Ecotoxicology and Environmental Safety 127 (2016) 193–198

Contents lists available at ScienceDirect

Ecotoxicology and Environmental Safety

journal homepage: www.elsevier.com/locate/ecoenv

Build-up of toxic metals on the impervious surfaces of a commercial seaport

Abdul M. Ziyath, Prasanna Egodawatta, Ashantha Goonetilleke *

Science and Engineering Faculty, Queensland University of Technology (QUT), GPO Box 2434, Brisbane, QLD 4001, Australia

A R T I C L E I N F O

Article history:
Received 20 April 2015
Received in revised form
27 January 2016
Accepted 28 January 2016
Available online 8 February 2016

Keywords:
Marine ecosystem
Water quality modelling
Experimental design
Stormwater pollutant processes
Stormwater quality

A B S T R A C T

In the context of increasing threats to the sensitive marine ecosystem by toxic metals, this study investigated the metal build-up on impervious surfaces specific to commercial seaports. The knowledge generated from this study will contribute to managing toxic metal pollution of the marine ecosystem. The study found that inter-modal operations and main access roadway had the highest loads followed by container storage and vehicle marshalling sites, while the quay line and short term storage areas had the lowest. Additionally, it was found that Cr, Al, Pb, Cu and Zn were predominantly attached to solids, while significant amount of Cu, Pb and Zn were found as nutrient complexes. As such, treatment options based on solids retention can be effective for some metal species, while ineffective for other species. Furthermore, Cu and Zn are more likely to become bioavailable in seawater due to their strong association with nutrients. Mathematical models to replicate the metal build-up process were also developed using experimental design approach and partial least squares regression. The models for Cr and Pb were found to be reliable, while those for Al, Zn and Cu were relatively less reliable, but could be employed for preliminary investigations.

1. Introduction

The marine environment is a sensitive ecosystem that is home to a range of fauna and flora. Several studies have confirmed that marine ecosystems around the world are under serious threat due to pollution generated by various anthropogenic activities (Gao and Chen, 2012; Kucuksezgin et al., 2011). In particular, the presence of metals, which are toxic and persistent, can cause adverse impacts on the health of fauna and flora in the marine environment (Owen and Sandhu, 2000). Metals are contributed to the marine environment by diverse sources including the surrounding urban areas and seaports.

Anthropogenic activities associated with urban areas such as increased traffic activities can contribute a significant amount of metals to urban impervious surfaces, which are eventually transported to the marine environment by stormwater runoff. The characteristics of metal build-up on urban surfaces, particularly impervious surfaces along with the mathematical replication of the build-up process has been extensively investigated in research literature (for example Egodawatta et al., 2013; Gunawardena et al., 2014), contributing to the development of effective strategies to control metal contributions from urban areas to the aquatic environment.

However, only limited studies have investigated metal build-up on impervious surfaces specific to a commercial seaport (Goonetilleke et al., 2009), where a range of intense anthropogenic activities which are unique to this type of infrastructure such as container handling and heavy vehicle traffic activities occur. The limited knowledge currently available is a significant constraint to the design of effective management and treatment strategies to mitigate metal pollution originating from commercial seaports.

The primary aims of the study presented in this paper were to: (1) characterise the metal build-up on the impervious surfaces specific to a commercial port; (2) investigate the relationships of metals with other pollutants such as solids, organic carbon and nutrients, which influence metal behaviour in the build-up process and thereby provide essential knowledge for the design of effective treatment strategies; and (3) develop mathematical models to replicate the metal build-up process on impervious surfaces that are typical to a commercial port. The outcomes of the study can be extended to other commercial ports since the land uses investigated are typical to any commercial port.

2. Materials and methods

The study was conducted at the Port of Brisbane, Australia located adjacent to the Moreton Bay Marine Park, which has a high

* Corresponding author.
E-mail addresses: mohamed.ziyath@qut.edu.au (A.M. Ziyath), p.egodawatta@qut.edu.au (P. Egodawatta), a.goonetilleke@qut.edu.au (A. Goonetilleke).

http://dx.doi.org/10.1016/j.ecoenv.2016.01.027
0147-6513/

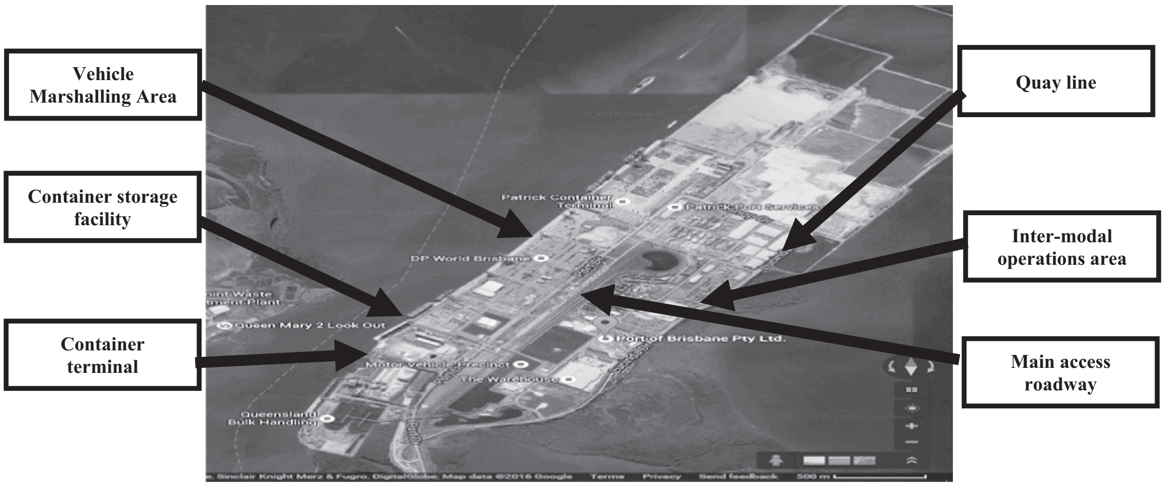

Fig. 1. Location of study sites.

ecological and conservation value. The marine ecosystem consists of over 150 ha of mangroves, large seagrass areas, variety of fish species and resident and migratory shorebirds. The surrounding areas have experienced high urban growth, and coupled with a booming economy and intensive agricultural and tourist activities. These in turn have resulted in an increase in anthropogenic activities such as increased cargo handling at the Port (Goonetilleke et al., 2009).

Six study sites encompassing different land use activities specific to a commercial seaport were selected at the Port of Brisbane (Fig. 1). The sites included a vehicle marshalling area (site 1), a container storage facility (site 2), a container terminal (site 3), a quay line (site 4), an inter-modal operations area (site 5) and the main access roadway (site 6). The pollutant build-up samples were collected from 2.0 m×1.5 m plot areas from the impervious surfaces of the selected study sites using a wet and dry vacuuming system. A detailed discussion on the build-up sampling protocol adopted can be found in Herngren et al. (2006). The samples were collected after a minimum of seven antecedent dry days as the total build-up asymptotes to an approximately constant value after this period of time (Egodawatta, 2007). The samples collected from the impervious surfaces were wet-sieved into different size fractions of <0.75 µm, 0.75–75 µm, 75–150 µm, 150–300 µm and >300 µm as the particle size plays a critical role in the adsorption of metals by particulates (Gunawardana et al., 2014).

The study investigated total suspended solids (TSS), total organic carbon (TOC), total nitrogen (TN), total phosphorous (TP), aluminium (Al), lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), arsenic (As), nickel (Ni), zinc (Zn) and mercury (Hg), which are common pollutants found in the environment (Gunawardena et al., 2013). The following methods were used for the laboratory analyses of pollutants: (1) TSS – 2540D and 2540C (APHA, 2005); (2) TOC – 5310C (APHA, 2005); (3) TN – 4500F and 4500B (APHA, 2005); (4) TP – 4500P (APHA, 2005); (5) Al, Pb, Cd, Cr, Cu, As, Ni and Zn – USEPA 200.7 (USEPA, 2001) and 6010B (USEPA, 1996); and (6) Hg – USEPA 7470A (USEPA, 1994) and 3112B (APHA, 2005). The data analyses were performed using univariate and multivariate data analysis techniques. Mutlivariate analyses such as principal component analysis (PCA) and partial least squares regression (PLS) were conducted using MATLAB (MathWorks, 2013).

3. Results and discussion

3.1. Metal build-up

The Hg load in the build-up was below the detection limit, while As, Cd and Ni loads were relatively very low. Consequently, these were excluded from further analysis. The average loads of other pollutants across the six study sites for the different particle size fractions are presented in Table 1(a) along with the corresponding standard deviation. As evident from Table 1(a), the pollutants were primarily present as fine particles <150 µm. The coarse particle fraction, i.e. >150 µm, was also present in significant amount. The predominant presence of finer particles is of concern since conventional sediment reduction approaches for stormwater treatment may not be effective in trapping finer particles.

In general, total solids load was found to be the highest followed by the total organic carbon load. Among metals, Al load was significantly higher than the rest. This can be attributed to the fact that Al is a major component in geogenic materials (Singh and Gilkes, 1992), and hence abundantly present in the environment. Though Zn, Cu, Pb and Cr are primarily contributed by the wear of vehicle components (Gunawardena et al., 2014), the Zn load was significantly higher than those of Pb, Cu and Cr, suggesting the presence of additional Zn sources such as container surfaces and roofs present at the study sites. However, their bioavailability is dependent on their association with other pollutants such as solids, organic carbon and nutrients as discussed in Section 3.2.

Table 1(b) gives the specific pollutant load in the total particulate build-up at the six study sites. Among the sites investigated in this study, sites 5 and 6 had relatively higher pollutant loads compared to the rest. Site 5 is the site of inter-modal operations and has inter-locking pavers, which can trap a relatively higher amount of pollutants in-between the pavers. On the other hand, site 6 is a roadway surrounded by unpaved areas and is used by heavy trucks. Consequently, a high amount of pollutants could have been contributed by geogenic sources and traffic activities. In contrast, sites 3 and 4 had the lowest amount of pollutants. Site 4 is the quay line, which has a smooth concrete pavement. Though appreciable traffic activities occur at site 4, its proximity to the shore could have resulted in the removal of a significant amount of pollutants from the smooth concrete surface by wind. Similarly, site 3 is used as a short term storage area, which could have limited the opportunity for the accumulation of a significant