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Elemental and ionic components of atmospheric aerosols and associated gaseous pollutants in and near Dar es Salaam, Tanzania

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HIGHLIGHTS

- Air pollutants of different anthropogenic origin were studied at Tanzanian sites.
- Ionic species and elements of aerosols were characterized by IC and EDXRF analyses.
- Seasonal and site-specific variations of gases and aerosols were evaluated.
- Gas-to-aerosol conversion, aerosol acidity and sea salt loss were calculated.
- Source identification was made by correlation and principal component analysis.

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ABSTRACT

Elemental and water-soluble ionic compounds (WSICs) of atmospheric aerosols (total suspended particulate – TSP) and some gaseous pollutants (SO_2, NO_2 and O_3) from a coastal, semi-urban and rural site in and near Dar es Salaam, Tanzania were investigated during dry and wet seasons of January 2005–November 2007. Na^+, Ca^{2+}, SO_4^{2-}, NO_3^- and Cl^- made up the dominant fraction of WSICs during the dry season with average concentrations ranging from non-detectable (n.d.)–5.4, 0.26–2.6, 0.74–14.7, 0.4–1.5 and 1.1–3.4 μg m^{-3}, respectively, while in the wet season, from n.d. up to 1.7, 1.2, 4.4, 2.1 and 3.0 μg m^{-3}, respectively. The total air concentrations of the detected elements (Al, Si, S, Cl, K, Ca, Fe and Zn) showed seasonal and site-specific variation in the range of 7.5–26.6 with an average of 14.5 μg m^{-3}. Most of the air concentrations of pollutants were observed to decrease with increasing distance from the coastal site, which is under urban and industrial pollutant emissions. Sulphur and nitrogen oxidation ratios during the dry season ranged from 0.08 to 0.91 and 0.013 to 0.049, respectively, while they were between 0.09–0.65 and 0.002–0.095, respectively, in the wet season. These values indicate the photochemical oxidation of SO_2 and a high extent of NO_3^- formation in the atmosphere. Neutralization ratios revealed the presence of acidic SO_4^{2-} and NO_3^- aerosols. Principal component analysis identified sea spray, local combustion, vehicular traffic, biomass burning and re-suspended road dust as dominant sources of aerosols at the studied coastal and semi-urban sites. However, at the rural site, besides sea spray, crustal sources, soil dust re-suspension and long-range transport are the possible origins of suspended particulates.

1. Introduction

Atmospheric air pollution is partly associated with anthropogenically emitted gases and aerosols (Seinfeld and Pandis, 2006). Aerosol composition varies in space and time and depends on the contribution from diverse sources, e.g., sea salts, mineral dust and anthropogenic emission as well as on

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meteorological conditions. Atmospheric particulate matter (PM) is responsible for negative effects on human health, natural and man-made materials, ecosystems and the global climate (Harrison et al., 2004; IPCC, 2007).

African countries are subject to a raising burden of atmospheric aerosols released by industrial sources, biomass burning, traffic and coal-fired power plant emissions (Jonsson et al., 2004). While many studies on the water-soluble, ionic compounds (WSICs) (e.g., SO_4^{2-}, NH_4^+ and K^+), being a considerable fraction of PM, have been conducted in Europe and Asia (e.g., Satsangi et al., 2002; Wang et al., 2002; Viana et al., 2007; Bencs et al., 2008), only a handful of such papers have been published for Sub-Saharan African countries (Baumbach et al., 1995; Jonsson et al., 2004; Bennet et al., 2005; Favez et al., 2008; Mkoma, 2008; Mkoma et al., 2009a, 2009b). Most of the papers on African aerosols report on the particulate (mass) concentration (Kinney et al., 2011) and/or the individual elemental air levels (Maenhaut et al., 1996; Koleleni, 1998, 2003; Gatebe et al., 2001; Nyanganyura et al., 2007).

NO_3^- and SO_4^{2-} salts present in WSIC are responsible for acidic rain, which is deleterious to the urban environment, e.g., via corrosion (RAPIDC, 2003). Mkoma et al. (2009a, 2009b) investigated the seasonal variation of WSICs in atmospheric aerosols at urban sites of Dar es Salaam and Morongo during the 2005 dry and 2006 wet seasons, and found that Cl^-, Na^+ and Mg^{2+} were the dominant ions in coarse particulate (PM_{10-2}), while NH_4^+, SO_4^{2-} and K^+ were the most abundant ions in fine aerosols (PM_2). Neither of these studies monitored any aerosols over coastal or rural areas surrounding Dar es Salaam, nor any ambient gaseous pollutants.

In this study, gaseous air pollutants (NO_2, SO_2 and O_3), the elemental content and WSICs of total suspended particulate (TSP), collected over coastal, semi-urban and rural sampling sites in and near Dar es Salaam, Tanzania, has been characterized. The seasonal variation, site-specific differences and correlation of the WSICs with ambient gaseous pollutants and the meteorological conditions are also studied. The formation of secondary aerosols of SO_4^{2-} and NO_3^-, as well as the conversion of sea salt particles over the continent and aerosol acidity are discussed. Possible emission sources of atmospheric pollutants are identified by means of principal component analysis (PCA).

2. Experimental

2.1. Site characteristics

The coastal and the semi-urban sampling sites, located 0.1 km and 15 km from the coastline, respectively, were in Dar es Salaam, while a rural sampling site is situated 40 km from the coastline (Fig. 1). The city is the commercial capital of Tanzania with a population ~4.4 million (NBS, 2013), which has an average growth of 4.3% per year. The study area has a tropic climate with dry (January–February, June–September) and rainy (March–May, October–December) seasons. Agriculture is the backbone of the Tanzanian economy, but Dar es Salaam is a fast growing city with extensive heavy and light industrial areas. The coastal site (6°48′37.76″ S, 39°17′50.31″ E) is surrounded by the Indian Ocean, harbour entry, a modern, large fish market and a tarmac road. The semi-urban site (6°46′51.03″ S, 39°12′13.29″ E), located at the roof top of a three-storey building of the Physics Department at the University of Dar es Salaam, is 0.5 km northeast of Ubungo, an area that includes various sources of pollutants: e.g., the city's diesel-powered electricity generating plant, local brewery, all-time heavy traffic junctions with more than hundred cars passing per hour and an upcountry bus terminal. The rural site (6°47′10.17″ S, 38°58′11.64″ E) is surrounded by forests, farms and a highway at a distance of 1.5 km.

2.2. Sampling of gases and particulate matter

Two-week-long sampling campaigns for gases and TSP in each season and site were conducted during 2005–2007. TSP was collected on Nuclepore membrane filters with 47 mm diameter and 0.4 μm pore size (Whatman International Ltd., England), using a stacked filter unit (SFU) operated at an air flow rate of 20 L min^{-1} for 6 h. There was no filter clogging observable during the air samplings, due to the low air flow applied and air volume sampled. The air volumes were recorded by common gas-metres. Each sampled filter was placed into a sealed plastic Petri-slide. Weather conditions (precipitation, air temperature (T_a), air pressure, relative

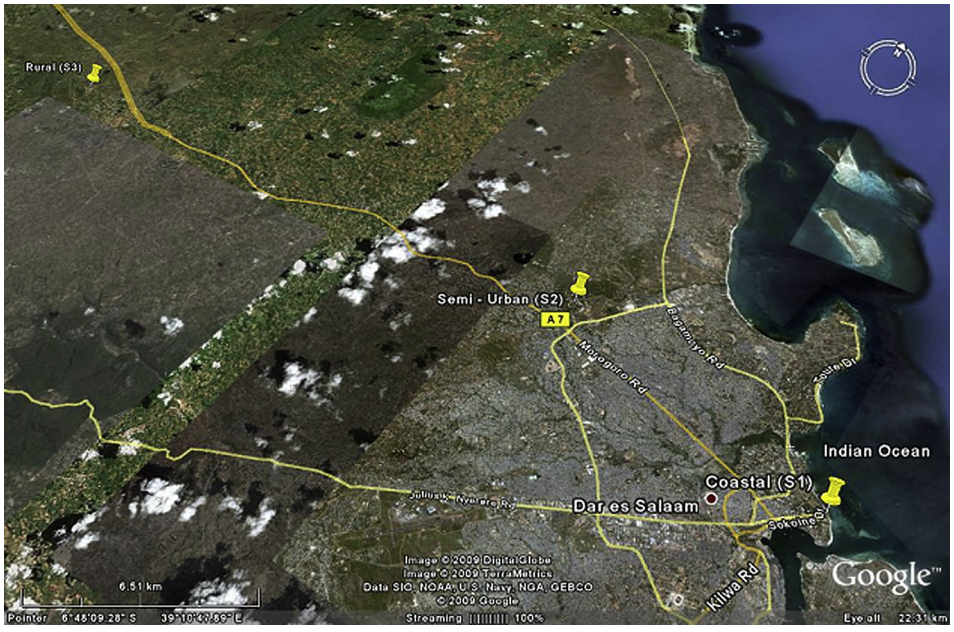

Fig. 1. Map showing the coastal (S1), semi-urban (S2) and rural (S3) sampling sites in and near Dar es Salaam, Tanzania (source: Google Earth).