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Tree bark as bioindicator of metal accumulation from road traffic and air quality map: A case study of Chiang Mai, Thailand

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ABSTRACT

Trees have been recognized as air quality bioindicators, but they have still not been fully implemented in tropical areas. In this study, bark of *Cassia fistula* was used to inspect accumulation of air pollutants (metals) emitted from road traffic in the city of Chiang Mai, Thailand. The mean concentrations of metal accumulated on tree bark (ng/cm^2) in descending order were Al (1,238) > Fe (707) > Zn (162) » Cu (21.1) » Pb (6.37) > Cr (2.14). Correlations of Enrichment Factors: EF_{TS} (metal concentrations on bark compared to those in soil) among metals were relatively strong ($r > 0.6$) meaning that they were probably generated from the same sources. Moreover, principal component analysis and cluster analysis of EF_{TS} values revealed that Al and Fe were generated from soil resuspension that were attached on vehicle wheels and on road surfaces, while Cr, Cu, Pb and Zn resulted directly from vehicle emissions. The results lead to the conclusion that tree bark is a good bioindicator for air pollutant accumulation in this area. In addition, pollution indices, including total geoaccumulation index ($I_{GEO\text{-}tot}$) and pollution load index (PLI), were applied to generate air quality maps of the city. The maps illustrated that the most polluted areas in the city are the areas that have high traffic volume and building density, in which hospitals and schools are located. The degree of pollution presented in each area was influenced by both road traffic volume and density of buildings in relation to air ventilation capacity.
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1. Introduction

Metropolitan cities have been suffering with air quality degradation due to the rapid growth that is associated with urbanization. Road traffic is the most important anthropogenic source of atmospheric pollution in urban areas. It has been established that pollutant levels are directly related to the number of automobiles present on the roadways. Road traffic pollutants can be generated from various activities including internal combustion, corrosion of vehicle parts and resuspension of dust on road surface caused by vehicle-generated turbulence. Metal pollutants including Cr, Cu, Fe, Pb and Zn are known to be significant vehicular pollutants which are produced from both exhaust and non-exhaust actions of engines such as in fuel combustion, lubricant oil combustion, tire wear, crash barriers corrosion and brake lining wear (Thorpe and Harrison, 2008; Pulles et al., 2012). Moreover, an increase in particulate matter (PM) and soil metals such as Al has also been observed due to transportation activity (Wilkinson et al., 2013). These soil metals (in traffic area) are typically distributed from soil resuspension. Currently, the traffic volume in the mega-cities of several countries in Asia is continuously increasing at alarming levels. Consequently, these circumstances have resulted in enormous deteriorating impacts on human health and urban ecosystem.

Chiang Mai City is a northern urban center located in Chiang Mai Province. It is considered the second largest urban center in Thailand by population and attracts over 7 million visitors each year. This province is located in the Chiang Mai - Lamphun basin, which is partially surrounded by high mountain ranges. The geographical features of the province have forced the people of the city of Chiang Mai to face a serious situation with regard to air quality degradation especially during the dry season. The possible sources of air pollutants within 30 km radius from the city center

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are mobile source including on-road vehicles as well as airplanes (Chiang Mai international airport located in urban area), area source (biomass burning) and point source (Northern Industrial Estate). Biomass burning was a major source of air pollutants in the dry season, while vehicle combustion (diesel and gasoline emission) was the main source of air pollutants during the rainy season. However, air pollutants emitted from engine-vehicles are also major concern as one of important air pollution sources of the city for the whole year round (Chantara et al., 2012; Wiriya et al., 2013). Moreover, Chiang Mai City is rapidly growing along with the number of vehicles on the city's road system. The number of registered vehicles in December 2015 was 1.32 million vehicles with increasing rate by 6% per year since 2010. Therefore, the level of air pollutants produced by road traffic would very likely become critical in the near future; hence, the monitoring of those pollutants is necessary for this area.

According to the study of Schulz et al. (1999) and Janta et al. (2016), metals accumulated on the outer bark were deposited from ambient air. Using trees as an atmospheric bioindicator is widespread globally because the method is cheap, easy to use, and can potentially detect long-term contamination (Satake, 2001; Ferreira et al., 2012). Various tree species can be used. Examples of tree species that have been used successfully to monitor levels of aerial heavy metals were *Azadirachta indica* (Odukoya et al., 2000), *Zelkova serrata* (Hokura et al., 2009), *Casuarina equisetifolia*, *Delonix regia* (Ukpebor et al., 2010), *Fraxinus pennsylvanica* (Fujiwara et al., 2011), *Pinus massoniana* L. (Kuang et al., 2007). Even though, using of tree as air pollution bioindicator is implied in many areas. However, it is not much implemented in Southeast Asia (SEA) in which has high biodiversity. Consequently, the aims of this study were 1) the first of using a native tree species of SEA (*Cassia fistula*) for assessment of metals emitted from traffic activity, 2) Estimation of seasonal impact on metals accumulation on the bark, 3) Application of pollution indices including total geoaccumulation index ($I_{GEO\text{-}tot}$) and pollution load index (PLI) for comparing the degree of pollution between areas and indication of contamination zones by mapping of air quality in the study area in the city of Chiang Mai, Thailand and 4) Calculation of the influence of building areas and traffic volume on air quality. The results of the study should prove useful for local and governmental organizations in terms of urban air quality management.

2. Materials and methods

2.1. Study areas

Study areas were located in Chiang Mai Province, which is the second largest province in the north of Thailand. It is in mountainous northern Thailand with the coordinates between 17.242° and 20.148°N (latitude) and 98.010°–99.513°E (longitude) at elevation 310 m above sea level. This province covers area around 20,110 km^2 which 83% of the area is forest. The province has a population 1,640,479 people and population density is 81.6 people per km^2. The average temperature and annual total rainfall are 27–28 °C and 1200 mm, respectively.

The study area was conducted on the main roads in the city of Chiang Mai (18.788°N and 98.988°E). The city covers 152 km^2 and has a population of approximately 240,000. The population density is 1600 people/km^2. Traffic density ranged between 3000 and 80,000 vehicles per day. This area was represented the polluted area (local site) in which it was divided into urban and sub-urban area based on population density and human activities (Bootdee et al., 2012). The urban area was categorized with a 5 km radius from the center, consisting of residential areas, schools and businesses. The sub-urban area was comprised of residential areas, agricultural areas and parks. Moreover, Phrao District, Chiang Mai Province (19.366°N and 99.202°E) was selected as a background site for comparison due to its low level of human activities and pollution. It is located about 90 km from Chiang Mai City in the north and has about 60 times less population density (25 people/km^2) than the city of Chiang Mai.

2.2. Sample collection

2.2.1. Tree-type selection

C. fistula is selected because it is a tree species native to Southeast Asia and the Indian subcontinent. This tree is deciduous and fast growing tree. When young, it has smooth and thin bark which the outermost layer can be easily peeled off, and its bark change to scaly in old trees. The *C. fistula* is commonly planted along the road, both inside and outside of towns, for decoration and shading. Therefore, determination of metals on the bark of *C. fistula* planted near roadsides can be expected to show the level of pollutants influenced by road traffic.

The sampling trees were selected from *C. fistula* species planted along roads at a distance of less than 3 m from the road edge. The trees with the age around 4–20 year old or diameter at breast height (DBH) in the range 5–30 cm were chosen for this study because the metal accumulation on the bark was not related the age of the tree within this range (Janta et al., 2016). Moreover, the selected trees must have a smooth bark surface. The criteria for selection of trees as a bioindicator for metals accumulation was mentioned previously in Janta et al. (2016).

2.2.2. Tree bark sample collection

A total of 115 *C. fistula* (<3 m distance from the road) were selected for sampling. Their geographical coordinates were recorded in order to indicate their locations. Sampling locations in urban area (the inner pink circle) and sub-urban area (the outer part of the pink circle) are shown in Fig. 1a. Bark sampling was carried out during two periods; January 2014 (dry season and high tourist season) and September 2014 (wet season). In the first sampling, 79 and 36 trees (green circle symbols on the map) were collected from urban and sub-urban areas, respectively. In the second sampling, 26 trees (urban) and 14 trees (sub-urban) were selected from some of the first sampling trees (black triangular symbols in the map). For the background area, four trees were selected and sampled in September 2014.

Bark samples were collected from the selected trees at around 1.5–2.0 m above ground level. Approximately 20 cm^2 of the outermost layer of the bark (gray color) was collected from trees with a plastic spatula. The bark from second sampling was collected from near the same level as the first sampling (Fig. 1b). The samples were kept in polyethylene bags and stored in a refrigerator at 4.0 °C.

2.2.3. Soil sample collection

Topsoil (0–10 cm depth) samples (40 samples) were collected from the area near the sampling trees of the second sampling. Each sample came from a mix of 3 random points around the selected trees.

2.3. Metal extraction

2.3.1. Bark sample extraction

The bark samples were dried in an oven at 60 °C for 2 h and then cooled. The dried samples were weighed by 4 digits balance. Sample weights ranged between 50 and 270 mg. The samples were transferred into the inner layer of a double-layer Teflon digestion tube, while the outer layer was filled with 4 ml of concentrated extra pure grade HNO_3. The samples were heated at 140 °C for 4 h.

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