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Green infrastructure practices for improvement of urban air quality

V.M. Jayasooriya*, A.W.M Ng, S. Muthukumaran, B.J.C. Perera

Institute for Sustainability and Innovation, College of Engineering and Science, Victoria University, Melbourne 14428, Australia

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ABSTRACT

Green Infrastructure (GI) practices have shown to be promising in mitigating the air pollution in urban areas of several cities across the world. GI practices such as trees, green roofs and green walls are widely used in United States and Europe to mitigate the air pollution. However, there is yet limited knowledge available in identifying the most suitable GI strategy for an urban area in improving the air quality. Furthermore, it is evident that Australia is still lagging behind in adapting GI to mitigate air pollution, compared with US and Europe. Therefore, this study analyzed the air quality improvement through several GI scenarios consisting of trees, green roofs and green walls considering a case study area in Melbourne, Australia by using the i-Tree Eco software. The results were compared with case studies in different cities across the world. The results showed that the i-Tree Eco software can be successfully applied to an Australian case study area to quantify the air quality improvement benefits of GI. The results were further assessed with several environmental, economic and social indicators to identify the most suitable GI scenarios for the study area. These indicators were quantified using different methods, to assess the effectiveness of different GI scenarios. The results showed that, trees provided the highest air pollution removal capability among the different GI considered for the study area. Combination of different GI such as green roofs and green walls with trees did not provide a significant increment of air quality improvement however, has provided more local benefits such as building energy savings. The results obtained from this study were also beneficial in developing policies related to future GI applications in major cities of Australia for the air quality improvement.

1. Introduction

Over the years, anthropogenic activities associated with urbanization have generated enormous pressure on the natural environment. Air quality deterioration is one of the major environmental problems stressed upon communities in urban areas, which can cause hazardous consequences for human health in the long term (Faiz, 1993; Akbari et al., 2001; Akimoto, 2003; Wang et al., 2004). According to the estimates of World Health Organization (WHO), urban air pollution accounts for 6.4 million years of life lost annually worldwide (Cohen et al., 2004; Chen and Whalley, 2012).

Air pollution in Australia is produced from numerous sources such as vehicular emissions, heating of wood, dust storms, energy production through fossil fuel burning, industrial activities, and bush fires (Johnston et al., 2011). Even though Australia has been able to maintain reasonable air quality levels compared to many other countries across the world, 3000 premature deaths occur in Australia annually due to air pollution (Environmental Justice Australia, 2014).

There are six major constituents that are specified as air quality indicators based on their effects on health or environment, which are named as criteria air pollutants. Carbon Monoxide (CO), Ozone (O_3), Nitrogen Dioxide (NO_2), Sulfur Dioxide (SO_2), Particulate Matter (PM10 and PM2.5) and Lead (Pb) are defined as criteria air pollutants in ambient conditions (US EPA, 2015). Among these pollutants, PM10 and O_3 are identified as the pollutants that are of major concern in affecting the health and environmental conditions in Australia, having concentrations above the ambient air quality standards for major cities such as Melbourne, Brisbane, Perth and Sydney (Department of the Environment and Heritage, 2001; Simpson et al., 2005).

Though it is inevitable that the degradation of air quality is a consequence of urban development, it is well-known that urbanization and associated activities are vital for the world's growth. Thus, researchers, ecologists and urban planners have identified the need for the opportunities to reduce the air pollution resulting from urbanization (Saunders et al., 2011). As a low cost mitigation

* Corresponding author.
E-mail address: varuni.jayasooriya@live.vu.edu.au (V.M. Jayasooriya).

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strategy, several researchers have studied the role of urban greening for air quality improvement in urban areas (Beckett et al., 1998; Nowak et al., 2006).

As an initiative of introducing urban greening concepts to reduce the impacts of harmful pollutants in the atmosphere, Green Infrastructure (GI) practices have been widely used in various urban areas across the world (Nowak et al., 1998, 2006; Yang et al., 2005a,b). GI practices such as trees, shrubs, lawns, green roofs and green walls have been proven efficient in reducing the harmful air pollutants and regulating the Green House Gas (GHG) emissions within the cities (Akbari et al., 2001; Tzoulas et al., 2007; Baró et al., 2014). The vegetation in GI intercepts gaseous air pollutants through the leaf stomata as the primary way of improving air quality. Furthermore, the vegetation can intercept particulate matter by absorbance or adherence to the surface with the aid of the wind currents (Currie and Bass, 2008).

Direct air quality improvement is achieved by the uptake and deposition of the pollutants through GI. However, GI practices can also contribute to the energy savings by providing cooling during summer months, which can lower the emissions of power plants as indirect air quality improvement benefits. Therefore, the cumulative air quality improvement obtained from GI can be estimated as the total of direct and indirect benefits in resource units or monetary terms (Akbari et al., 2001; Foster et al., 2011).

One of the widely used techniques to assess the pollution reduction capability of GI is through the use of dry deposition models (Yang et al., 2008). Models such as Urban Forest Effects Model (UFORE) that use the concepts of dry deposition modeling, were used in several United States case studies to quantity the air pollution reduction through GI such as trees, green roofs and green walls (Nowak and Crane, 2000; Nowak et al., 2005). More recently, i-Tree Eco was introduced as an enhanced version of UFORE, which can also evaluate the monetary values of environmental services of GI (Martin, 2011; Hirabayashi et al., 2012). The i-Tree Eco is a peer reviewed open source software which is developed by the United States Forest Service. This has been initially used for several cities in United States to assess the air quality improvement and numerous ecosystem services of GI such as carbon storage, carbon sequestration and energy savings (Nowak and Crane, 2000; Hirabayashi et al., 2012). In 2011, i-Tree Eco was introduced as an Australian compatible version which includes integrated air pollution and local weather data for New South Wales, Australian Capital Territory and Victoria (I-Tree Eco Australia, 2012).

There are several studies presented in the literature which quantify the air quality improvement through GCurrie and Bass (2008) used UFORE to analyze the air quality improvement by different GI such as green roofs, trees and green walls in Toronto, Canada. This study showed that green roofs can significantly improve the urban air quality. A study conducted in Portland Oregon using UFORE showed that a green roof can contribute to a direct air quality improvement of 0.001 kg per square meter annually with a GHG reduction of 7100 kg per year (City Of Portland, 2010). Nowak (1994a, 1994b) used dry deposition modeling to estimate the air quality improvement of urban trees in Chicago, USA, which is equivalent to 9.2 million dollars and removal of 5575,000 kg of air pollutants annually. Using i-Tree Eco, Baró et al. (2014) estimated that the urban forest in Barcelona, Spain, removes 305,000 kg of air pollutants annually. Saunders et al. (2011) used UFORE in Perth, Australia to assess the differences of pollutant removal for different tree species and identified that, trees with needle like leave forms are more effective in air pollutant uptake.

Although i-Tree Eco has been widely acknowledged in literature for its capabilities in quantifying the air quality improvement through different GI, there are yet limited studies conducted in Australia on its applications (Saunders et al., 2011; Amati et al., 2013). Furthermore, it is evident that GI practices such as green roofs and green walls are not yet popular in Australia, despite their wider applications in US and Europe (Wilkinson and Reed, 2009). Thus, quantifying the air quality improvement of GI within the Australian context will provide more information on developing policies and guidelines on future applications of GI. Such studies will also raise the awareness among the general public on more tangible and long term benefits of GI. Moreover, assessing the air quality improvement, its economic value and other ecosystem services, can provide information on selecting the most suitable GI for a particular area among number of alternatives. Potential GI practices that are used for air pollution mitigation may have different indicators related to environmental, economic and social objectives. Hence, comparison of the various indicators of these different GI practices used for air pollution mitigation will provide assistance in selecting the most suitable GI for a particular area (Yang et al., 2005a,b; Berger, 2011; Ten Brink et al., 2016).

This paper focuses on addressing two major aims. The first aim is to assess the applicability of the i-Tree Eco software in Australia to quantify the air quality improvement from different GI (trees, green roofs and green walls) using a case study. The second aim is to assess the GI using several environmental, economic and social indicators to identify the most suitable GI among several alternatives. The remainder of the paper is organized in the following order. Section 2 presents a brief literature review on i-Tree Eco software followed by the study area in Section 3. The methodology, results and conclusions which are drawn from the study are discussed in Sections 4–6 respectively.

2. i-Tree—Eco

The i-Tree Eco software provides functionalities to analyze the urban forest structure including the species composition, tree health and leaf area. It estimates the amount of pollution removed by urban forest within a year for criteria pollutants (O_3, SO_2, NO_2, CO, PM10 and PM2.5) except for Pb, through dry deposition modeling. The i-Tree Eco software can also assess the air quality improvement by different tree species though the species list included in the model. Additionally, i-Tree Eco is capable of evaluating other ecosystem services provided by urban forests such as the effects of trees on building energy use and the consequent effects on CO_2 emissions from power plants, avoided runoff and the economic value of pollution removal, carbon storage and carbon sequestration (Nowak and Crane, 2000).

2.1. i-Tree Eco model development

The i-Tree Eco software estimates hourly dry deposition of pollutants from trees for O_3, SO_2, NO_2, CO, PM2.5 and PM10 throughout a year. The i-Tree Eco model development and calculation for air quality improvement can be explained in four major steps as shown in Fig. 1.

2.1.1. Identification of field data collection requirements

The first step in the i-Tree Eco model development is to identify the suitable sampling method to define the plots. Locating the plots for field sampling in a study area can be done by three different approaches namely random, stratified random or grid. The random sampling is done by laying random plots throughout the study area without any stratification. Within the stratified random sampling process, the area is stratified (e.g. based on their land use classes) and the plots are located randomly within each of the strata. In the grid based sampling, the plots are located within a predefined grid, which enables to distribute the plots evenly within the study area (I-Tree Eco Users Manual, 2014).

After identifying the suitable field sampling method, the number of plots required should be decided by considering factors such