contaminated rivers and dams are sites for mercury exposure to populations residing in close proximity. Since large dams are a source of drinking water, irrigation for farming, and subsistence fishing in South Africa, the formation of MeHg in the reservoirs may impact human and environmental health (Williams et al., 2011).

There is a paucity of data on population exposures to environmental pollutants in the southern hemisphere, including most of Africa, and South Africa in particular. The World Health Organization (WHO) acknowledged that a large load of Africa's burden of disease is related to the environment (WHO, 2009). Furthermore, it is understood that human toxicity of all contaminants, including mercury, may be exacerbated in these regions not only by poor economic, nutritional and health status of populations, but also by climate change (Confalonieri et al., 2007). It is expected that climate change during the next 50 years will be most evident in the coastal regions of the southern hemisphere and particularly along the shores of the African continent (IPCC). In this context, there is also concern regarding the possibility of re-distribution and biomagnification of pollutants, including mercury and pesticides, in water-rich areas (wetlands, dams, rivers and oceans), because of excessive flooding episodes expected to be caused by climate change.

In response to the limited data on prenatal exposure to persistent toxic substances (PTS), including mercury and its possible detrimental