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Arsenic and mercury concentrations in marine fish sourced from local fishermen and fish markets in mine-impacted communities in Ratatotok Sub-district, North Sulawesi, Indonesia

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ABSTRACT

Mesel gold mine, Ratatotok Sub-district, North Sulawesi, Indonesia deposited about 4.5 million m^3 of detoxified tailings containing arsenic (As) and mercury (Hg) via a submarine pipeline into Buyat Bay. As and Hg analysis of 216 fish muscle tissue composites from subsistence fishermen, local markets and a reference market confirmed that mean As levels were comparable between locations (range 1.71 to 2.12 mg/kg wet weight (ww)) and < 10% of the Australia New Zealand standard. Mean Hg concentrations were highest for the artisanal fishermen group (0.23 mg/kg ww), similar between the local markets (0.11–0.14 mg/kg ww) and lower at the reference market (0.04 mg/kg ww). A 12-month fish availability study identified that the results were due to the different coral and deep ocean species assemblages. All mean values were < 50% of the FAO/WHO/Codex standard for Hg. The results confirmed that there was no contamination from the deposited submarine tailings.

1. Introduction

Anthropogenic gold recovery, both artisanal and on an industrial scale, has been and continues to be a major economic activity in North Sulawesi, Indonesia. Ratatotok Sub-district is in Minahasa Regency on the South East coast of the North Sulawesi peninsula, about 80 kilometres south of Manado. Artisanal gold mining in the Ratatotok Sub-district commenced in the Totok River catchment in the 1930s, with estimated gold recovery varying widely being reported as between 500 kg (2000) and 8000 kg (1980s) (Kambey et al., 2001). The sediments of the Totok estuary and Totok Bay are severely affected by Hg from gold extraction and amalgamation (Castilhos et al., 2006).

An industrial scale (700,000 t per annum) gold mine at Mesel in the Buyat River watershed operated between 1996 and 2004. The pre-mining environmental assessment, confirmed that the Buyat Bay (BB) eco-system had not been impacted by the historical artisanal gold mining. The Ratatotok and Buyat catchments are separate and the respective rivers flow into separate bays, divided by the Ratatotok peninsula (Fig. 1). The Mesel mine neutralised and detoxified tailings was disposed through an engineered submarine tailings placement (STP) into BB, a relatively small embayment (approximately 1.2 km^2) in the Molucca Sea. As and Hg were removed from the tailings, using ferrous sulphate and sodium sulphide precipitation of the tailings liquor. The tailings was deposited at a depth of 82 m and some 900 m from the shoreline.

The Mesel mine and STP were perceived by the local communities as having significant adverse impacts on their health and the local environment, both during the operational period and following cessation of operations. In particular, the Buyat Pantai (BP) beachfront community at BB (population about 200) having traditional fishing as their main occupation, were adversely economically impacted. The BP fishermen as a result of their fish being unsaleable, lost their source of income. In 2005, > 50% of the BP community left the area to re-settle in Central Sulawesi. The impact on other communities was less traumatic, but at Buyat Village (BV) population 450 and Ratatotok township (RT: population 1600) economic hardship from a loss of marine tourism and the local fishing industry, compounded existing health concerns from the artisanal gold mining in the Totok River watershed.

Following closure of the mine and cessation of tailings release, PT NMR, together with the Government of Indonesia, established an Independent Scientific Panel (ISP) to undertake a 10-year physical and chemical oceanography, marine ecology and fish tissue monitoring program between 2007 and 2016. The environmental fish monitoring, included the contaminant metal concentrations in raw fish tissue digests from BB and from a distant non-mine-affected reference site at

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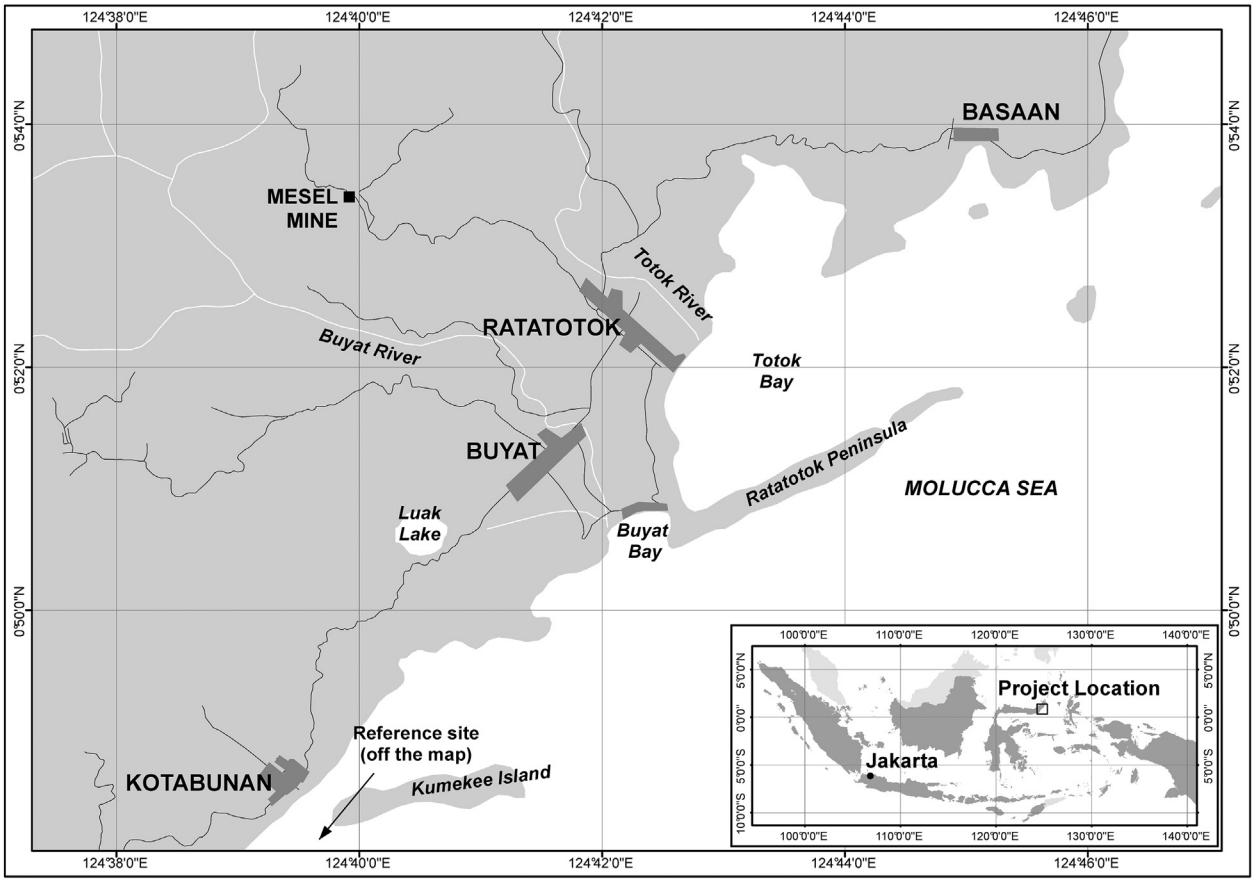

Fig. 1. Map of the main features in the Ratatotok Sub-district study area.

Pulau Nanas (PN). Monitoring also included a selective diet study for the local communities. This study undertook the determination of As and Hg in FAO/WHO/Codex-prepared "as consumed" fish tissue composite samples from local fishermen's catch and market-purchased fish.

The ISP environmental fish monitoring program had a particular focus on As and Hg, which are actively bio-accumulated in fish, crustaceans and other seafood. The concentrations are dependent on the particular species, habitat, maturity, weight, length and diet. The Hg concentrations for a given species differ between non-polluted locations (Kim et al., 2016). There are only very limited results available for the levels of As and Hg in the Asia-Pacific tropical species from natural and polluted environments (Kumar et al., 2004; Chouvelon et al., 2009).

The selective diet study targets the intake of As and Hg in local-caught and market-purchased fish from the perspective of the consumer. The results provide a surveillance, monitoring and assessment tool, by comparison with the appropriate contaminant standards. For non-occupational groups, methylmercury (MeHg) in seafood is accepted by regulatory agencies as providing 100% of total exposures (e.g. Health Canada, 2008). A fraction of the total exposure to inorganic arsenic (Asi) can be allocated to seafood intake as part of the allocation to other pathways, such as drinking water, rice and fruit and vegetables (EFSA, 2014).

As and Hg concentrations in raw fish muscle tissue from the ISP 2007–2015 environmental monitoring at BB and the PN reference site have been compared with those of the BB subsistence fishermen. The "as consumed" composites and environmental fish tissue results were from similar locations and represented comparable species, habitats and trophic levels. The detailed results of the environmental fish tissue monitoring studies are being reported separately (Shepherd and Rumengan, in preparation).

2. Materials and methods

Six surveys were undertaken between 2007 and 2011, three in each of the wet monsoonal (May) and dry (September) seasons. On each sampling occasion, 27 fish were randomly purchased at sea from the BB fishermen, or were caught by the survey team, using the hook and line method. A similar number of fish, representing a range of species, habitats and trophic levels were purchased from the BV and RT community markets and from the fish market in Manado. The criteria for inclusion of individual fish were that they were of a species widely available and were regularly consumed by the BP, BV, RT and Manado communities.

The length, weight, scientific name and local name of each specimen was recorded, a unique sample code allocated and the samples digitally photographed as a permanent field record. Initial sample preparation, including the removal of non-edible parts (scales, fins, head and internal organs) was undertaken before the samples were sealed in plastic bags and transferred at − 18 °C from the field sampling sites to the analytical laboratory in Jakarta.

Following receipt by the laboratory, the specimens were individually filleted using powder-free disposable latex gloves, plastic cutting boards and a new stainless steel scalpel blade for each specimen. Deionised water was used for washing the implements between samples. The muscle tissue samples were randomly assigned into four groups of nine location-specific composites. Preparation to the FAO/WHO/Codex "as consumed", involved cooking in a minimum amount of unsalted deionised water for 3–4 min, until the flesh could be removed from the skin and bones using stainless steel tweezers. The flesh was chopped into pieces no larger than 1 cm^3, before being mixed and homogenised using a Waring type blender with stainless steel blades. The samples were digested using standardised methods (US EPA Method 200.3, 1991). Five grams of the wet flesh sample was weighed