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Composition and source apportionment of dust fall around a natural lake

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ABSTRACT

The aim of this study was to determine the source apportionment of dust fall around Lake Chini, Malaysia. Samples were collected monthly between December 2012 and March 2013 at seven sampling stations located around Lake Chini. The samples were filtered to separate the dissolved and undissolved solids. The ionic compositions (NO_3^-, SO_4^{2-}, Cl^- and NH_4^+) were determined using ion chromatography (IC) while major elements (K, Na, Ca and Mg) and trace metals (Zn, Fe, Al, Ni, Mn, Cr, Pb and Cd) were determined using inductively coupled plasma mass spectrometry (ICP-MS). The results showed that the average concentration of total solids around Lake Chini was 93.49 ± 16.16 mg/(m^2·day). SO_4^{2-}, Na and Zn dominated the dissolved portion of the dust fall. The enrichment factors (EF) revealed that the source of the trace metals and major elements in the rain water was anthropogenic, except for Fe. Hierarchical agglomerative cluster analysis (HACA) classified the seven monitoring stations and 16 variables into five groups and three groups respectively. A coupled receptor model, principal component analysis multiple linear regression (PCA-MLR), revealed that the sources of dust fall in Lake Chini were dominated by agricultural and biomass burning (42%), followed by the earth's crust (28%), sea spray (16%) and a mixture of soil dust and vehicle emissions (14%).

Introduction

Lakes are sensitive areas due to the potential exposure to pollutants from various sources. Pollutants can enter the water body of a lake through the connecting rivers, run-off water and from atmospheric deposition (Honkonen and Rantalainen, 2013). The limited water movement within a lake influences the degree of pollution within a lake environment. High concentrations of pollutants can decrease the biodiversity of the lake ecosystem and change the physical environment surrounding the lake (Lydersen et al., 2002; Dudgeon et al., 2006). High amounts of soil and particle intrusion increase the amount of pollutants and at

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the same time reduce the depth and area of a natural lake in many parts of the world (Sutherland, 2000; Dudgeon et al., 2006).

Atmospheric deposition is one of the major contributors to the amount of pollutants in a lake (Hillery et al., 1998; Vuorenmaa et al., 2014). The emissions from industry, motor vehicles and agricultural activities are released to the atmosphere, blown by the wind, interact with each other or with water and fall down to ground through wet or dry deposition. These gases and particulates settle as dust due to gravitational pull (dry deposition) or fall during rain as acid rain and fine particles (wet deposition) (Driscoll et al., 1995). Particles settling down to the surface of the earth can bring nutrients and trace metals into aquatic ecosystems such as lakes (Burton et al., 2013). Nitrogen has a significant impact on the process of eutrophication in lakes (Geng et al., 2014). The deposition of sulphates and nitrates increases the acidity of a water body (Sjöstedt et al., 2013; Ding et al., 2014). Excessive trace metals from atmospheric deposition are toxic to aquatic organisms such as fish and microorganisms (Ashraf et al., 2011; Walraven et al., 2014). Trace metals deposited into lakes are usually buried in the layers of sediments on the bottom of the lake and can be recycled into the water body by any interruption to the sediments (Percival and Outridge, 2013).

Knowledge of the source contribution of dust fall is important to the success of maintaining healthy air quality levels. To study the source information of environmental pollution, the receptor model is a most effective tool and consequently, is widely applied in environmental studies (Wang et al., 2012). Several models have been developed and are widely used to estimate source apportionment, including a combined model of principal component analysis and multiple linear regression (PCA-MLR), chemical mass balance (CMB) and positive matrix factorisation (PMF) (Vallius et al., 2005). In this study, PCA-MLR was adopted in order to determine the possible sources and their contributions to air quality. This model can extract certain factors from an ambient dataset. The factors can be identified as the actual source categories according to the source markers (Zeng et al., 2010). Several studies have applied this method for similar purposes, for example, Balakrishna et al. (2011); Moore and Attar (2011); Alahmr et al. (2012); and Qin et al. (2012).

Realizing the significant effects of dust fall through wet and dry deposition to a lake ecosystem, this study aims to determine the characteristics and water soluble composition of dust fall around the second-largest natural lake ecosystem in Malaysia (Lake Chini). The water soluble composition is expected to influence the water body of the lake ecosystem. Pollutant sources were determined using the statistical method PCA-MLR based on the composition of major ions and elements determined in rainwater samples. The influence of wind direction on the composition of the dust deposits was also studied using trajectory analysis.

1. Materials and methods

1.1. Study area

Lake Chini is located within the state of Pahang, which is on the east coast of Peninsular Malaysia. It is the second-largest natural lake in Malaysia after Lake Bera. Its surface area covers 12,565 acres and it was originally surrounded by natural forest and aboriginal settlements. The lake has a unique shape, comprising 12 small lakes interconnected by natural channels. Lake Chini has recreational value, as well as being of ecological importance in terms of its biodiversity (Hanif et al., 2009; Khairil et al., 2014). As an alluvial riparian swamp system, this wetland forms a unique ecosystem and has a high biodiversity of flora and fauna of conservational value. According to the Malaysian Nature Society (MNS, 1999), this area is richly endowed with biological resources and some 288 species of plants, 21 species of aquatic plants, 92 species of birds, and 144 species of freshwater fish have been found here. It has been designated a United Nations Educational, Scientific and Cultural Organisation (UNESCO) biosphere reserve in 2009 (Sharip et al., 2014).

Lake Chini is connected to the longest watercourse in Peninsular Malaysia, the Pahang River *via* the Chini River, which meanders for about 4.8 km. Lake Chini has a humid tropical climate with an annual rainfall of 1488–3071 mm and experiences the "rainy season" (wet season) from October to December. In a "normal season", water flows from Lake Chini into the Pahang River through the Chini River (January, February, March, and April). In the dry season (July, August, and September), no water flows into the Pahang River from the lake or the Chini River because the water level in the Chini River is lower than that of the dam (Hanif et al., 2009; Ebrahimpour and Mushrifah, 2010; Sharip et al., 2014).

More recently, anthropogenic activities such as mining, logging and agricultural activities, in particular palm oil plantations, can be found in the surrounding areas. In this study, seven monitoring stations around Lake Chini areas were chosen for dust fall collection. The coordinates and the sampling locations are shown in Fig. 1.

1.2. Sampling for dust fall

Samples were collected monthly between December 2012 and March 2013. To collect the rainwater and dust samples, polyethylene bottles equipped with a plastic filter funnel with a diameter of 20 cm were used. Prior to sampling, the polyethylene bottles were covered to avoid contamination due to dry deposition (Anatolaki and Tsitouridou, 2009; de Moraes Dias et al., 2012). The polyethylene bottles were mounted at a height of 2 m from the ground surface to avoid the accumulation of dust from soil and particulates. The funnels were opened for one month (30 days) to collect dust fall from dry and wet deposition into the polyethylene bottles. To avoid lichen growth during the sampling period, 10 mL of 0.01 mol/L copper sulfate ($CuSO_4{\cdot}5H_2O$) was added to each polyethylene bottle. The amount of dissolved SO_4^{2-} from the $CuSO_4{\cdot}5H_2O$ has been considered for SO_4^{2-} determination in the dust fall (BSI, 1969; Alahmr et al., 2012). Samples were kept in 4°C prior to analysis in the laboratory.

1.3. Analysis for dissolved and undissolved solids

To determine the concentration of undissolved solids, each sample was filtered using Whatman glass microfiber filters (47 mm diameter with a 0.45 μm pore size) (Grade GF/C,